Portugal SB10

Sustainable Building

Affordable to All

Low Cost Sustainable Solutions

edited by
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iiSBE PORTUGAL
Universidade do Minho
INSTITUTO SUPERIOR TÉCNICO

PORTUGAL SB10
SUSTAINABLE BUILDING
AFFORDABLE TO ALL
Low Cost Sustainable Solutions

Organized by

Universidade do Minho

INSTITUTO SUPERIOR TÉCNICO

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UNEP

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Foreword

The conference Portugal SB10 - Sustainable Building Affordable to All is organized by University of Minho – UM, Technical University of Lisbon – IST and the Portuguese delegation of the International Initiative for a Sustainable Built Environment – iiSBE Portugal in Vilamoura, Algarve - Portugal, from the 17th till the 19th of March 2010.

This conference is included in the "SB10" series of international conferences that are being organized all over the world. The event is supported by high prestige partners, such as the International Council for Research and Innovation in Building and Construction (CIB), the United Nations Environment Programme (UNEP), the International Initiative for a Sustainable Built Environment (iiSBE), Ordem dos Engenheiros (OE – Portuguese Engineers Professional Association) and Ordem dos Arquitectos (OA – Portuguese Architects Professional Association).

Currently it is undeniable the importance of buildings on sustainable development due to their potential environmental impacts. It is also undeniable the role that the construction sector can play against climatic changes through the integration of high performance and low emission construction solutions, contributing to the reduction of the environmental impacts throughout the buildings life cycle. Several solutions are already available on the market that allow performance improvements, proving that it is actually possible to contribute to the formulation of new construction strategies, not only with improved technical and environmental quality, but also economically feasible, innovative and capable of promoting the sustainable development.

The international conference Portugal SB10 is an excellent opportunity to discuss and reflect on good technical practices applicable not only to buildings but also to urban areas and communities. With the organization of this event, we expect to share knowledge, examples and strategies, to formulate proposals that include new principles and initiatives for the creation of a more sustainable environment and to stimulate sustainable construction policies that can lead to more responsible construction, affordable to all.

The subjects discussed in this conference cover a wide range of important issues related with sustainable construction. The contributions given by the authors are the reflection of profound work and critical research that will give an important contribution towards sustainable development. The issues presented include:

- Six invited keynote papers (Chapter 1);
- Policies to low cost sustainable construction (Chapter 2);
- Low cost sustainable building solutions (Chapter 3);
- High performance sustainable building solutions (Chapter 4);
- Monitoring and evaluation (Chapter 5);
- Case-studies (Chapter 6).

Sustainable Construction, affordable to all, undeniably responds to the actual strategies of responsible and sustainable development, strongly contributing to innovative partnerships and for local employment, becoming thus an engine of social cohesion and an important instrument of economic, environmental and social policy for present societies.

Besides the keynote papers in Chapter 1, all the other papers selected for presentation and published in these proceedings, went through a systematic process of revision and were evaluated by at least, two reviewers.

The Organizers want to thank all the authors who have contributed with papers for publication in the proceedings and to all reviewers, whose efforts and hard work secured the high quality of all contributions to this conference.

The Organizers want also to thank the support given by InCI (Instituto da Construção e do Imobiliário) that sponsored and made possible the edition of these Proceedings.

The organizers are also grateful to the following institutions that contributed to this event: STAP, FCT, IRHU, CIN, Soares da Costa, DST, CASAIS, energypark, SECIL, CIMPOR, Turismo de Portugal Algarve, Câmara Municipal de Loulé, Câmara Municipal de Lagos e Universidade do Algarve.

A special gratitude is also addressed to Eng. José Amarílio Barbosa that coordinated the Secretariat of the Conference, to Eng. Miguel Silva that prepared and made available the Conference Webpage and to Eng. Catarina Araújo, Eng. Daniel Pinheiro and Eng. Deolinda Chaves for their help in administrative matters.

Finally, "Portugal SB10 - Sustainable Building Affordable to All" wants to address a special thank to CIB, UNEP, iiSBE, OE and OA and wish great success for all the other SB10 events that are taking place all over the world.

The Proceedings Editors

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Welcome

The strategy defined by the Portuguese Government for construction and real estate is based in sustainable concepts, optimizing the State regulatory functions in view to reduce bureaucracy, improve processes transparency, strengthening cooperation and guarantying an effective coordination in the definition and implementation of Government Program policies.

As a result of the above mentioned strategy, the Portuguese Government recently assigned a new mission and new challenges to InCI - Instituto da Construção e do Imobiliário, I.P. (Institute of Construction and Real Estate).

The mission of InCI, I.P. comprehends the regulation of the construction and real estate markets being the new challenges the promotion and implementation of solutions that achieve sustainability priorities, reduce environmental impact, enable energy efficiency in buildings, contribute to energy and environment certification, improve the rational use of materials and the construction waste management in Portugal. Summarizing, InCI, I.P. has an ambitious and challenging aim that is the modernization of the Portuguese construction sector contributing to the efficiency and sustainability of construction in general and of buildings in particular.

The aims of InCI, I.P. are fully in line with the scope of the conference "Portugal SB10 - Sustainable Building Affordable to All" and, therefore, participating in the edition of these Proceedings is a contribution to positively changing the construction industry towards the adoption of sustainable and efficient building practices.

InCI's support will also promote the opportunity to increase awareness and interest among the economic operators to the issues related to sustainable construction, through the exchange of practices, experiences and information.

It is with a great pleasure that InCI, I.P. warmly welcomes all the participants and wishes a great success to the conference Portugal SB10 - Sustainable Building Affordable to All.

The Executive Board

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Chapter 1

Keynote Lectures

Net-Zero Energy Buildings: The Next Shift in Green Building?

Charles J. Kibert
University of Florida, Gainesville, Florida, USA

ABSTRACT: The increasing cost of energy and international pressure to address climate change are forcing some major shifts in high performance building strategies in the U.S. and elsewhere around the world. Coupled with lower construction costs, tax breaks and other incentives, and more favorable pricing for renewable energy systems, particularly photovoltaics, the implementation of net-zero energy (NZE) strategies for commercial and residential construction is rapidly moving from concept to reality. Migrating to NZE buildings is being embedded in U.S. energy strategy and California has already mandated NZE residential buildings by 2020 and NZE commercial buildings by 2030 (Wendt 2008). This paper will describe the concept of NZE buildings, provide information on the growth of the photovoltaic industry supporting the deployment of NZE buildings, discuss the state of the art of current U.S. residential and commercial NZE buildings, and describe a recent large-scale NZE project in Florida. Finally the barriers and problems with the NZE concept will be described to provide closure on this subject.

1 OVERVIEW

The built environment is a major consumer of resources, both in its construction and operation. Buildings consume about one-third of global energy, and the built environment continues to grow as population, affluence, and urbanization increase. In the U.S., buildings consume 40% of primary energy, while the industrial sector consumes 32% and transportation accounts for 28%. According to Torcellini, Pless, Deru and Crawley (2006), commercial and residential buildings use almost 40% of the primary energy and approximately 70% of the electricity in the United States. The power required to heat and cool buildings causes about 40% of greenhouse gas (GHG) emissions, and if current trends continue, buildings will be the major energy consumers by 2025, using as much energy as industry and transportation combined. The challenge is to develop radically new, holistic strategies that can reverse this trend and reduce both energy and GHG emissions. One of the hopeful new strategies is the development of net-zero energy (NZE) buildings which, over the course of a year, produce as much energy from renewable sources as they consume, the result being buildings that are energy self-sufficient. According to Madsen (2007), "the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) in a June 2006 conference paper titled Assessment of the Technical Potential for Achieving Zero-Energy Commercial Buildings, 22 percent of buildings today have the potential to be ZEBs. Through advancements in technology, an estimated 64 percent of buildings could be ZEBs by 2025." This statement embodies the ideal that although net zero energy building is not a brand new concept, it is still in its infancy. With the tremendous amount of money that the new U.S. presidential administration has allotcated for research and development in the building sector, the idea of net zero energy building is growing in popularity and implementation.

As a side note, by way of a deal reached on 17 November 2009, the European Union is expected to enact laws to set energy efficiency standards for all public buildings by 2018 and thereafter all commercial buildings and homes. Converting existing buildings to near-zero energy standards was a major part of negotiations that took place between European Parliament and Council in hopes of using the public sector as an example for the rest of Europe's buildings and homes. All new buildings built after 2020 must rely mostly on renewable energy under this plan. By mid-2011, EU Member States must identify financial and other incentives for the transition, such as technical assistance, subsidies, loan schemes and low interest loans.

2 THE NZE CONCEPT

In general it is assumed that the NZE building is connected to the grid and that energy flows to and from the grid over the course of a typical day. Rather than have an energy storage system on-site, the grid is used as the storage device. The following are several variants of the definition of NZE buildings by the U.S. National Renewable Energy Laboratory (Torcellini, Pless, Deru and Crawley 2006; Malin and Boehland 2005):

Zero-net-annual site energy. This is probably the most commonly understood definition for NZE buildings and the concept is that on an annual basis, an equal amount of energy is exported from the building footprint as is imported in the form of electricity and/or natural gas. The site generated energy is normally electricity and the accounting is done at the site boundary. Energy derived from wood on-site or methane generated onsite are not included in the accounting, only energy generated within the building footprint.

Zero-net-annual source energy. The total energy used off-site to generate the energy imported to the building must be matched by on-site generated energy. In the U.S. for electrical energy, each unit of energy generated requires a factor of 3 units of fuel energy. For natural gas 1.1 units of fuel energy are required to deliver each unit of natural gas energy to the building. This definition tends to favor the use of fossil fuels over electricity as an energy source.

Zero-net-annual energy cost. For a zero-net-annual energy cost building, the amount of money collected by the building owner from the utility for exporting on-site generated electricity is equal to the electric and natural gas utility bills. Because natural gas is cheaper, less site generated electricity can be used to offset the same amount of natural gas energy.

Zero-net-annual emissions. This definition is based on offsetting the emissions of the energy source used to power the building and generally refers to greenhouse gas (GHG) emissions. As a result another name for a zero-net-annual emissions building is a *climate neutral building*. Offsets can be created by onsite generated PV electricity, or through the purchase of, for example Renewable Energy Certificates (RECs) or Green Tags that support the generation of off-site renewable energy.

Although NZE generally applies to individual buildings, it can also be applied to groups of buildings. For example a recently completed research report into the feasibility of using PV energy at large scale by the Florida Department of Transportation concluded that it was possible to make large turnpike plazas self-sufficient for meeting their energy needs (Kibert et al. 2010). A description of this project is included as a case study in this paper.

Achieving NZE buildings is a challenging process because it is heavily dependent on several factors, all of which must be favorably addressed for a building to achieve this level of performance:

- The building must be designed to consume the minimum energy possible.
- The occupants must be willing to conserve energy in the operation of the building (system scheduling, setpoints, maintenance, recommissioning)
- A feedback and control system designed to inform occupants and assist in reducing energy consumption must be provided.
- Adequate site and building roof area must be available for installation of a renewable energy system, most often PV system.

These factors point to some significant constraints on PV powered NZE buildings. An average PV panel may generate about 110 Kwh/m^2 annually which represents a highly efficient commercial office building. A NREL study which monitored six relatively efficient office or academic buildings across the U.S. concluded that a single story office building could achieve NZE performance but that a two story building could not (Torcellini et al. 2004). If additional area is available over parking areas or other on-site locations, then there is potential for multi-story NZE buildings. If collecting wind energy is feasible, then much larger NZE building, even high-rise buildings may have potential.

Occupant behavior is an important factor which must not be ignored in NZE building design. A factor of 3 difference in home energy use has been observed even in co-housing communities where environmntal awareness is generally high. Being able and willing to shift to natural ventilation, for example, by opening doors and windows, makes achieving NZE performance achievable.

3 STATUS OF U.S. PHOTOVOLTAIC INDUSTRY AND PHOTOVOLTAIC INSTALLATIONS

The demand for solar PV is growing rapidly as indicated in Figure 1. which shows data for world PV market growth in 2008, the last full year for which data is available. Figure 2. indicates present and future forecsted growth in the global PV market. U.S. demand for PV in 2008 was just 6% of world demand but the economic downturn, a new administration favorable to renewable energy investments, a growing public demand for significant utility investment in renewable, may change this scenario.

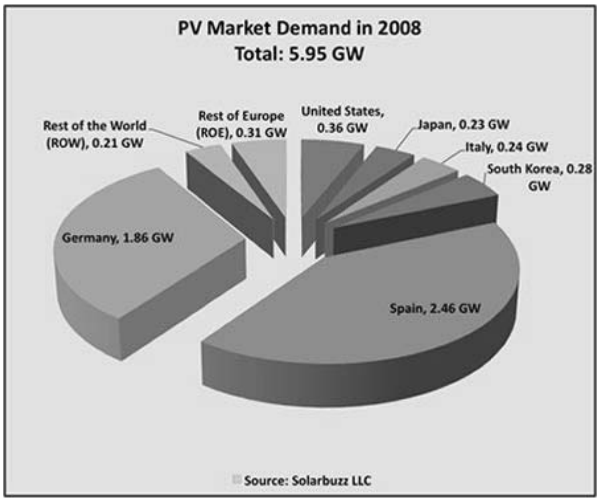
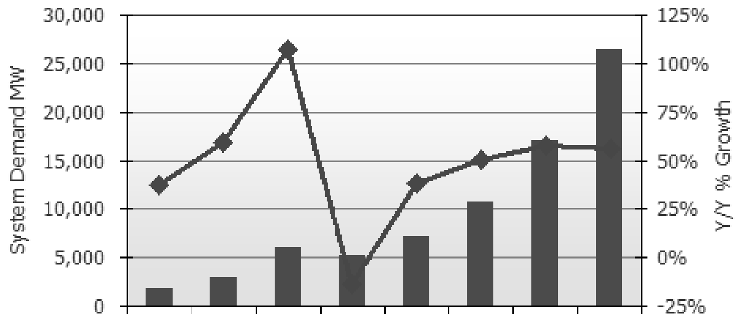


Figure 1. Solar PV market demand for 2008 reached 5.95 GW. (Source: solarbuzz.com 2010)



	2006	2007	2008	2009	2010	2011	2012	2013
Demand	1,818	2,896	6,006	5,169	7,140	10,753	16,975	26,491
Y/Y %	38%	59%	107%	-14%	38%	51%	58%	56%

Figure 2. Global solar PV growth. Data is through 2009 and forecasted for 2010 – 2013 (Source: ecn.com 2010)

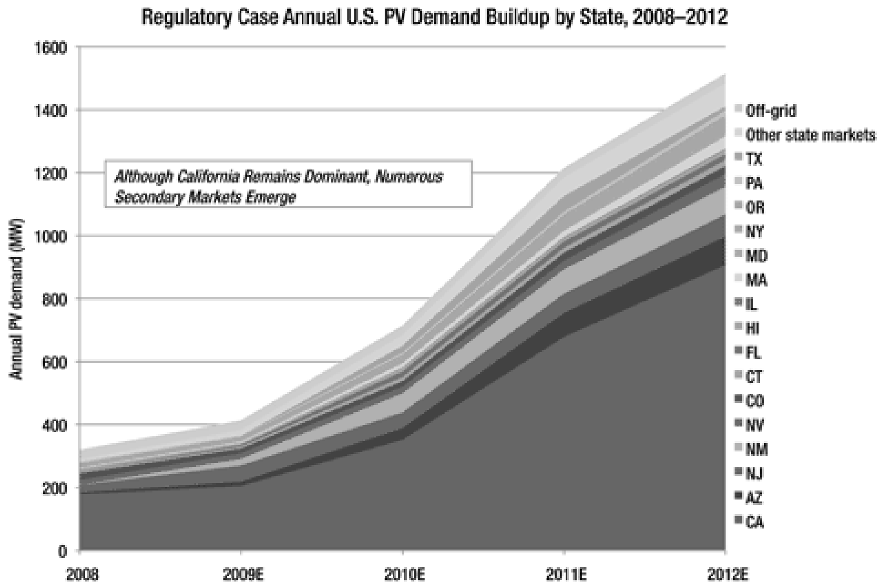


Figure 3. Annual buildup of demand by U.S. State 2008-2012 in MW of annual installation (Greentech Media 2010)

In spite of the lagging U.S. market compared to Spain, Germany, and Japan over the next four years, the U.S. may well experience the most rapid demand growth of any major PV market. Base case U.S. PV demand indicates growth to 1,515 MW in 2012, with annual growth from 2008 to 2012 averaging 48 percent. The upside scenario sees demand reaching 2,022 MW in 2012. During this period, the U.S. surpasses Spain, and potentially Germany, to become the leading global PV market. Although California's market share remains relatively steady at around 50 percent of national capacity second-tier markets gain increasing value as their absolute size increases. The U.S. market is unique in the world because it is actually comprised of 50 state markets with various programs and incentives inducing PV installations. Renewable Portfolio Standards (RPS) in which a state requires its utilities to generate a minimum level of electricity via renewables is one of several forces causing the growth of solar PV in the U.S. By 2012, combined base case demand from leading secondary states Arizona, New Jersey, New Mexico, New York, Nevada and Massachusetts reaches 376 MW. A recent December 2009 forecast by Greentech Media Inc. indicates that the cost of PV generation and grid electricity is rapidly converging (Greentech Media 2010). In their report,Greentech Media modeled 16 states to determine when post-incentive PV generation costs and grid electricity will converge. Each state offers an incentive package that favors some market segments over others. Price convergence in these markets is heavily sector-dependent. States with high levels of demand, such as New Jersey and California, have already experienced price convergence in particular market segments, while others stand on the precipice. By 2012, 11 of 16 states will have surpassed price convergence in the commercial sector, and ten will have done so in the residential sector. The active engagement of solar developers offering Purchase Power Agreements (PPA), assisted by substantial finance and tax incentives, is obviating the need for capital investment by residential and commercial customers.

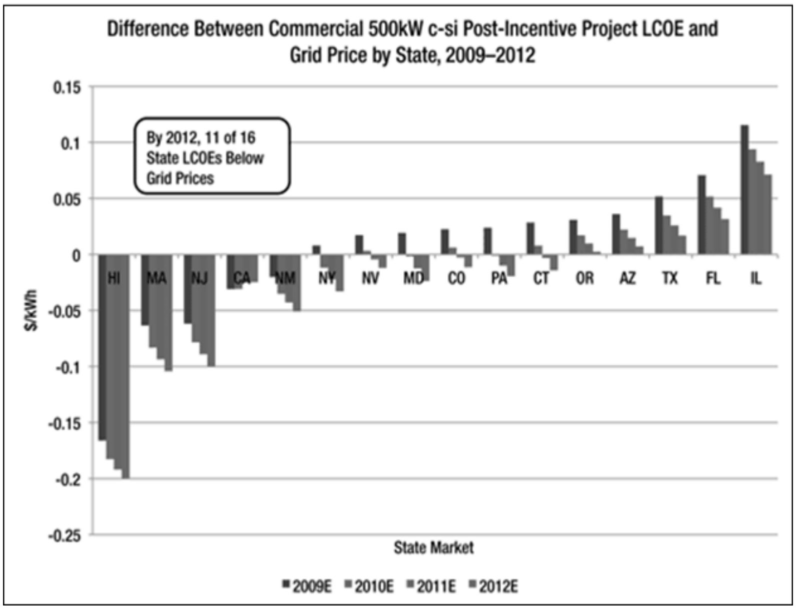


Figure 4. In 10 of 16 U.S. states in a recent report forecasting solar PV growth in the U.S., the cost of PV electric generation is less than grid-connected electricity by 2012 (Greentech Media 2010).

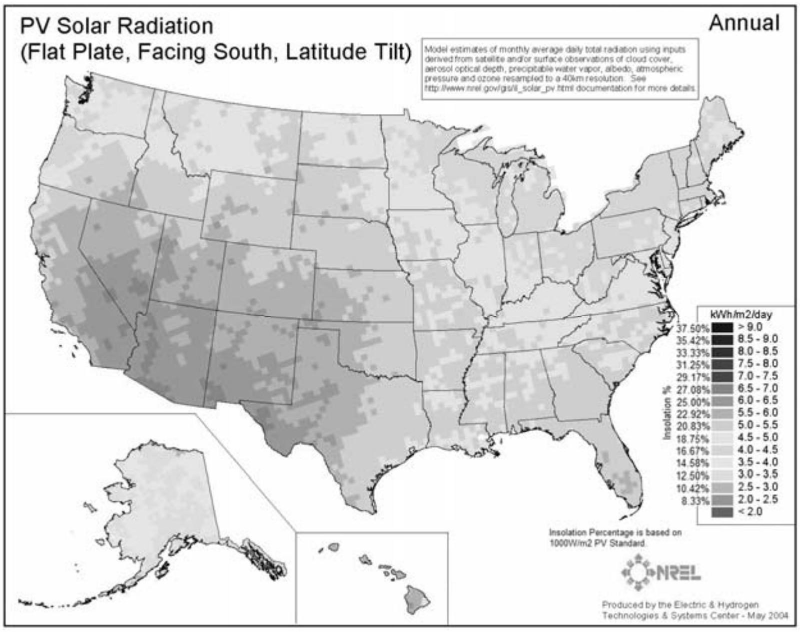


Figure 5. Solar insolation in the U.S. varies from 8 $KWh/m^2/day$ to about 3 $KWh/m^2/day$ with most of the U.S. receiving 4 to 6 $KWh/m^2/day$ (Source: U.S. National Renewable Energy Laboratory)

The U.S. has enormous potential for renewable energy for both solar and wind applications. Solar insolation ranges from about 8 $KWh/m^2/day$ in some areas of the southwest to 6 in Hawaii to about 5.5 in Florida, 4 in the northeast, 3.5 $KWh/m^2/day$ in portions of the Pacific northwest, and to 3 $KWh/m^2/day$ or less in Alaska. On the average it is in the 4 to 6 $KWh/m^2/day$ range over most of the U.S. (See Figure 5.) By some estimates virtually all of the energy needs of the U.S. could be met by solar thermal or solar electric energy systems. At present the total grid connected solar PV is about 800 MW out of a total 1,000 GW of generating capacity in the U.S., about 0.1% of generating capacity. This compares to wind energy which now comprises 35,000 MW of generating capacity, a factor of more than 40 greater than solar PV.

4 NET ZERO ENERGY COMMERCIAL BUILDINGS

Research and development of NZE commercial buildings became national policy in the U.S. by virtue of the Energy Security and Independence Act of 2007 (ESIA 2007) which established the Net-Zero Energy Commercial Buildings Initiative. The stated goal of this initiative is: To develop and disseminate technologies, practices, and policies for the development and establishment of net-zero energy commercial buildings for: (1) Any commercial building newly constructed in the U.S. by 2030; (2) 50 percent of the commercial building stock of the U.S. by 2040; and (3) All commercial buildings in the U.S. by 2050 (NSTC 2008 and Butcher 2009). In addition to national and state policy drivers behind the move to produce NZE commercial buildings, the recent launch of the Building Energy Quotient (Building EQ) program by the American Society of Heating, Refrigeration and Airconditioning Engineers (ASHRAE) in December 2009 poses NZE buildings as the highest achievement level for a commercial buildings (See Figure 6.) (ASHRAE 2009).

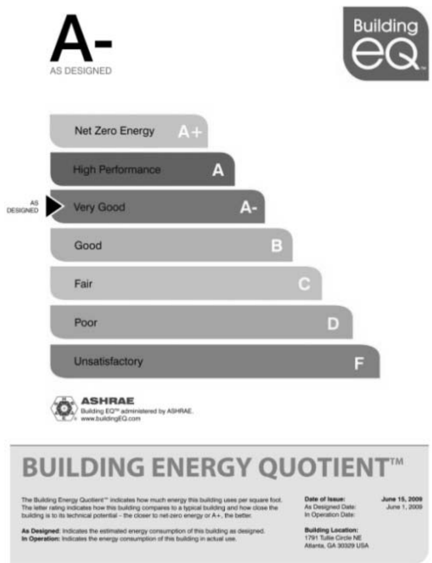


Figure 6. The ASRAE Building EQ label reserves the highest level of building energy performance, an A+, for NZE buildings (ASHRAE 2009).

In fact at present there are just eight few non-residential buildings in the U.S. Zero Energy Buildings Database and most of these are relatively small buildings (See Table 1.)

Table 1. List of non-residential NZE buildings in the U.S. (USDOE 2010)

Name	Location	Building Type	Floor area, m^2
Aldo Leopold Center	Wisconsin	Commercial office	1,190
Audubon Center at Debs Park	California	Recreation center	502
Challengers Tennis Club	California	Recreation building	350
Environmental Technology Center	California	Higher education/laboratory	220
Hawaii Gateway Energy Center	Hawaii	Commercial office	360
IDeAs Z2 Design Facility	California	Commercial office	656
Oberlin College Lewis Center	Ohio	Higher education/library	1,360
Science House	Minnesota	Museum/interpretive center	153

5 NET ZERO ENERGY HOMES (NZEH)

Of particular importance in reducing U.S. energy consumption are residential buildings, especially single family homes. Table 2. indicates the characteristics of housing in the U.S. from the latest version of “American Housing Survey for the United States” for the year 2007. Although most housing is comprised of the existing housing stock, an enormous number of new homes, estimated at 34 million, were forecast to be constructed between 2005 and 2030 (McKinsey

Company 2007). Consequently rapidly raising the bar for new residential construction is crucial to reducing U.S. energy consumption and shifting to renewable energy resources.

Table 2. Characteristics of Residential Buildings in the United States (AHS 2008)

Total Housing Units (millions)	Single-Family Houses (millions)	Multifamily Housing(millions)	Manufactured Housing (millions)
128.2	87.5	31.9	8.7

Some jurisdictions are already making policy changes that would require NZEH and other buildings in the not too distant future. Every two years, the California Energy Commission (CEC) releases an Integrated Energy Policy Report in which it makes recommendations for energy policy in the state, including changes to Title 24, the energy efficiency portion of the building codes (Pfannenstiel and Geesman 2007). In its 2007 report, CEC recommended adjusting Title 24 to require net-zero-energy performance in residential buildings by 2020 and in commercial buildings by 2030. The CEC believes that new legislation to incorporate these goals is not needed and is already moving to put them in place. The goals set in California were inspired by the 2030 Challenge goals, in which the nonprofit organization, Architecture 2030, called for no fossil fuel use by buildings by 2030. California's goals are focused on net-zero-energy performance instead of fossil fuel use. CEC based its definition of net-zero-energy performance, and many of its recommendations, on a report by the California Public Utility Commission (CPUC), which states that a goal of "no net purchases from the electricity or gas grid" may be met with energy-efficient design and "onsite clean distributed generation."

On September 5. 2007 the City Council of Austin, Texas passed a resolution to establish the Zero Energy Capable Homes (ZECH) program which requires new single-family homes to be ZNE capable by 2015 (Austin 2007). These homes will be 65% more efficient than homes built to the Austin Energy Code in 2006, and it will be cost-effective to install renewable on-site generation and become zero energy homes. The program will be implemented in phases. The first of four planned local amendments to the International Energy Conservation Code (IECC) was approved by the City Council in October, 2007. Austin's program demonstrates that increasing energy efficiency and decreasing greenhouse gas emissions can both be cost-effective. When the increased cost of building the home is rolled into a 30-year mortgage, reduced energy costs are greater than increased mortgage payments. Historically, the main obstacle to adopting effective energy codes has been resistance from the home building industry and affordable housing advocates, due to cost concerns. Austin overcame this resistance by forming a task force that included representatives from these groups as well as industry trade associations, energy efficiency advocates, the Electric Utility Commission, Texas Gas Service, and City Staff. A positive and productive task force addressed the needs of stakeholder groups, increased buy-in from the community, enhanced participation in the program, and will help insure the long-term success of the project. These program's initial amendments increased the overall efficiency of homes by 11% and electric energy efficiency by 19%. For 2008, based on average annual construction of 6,400 new homes, this translates into an annual reduction of 9,367 metric tons of CO2. The first amendments also reduced annual household energy consumption by 2515 kWh and 4 therms of gas. This decreases household energy costs by $227.68 per year, with an estimated payback of 5.2 years. And finally, the changes will reduce SO_2 emissions by 3.9 tons and NO_x by 19.8 tons.

On July 14, 2009 General Electric unveiled plans for a "Net Zero Energy Home" project which combines GE's most efficient appliances and lighting, the company's new energy management systems, and GE power generating and storing technologies in new home construction (LaMonica 2009). When applied together, the system would enable a homeowner to achieve net zero energy costs by 2015. The Net Zero Energy Home project – and new smart grid consumer poll data from the U.S. and the U.K. – were introduced at GE's smart grid symposium at its Global Research Center in upstate New York. As part of the company's Ecomagination strategy, the GE Net Zero Energy Home offerings will be comprised of three major groups within the product portfolio: energy efficient products including appliance and lighting products that will reduce energy consumption in the home; energy management products that will enable consumers to manage their costs and energy consumption; and energy generation/storage products like solar PV, advanced energy storage and next generation thin film solar that will play an integral part in the net zero energy home. In 2010 GE will introduce the *Home Energy Manager*, their version of a central nervous system for the Net Zero Energy Home that will work in conjunction with all the other enabling technologies in the home to help homeowners optimize how they consume energy. GE will also introduce a line of smart thermostats in 2010 that, together with the Home Energy Manager, will inform consumers on their energy use and empower them to make smarter decisions on their energy

Key to the NZEH strategy are radical improvements in the energy performance of homes, with reductions in typical home energy consumption on the order of 60% to 70% needed to bring NZEH to reality. This improvement in performance, coupled with advanced control technology and an optimized feedback system, and on-site generation of electricity from solar photovoltaic systems, provides a realistic and achievable pathway to NZEH's. Although NZEH's are rapidly becoming a reality, there are several gaps in technology that make the transition difficult. The advent of the smart grid will help close some of the key gaps needed to make the overall building stock shift to a NZE status. A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources (DOE/OEDER 2008a). The information networks that are transforming our economy in other areas are also being applied to applications for dynamic optimization of electric system operations, maintenance, and planning. Resources and services that were separately managed are now being integrated and rebundled as society addresses traditional problems in new ways, adapts the system to tackle new challenges, and discovers new benefits that have transformational potential.

Although the smart grid provides some level of data that a homeowner can access to understand and respond to reduce their energy consumption, it does not provide adequate feedback for a NZEH owner to be immediately aware of the home's energy consumption profile and patterns. Additionally the owner must log into a utility website to view data that is not real time and not adequately fine-grained for response. Ultimately the control of a NZEH and the integration of feedback loops will be key to the successful implementation of this concept. An Advanced Controls System for Net Zero Energy Homes (AFCS-NZEH) will have two major components: (1) an automatic control system that minimizes energy consumption based on inputs by the owner to the controller, and (2) a real-time feedback system that provides the homeowner with information on energy generation, consumption, and costs, and allows the NZEH owner to change strategies based on their response to the feedback.

The automatic control system will be connected, either via hard-wiring or wireless connection, to the major energy consuming devices in the home: air-conditioning, hot water heater, refrigerator, range, clothes dryer, lighting system, and plug loads. It will also be connected to the renewable energy system powering the home to optimize its performance based on conditions. For example it could be used to help a photovoltaic (PV) system track the sun to maximize electricity production and could provide information about the performance of the system to indicate any unexpected degradation of performance. The control system would similarly monitor all major appliances to assess their performance and indicate when performance is degraded. For an air-conditioning system this could occur due to dirty filters, leaking coolant, corroded and condenser or evaporator coils. The control system could, for example, close windows or indicate windows are open when the air-conditioning system is operating. It could also indicate when outside conditions are such that leaving the windows open during cooler periods would minimize energy consumption. Indoor air quality (IAQ) will be also be monitored with ventilation air controlled via the automatic control system.

The feedback component of the AFCS-NZEH will provide the owner with real-time information about the energy performance of the home including instantaneous power consumption, daily energy consumption and costs, monthly and billing period energy consumption and costs, renewable energy generation and energy value, and net energy for the month and billing period. It could also provide other information such as trends in consumption, energy generation, net energy, and performance of major systems. As important, the feedback system would allow the owner to alter the current strategy of the home by changing setpoints and schedules and providing them the opportunity to change their behavior. For example, if energy consumption was trending to exceed energy production, the owner could raise the setpoint of the air-conditioning system from 24°C to26°C. The owner could opt to hang clothes out to dry instead of using electrical energy for this purpose or they could opt to purchase a clothes dryer that relies on much higher spin rates to remove moisture from clothes. They would be informed that perhaps plug – loads are trending high and also be informed of the levels of so-called *vampire loads*. Vampire loads are energy consumption caused by computers, printers, chargers for cell phones, ipods, home video games, microwaves, laptops, and high definition televisions, the sum of which can add 10% to 20% to the energy consumption of an average home. By using smart switches connected to the feedback component that turns off devices that cause vampire loads, significant reductions in energy consumption can be experienced.

6 CASE STUDY FOR NZE CONCEPT: TURKEY LAKE SERVICE PLAZA, FLORIDA TURNPIKE, FLORIDA

A study of the application of solar PV power to the Turkey Lake Service Plaza in Ocoee, Florida, near Orlando, Florida, was accomplished through the extensive research into solar technologies, PV system design criteria, and energy simulations. Numerous solar technologies, as well as their mounting systems and interconnections, were analyzed based on their efficiencies and potential areas of application. Different areas of the Turkey Lake Service Plaza required different technologies depending upon on the requirements for that specific area. The flat open areas to the north and south ends of the site, for example, are ideal for a fixed ground mounted crystalline PV system, while the building roofs require a thin film or self-ballasting system in order to retain roof warranties on newly replaced roofs. The noise walls provided unique design challenges pertaining to mounting, shading, and heavy wind loading.

6.1 *PV System Design Criteria*

The unique challenges facing this study were met primarily through the use of three dimensional modeling via Autodesk's Revit software. The entire Turkey Lake Service Plaza was modeled along with several of the best performing PV mounting systems (see Figure 7.).

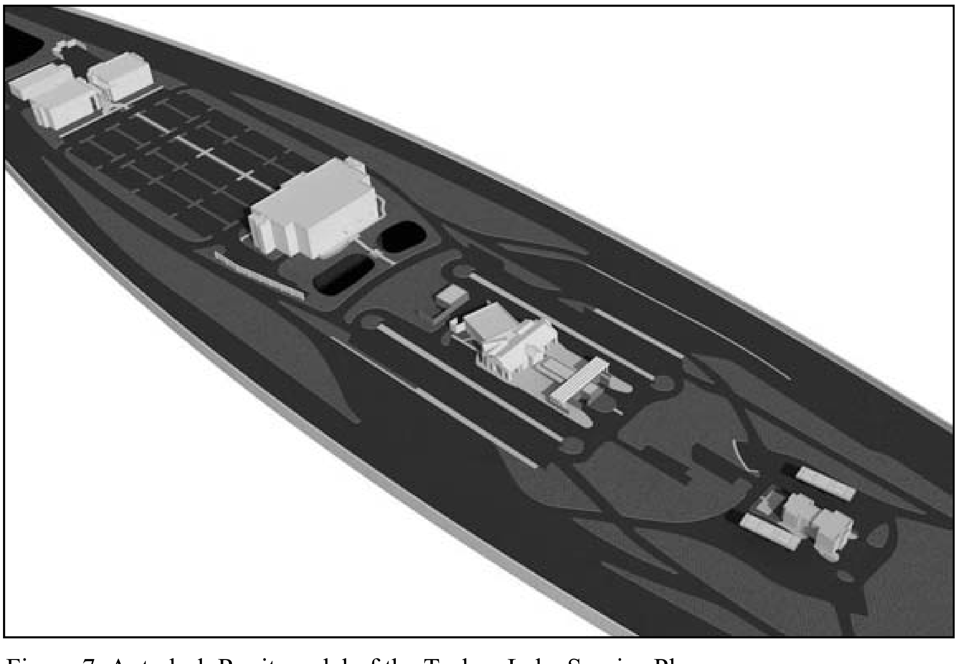


Figure 7. Autodesk Revit model of the Turkey Lake Service Plaza

A generic panel size of 82 mm x 157 mm was used for all simulations. Shading simulations used the Plaza's coordinates of -81.5^{o} West Longitude and 28.5^{o} North Latitude for all sun studies to determine the optimum locations for PV systems and the adequate spacing required for each system between the hours of 10:00am to 4:00pm (see Figure 8.).

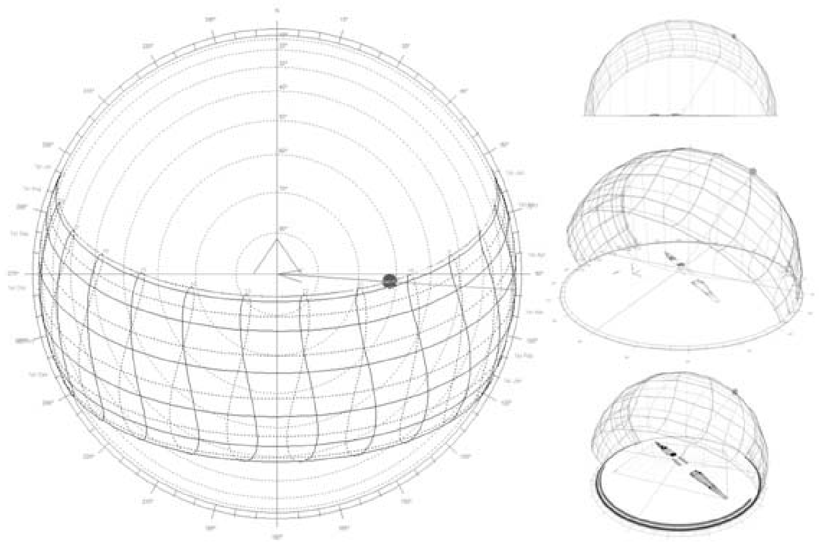


Figure 8. Annual solar path diagrams indicate the sun's position over the Turkey Lake Service Plaza at 10:00am

6.2 *PV Power Simulations*

Energy power simulations were created and analyzed using the SunPower SPR-315 panel. The SPR-315 was evaluated in PV-DesignPro (see Figure 9.) to determine the optimum degree tilt that would produce the maximum power output. Through this process it was determined that a 27 degree tilt from horizontal (very close to the 28 degree latitudinal position) would be the most productive angle for the Turkey Lake Service Plaza .

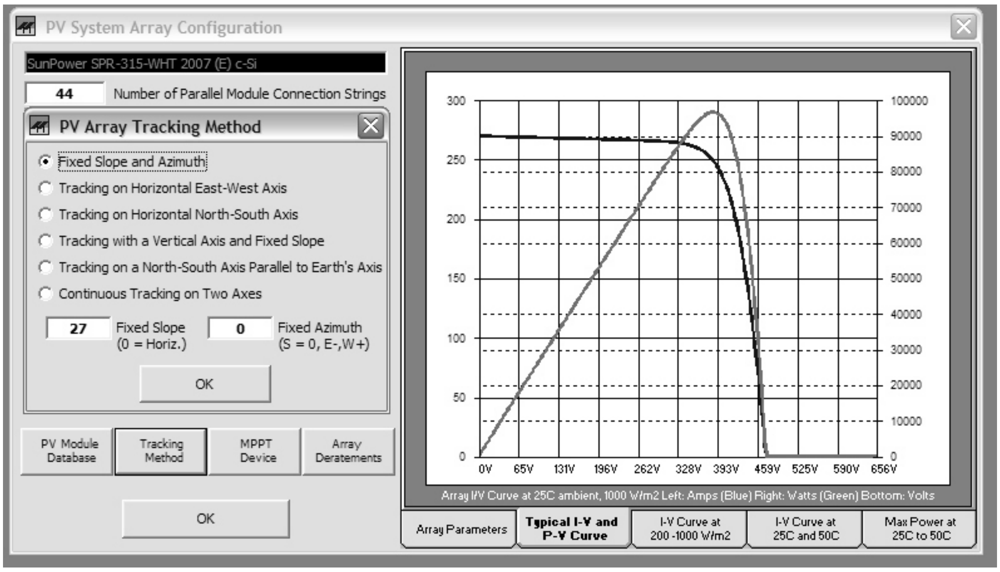


Figure 9. Energy simulation software PV-DesignPro v6.0

6.3 *Solar Energy Potential for a Service Plaza*

In assessing the FTE facilities, there were several buildings for servicing the Turnpike customers including shops, restaurants, and a service station that were not part of this study. The property that was assessed consisted of:

- FTE Headquarters – 1 590 m^2 of Panel Area
- Operations building – 370 m^2 of Panel Area
- Florida Highway Patrol building – 400 m^2 of Panel Area
- Trades building/associated maintenance yard – 270 m^2 of Panel Area
- Open Areas 14 200 m^2 of Panel Area

- North/South Retention Ponds – 8 500 m^2 of Panel Area
- Noise Walls – 12 700 m^2 of Panel Area

The analysis of technologies and the system design for Turkey Lake Plaza was based on three scenarios and eight phases. The eight phases of the project corresponded to the various areas that had the potential for installation of PV panels. The following are the eight phases that were examined for their installation potential together with the PV technologies that were examined for their feasibility and other technical areas of examination (see Table 3.).

Table 3. Eight phases for the Turkey Lake Service Plaza

Phase	PV Systems	Other
1. Open Areas	Thin film, crystalline, organic PV	Tracking options
2. Building Roofs	Thin film, crystalline, organic PV	Tracking options
3. Employee Parking	Thin film, crystalline, organic PV, EV charging stations	None
4. Visitor Parking	Thin film, crystalline, organic PV, EV charging stations	None
5. Truck Parking	Thin film, crystalline	None
6. Noise Walls	Thin film, crystalline	Tracking/Mounting
7. Retention Ponds	Thin film, crystalline, organic PV	Floating/Fixed
8. Education and Marketing	All	Displays, solar walk

The layout of the Turkey Lake Service Plaza is shown in Figure 10. It is located between the northbound and southbound two lane roads that comprise the Turnpike in this area. The site is largley paved and has several large structures. There are two major grassy areas on the north and south sides of the road and two retention ponds, one on the north and one on the south section of the Plaza. Figure 11. depicts the proposed installation method for PV panels in the open areas, namely rail mounted thick film panels at optimum azimuth and elevation. Figure 12. Depicts an array of PV panels on an elevated struture above the employee parking area between the two major buildings on the north of the siteand Figure 13. provides a closer view of the mounting system which is a lightweight structure supporting the panlels about 4 meters over the parking areas. The roadways running on either side of the Plaza have noise walls that serve as barriers to prevent noise from affecting neighborhoods on either side of the Turnpike. These walls provide the potential opportunity for serving as a mounting surface for PV panels and Figures 14., 15., and 16. provide several alternative mounting approaches. Figure 17. shows an approach where thin film panels could be mounted vertically on the noise walls. Even the retention ponds provide a potential area for mounting solar PV panels and a pontoon system to accomplish this is depicted in Figure 18.

Table 4. below is a summary of the various scenarios examined for each of the seven major Phases for this project. In Phase 1., for example, which addresses the open, grassy areas of the Plaza, six potential scenarios were examined. These included crystalline and thin film panels, with and without tracking, as well as concentrating systems. The selection of an option was based on a combination of two factors: power output and cost per Kwh of generated electricity. For example, for Phase 1, Option E, Enclosed/Mounted Thin Film, is the least cost option but produces a little more than half of the energy output of Option A, Rail Mounted Crystalline panels and Option B, Passive Tracking Crystalline. As a result it was recommended that Option A or B be selected rather than Option E for Phase 1.

Table 4. Summary of each scenario by phase

SUMMARY OF SCENARIOS

Scenario	MW	kWh/yr	$/kWh	System Cost
PHASE 1 - Open Areas				
A: Rail Mounted Crystalline	1.97 MW	3,221,000 kWh	$ 0.18	$ 9,835,000.00
B: Passive Tracking Crystalline	1.97 MW	3,804,000 kWh	$ 0.15	$ 9,835,000.00
C: Single-Axis Tracking Crystalline	1.97 MW	3,804,421 kWh	$ 0.16	$ 10,818,500.00
D: Dual-Axis Tracking Crystalline	1.97 MW	4,142,664 kWh	$ 0.16	$ 11,802,000.00
E: Enclosed/Mounted Thin Film	1.07 MW	1,744,151 kWh	$ 0.14	$ 4,260,000.00
F: Concentrating PV	1.81 MW	2,960,962 kWh	$ 0.25	$ 12,656,000.00
PHASE 2 - Roof Mounted				
A: Solyndra	0.21 MW	350,468 kWh	$ 0.14	$ 856,000.00
B: Flat Thin Film	0.20 MW	291,855 kWh	$ 0.12	$ 585,000.00
C: SunPower	0.45 MW	732,052 kWh	$ 0.14	$ 1,788,000.00
PHASE 3 - Employee Parking				
A: Crystalline Engineered Structure	1.34 MW	2,199,431 kWh	$ 0.21	$ 8,058,000.00
B: Thin Film Engineered Structure	0.73 MW	1,192,246 kWh	$ 0.18	$ 3,640,000.00
C: Envision Solar Grove	1.65 MW	2,700,567 kWh	$ 0.21	$ 9,894,000.00
PHASE 4 - Visitor Parking				
A: Crystalline Engineered Structure	0.75 MW	1,225,000 kWh	$ 0.21	$ 4,488,000.00
B: Thin Film Engineered Structure	0.41 MW	663,269 kWh	$ 0.18	$ 2,025,000.00
C: Envision Solar Grove	0.92 MW	1,503,409 kWh	$ 0.21	$ 5,508,000.00
PHASE 5 - Truck Parking				
A: Crystalline Engineered Structure	0.51 MW	838,502 kWh	$ 0.21	$ 3,072,000.00
B: Thin Film Engineered Structure	0.28 MW	455,281 kWh	$ 0.18	$ 1,390,000.00
C: Envision Solar Grove	0.63 MW	1,030,113 kWh	$ 0.21	$ 3,774,000.00
PHASE 6 - Noise Walls				
A: Dual-Vertical Row Crystalline	1.43 MW	2,214,674 kWh	$ 0.21	$ 7,881,500.00
B: Dual-Horizontal Row Crystalline	0.82 MW	1,265,749 kWh	$ 0.21	$ 4,504,500.00
C: Two Rows of Vertical Crystalline	1.43 MW	2,214,674 kWh	$ 0.21	$ 7,881,500.00
D: Two Rows of Horizontal Crystalline	0.82 MW	1,265,749 kWh	$ 0.21	$ 4,504,500.00
E: Two Rows of Vertical Crystalline - South	0.82 MW	1,341,276 kWh	$ 0.19	$ 4,504,500.00
F: Top Mounted Crystalline	0.68 MW	1,054,018 kWh	$ 0.21	$ 3,751,000.00
G: Flush Thin Film	0.95 MW	1,468,207 kWh	$ 0.17	$ 4,275,000.00
PHASE 7 - Retention Ponds				
A: Floating Crystalline	1.18 MW	1,927,573 kWh	$ 0.23	$ 7,650,500.00
B: Mounted Crystalline	1.18 MW	1,927,573 kWh	$ 0.23	$ 7,650,500.00

Notes:
Summary uses the mean performance numbers for each scenario.
$/kWh includes gross first cost based on the cost/Watt installed with a production life of 20 years.

Figure 10. Aerial view of Phase 3: Employee Parking

Figure 11. Rail mounted thick-film crystalline PV panels on rail mounted system at the Turkey Lake Service Plaza

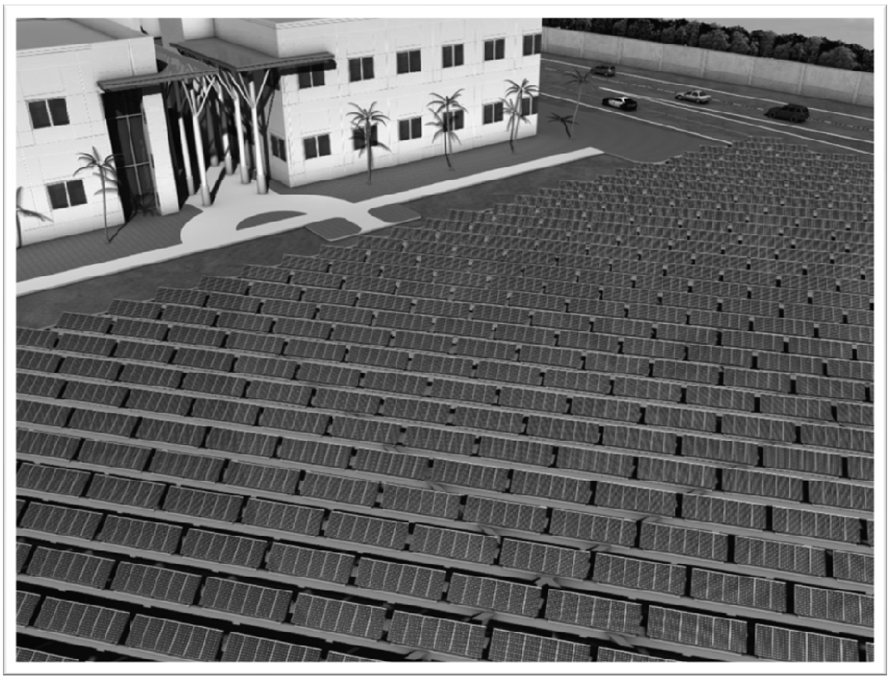


Figure 12. Crystalline engineered structure located over employee parking areas at the Turkey Lake Service Plaza

Figure 13. Crystalline engineered structure mounted on rail system in open areas of the Turkey Lake Service Plaza

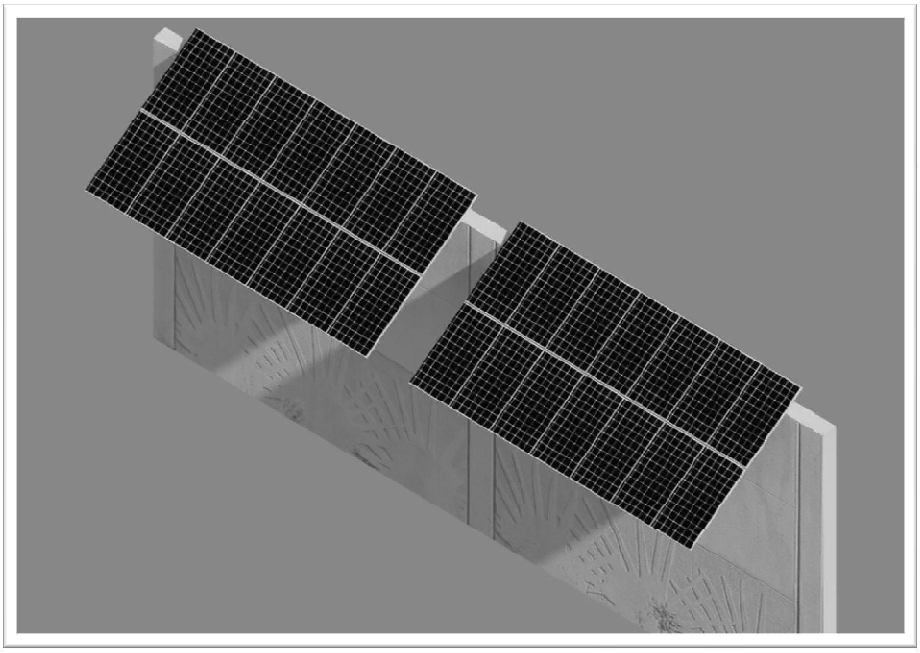


Figure 14. Dual-vertical row crystalline photovoltaic panels mounted on noise walls along the Turkey Lake Service Plaza

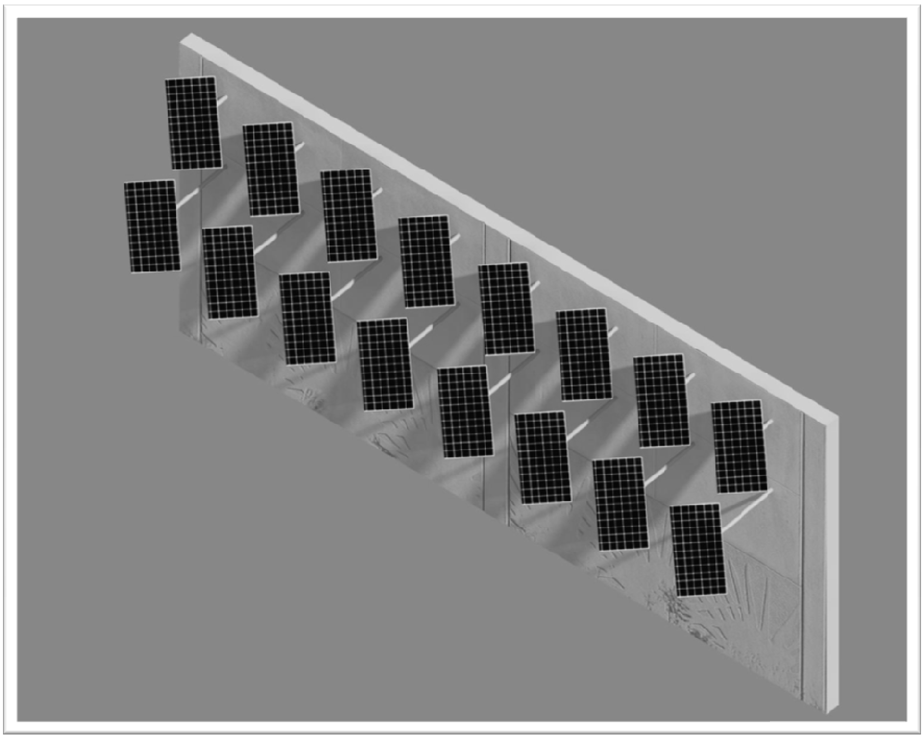


Figure 15. Two rows of vertical thick film crystalline PV panels inclined and rotated to face at optimal angle due south on noise walls along the Turkey Lake Service Plaza

Figure 16. Top mounted thick film crystalline panels located on top of the noise walls along the Florida Turnpike in the vicinity of the Turkey Lake Service Plaza

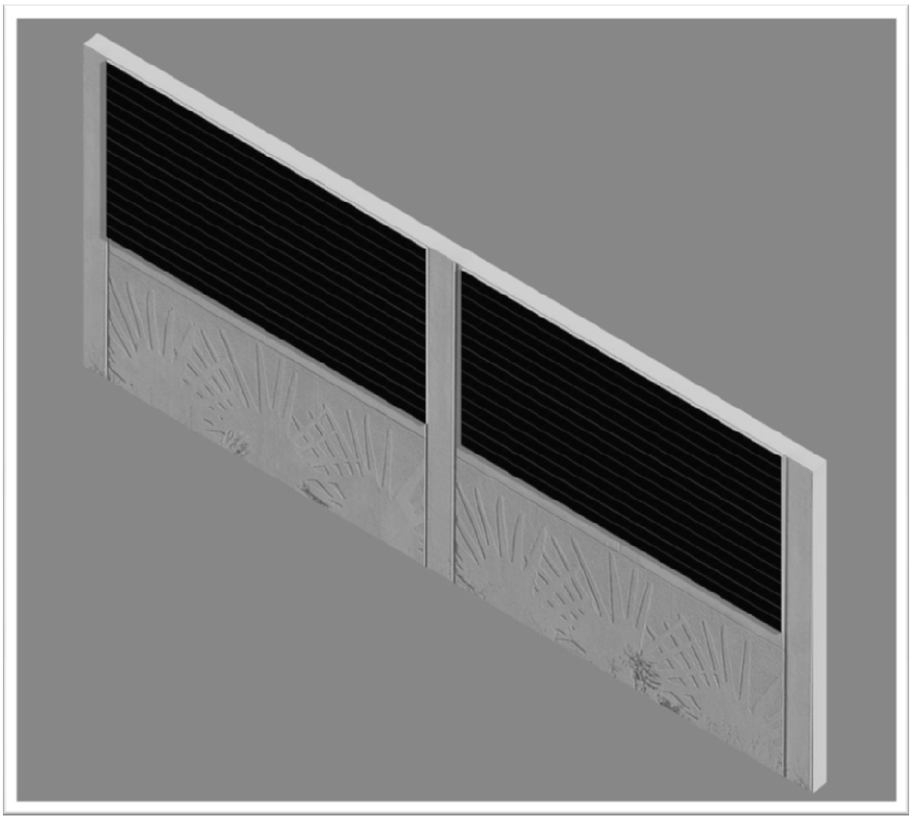


Figure 17. Flush thin film mounted on noise walls on Florida Turnpike in the vicinity of the Turkey Lake Service Plaza

Figure 18. Thick film crystalline panels floating on retention ponds at the Turkey Lake Service Plaza

7 CASE 1: NET ZERO ENERGY

This case (see Table 5.) is based on eliminating high cost/low benefit options and focuses on relatively high energy outputs utilizing only a portion of the proposed systems. The number used to achieve net zero energy is 3.8 MW, which may vary slightly depending on the weather conditions and efficiencies of the PV panels. The selections used below are the mean values derived from the base case design alternatives for each of the following four Phases: Open Areas, Building Roofs, Employee Parking, and Visitor Parking. While visitor parking represents the same unit cost as employee parking, it is more visible and accessible to the public, and is weighted more heavily.

Table 5. Case 1: Net Zero Energy

Phase	Description	Scenario	Percentage of Scenario	System Size (MW)	System Cost	Production (kWh)
1	Open Area System	A. Rail Mounted Crystalline	100%	1.97	$ 9,835,000.00	3,221,000
2	Building Roofs	A. Solyndra	100%	0.21	$ 856,000.00	350,468
3	Employee Parking	A. Crystalline Engineered Structure	76%	1.02	$ 6,124,080.00	1,671,568
4	Visitor Parking	A. Crystalline Engineered Structure	80%	0.60	$ 3,590,400.00	980,000
5	Truck Parking		0%	0.00	$ 0.00	0
6	Noise Walls		0%	0.00	$ 0.00	0
7	Retention Ponds		0%	0.00	$ 0.00	0
8	Education/Marketing					
Total				**3.80**	**$ 20,405,480**	**6,223,036**
Average $/Watt					**$ 5.37**	

8 CASE 2: MAXIMUM ENERGY

The goal of this case (see Table 6.) is to demonstrate the maximum solar potential of a service plaza and to use virtually all the available surfaces on the Turkey Lake Service Plaza for installing PV panels. The maximum energy production equates to 9.15 MW, which may vary slightly depending on the weather conditions and efficiencies of the PV panels. This is achieved by selecting the best performing technologies while utilizing 100% of the areas allotted in each Phase. The scenarios used below are the maximum values derived from the base case design alternatives for all Phases.

Table 6. Case 2: Maximum Energy

Phase	Description	Scenario	Percentage of Scenario	System Size (MW)	System Cost	Production (kWh)
1	Open Area System	D. Dual-Axis Tracking Crystalline	100%	2.55	$ 15,282,000.00	5,364,191
2	Building Roofs	C. SunPower	100%	0.47	$ 1,864,000.00	763,168
3	Employee Parking	A. Crystalline Engineered Structure	100%	1.34	$ 8,058,000.00	2,199,431
4	Visitor Parking	A. Crystalline Engineered Structure	100%	0.75	$ 4,488,000.00	1,225,000
5	Truck Parking	A. Crystalline Engineered Structure	100%	0.66	$ 3,984,000.00	1,087,433
6	Noise Walls	A. Dual-Vertical Row Crystalline PV	100%	1.86	$ 10,208,000.00	2,868,413
7	Retention Ponds	A. Floating Crystalline	100%	1.53	$ 9,912,500.00	2,497,493
8	Education/Marketing					
Total				**9.15**	**$ 53,796,500**	**16,005,129**
Average $/Watt					**$ 5.88**	

For each of these two cases, there is an infinite number of options depending upon the PV technologies selected and the percentage of their implementation. These options only represent the most economical and not necessarily the most appropriate selections. Infrastructure issues, such as mounting systems and electrical connections, should also be considered to determine the feasibility of the selected installation. The energy consumption profiles presented here for the Turkey Lake Service Plaza clearly demonstrate the potential for creating a Net Zero Service Plaza.

9 SUMMARY AND CONCLUSIONS

Strategies and technologies to create NZE buildings is a response to rapidly rising energy prices, overdependence on foreign energy sources, and the imperative to take action regarding climate change. National, state, and local jurisdictions throughout the U.S. are embracing the NZE approach as one that can successfully address these challenges and provide building owners with a degree of control and energy independence. The development of several technologies that are critical to the support of NZE buildings is rapidly advancing, namely in the area of PV panel efficiency, appliance efficiency, feedback and control systems, and increased lighting and appliance efficiency. The NZE concept can be applied not only to individual buildings but also to groups of buildings served by a renewable energy system. One limitation of the NZE concept that it is very difficult to apply to a single story building and virtually impossible to a multistory building, unless substantial site area is available for PV systems. In spite of the difficulties in implementation, it appears that NZE marks a major shift in high-performance green buildings, one that combines extreme energy conservation and efficiency with renewable energy systems to produce buildings that are energy self-sufficient.

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Beyond Green: Changing Context - Changing Expectations

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ABSTRACT: This paper explores the changing context, expectations and priorities that directly and indirectly affect building environmental progress Whereas the current focus is on "green" design - reducing or mitigating the environmental consequences of buildings - the future concerns will embrace mitigation, adaptation to the new conditions and restoring previous adversely impacted regions and human settlements. The paper looks beyond current ideas of green building to the emerging notion of Regenerative design. The primary objective of the paper is to identify which dictates of Regenerative design could constructively reframe performance assessment tools.

1 INTRODUCTION

Green building practices have become increasingly commonplace over the past decade, in part due to the introduction and widespread use of green building rating systems. While an important initial step, simply producing buildings that are incrementally better than current practice will prove insufficient to meet the requirements of a built environment that can support sustainable patterns of living. Within the context of climate change and rapid urban development, greater performance leaps will be necessary and at a faster rate. This will challenge many existing norms and expectations and, in particular, redefine how we conceive the design, construction and operation of buildings.

Whereas the current focus is on "green" design - reducing or mitigating the environmental consequences of buildings - the future concerns will embrace mitigation, adaptation to the new conditions and restoring previous adversely impacted regions and human settlements. "Regenerative" design is emerging as perhaps the most comprehensive basis for rethinking the role of building as a catalyst that positively supports the co-evolution of human and natural systems. Moreover, its proponents argue that it is an approach which bridges physical and functional, emotional and spiritual attributes and set the relationship between humans and nature from a co-evolutionary perspective than a managerial one.

This paper explores the changing context, expectations and priorities that directly and indirectly affect building environmental progress and looks beyond current ideas of green building to the emerging notion of regenerative design. The primary objective of the paper is to explore how the dictates of Regenerative design can constructively reframe performance assessment tools.

2 GREEN DESIGN

Green building design is widely understood as the creation of buildings that are less resource intensive, place less load on natural systems and offer higher indoor environmental quality than conventional buildings. The focus of green building design is environmental mitigation – doing less environmental harm than conventional buildings. Increasingly, performance aspirations such as "Net-zero" energy, Carbon "neutral" and "One-Planet Living" are presented as embodying a situation whereby human activity – including building – must respect and live within the planet's biophysical limits.

2.1 *Green Building Performance Assessment*

Building environmental assessment methods have played a significant role in mainstreaming green building and the major systems have been increasingly widely adopted by institutions and authorities as a required standard. Their increasing momentum suggests that it will continue to fulfill this role of raising performance expectations. LEED®, for example, was conceived to represent leading edge environmental performance and has become a prominent "brand" for green building practice in North America and increasingly worldwide. Although numerous changes and refinements have been made since Version-1 was first introduced in 1996, and will continue to be made, the success of the LEED® brand is also constrained on its continued development. The fundamental structure of LEED® – the five major categories and constituent performance requirements – are now difficult for the US Green Building Council to change or for it to be easily reframed to reflect emerging ideas of the relationship between human and natural systems. All modifications or enhancements must be add-ons rather than fundamental changes. Given this "lock-in" situation, other complementary tools are necessary to bring fresh, innovative and more comprehensive ideas to improving building design and construction practices.

The Living Building Challenge (LBC), launched in August 2006, is emerging in North America as a recognised demanding and complementary performance aspiration to LEED®. Despite requiring all sixteen demanding performance requirements – including net zero energy – to be met before the designation of Living Building is granted, it is also quite similar to LEED® in many regards. Although a key initial concept within the LBC was that buildings should strive for greater self-sufficiency and security, the latest version "inserted the concept of Scale-Jumping to allow multiple buildings or projects to operate in a symbiotic state – sharing green infrastructure as appropriate and allowing for Living Building status to be achieved as elegantly and efficiently as possible." The notion of "inserted" is indicative of the need to expand and refine the requirements not envisaged in the initial conception. Moreover, while it references natural systems and uses a flower/petals metaphor, there is no recognizable organization of the issues based on ecological or systems theory. Similar to LEED® and the majority of other current assessment methods, the structure is simply a list of required performance requirements set within a defined set of categories.

3 SUSTAINABILITY

3.1 *Sustainable Building*

Green building design typically covers "environmental" performance issues and human comfort and health requirements. The notion of "sustainable building" is increasing used in place of, or interchangeably with "green building" as a means of acknowledging social and economic issues. However, whereas it is possible to meaningfully describe environmental issues at the level of an individual building, this becomes more problematic for the social and economic dimensions of sustainability.

3.2 *Sustainability Assessment*

A number of assessment tools have been introduced that expand on the range of performance issues to explicitly include social and economic criteria and thereby attempt to provide a measure of "sustainable" performance. The inclusion of these requirements are incorporated in a variety of ways but none have been explicitly directed at regenerative design or informed by natural systems and processes and their integration with social and cultural requirements.

4 REGENERATIVE DESIGN

The term "regenerative" references the self-organizing and self-healing capabilities of living systems and implies their functioning and renewal. Regenerative design draws on these capabilities, along with the natural and cultural characteristics of 'place,' as drivers of design. Whereas green building design has focused on improving the environmental performance of individual buildings, regenerative design is equally attentive the consequences of the relationship between the building and its community context.

In contrast to green design that typically addresses discrete performance features, Regenerative Design embraces systems thinking - emphasizing wholes over parts and process over structure. Buildings are not considered as individual objects, but rather are designed as parts of larger systems allowing complex and mutually beneficial interactions between the built environment, the living world, and human inhabitants. A systems approach applies equally to the various systems and components that comprise buildings and seeks positive synergies between them as a means of attaining an optimised system. This ensures that a constantly dynamic and responsive built environment evolves over time. These are not the underpinnings of currently green building environmental assessment tools, nor are they easily superimposed upon them.

Eisenberg and Reed (2003), Reed (2006 & 2007) and the Regenesis Group[1] identify a number of key attributes of Regenerative design that include:

- It sits within the emerging notion of the built environment as a socio-ecological system – seeking the positive co-evolution of natural and human systems.
- It regards the self-organizing and self healing properties of living systems together with the natural and cultural characteristics of 'place' as the drivers of design.
- It unites functional, emotional and spiritual attributes of both nature and human systems as they relate to place.
- It employs a process-oriented systems thinking approach. The basis is derived from natural systems with a closed loop input-output model or a model in which the output is greater than the input.
- It concerns an understanding of a system by examining the linkages and interactions between the elements that compose the entirety of the system.

Whereas green building design has focused on improving the environmental performance of individual buildings, regenerative design is equally attentive the consequences of the relationship between the building and its community context and, importantly, a participatory approach in design that creates and maintains a positive relationship in a community through their engagement in the development process. Pedersen Zari and Jenkin (2008) identify a number of social benefits of a more participatory approach, including:

- An improved correlation between user needs or aspirations and design outcomes.
- The creation of stronger, healthier, more equitable communities and an enhanced sense of community.
- Enhanced democratic processes.
- An enhanced sense of physical and psychological health and well-being.

[1] www.regenesisgroup.com

- An increased sense of ownership and belonging to the project.
- An emphasis on understanding local traditions and indigenous knowledge, which can create and preserve cultural identity.

4.1 Systems Approach

In contrast to green design that evaluates discrete performance features, Regenerative Design embraces systems thinking - emphasizing wholes over parts, relationships over things and process over structure. A systems-based approach is crucial. Buildings are not considered as individual objects, but rather are designed as parts of larger systems allowing complex and mutually beneficial interactions between the built environment, the living world, and human inhabitants (Pedersen Zari and Jenkin, 2008).

A systems approach applies equally to the various systems and components that comprise buildings and seeks positive synergies between them. This ensures that a constantly dynamic and responsive built environment evolves over time. These are not the underpinnings of currently green building environmental assessment tools, nor are they easily superimposed upon them. Indeed within a system-based approach, design must not be constrained by are essentially the “artificial” legal bounds of site, but rather must work in the larger ecological system, both naturally and constructed.

5 FROM GREEN TO REGENERATIVE

Settlement patterns and building practices together with other human activity have significantly altered and, in the majority of cases, degraded preexisting natural ecosystems. Restoration, as a necessary precursor to Regenerative Design, attempts to repair or return a degraded site condition back to something resembling its previous biological health, such as *Brownfield restoration and the* “*Daylighting” of streams.* In contrast to the idea of restorative design, regenerative design refers to the emerging notion that the act of building design not only restores a preexisting degraded condition, but can act as a catalyst for subsequent self-improvement.

Van der Ryn (2005) and Reed (2006) each present models illustrating an evolutionary spiral that moves from current building design, through sustainable design and restorative design, toward a regenerative condition. Van der Ryn (2005) presents a spiral that begins with standard practice opens and expands through “Green” design, “Restorative design” and finally “Regenerative” Design. Reed (2006) describes this process as one that also evolves in a gradual unfolding or emergence as the field changes and as our knowledge of whole systems matures. However, a key difference between the models presented by Van der Ryn and Reed is that the former suggests a continuing evolution from green to sustainable whereas the latter explicitly acknowledges the need for a fundamental mental shift from a reductive, technical solution-based approach evident in current green building practice to one based on a holistic, living systems thinking.

6 CONCLUSIONS

Green building assessment tools have been enormously effective in providing both a guide and measure of the ways and extent that buildings can be less resource intensive and place less burden on natural systems. This is a critical and necessary step, but one that must be viewed as precursor to rethinking the role of buildings rather than a final goal. This paper has explored the transition from green design and assessment to the reframing of building environmental performance within the context of “Regenerative” design.

Regenerative design is emerging as perhaps the most comprehensive basis for rethinking the role of building and development as a catalyst that positively supports the co-evolution of human and natural systems. However, while the scope and emphasis Regenerative design as well as its key attributes and dictates can be readily understood, its widespread adoption will require supporting tools to assist design professionals in making the transition from current green practice.

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Dealing with climate change and resource depletion in Europe

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ABSTRACT: An outline of the current issues facing western countries and Europe in particular is presented, including climate change effects, resource depletion and the current major recession. Major actions required are described, but it is apparent that resolute measures will not be implemented at the international level. However, significant steps are being taken in Europe and in some selected European countries.

1 CLIMATE CHANGE AND ITS PROBABLE EFFECTS

The anthropogenic driver of climate change is the increasing concentration of greenhouse gases (GHG) in the atmosphere, chiefly CO_2. The *World Resources Institute* (WRI) estimates that buildings are directly responsible for 15.3% of global GHG emissions. To this should be added a share of industrial emissions (for materials) and for road transport. A very conservative estimate of building-related GHG share would therefore be in the range of 20% to 25%, and this would be higher in developed countries. It is therefore clear that a strategy for the diminution of GHGs will have to include the building sector as a main target.

One of the most sobering aspects of the work done by the IPCC is their exposition of the time scales involved. IPCC demonstrates that CO_2 emissions today have a positive feedback on global mean temperature that lasts for over one hundred years, and the resulting sea level rise due to thermal expansion lasts well over a thousand years. Even if action to reduce greenhouse gases is immediate, the effects of current emissions are still to come. Action is therefore needed, but in addition to the difficulty of obtaining political action, the slow rate of change in the building sector creates a special problem.

Table 1: Predicted climate change impacts: from IPCC 2007.

Global effects	Likelihood of future trends	Examples of major projected impacts
Warmer and fewer cold days and nights over most land areas. Warmer and more frequent hot days and nights over most land areas.	Virtually certain (99% probability)	Reduced energy demand for heating: increased demand for cooling; declining air quality in cities.
Warm spells / heat wave frequency increases over most areas.	Very likely (90% probability)	Reduction on quality of life for those people in warm areas without appropriate housing; impacts on the elderly, very young and poor.
Area affected by droughts increases.	Likely	Water shortages; reduced hydro generation; potential for population migration.
Heavy precipitation events. Frequency (or proportion of rainfall from heavy falls) increases over most areas.	Very likely (90% probability)	Disruption of settlements, transport and societies due to flooding; pressures on urban and rural infrastructure; loss of property.
Intense tropical cyclone activity increases.	Likely	Disruption by flood and high winds; loss of insurance; population migration; loss of property.
Increased incidence of extreme high sea level (excludes tsunamis).	Likely (long term)	Costs of coastal protection v. Relocation; loss of insurance; population migration; loss of property.

IPCC predicts that temperature increases will be most pronounced towards the end of the century, with the Northern Hemisphere the most exposed. Another major impact will be changes in precipitation patterns, with mid-latitude regions, up to and including southern Europe suffering 10% to 20% reductions in annual precipitation. River flooding is likely to be a more immediate problem, as some rivers and surrounding terrain will be unable to cope with heavy rain events.

A considerable number of papers produced by IPCC and others have outlined the science behind climate change predictions, possible impacts, mitigation measures and potential adaptation measures. In this short paper, we attempt only to identify some of the key links between climate change and the building sector, followed by an overview of actions being taken in Europe.

Resource depletion and scarcity

Climate change impacts are not the only challenges that will be faced by the building industry during the next century.

There is a great deal of uncertainty about when oil and natural gas will run out, but no doubt at all that these two fuels will become increasingly expensive and scarce during the 21st Century, according to ASPO, and predictions of declining natural gas output made in *Canada's Energy Outlook: the Reference Case 2006, Natural Resources Canada*. As these are the only fossil fuels that can be used at a significant scale to heat buildings, this means that buildings designed today will almost certainly have to be retrofitted for some other form of energy source during its lifetime. Hopefully, affordable renewable energy technologies will emerge in time, but given humanity's tendency to avoid unpalatable facts, it seems more likely that there will be demand to use electric power for heating as well as cooling, generated by coal or nuclear. This is not a very good or logical prospect.

Fuel costs and possible shortages will also create problems for automobile owners, especially for those large segments of North American society who have houses in outer suburbs and have one car per adult occupant. There may be respites in cost hikes in the form of greatly increased fuel efficiencies or car sharing, but no general solution save that of increasing densities in such areas to a point where public transport becomes economical, something that would take decades.

Another factor to be considered is the increasing prices for certain building materials, such as cement, steel, copper and nickel. Some of the increase is due to temporary shortages caused by the huge demand for cement to satisfy the extremely rapid growth of China and India, but there are also some longer-term difficulties in increasing the supply of certain materials because of increased difficulty in accessing the remaining resources. No doubt suitable alternatives will be developed, but this will take time.

Leaving aside the effects that climate change will have on precipitation, there is the question of diminution of non-renewable water resources in aquifers, lakes or river systems, all diminishing from the pressures of increasing per-capita consumption and, in some cases, increasing total population.

The problem for the building industry is that all of the climate change impacts and the other trends and effects described above will be playing out at the same time, although the relative importance of trends will vary according to location. For example, developers in southern Spain may be hard-pressed to obtain development permits in the future, as sources of potable water diminish still further, while designers in northern Europe may be finding ways of coping with excess precipitation.

In all of these regions, government and industry leaders will have to deal with these region-specific issues while simultaneously coping with the more general effects of climate change that will slowly emerge, but will accelerate during the last half of this century.

We may retain a sense of optimism, by assuming that we will learn how to cope with climate change impacts and resource deficiencies and that building costs, after rising to deal with these problems, will again stabilize as new efficiencies bear fruit. But it seems clear that even advanced countries will pass through a period of difficult adjustments to changed circumstances.

1.1 *The Great Recession*

We have sketched the outlines of the two very large problems of climate change and resource depletion and their effect on urban life and the building sector. A third element, the current major recession, is much more transitory in its effect, but does provide some interesting opportunities for action. The slowdown in world-wide production of construction and consumer goods has provided a lull in the generation of GHG emissions and depletion of materials, and has also given us an opportunity to correct some structural deficiencies on the economy and the building sector before the economy again gathers momentum.

1.2 *What needs to be done?*

The obvious and over-riding priority has to be a rapid and deep reduction in GHG emissions throughout the West, to set an example that may influence RDC countries to join in the action. This can be achieved by a combination of fiscal and regulatory measures.

It is also clear that the excessive rate of consumption in western countries is part of a rebound effect that obviates the energy efficiency gains made in many building-related technologies. Therefore, swift action has to be taken to discourage new construction and to focus instead on renovation and infill in existing neighborhoods. This can best be done through the following measures:

- Imposition of carbon taxes or a more specific form of tax aimed at new construction;
- Requirements for deep reductions on operating phase GHG emissions for new buildings, to zero or close to it;
- Tax relief on infill construction and on renovation activities in existing neighborhoods;

These basic and structural steps must be accompanied by action to stop new construction in areas of scarce water resources or sensitive ecological conditions, and to ensure also that new construction, where it occurs, is of sufficiently high density to warrant the use of land for this purpose. The best approach will be to focus on a triage approach within existing neighborhoods as shown in Fig. 2.

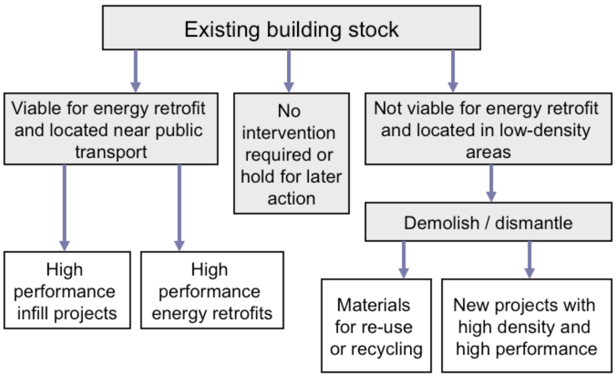

Figure 1: Triage of existing neighborhoods and building stock

The high design and construction quality levels needed for high performance will require the launching of massive renovation programs to reach the very high performance levels needed, and to launch complementary training programs to build up the required analytic and construction skills. This would be one of the best ways to re-start crippled economies, but does not seem to have yet captured the imagination of most policy-makers.

2 ACTION TO MITIGATE CLIMATE CHANGE

The area of mitigation is the subject of much public debate, goal-setting by IPCC and many national governments, but very little immediate action, except in Europe. Action related to adaptation and remediation is now beginning to be established as a parallel long-term activity in a few countries as climate-change science has become more generally accepted.

In the area of mitigation of GHG emissions, current government plans are crafted at the level of national policy and seldom deal with specific initiatives or economic sectors. This is understandable, but it does leave a hole in our understanding of how individual organizations might act to reduce emissions. Further, given the slow pace of governmental action in the mitigation arena, it is virtually certain that there will be no reduction in the global emissions of greenhouse gases at the pace and scale required to minimize climate change impacts, and it is even very unlikely that *rate of growth* in global GHG emissions will be reduced over the next decade. This should be considered in the context of targets established in the EU of limiting global temperature increases to 2 deg.C, which implies a GHG limit of 450 ppm, cuts of 40% in emissions by 2020, and 80% by 2050.

While many governments and non-governmental organizations have developed plans to address climate mitigation or adaptation, these activities have been formulated within the bounds of currently acceptable social, political or economic boundaries, which greatly limits the intensity of these efforts. The breadth and complexity of the problem, which requires a restructuring of many aspects of modern industrial economies, is certainly one impediment to more resolute action in developed western countries.

In this context, and given the major role of the building sector in energy consumption, emissions and the use of resources, it is surprising and disconcerting to see that the building sector was not a topic of major discussion at the recent COP 15 meeting in Copenhagen. Clearly, it will be regions and individual countries that will have to lead the way over the next several years.

2.1 *Mitigation action within the EU*

The European Union has been one of the few regions that show a willingness to take action in a comprehensive way.

In 2006, the EU's climate and energy policy established the following targets for 2020 for all sectors, including construction:

- Cutting greenhouse gases by at least 20% of 1990 levels;
- Increasing use of renewables (wind, solar, biomass, etc) to 20% of total energy production (currently ± 8.5%);
- Cutting energy consumption by 20% of projected 2020 levels.

It is important to note that these targets are for EU-wide results. This means that results may vary considerably within specific member States. Nevertheless, the overall savings are projected to be considerable, as shown in Figure 3:

Table2: Estimates for full energy saving potential in end-use sectors
(from EU-25 baseline scenario and Wuppertal Institute, 2005)

Sector	Energy consumption (Mtoe) 2005	Energy consumption (Mtoe) 2020 (BAU)	Energy saving potential 2020 (Mtoe)	Full energy saving potential 2020 (%)
Households (residential)	280	338	91	27%
Commercial buildings (tertiary)	157	211	63	30%

The EU already implemented the *Energy Performance in Buildings Directive* (EPBD) in 2002, and it came into effect at the beginning of 2006. As with all EU Directives, EU countries must implement the intent of the Directive, but can do so in ways that reflect different national conditions. In addition, most countries obtained a three-year delay in their implementation schedule. According to Ticau (2009), some of the new Member States still face substantial problems in implementing EPBD largely due to their legacy of a highly energy inefficient building stock, and they also need to devise cost-effective ways of providing incentives to private sector owners to upgrade their properties.

A useful history of EPBD and its recasting process is provided by Dolmans (2009). A short summary of the points made includes the following elements:

- November 2008: because many members failed to implement EPBD on schedule, the EC decided to propose to recast the Directive. The EC proposed a draft text that included solar shading of the envelope for the first time and removed the 1000 m2 area threshold. The EC estimated that the recast EPBD would reduce energy consumption in the EU by 5% to 6%.
- April 2009: The European Parliament amended the text to include a requirement that all new buildings should be net zero beginning in 2019.
- July 2009: Sources in Brussels reported that some governments criticized the amendments as going too far.
- 17 November 2009: According to Dolmans, … *The long-awaited compromise will have far reaching effects. First, the 1000 m² threshold for refurbishment is removed so that virtually all renovations will be covered ... Second, 'best rated components' must be installed in refurbishment projects. Further, all building codes must include a procedure leading to 'nearly zero energy buildings' by 2020 (and even 2018 for public buildings), while the energy certificates must be displayed in all buildings.*

The commentary on the recasting process goes on to support new requirements for solar shading, seen as of increasing importance because of the growing need for avoiding excessive solar gain during warm seasons.

2.2 *The Marguerite Fund*

One of the major issues identified earlier is the need to re-start the economy after the recession, and to do so in a way that helps in the climate change battle. According to Europolitics (2009)…*six of Europe's leading public financial institutions have launched the pan-European '2020 Marguerite Fund', with an initial capital of €600 million and intended to finance large infrastructure projects…. The Marguerite Fund is a pan-European equity fund, which aims to act as a catalyst for infrastructure investments implementing key EU policies in the areas of* *climate change, energy security, and trans-European networks. The Marguerite Fund is the first joint initiative of Europe's leading public financial institutions. It has received the active support of the European Commission since it was initiated last year, under the aegis of the European Council, as part of the EU's economic recovery plan.*

2.3 *The Netherlands*

In the Netherlands, there is a long history since the early 1990s of well-coordinated measures to promote sustainable building. These range from the Sustainable Building Plan of 1995, about 50 demonstration projects, extensive research and tool development and, coming soon, a subsidy on residential high-performance houses, a subsidy for solar energy and green loans that have interest reductions of from 1% to 2%.

2.4 *United Kingdom*

The new *Climate Change Act* in the UK, which is part of the UK *Energy Efficiency Action Plan 2007,* obliges the UK to reduce its greenhouse gas emissions by at least 80% below 1990 levels by mid-century;

- The act puts in place a framework through which the long-term target can be achieved, and it commits the UK to a series of legally-binding five-year carbon budgets that will guide the country toward the long-term goal;
- The budgets provide a benchmark against which the country's emissions performance can be measured. They help to create regulatory certainty for investors, while maintaining enough flexibility for mid-term corrections;
- The Carbon Trust proposes to reduce carbon emissions from non-domestic buildings by 35% by 2020 (The UKGBC has called for a 50% reduction);
- However, the government has not proposed financial incentives for cutting emissions in existing buildings.

2.5 *France*

In France, the *Grenelle de l'Environnement* (2007) outlines the following plans within an overall objective of reducing energy consumption by 38% and GHG by 50% by 2020.

- From now on (2010) all buildings and public facilities must be constructed according to low consumption (50 kWh/m2) or passive or positive energy standards.
- There is emphasis on the energy-efficient renovation of existing tertiary buildings, with all new tertiary buildings to be low-energy by 2012 and energy positive by 2020;
- All new housing to be passive or energy positive by 2020, and the performance of some 600,000 social housing units is underway;
- A large-scale program has been launched for the professional training, recruitment and qualification plan for construction professionals, integrating energy-efficiency, reduction of greenhouse gas emissions, climatic adaptation and indoor environmental quality;
- The Grenelle plan also calls for the creation of a professional industry sector devoted to "building renovators" and multidisciplinary management, capable of providing global services to individuals and professional project managers.

2.6 *Germany*

Germany has launched an ambitious program of regulations and incentives to cover new and renovated buildings. As Figure 4 shows, the requirements for heating (the largest load in Germany) have been tightened considerably since 1977, the year that thermal regulations were introduced. It will be interesting to see if the regulations are soon revised to cover cooling and electrical consumption, as these types of loads become more significant.

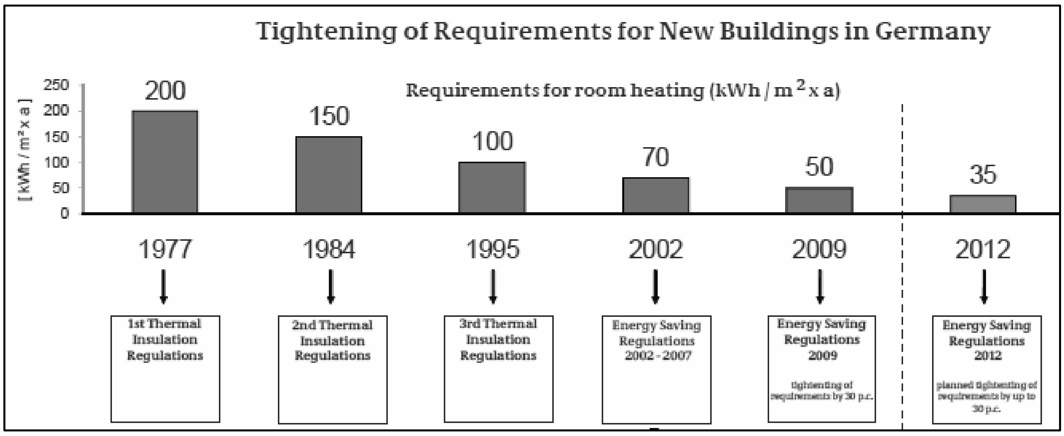

Figure 2: Requirements for maximum heating energy in German buildings, 1977 to 2009 (*Energy and Climate Strategy of Germany*, Federal Ministry of Transport, Building and Urban Affairs, 2009

The current programs have resulted in major improvements in the building stock, especially in the residential sector that has historically been responsible for a major proportion of energy and emissions in the building stock. Figure 5 shows the fact that most attention in Germany is focused on existing buildings, which is where most gains can be made.

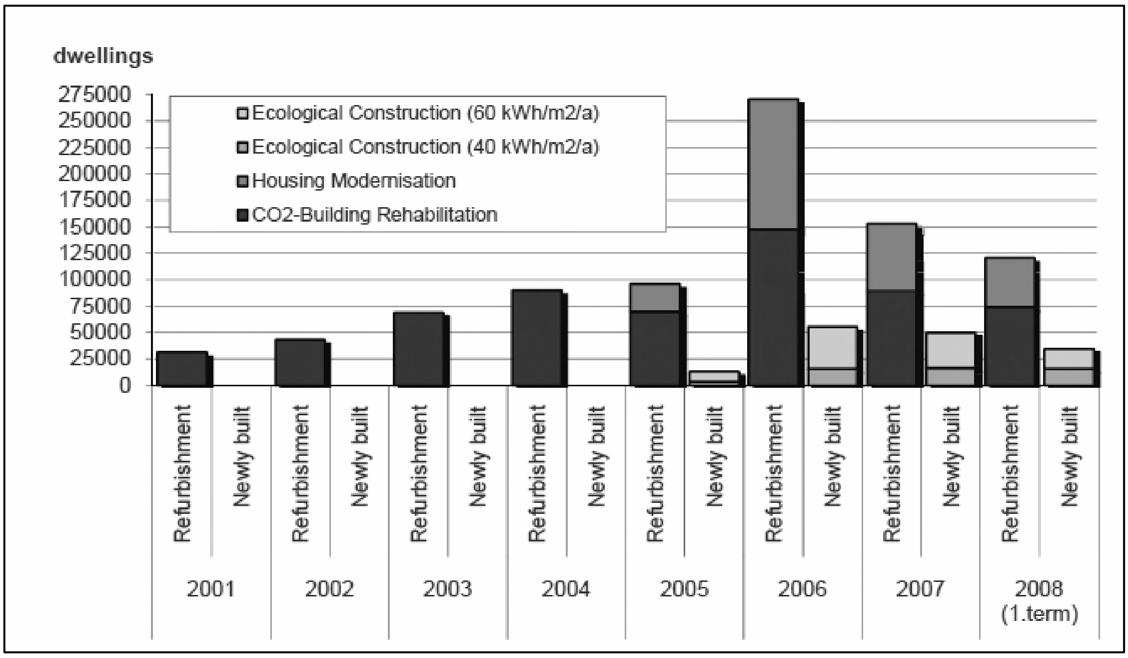

Figure 3: Overview of energy-efficient refurbished and newly built dwellings from 2001 to 2008, by German federal government programs (*Energy and Climate Strategy of Germany*, Federal Ministry of Transport, Building and Urban Affairs, 2009)

2.7 *Europe: conclusions*

It can be seen that meaningful initiatives have been launched in Europe. At the level of individual European countries, examples from the Netherlands, UK, France and Germany show that significant measures have also been launched there.

3 STILL TO BE DONE…

The current EU Directives cover issues of embodied energy and emissions of products and materials, through the Eco-Products Directive, and the potential and actual operational energy and emissions performance is covered within the EPBD (now the recast EPBD). This approach, however, does neglect the important connection between embodied and operational performance, which can only be assessed if a life-cycle approach is taken for overall building performance. The consequence of such a two-pronged approach is that materials and equipment that can greatly reduce operating emissions (e.g. shading devices, insulation) may be penalized from an LCA analysis, without obtaining credit for operating efficiency improvements.

An operational problem inherent in a whole-building LCA approach is that assumptions must be made about the service life of buildings, something that is impossible to control at the design and construction stage. However, we are able to predict service life for various building types in the aggregate, and that is close enough to the needs to warrant the introduction of whole-building lifecycle performance regulations.

The extent to which government regulations and incentive programs are aggressively pursuing performance improvements, and the volume of such work, is of course the key to climate change mitigation. In this regard, the current work being undertaken in France, Germany and Netherlands, and the work that is foreseen for the UK, are hopeful signs.

An issue that does not seem to receive adequate attention in European initiatives, except in France, is the need to provide intensive training in analytic or management techniques and construction skills that are required to ensure that we can produce and maintain buildings to the very high level of quality that is required for high performance. A rapid escalation of such programs would also bring benefits in stimulating economic recovery.

Finally, there appears to be little concerted (European-wide) action in the area of water conservation. This may be due to respect for the principle of subsidiarity, but it results in national governments being too exposed to political pressures within their States.

4 CONCLUSIONS

Much is being done, but much more is required if we are to survive the coming combined effects of climate change and resource depletion that await us in the 21st Century. The lack of resolute action at the international level requires that regions (e.g. EU) and individual countries continue to take the lead in showing the way.

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Procuring and Financing Sustainable Buildings

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ABSTRACT: A contribution to the implementation of principles for sustainable development consists in the increased construction and use of energy-saving, resource-efficient, healthy and cost-effective buildings that offer high quality in terms of aesthetics and their integration into urban planning as well as above-average technical and functional performance. Even though the importance of sustainable buildings has been gaining in recognition in recent years (not only to environmental protection and health and safety but also to job retention, the further development of technologies and the profitability of property companies), a question remains over how a wider propagation and increased market transformation can be supported. This paper analyses whether and how the instruments of procurement and financing, as well as new products (e.g. sustainable property funds), are able to support this development and which prerequisites will need to be fulfilled.

1 CURRENT THEMES AND TRENDS

1.1 *Strengthening the demand for sustainable properties*

While planners and contractors offered building designs aligned with the principles of sustainable development in the form of green buildings or sustainable properties for some time, these concepts aroused little interest on the part of investors, property owners and lessees. In the private property industry, this resulted in a vicious circle, which has initially hindered demand growth and must now be overcome. (Cadmann 2000; RICS 2008). Although the public sector would incorporate traditional aspects of environmental protection and health and safety into its invitations to tender for construction work and its decision to allocate contracts, there was often a lack of solid guidance and assessment benchmarks. This situation has completely changed since.

In many countries, the public sector is trying to play an even stronger leading role in the implementation of sustainable development principles in the construction and property industries, including properties for own use. Laws and regulations are being drafted, funding programmes are being developed, requirements for spatial development, urban development and individual buildings are being integrated into national sustainability strategies, and aspects of sustainability are being taken into consideration as part of public procurement, including in the invitation to tender for construction work and the allocation of contracts. In the process, the basis for assessing the cost-effectiveness of a package of measures often shifts from assessing investment costs to determining and evaluating life cycle costs.

In connection with a social change in values, the use of sustainable properties is increasingly helping to build a positive image. It is a means by which stakeholders can demonstrate their heightened awareness of their responsibility to the environment and society (CSR). Planners and building contractors as well as investors and companies, whether they own or lease their properties, are capitalising on this situation and are establishing additional tie-ins with their corporate sustainability reporting framework. Yet, sustainable buildings are also increasingly proving to be less risky, more stable in value and quicker and easier to lease and market. They facilitate access to land and funding and, in the best case scenario, more favourable financing and insurance terms. In this respect, the rise in demand for sustainable properties can, in the case of some stakeholders, be increasingly attributed to financial reasons. However, the financial advantageousness of sustainable properties is not always empirically verifiable, but the results of initial studies do point in this direction. (Eichholtz et.al. 2009); (Fuerst & McAllister 2009); (Dermisi 2009)

Investors (e.g. pension funds) are increasingly interested in sustainable investment opportunities, or, on the basis of existing rules, are obliged to be and to prove so. For indirect property investments, this is leading to demand growth in sustainable property funds. The first providers and products can be seen entering the market, with tendency for growth. (Rohde & Lützkendorf 2009). The development of such products is, in turn, strengthening the demand for sustainable buildings in order to launch corresponding fund products and to provide them with the appropriate properties.

1.2 *Improved describability and assessability of sustainable properties*

If the market position of sustainable buildings is to be improved, it must first be possible to describe, assess and illustrate their contribution to sustainable development by means of a transparent and recognised procedure. In the last few years, the available systems for assessment and certification, including the awarding of labels, have undergone further development. While these systems originally concentrated on energy, environment and health, and were focused on describing and assessing the fundamental technical components of the building, they have since been superseded by a second generation. Through use of environmental accounting and life cycle costing, these systems operate based on the method of life cycle assessment and do not only factor in the ecological and social dimensions but also the economic dimension. They are supplemented by assessment results relating to technical and functional quality and are in conformity with CEN TC 350 (debate status), currently under development by the European Committee for Standardization.

It is the author's view that the second generation of assessment and certification systems, which include the new German Certificate for Sustainable Buildings, will make it easier to estimate future leasability and marketability by detailing technical and functional quality and to assess cost-effectiveness by detailing life cycle costs. In this regard, it is now possible to address questions over property investment returns directly.

With the EU's ‘SuPerBuildings’ project and the activities of the SB Alliance network, work on the further development and completion of an assessment and certification solution for sustainable buildings is also being undertaken at European level.

1.3 *Further development of policy instruments*

‘Sustainable construction’ is one aspect of the Lead Market Initiative (LMI) for Europe. The LMI provides a methodology to identify promising emerging markets and to support them through a package of coordinated innovation-friendly policy actions that would facilitate growth in the demand for innovative goods and services. The action plans deploy a core set of policy instruments (legislation, public procurement, standardisation, labelling and certification and complementary instruments. Provision is made for the following actions: screening of national building regulations, industrial leader panel on cumulative administrative costs/benefits, guidance and pilot schemes on award criterion and LCC use, establish a network between public authorities in charge of procuring sustainable construction, framework & assessment method and benchmarks for the assessment of sustainability performances, Eurocodes 2nd generation, Construction Products Regulation and sustainability requirements, small and medium enterprises (SME’s) guide on collaborative working schemes in construction projects, alternative warranty/label schemes related to construction insurance, EU-wide strategy to facilitate the upgrading of skills and competence in the construction sector.

2 PROCURING SUSTAINABLE CONSTRUCTION

2.1 *Green procurement*

Green public procurement (also environmental public procurement, eco-purchasing or green purchasing) is an instrument for leveraging the market power of the public sector as a contracting party (consumer) in order to strengthen demand for environmentally friendly (sustainable) goods and services. In this context this concerns appropriate planning, construction and management services, construction products and buildings. It involves the integration of, for example, the requirements of environmental protection, health and safety and resource preservation (sustainability) into the processes by which tenders for planning and construction work are invited and contracts are awarded. At the same time, these requirements must be precisely formulated in such a way that they can be identified and implemented by the tenderer and checked for compliance by the contracting party. Attention is drawn to the need for complexity management arising from compliance with technical and functional requirements on the one hand, and the ability to assess the ecological and economic advantageousness of the solution on the other hand. The handbook on environmental public procurement of the EU (Commission 2004a) proposes the following steps:

- Development of green purchasing strategies
- Organisation of public procurement
- Formulation and definition of the requirements of the contract
- Selection of suppliers, service providers or contractors
- Awarding the contract
- Formulation of contract performance clauses.

Special emphasis is placed on the inclusion of the following aspects in the selection of the “economically most advantageous tender” (EMAT): quality, price, technical merit, aesthetic and functional characteristics, environmental characteristics, running costs, cost-effectiveness, after-sales service and technical assistance, delivery date and delivery period, and period of completion.

For public construction projects, these general steps and recommendations will have to be adapted to the particular nature of the invitation to tender and allocation of construction contracts. One task that needs to be accomplished is the selection of the appropriate procedure for formulating requirements of environmental and health and safety protection (sustainability) in the invitation to tender. In countries where national assessment and certification systems are available or international systems are recognised, the public sector (occasionally also major corporations) is increasingly tending to demand fulfilment of a specific quality level defined in the certification system (e.g. GOLD or SILVER standard). However, the advantage of having an easily communicable objective and a well publicised illustration of the quality level required is not without its disadvantages. Unless the highest quality level is selected (e.g. if SILVER level were specified from a rating system offering BRONZE, SILVER and GOLD), it would no longer be automatically guaranteed that the quality level desired by the state would be achieved in all criteria (depending on the rating system). In this scenario, it is strongly recommended that, in addition to the averaged rating to be achieved, the contracting party should define a set of minimum requirements (e.g. for energy efficiency, indoor air quality), secondary requirements (here, a minimum standard to be achieved in all criteria before SILVER level can be awarded), and a range of KO criteria (noncompliance results in rejection). Moreover, the requirements set forth in a certification system generally contain no information or instructions for the appointed building contractor, which can prove problematic.

In addition to, or as an alternative to, formulating building requirements based on one of the quality levels defined in an assessment and certification system, requirements for environmental and health and safety protection (sustainability) detailed in the invitation to tender for construction work can be integrated into the statement of work at work item level. Numerous examples and suitable tools already exist, not only in individual countries (e.g. Switzerland, Germany, UK), but also at European level. It is possible to develop requirements for both the selection of construction products and technologies (environmental protection and health and safety) on the building site and for the environmental and social standards to which the building contractor itself must adhere. Any detailing of requirements for construction products based on individual work items could include the following:

- Naming of recommendation and rejection criteria
- Use of positive and negative lists
- Requirement to use products with eco labels (specifically for product groups)
- Provision of information (e.g. environmental product declaration - EPD)

Construction projects instigated by the public sector find funding through schemes such as public-private partnerships (PPP) or private finance initiatives (PFI). In Germany, some of the resulting buildings have already managed to gain recognition for their above-average energy efficiency and received certification thanks to their contribution to sustainable development. With construction projects of this kind, it is recommended that requirements for environmental protection and health and safety (sustainability) be integrated into the performance-oriented, functional invitation to tender explicitly (e.g. energy efficiency, indoor air quality, environmental impact) without specifying the technical solutions by which they should be accomplished. This would enable the appointed companies to fully exploit their innovation potential. It is also advisable to implement some form of systematic monitoring (in respect of energy consumption and user satisfaction, for example) and reporting to the user of the building. Arranging a systematic commissioning of the building and adapting the domestic engineering are just as important.

Green procurement is an influencing factor not only for the public sector, but for investors, too. A survey of investors, fund managers and companies that lease their property showed that more than 80 % consider sustainability to be relevant and plays a moderate to significant role in decisions to purchase or lease properties (with a still increasing tendency). Value is also placed on information detailing running costs. (Frensch 2008)

2.2 *Life cycle oriented tendering*

The greater inclusion of aspects of sustainability in the invitation to tender for, and the planning of, property calls for there to be a better flow of information between the contracting and the tendering party, particularly where this information has implications for property life cycles. The contracting party should not only formulate requirements for the building and its parts in respect of environmental protection and health and safety (sustainability), but also press for the provision of related information in the tender. The identification of ‘strategic components’ has proven to be especially important for the functional, ecological and economic performance of the building. In response to this, the tendering party should incorporate at least the following details into the creation of the tender:

- Information on environmental and health and safety characteristics (e.g. LCA, EPD)
- Information on long-term performance and technical life span
- Information on take-back and recycling opportunities
- Information on life cycle costs
- Information on maintenance (maintenance contract as part of the tender, where applicable).

The efforts of CEN TC 350 with regard to developing formats for the communication of environmental and health and safety product information may make a positive contribution to this process, but the information included to date should be expanded further.

3 FINANCING SUSTAINABLE CONSTRUCTION

3.1 *Objectives and prerequisites*

As early as 2004, the European Commission expressed its hope and expectation that certification of the sustainability of buildings combined with an illustration of their economic benefits would result in increased demand and greater willingness to pay on the part of purchasers and lessees as well as more favourable terms in the financing and insuring of these types of property. (Commission 2004b). The question is thus whether, and to what extent, banks and insurers will recognise and appreciate the economic benefits associated with sustainable buildings. More favourable financing and insurance terms would then be seen as another advantage, which would in turn contribute to a strengthening of demand. To date, however, any examples are few and far between and can be classified by type as follows:

- Banks (KfW in Germany, for example) that act as ‘economic development banks’ and conduct development programmes on behalf of the state using public funds: they channel public money through
- Banks that, as part of a marketing campaign or an awareness of their responsibility to the environment and society, grant special offers valid for defined, individual measures for a limited period of time (usually cheaper interest rates for measures related to energy conservation)
- Banks that specialise in the financing of measures for environmental protection and sustainability
- Banks that are aware of the reduced energy and running costs of sustainable buildings and take this into account when assessing the creditworthiness of the borrower (e.g. for single-family homes) and the amount of credit to give (e.g. energy efficient mortgage)
- Banks that, as part of project financing, grant more favourable terms in recognition of the economic benefits of sustainable buildings (or demand risk surcharges for non-sustainable properties) after having weighed up the property risks

Only in the last example is there a direct relationship between financing terms and recognition of economic benefits as part of property and risk assessments and estimates of performance and probabilities of failure. Subsequent analysis focuses on this relationship. For further steps in this desired direction, the following questions need to be clarified in terms of which prerequisites are created:

- Can the contribution of buildings to sustainable development be described and evaluated in a transparent, auditable and recognised manner? This necessitates, for example, further development of assessment and certification systems and of criteria grids and benchmarks.
- Which attributes and characteristics of sustainable buildings have a direct or indirect impact on the financial risks and prospects of property? Identification of ‘success factors’ is required.
- Can aspects of sustainability be integrated into property and risk analyses and value appraisals and can their positive effects be illustrated? This requires the further development of appropriate methods and instruments.
- Can the greater willingness to pay for sustainable buildings on the part of lessees and investors be proven empirically? For this to be possible, the way in which buildings are described and transaction data are evaluated must be improved.

3.2 *State of development*

As illustrated above, evidence of a relationship between the attributes and characteristics of sustainable buildings and financial risk, value stability and potential for positive growth is a prerequisite for including aspects of sustainability into the process by which financing rates are set.

In terms of integrating aspects of sustainability into methods for risk analysis, property analysis and property and market rating, the first steps have been taken with the incorporation of ecological sustainability. (TEGoVA 2003).

Fig. 1 presents an approach developed in collaboration with the author. It has been shown that all risks related to the market, location, the building itself as well as the planning and operation of the building have economic consequences. These all have impacts on cash flow, growth and in so far also on financial risks. By developing strategies on the basis of improving the relevant characteristics and qualities these risks can be reduced. In particular, any characteristics directly or indirectly related to sustainability, but also those that relate to the quality of planning and sustainable site selection can contribute here. In the end a reduced risk should result in better (financing) terms when considering the financing options for a project.

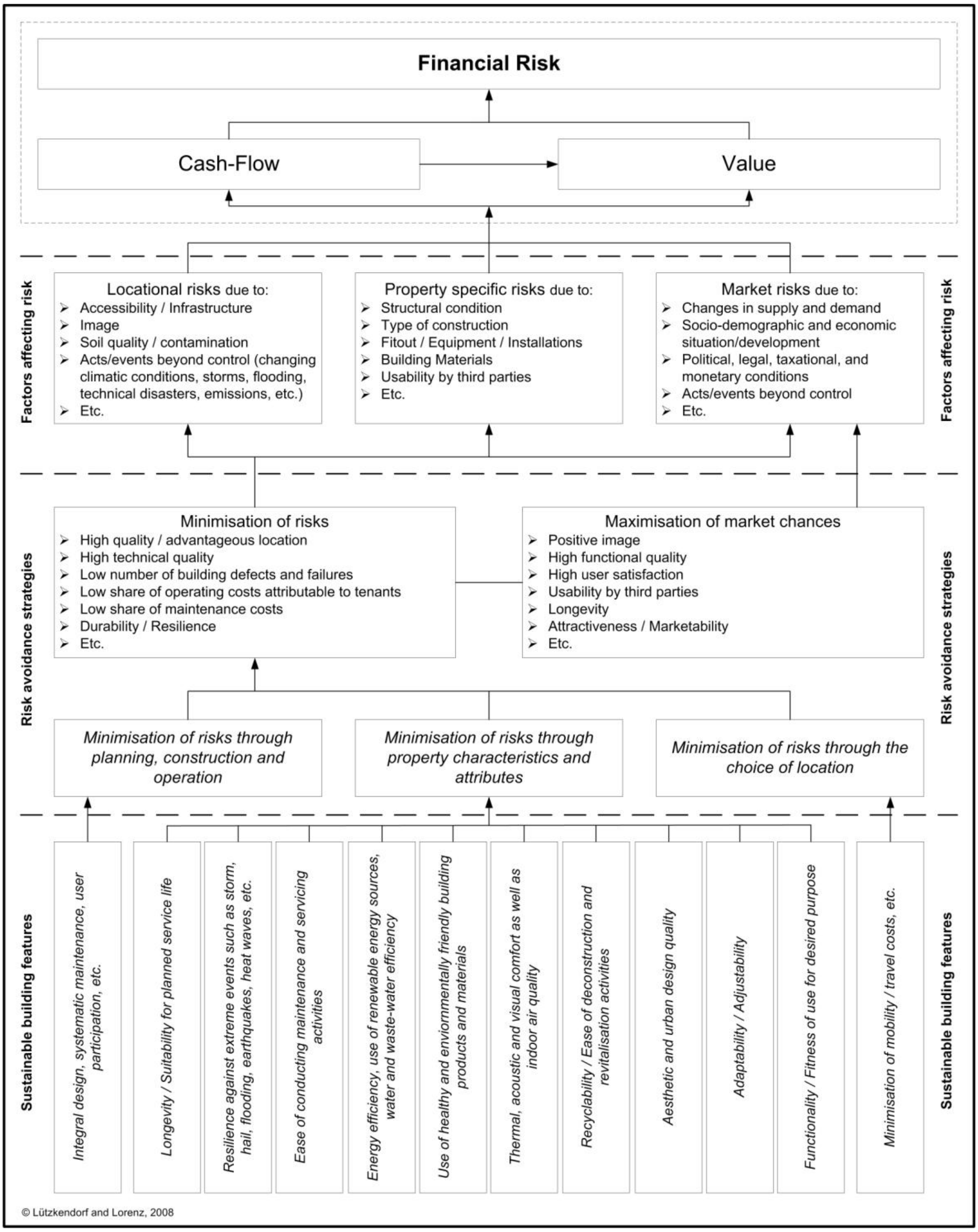

Figure 1: Relationships between property features and financial risks (Lützkendorf & Lorenz 2008)

Attention is drawn to the fact that, on the one hand, not only do direct aspects of sustainability (e.g. energy efficiency, water-saving measures) have an impact on sustainability, on the other hand they also affect risks. There is often failure to recognise that traditionally recorded attributes, such as aesthetic, technical and functional quality, similarly contain references to sustainability. As a result, the inclusion of aspects of sustainability is already more pronounced than is usually assumed. On the other hand, not all attributes and characteristics relevant to sustainability are immediately crucial to future leasability and marketability and thus to financial risk of constructions in the short and medium terms (e.g. recyclability). In collaboration with the author, the possibilities for integrating aspects of sustainability into risk analysis and portfolio management are being analysed in Germany as part of the 'IMMOwert' project.

The integration of aspects of sustainability into value appraisals is currently the subject of intensive work internationally. (Lorenz 2006), (Ellison et.al. 2007), (Lorenz et.al 2008) After development has been driven forward by research projects from the academic field first, practitioners and their associations will increasingly recognise the need for examination of this matter. The first workable proposals are available. (Meins & Burkhard 2009)

For the time being, it remains to be seen whether, and to what extent, banks will acknowledge the benefits of sustainable buildings by taking them into account in their decisions to grant credit and, in doing so, make it easier to secure financing. It can, however, be assumed that this topic is being actively addressed in that respect.

4 CONCLUSION AND OUTLOOK

The subject of 'green building' and 'sustainable property' has taken hold in the property industry. Growing demand, also in connection with new products such as 'sustainable property funds', can already be observed. This demand can be strengthened further by the purposeful alignment of public procurement with the principles of sustainable development, the further development of framework conditions (laws, regulations, standards, funding programmes) and the use of market mechanisms. Prerequisites include:

- further development of systems and tools for describing and assessing buildings and their harmonisation
- improvement of the empirical basis through the surveying and publishing of transaction data, supplemented by the fundamental attributes and characteristics of properties
- extension of empirical studies to provide evidence of the ecological advantageousness of sustainable buildings, e.g. by determining the relationships with financial risks and value performance
- development and dissemination of tools to aid the tender invitation process
- integration of sustainability-relevant information about products, designs and buildings into the tender documents
- integration of aspects of sustainability into PPP and PFI models.

Subsequent work consists in developing standardised criteria grids and practices that can be adapted in a straightforward manner to the particular nature of individual countries, regions or climate zones. With ISO TC 59 SC 17 and CEN TC 350, for example, the International Organization for Standardization and the European Committee for Standardization can make a contribution in this respect. It is important that the complexity of sustainability assessment be preserved. One-sided overemphasis of energy efficiency or carbon footprint must be avoided, while endeavours to operationalise life cycle costing should be intensified. It is recommended that the work already commenced by UNEP-FI and UNEP-SBCI on developing assessment criteria designed to represent the viewpoint of investors and users be continued and intensified. References to the sustainability reporting (alignment with the principles of the Global Reporting Initiative (GRI)) of companies in the construction and property industries are also recommended.

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http://www.umweltbundesamt.de/building-products/index.htm
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http://ec.europa.eu/environment/gpp/pdf/toolkit/construction_GPP_product_sheet.pdf
http://ec.europa.eu/environment/gpp/construction_work_en.htm
http://www.unepfi.org/work_streams/property/
http://www.equator-principles.com/
http://www.greenbuildingfc.com/

Useful links: Assessment Systems, lead market and others

http://www.nachhaltigesbauen.de/bewertungssystem-nachhaltiges-bauen-fuer-bundesgebaeude-bnb.html
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The shift from “less bad” to “0-impact”

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ABSTRACT: Around 1860 the “party” started. Humanity bought itself time with new technologies driven by fossil fuels, and materials and fossil fuels could be deployed in an accelerated manner. Base materials could be fetched from places that were further and further away. If in some places a society from so called “undeveloped countries” still tried to manage their resources, this was completely thrown in disarray in the 20th century.
The entire world became the hunting ground of the industrialised world. Every time that there was a threat of a short-lived crisis in “developed” countries, we could again sidestep to stocks from other regions. The Hunting--gathering had again risen in all its glory.

1 SIX BILLION HUNTERS AND GATHERERS

You could actually say, in fact, that natural selection as described by Darwin in 1859(!) had been ‘deferred’ for large parts of humanity. There were no more natural enemies, no food or other resource shortages and humanity itself could grow in number without restraint.

150 years later we are on this world with nearly seven billion peers and all available land has been subdivided and is being developed or is occupied by people. There is no virgin territories any more that can be claimed except Antarctica perhaps but this is for the time being (…?) still under ice. Stocks and (fossil) energy are running out and society is running against a new limit. The last convulsions are taking place: the hunter can only secure resources by force of arms as in Afghanistan where three months after the incursion, contracts for the oil pipeline were signed. The gatherer is stripping the last areas using beads and mirrors as China currently does in Africa with road construction in exchange for base material extraction. Hunting and gathering, or might we say it changes to steeling and plundering. ..

The physical and political limits have again been reached after 150 years. The postponement, bought with fossil fuels, has reached its end. Again we must search for the balance but now with more than six billion people and with an unprecedented consumption pattern. The credit crisis story is, by the way, not simply a financial one. It is based on wanting to buy and own products and base materials without limit and to conclude lines of credit for this because the resources cannot be acquired fast enough or have been distributed incorrectly. We are literally living on credit.

Many are no longer aware of the link with the foundation for affluence, base materials: it is as if mobile phones are growing on trees; that is the way they are used (“the new harvest has been collected”). Technology has become a natural phenomenon. It is available and it works. Should it not, there is a replacement since maintenance no longer exists. We process and manage but are no longer related to the base. For the Flower Power generation: it is Zen, but without the art of motorcycle maintenance .

Figure 1. Turning Torso: 150 years of playing and experimenting, depleting planet: building consuming ~ 3400 kg / m2,

We are frenetically continuing to search for fossil fuels that are becoming scarcer by the day and are plundering the whole world. When they are found, they are becoming more and more difficult to extract. They will, therefore, become an assault on financial and energy resources with further price increases and economic crises as the result.

We only have to look at the Netherlands: we preach renewable energy, a modest 20% more in 2020 but oil extraction is again being pursued in Drenthe with huge investments in steam to make this oil fluid; energy efficiency drops considerably due to this. Exploring for gas is again being pursued. We, of course, also have planned new coal-fired power plants under the guise of the fact that we can store the CO_2. In 20 years time. Perhaps. Maybe.

We also have biomass: cultivate energy ourselves on agricultural land. The available land in the world is the first official scarce item in accordance with the EU. So we use biomass for our "energy hunger" This could, theoretically be possible as shown by research. We could cultivate both food and energy on the currently available area of fertile land. All of production on a global scale must then, however, be brought to the yield level of the Netherlands (which is among the highest in the world due to artificial fertilisers) and we must all become vegetarians. This is already inconceivable from a human perspective and also impossible because of fertiliser base materials becoming scarcer…

We may perhaps be able to stretch things a little by developing technologies but that the hunting ground is finished, is clear. That is to say, it has been subdivided, it is in use and there is no way out. The world itself has become an island. The only hunting grounds are those of our own species: Darwin revised. We are having more selection: a fight for resources that Darwin could never have envisaged through, for example, wars or, rather, unnatural selection?

How will this go on if we do not change anything? In research carried out by Barclays Bank into the operation of financial markets, they have currently arrived at the following conclusion:

"Major risk is business-as-usual, which equates to a degeneration into widespread resource conflict and ecosystem collapse."

Its is time to change things. To stop hunting an gathering, and start sowing and harvesting, in a way that we can continue for long in a balance with natures potentials.

We started thinking about this at the end of the last century. Awareness was growing, at least on our energy situation, and , as in our field of knowledge, buildings should become more energy efficient, less energy demanding. So we started improving these buildings, products from a century of abundance, and reduced energy demand of new constructions by 10 pct or so. That was the first step.

It was still a amaturistic attempt: trying to survive our way of life, with just a little bit of improvement, but nevertheless, there was a beginning. Since the nineties of the 20th century however we have slowly faded away of this direct attempt to improve at least energy performance:

Slowly the holistic approach has entered the scene, in which everyone should be happy: the planet, the people and the profit. The PPP syndrome. That is the most astonishing move stakeholders have been able to establish: The energy ambitions have not been fought, They have been able to pack these in a ever growing list of "sustainable" ambitions, .

Which enables a high score without even having saved a single Joule (except for countries with mandatory energy standards) Because both the people and the profit should score well, its more like "People making profit depleting Planet"

When will the notion emerge that resources are at the basis of society: food, energy, water and materials. If they are not available or if they are not managed properly, a society cannot exist and certainly not grow. And these base resources are used by people to give shape to their affluence and wellbeing. Economy and policy are there just to facilitate and give direction to this. They can be adjusted since these are not natural phenomena : we invented them ourselves, somewhere in mediaeval times. And it is rather logical when you are going to steer resources based on an economical profit principle that has proven to be aiming for the opposite that sustainability will remain a farce.

The tools we use have undergone similar trends: more and more is included, from performance to proces management, from architecture to re-use of products, and comfort and health. To make this work we had to find all kinds of innovative ways of calculations. And start using weighing factors to compare what was not comparable. Even in LCA tools…

And compare things with the past:. Even at high policy level, this approach has been practiced: The Kyoto protocol measures everything compared to 1990. (We have created a bad concept, and measure in how far we improved a little from that, forgetting that it remains a bad concept…

So now we have arrived at using either broad holistic tools disguising any progress or failure, or on the other side a focus on CO2 reduction, which is a end of pipe approach of a single issue.

2 WHERE TO GO

With Regard to Building and construction : 150 years of experimenting by architects and and depleting resources by construction, its time to conclude that there is a need for a new architectonic and urban language. With choices made out of the unlimited options explored the past age, and to select a few that support and maintain modern society. Not only with regard to an individual building but also with regard to a new approach towards the urban organism, the 'orbanism' , to ensure it no longer consumes and wastes, but learns to behave as it is becoming in a decent habitat. Forming the biotope together with landscapes in which we can live and reside for many a day.. If we do not, it will be very inconvenient for all of us: and its either we do it ourselves, create a post carbon society, or society will do it for us: A post Crash Society We need a transition from (less..)consuming cities and landscapes to productive cities and landscapes.

And It is about time to define where to go to, instead of improving where we came from. And that's what we need to evaluate therefore: in how far are we away from a 100 % renewable sources based building? Of course, we do *not* add up energy and materials to one score… We need to establish a sustainable balance for both, not for the average!

This creates the approach for a closed cycle management of our resources, and building an built environment management: A use of resources, that can be maintained for long. There is however limits to such an approach: The use of renewable sources requires to renew them, and the potential worldwide is limited, see the calculations on biomass. And therefore the renewable resource base sets limits to what can be done: It will most likely require that not only we make a shift for renewables, but to slow down the rate of use, and the speed by which they go in and out a cycle, as well, as to reduce the energy to drive the cyclic use. Or in other words, we will have to divide the growth potential of renewables equally over the population. For energy this seems not such a great problem, for materials that’s an other story, it will create the need for highly efficient management of resources and maintenance of building stocks.

Figure 2. Ijburg III :Neo-canalhouse in Amsterdam: 5 levels in prefab timberframe with strawbales.

Now how to establish this? How to design new buildings and districts with optimised energy and water systems, and with materials that do not deplete resources, nor created CO2 emissions? And how to re-develop our neighbourhoods and districts in a transition for 0-impacts? How to plan a route for cities to become energy neutral?

Things have started to happen already though not fully recognised like that . Think of FSC wood: a attempt to manage wood in closed cycle manner, controlled. We see similar trends in fish (fishfarms) and food in general (slow food movements). Even in biofuels: to grow and renew the resources for fuels. (by the way: a temporary experiment, due to the scarcity of land, but nevertheless an example of the search for manageable resources)

And “0-energy buildings” are popping up in every country, and are approaching mainstream. In the Netherlands stakeholders agreed with the government to increase gradually to 0-energy new houses over 25 pct in 2012, and 50% in 2016 and 100 % in 2020. The UK already adapted a policy where all houses should be CO2 neutral by 2016. In Belgium the industrial areas develop 0-CO2 strategies, and in Germany we find the first energy producing buildings and houses. Its obvious that the notion is growing that we no longer should improve bad concepts from the past, but have to look forward: how far are we from the ideal situation. Even cities more and more introduce and explore policies to become energy neutral or even Climate neutral. And this is still only energy. With water, materials and land we face similar approaches: resources are getting scarce or require more and more energy to quarry or produce. Strategies for 0-water districts are tested and a few pilot projects have been established. Food supply will become more critical, if ever more people start living in cities. Urban Agriculture is gaining ground, and integrated in new town planning.

And With G20 just recently in July 2009 agreeing on 80 pct CO2 reduction by 2050, (However not materialised in a treaty in Copenhagen) its obvious there is no escape anymore as to explore the situation where buildings and Built environment have 0 or near 0- impacts.

It makes things easier as well: In the case of 0-energy buildings (defined as buildings that on site provide the renewable energy to meet the buildings demand) its no use to measure CO2: its not an issue anymore. By transferring to renewable energy, we have both tackled depletion of fossil fuels and by definition have eliminated the side effect of CO2 emissions.

And with materials the same: They should be provided from renewable materials, and the eventual energy involved from renewable energy sources. Lets be clear about this: The future will be based on closing cycles: to be able to maintain our lifestyle with a circular management of resources. Circular as O as a circle , or 0 as zero regarding impact for the different use of (re-) sources, for ages to maintain.

3 THE CONCEPT OF O

Reated to building and construction the approach can be summarised as follows:

O-energy

No life without energy… But only life with 0-energy: the use of energy without climate impacts or depletion.: 0- fuels degradation, or 100 % renewable. With Buildings and Built Environments that manage within their system borders the energy needs.

Figure 3. Winning student design to be constructed in the District of Tomorrow Eco/nnect, Roel Derkx en Leroy Merks: energy plus, and > 50 renewable materials, with 0-landuse: the roof has become productive.

O-materials

Energy and mass are two of the same, and materials, as the earthen form of mass, are diluted and depleted, unless based on a renewable source, indeed: here comes the sun, again. 0-materials, therefore is similar to 0-energy: the use of renewable sources, and to renew these in a similar time-space frame, to compose and maintain buildings and built environments.

O-water

Water is at the heart of life, and there is enough for everyone, in principle. And in fact like energy is never lost as well , only degraded , by dilution ,contamination and poisoning. No problem to use it, however to clean up for re-use as well, and remain available in the area: Leading to a 0-water approach and eco-sanitation concepts for built environments .

O-land

Land is where it all comes together: to collect and convert solar radiation into food, biomass and energy. And with 7 billion people and growing the most scarce ‘resource’. How can we create buildings and built environments that have the least occupation of land? Productive buildings in stead of consumptive built environments , and house 7 billion with a acceptable level of welfare?

O-air

The air carries rain, lets sun rays pass, distributes seeds and makes us breathe. If we change the balance, everything else changes. To live, without unbalancing the air around us, is about designing built environments that are and keep clear of smog, fine dust and other nasty elements. Leading to the concept of 0-air (pollution) .

4 CONCLUSION

A future system wll have to be based upon a closed cycle operational use of our resources. And by definition this ca n only be renewable sources: The ones that can be regenerated over their time of functional use. All others will deplete our resources, and with 7 billion people and growing, this will be even the more urgent.

Figure 4. Hundertwasser: “The vertical is for man, the horizontal for nature”

It will require a whole different approach to buildings, and proceeding the current way of construction , and only a little bit better can not be maintained as a strategy.

This is what has led to the initiative for a research institute Built environment of Tomorrow, that solely focuses on research to make the 0-options happen; Simmarised a s The concept of O . O stands for a cyclic approach leading to 0-depletion, 0-pollution, 0-climate change etc, by approaches that aim for 0-energy , 0- water etc. And its not only The concept of O in the western technocratic way of things, it also relates to the Eastern notion of O : O as in the Japanese Wa, for Harmony, or in the Chinese Ying Yang, for balance. O is where all comes together, in a balanced way of managing our resources, to be maintained for ever.

It’s the only way we can house over 7 billion people, and remain a certain level of standard, without depleting alle earth bound resources and biotopes. It might require us to adapt as well, to settle a t a lower level of materials throughput, but at the end it’s the only way. It will take time, of course, we cant establish this overnight. But we should start measuring and evaluating our activities, towards this target, to keep the focus straight and gradually change to this ideal future. In stead of trying to maintain , what cant be maintained.

Construction Counts for Climate – Also after Cop15 in Copenhagen

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ABSTRACT: The text explores the role of sustainable – not just green – buildings and construction in climate change mitigation. What is the potential of the many different actors and stakeholders to make a difference during the whole life cycle of a building? How can public policies support energy efficiency in buildings? What is the role of the construction and real estate sector in global climate change strategies? This text is based on the *Sustainable Development Innovation Brief on Sustainable Buildings and Construction,* compiled by Dr. Kaarin Taipale, to be published by the UN DESA in 2010.

1 INTRODUCTION

The global level of urbanization has only recently reached the 50 per cent watershed. Urbanization will continue to expand rapidly. It will touch upon the lives and energy consumption patterns of hundreds of millions of people, who are going to move to urban areas which are being built right now. One of the crucial questions of our time is how to mainstream sustainability, and sustainable use of energy in particular, as a key principle of urban development.

Buildings and urban infrastructure create the framework for our daily life. Real estate represents a massive share of public and private property, and its long-term value is linked with financial stability. As major sectors of national economies, both production of building materials and construction create hundreds of millions of jobs all over the world.

From a life-cycle perspective products from only three areas of consumption – food and drink, private transportation, and housing – together are responsible for 70-80 percent of the environmental impacts of private consumption. Both housing and mobility are interdependent key elements of the built environment. About 30 per cent of carbon dioxide emissions are caused by fossil-based energy that is used in buildings

Achieving sustainability of the built environment is not only a local but also a global challenge. It depends on overcoming major hurdles illustrated by the following numbers. 1.8 billion people are expected to suffer from fresh water scarcity by 2025, mostly in Asia and Africa. 1.6 billion people are without access to modern energy. Each year, 2 million people globally die prematurely due to indoor and outdoor air pollution. Currently, 1 billion people are slum dwellers, lacking clean water and sanitation. Millions of people are constantly threatened by flooding related to climate change.

The overall challenge of the land use, construction and real estate sectors is massive throughout societies, both at the macro and micro levels. The impact of decisions in these sectors can be immeasurably long-term. It is not possible to reach any sustainability targets if the built environment and its stakeholders are not included in the effort.

2 WHAT IS SUSTAINABLE CONSTRUCTION, WHAT IS A SUSTAINABLE BUILDING?

In this text, *construction* refers to the production processes of new buildings and infrastructure, as well as to their refurbishment and reconstruction. *Buildings* refer to the consumption phase, which covers the use, operation and maintenance of existing buildings. The production processes represent the supply side with the involvement of the building materials and construction industries, as well as engineering and design professions, among others. Occupation of spaces and maintaining the functionality of their structural and mechanical systems can be understood as the demand side, with both the owners of real estate and users of space in charge.

With a few exceptions this text focuses on buildings, even if it is difficult to outline system boundaries between a house, a city block, a community, an urban or rural settlement, and a megacity. Mobility and urban infrastructure are elements linking individual buildings with each other. However, municipalities as systems of governance and providers of basic services are much more than just built environments.

There is no universal definition of sustainable construction. It is constantly evolving as our understanding of the complexity of the issues increases. Out of a variety of possible formulations, one is included here as food for thought. It is based on an ISO description: "Sustainable construction brings about the required performance with the least unfavourable ecological impacts while encouraging economic, social and cultural improvement at local, regional and global level."

The concept of sustainability of buildings and construction covers not only environmental or ecological ("green") aspects, but also economic, social and societal aspects of the built environment. All these dimensions have to be considered from a long-term, life-cycle perspective. The assessment of economic sustainability considers not only the initial investment in land and construction, but also questions such as the cost of maintaining and operating a building over a longer period of time. Social and societal sustainability cover issues which are often closely linked with economic and environmental ones, such as access to basic services, upgrading poor housing conditions, creating decent jobs, fair trade of construction materials, transparency of tenders for contracts, cultural values embedded in old buildings, and accessibility to buildings.

A figure by Nils Larsson, iiSBE, which unfortunately could not be included in this text, but will be shown in my keynote presentation, illustrates the differences between the scopes of issues to be assessed in green or sustainable buildings. The smallest box highlights the current view that the environmental loadings caused by energy and resource consumption during the operational phase of a building are the core variables to be monitored. In buildings, life-cycle thinking translates into this performance-based assessment. The selection of these core issues also reflects the present emphasis of both the public and professional debates on climate issues. However, sustainable buildings have many more criteria to fulfil. Two more dimensions are often added to the full system: the impacts of the production and transport of construction materials, and the mobility impacts of the selection of a certain construction site.

The life-cycle of a building is a process, which starts with the formulation of a need to construct, the selection of a site and preliminary planning. Construction itself covers a rather short period, in contrast to the use and reuse of buildings, eventually ending in the demolition of the building and waste management, or deconstruction and reuse of building elements. The process can take anything from a few years up to hundreds of years. During every phase of the life cycle, decisions are made concerning the performance of the building, with or without consideration of the full potential impacts of these decisions.

Measuring progress. The implementation of sustainability requires that there is a consensus at the local level of what is the baseline condition of each issue, the "business as usual", against which progress is measured. This means that measurable targets and minimum requirements and their indicators have to be defined. Additionally, a system and a timeline for monitoring performance and reporting of it have to be decided upon, including sharing of responsibilities – who does what.

At the beginning of any construction project, before setting their own priorities, the stakeholders need to be aware of the great variety of issues that should be re-evaluated from the perspectives of sustainability and life-cycle. A similar evaluation is needed when the appropriateness of national or municipal building policies is assessed.

Assessment, rating, labelling and certification. Different evaluation systems have different tasks to fulfil, depending on the phase of the building's life-cycle during which they are used. The basic questions are: How well does your building perform? What kind of performance is meant, and when is it measured – is it the predicted performance which is assessed at the design stage, or the actual performance during the operation of the building? What is the performance of the building compared to – is it compared to set standards or other similar buildings? For what purpose is the performance assessment needed – for evaluating return on real estate investments or for measuring national contributions to climate change mitigation?

Rating gives a score or result relative to a norm or global benchmark. Ratings can be based on self-assessment or carried out by third parties. Certification means the validation of a rating or assessment result by a knowledgeable third party that is independent of both the developer and designer, and the developer of the tool used. Labelling gives proof of a rating or certification result which has been issued by the certifier. A great number of evaluation and certification systems have been developed, such as LEED in North America, BREEAM in the UK, HQE in France, CASBEE in Japan, GRIHA in India, HK-BEAM in HK, PromisE in Finland, SBTool as a generic R&D platform, and several others. Even if many of the challenges are global and similar indicators can be used, any rating or labelling system should be adapted to its region of use.

When the rating system is developed within a specific region, it can contain assumptions about appropriate performance benchmarks and the relative importance of issues such as water resources, energy resources, risk of earthquakes or flooding, local climate, solar hours, cultural aspects, availability of some materials, and so on. An overview of some of the systems has been published, among others, by UNEP SBCI and FI: *Financial & Sustainability Metrics Report.*

Availability of technology. Sustainable construction does not require new expensive technology. It is necessary to acknowledge the many advances of the 20th century modern architecture, such as an increased interest in housing issues, and the development of industrial mass production of building elements, which has made many products available at a lower cost. But by now, we are also familiar with the negative impacts of the so-called International Style, which led to a non-analytical dissemination of the same modes of construction all over the world. It resulted in buildings that apply similar solutions and technologies regardless of the local climate, or local patterns of space use and maintenance. These buildings not only waste resources, but age rapidly and are difficult to refurbish and reuse.

In every climatic and cultural region, a lot can be learned from traditional architecture; for example, orientation of buildings on the site, the use of local materials, or heating and ventilation systems. The skill needed now is how to translate the traditional knowledge into responses to contemporary demands. Great examples all over the world show that this is possible.

Connecting stakeholders. The process of financing, commissioning, designing, constructing, using, operating, maintaining and refurbishing buildings is long and complex. This means not only that several different actors and professions are going to be involved, but also that the owner, the user and the operator of a building do not automatically share the same priorities. In order to have a positive impact, it is necessary to address several different stakeholders and have input at several stages of the process, starting with the land owner and ending up with the caretaker of the building. The design decisions that are made at the beginning of the process have the greatest impact. For this reason, the viewpoints of as many experts and stakeholders as possible should be integrated into the process as early as possible.

CSER. The concept of Corporate Social and Environmental Responsibility (CSER) implies that a private company not only acts according to local legislation but is proactive in looking for solutions to improve its sustainability performance. The Global Reporting Initiative (GRI) offers tools for companies to assess their performance. GRI is presently working with construction and real estate companies and their stakeholders to create sector-specific commentary on their more generic G3 reporting guidelines and additional sector-specific performance indicators. The UNEP Finance Initiative (FI), together with sector stakeholders, has developed Principles for Responsible Investment (PRI). UNEP FI has a specialized working group on property investing, which has published a number of useful reports and toolkits, including *Owner-Tenant Engagement in Responsible Property Investing* and *Responsible Property Investing – Committing and Engaging*, both of which are available on their website.

3 BUILDINGS AND CLIMATE CHANGE

Worldwide, roughly 40 per cent of all energy produced is consumed in buildings, which translates to about 30 per cent of all carbon dioxide emissions. The 4th assessment report (2007) of the Intergovernmental Panel on Climate Change (IPCC) compares the emission reduction potential of various sectors with the costs of implementing them. The comparison makes it clear that buildings are one of the "low-hanging fruits", where the huge emission-savings potential is the cheapest to implement. Again, the IPCC graph which unfortunately could not be included here, is shown in my keynote presentation.

The key fact is that while the high level of emissions from the production of construction materials and the resulting embodied energy must not be underestimated, the focus has to be on the operational phase of the building, when at least 80 per cent of the energy is used. Thus, any decision taken today on *how* buildings and cities are built will have a long-term impact. From today, each new building constructed in an energy-wasting manner or retrofitted to a suboptimal level will lock us into a high climate footprint future.

The other side of the coin is that we cannot focus on *new construction* only, as *existing buildings* also need to be refurbished so that their energy consumption is reduced radically. Buildings are key to climate change mitigation in each world region and that the greatest potential is in the refurbishment of old buildings. By 2050 (as compared to 2005) as much as 77 per cent of final thermal energy consumption can be eliminated by building codes, while living standards increase and energy poverty is eliminated. However, the level of emissions in 2050 is extremely sensitive to the retrofit rate: The 77 per cent energy savings is based on a 3 per cent retrofit rate, but if it drops to 1.4 per cent, energy savings drop to 37 per cent! At the same time, suboptimal retrofit represents a major climate lock-in risk for many decades. For this reason, suboptimal retrofits should not be supported. Instead, it would be better to wait if an optimal retrofit is not yet possible.

A frequently heard counter-argument is that energy efficiency requirements increase the cost of construction. A recent example documented by the International Energy Agency (IEA) shows that when using passive house technology, the extra costs can be 3–5 per cent of the total costs, with a payback period of 9–10 years. Measures increasing the energy efficiency of buildings have the potential for a negative net cost over time, as the initial investment pays itself back and can be reinvested back into the community. Energy efficiency leads to positive economic and employment growth.

With existing technology we can build and retrofit buildings to achieve energy savings of 60–90 per cent, as compared to standard practices in all climate zones, while providing similar or increased service levels. It has been estimated that a worldwide transition to energy-efficient buildings would create millions of jobs as well as "green" existing employment for many of the estimated 111 million people already working in the construction sector. Investments in improved energy efficiency in buildings could generate an additional 2-3.5 million green jobs in Europe and the United States alone, with a much higher potential in developing countries.

Construction materials. One of the starting points of construction is the production of building materials, a process which is often highly energy intensive. However, during the life cycle of a building, the impact of construction and construction materials varies between 10 and 20 per cent of its total energy use. Thus, as far as energy consumption of buildings is concerned, the use and operational phase will consume the major share of energy. This, however, does not mean that the resource consumption of the production and transport of construction materials should not be analysed and taken into account.

Principles for increasing the energy-efficiency of production include technological improvements of production processes, use of recycled or alternative materials, and use of alternative fuels, such as waste materials. Among the most energy intensive basic materials are aluminium, iron, steel and cement. The cement industry contributes about 5% to global anthropogenic CO_2 emissions. Polymers such as plastics and bitumen have a large carbon footprint. Construction materials like glass, ceramic tiles and brick also require high temperatures in the production process. In 2007, the Chinese government released new standards for the cement industry. Producers are expected to reduce energy use by up to 15 per cent by 2010. Similar initiatives have been undertaken by the three largest cement companies: Cemex, LaFarge, and Holcim. Cemex plans to reduce its emissions by 25 per cent by 2015, while LaFarge and Holcim aim to reduce their emissions by 20 per cent each by 2010.

Common Carbon Metric. A broad group of experts and organizations agreed that the following metrics, taken from building performance data, should be used to compile consistent and comparable data: *energy intensity* is measured as as kWh/m^2 per year and kWh/occupant per year; *carbon intensity* is measured as $kgCO_2e/m^2$ per year and $kgCO_2e$/occupant per year.

A report published by UNEP SBCI, *Common Carbon Metric for Measuring Energy Use & Reporting Greenhouse Gas Emissions from Building Operations* (2009), now provides a consistent and verifiable methodology to measure the climate footprint from buildings that had been missing until now. It is accompanied by a globally consistent common carbon metric for buildings which provides the required common language for measuring greenhouse gas emissions and energy efficiency of buildings. The globally harmonized method for measuring, reporting and verifying energy use and carbon dioxide emissions provides the basis for establishing baselines, performance benchmarking, and monitoring improvements in building performance. These activities are in turn fundamental to informing international mechanisms for carbon trading, policy development and analysis, and progress reporting on the mitigation of CO_2 emissions from buildings. Policy- and decision-makers can produce reports from the data collected through these metrics for jurisdictions, regions, owners of large building stock, and cities. Additionally, the data can be used at a national level to form baselines that can be used to set targets and show improvements in carbon mitigation in the building sector.

NAMAs, Nationally Appropriate Mitigation Actions are voluntary emission reduction measures by developing countries that are reported by national governments to the United Nations Framework Convention on Climate Change (UNFCCC). They are expected to be the main vehicle for mitigation action in developing countries under a future climate agreement, and can be policies, programs and projects implemented at national, regional, or local levels. NAMAs are a very new concept, and consequently there are opportunities for developing countries to define potential design options and shape concrete policy measures. The above-mentioned carbon metrics provides a framework for measuring emission reductions in buildings, so as to support also the formulation of NAMAs.

The buildings and construction sectors have four recommendations for the policymakers involved in climate change negotiations:

- Prioritize the buildings sector as a means of achieving national GHG emission reduction targets
- Recognize energy efficiency and GHG emission reduction programmes in the built environment as Nationally Appropriate Mitigation Actions (NAMAs)
- Reform the Clean Development Mechanism to support investment in energy efficient building programmes in developing countries
- Develop base-lines for building-related GHG emissions using a consistent international approach to performance monitoring and reporting.

4 POLICY PRIORITIES FOR SBC

The implementation of sustainability in the built environment can be supported by a mix of policy measures, targeting both consumer and the citizen, and the producers. Until recently, public awareness in terms of buildings' sustainability was low. Not only policy-makers but also professional and industry associations and trade unions have a vital part in formulating visions, taking care of capacity building and disseminating information about their particular roles in sustainable construction. As people's awareness grows, they will be able to make more educated choices. As a result, producers will have to react to consumer demand. The market also can be a driver for the most innovative companies that want to become forerunners in their fields. These are the ones who will develop their products and services based on future demand. At the same time, the public sector can push development with regulatory policies and with various financial and taxation tools. One process with a major potential to shift the market to more sustainable production patterns is public procurement. This is as true for buildings and construction as for any product or service.

The goals of and political arguments for the policy priorities outlined below are the need to combat climate change; the need to save money in new construction, maintenance, use of buildings and refurbishment; and the need to combat poverty, raise the standard of living and secure healthy living environments. Studies prove that policies are the cheapest and the most effective tools to initiate change towards sustainability. The UNEP SBCI report *Assessment of Policy In-*

struments for Reducing Greenhouse Gas Emissions from Buildings (2007) compared different tools, analyzed barriers and made recommendations for effective combinations of policy instruments. Policies are also discussed in UNEP SBCI's report *Buildings and Climate Change. Summary for Decision Makers* (2009).

One key area where policies need to focus is *energy efficiency*. Being directly linked with climate change mitigation, improvements in the energy efficiency of buildings should be included in international discussions on climate change. In the reduction of energy consumption, the main concern is the use of fossil fuels. Increasing the share of *renewable energy* in heating, cooling and provision of electricity is one part of the equation. In many countries, recently also in China, the introduction of Feed-in-Tariff legislation has supported a quantum leap to using renewable energy sources. The final goal should be to have *energy-autonomous buildings* that produce all the energy they need. In their recommendations for the buildings sector, the IPCC listed the following key mitigation technologies and practices currently commercially available: efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycling of fluorinated gases; integrated design of commercial buildings, including technologies such as intelligent meters that provide feedback and control; solar photovoltaics integrated in buildings. A tool that gets the attention of real estate owners is an energy audit which includes recommendations on how to refurbish the building. It is also useful to remind house owners that since buildings have to be renovated from time to time, it makes economic and environmental sense to improve their energy performance at the same time.

*For new construction***,** the priority should be given to optimizing energy efficiency during use and in maintenance, by strengthening focus on *maintenance and operation* of buildings, mainstreaming low-energy and zero-energy construction, including passive technologies, and supporting housing schemes that raise the standard of living and are based on energy efficient technologies and renewables, local materials and local labour.

*For refurbishment***,** efforts should focus on raising awareness about the need to refurbish existing buildings for energy efficiency, and designing industrial solutions for "*mass implementation*" of the retrofit of existing buildings including housing, to make them more energy efficient and convert them to the use of renewables.

Tools to facilitate these goals include awareness raising about the *added value* that can be gained through increased energy efficiency (e.g. using energy certificates as tools**,** public awareness campaigns to influence human behaviour in energy consumption, include health externalities into economic calculations for improving indoor air quality. Financing is also important in order to develop and mainstream models for *affordable housing*, including processes and funding mechanisms; create incentives to generate employment with to retrofit existing buildings to conserve energy; and to create investment incentives for local energy production from renewable energy sources, integrated into buildings, and secure the development of resource neutral distribution systems.

Building codes need to be universal and fully implemented. Codes need to cover major retrofit as well, not only new buildings. The most advanced low-cost know-how needs to be mandated. The construction industry needs to gear up to be able to meet with new standards. Mandatory regulations are needed to guarantee a minimum level of performance in areas like structural safety, fire safety, accessibility and energy performance.

Urban planning. Even if a building fulfilled every conceivable energy efficiency requirement, but was located in a place that can only be reached by private car, most of the "greening" efforts would be in vain. Land use and transport solutions are crucial for climate change mitigation. Every effort to improve the energy efficiency of the built environment has to confront the challenges of urban sprawl and mobility, which also have profound social and economic implications. Building codes alone will not do the trick.

Financial and fiscal tools can also help. Typical examples are government grants and tax credits for qualified refurbishment of buildings. The level of real estate tax can be linked with the performance of the building. Another powerful tool is sustainable public procurement.

The *public sector* plays a focal part in providing building policies and guidelines. Its roles are multiple and include: to set an example in energy issues and create markets by encouraging all government agencies and public organizations to initiate and implement energy savings, energy efficiency and renewable energy programmes; to initiate and implement programmes that secure access to clean energy for those who lack modern energy services; to introduce energy efficiency criteria into the public procurement of construction work and buildings, and the maintenance and refurbishment of buildings; to integrate climate change and energy efficiency aspects in urban development policies; to structure financial incentives to support building activities that take a long-term energy efficiency perspective and facilitate the transition to renewable energy sources; and to collect (energy consumption and production) data and establish baseline information in order to assess the impact of policies.

Governments - local, national and federal - have to *lead by example*. They can do this by introducing sustainability criteria into the management of their real estate and construction and refurbishment of buildings that are built with public money or used for public purposes, be they offices, schools, museums, sports facilities, roads, bridges, or energy and water utilities, for example. This means introducing the appropriate sustainability criteria into procurement of space, or when commissioning the construction of new buildings and providing for their operation and refurbishment. If the public sector does not implement sustainability targets in construction and in the management of its own spaces, who will?

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Chapter 2

Policies to Low Cost Sustainable Construction

Benefits of water efficiency

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ABSTRACT:As water is a limited resource which has to be safeguarded and conserved, its efficient use is a sustainable imperative in every country in the world. Climate change in Mediterranean countries, like Portugal, could significantly affect the short- / medium-term availability of this resource, and so measures must be developed in all sectors, as a matter of urgency, to improve water-use efficiency.

This paper describes some of the actions being promoted in Portugal that have this goal in mind, and demonstrate the benefits of the water efficiency measures, not only on the environmental perspective, with conservation of water and energy, but also in an economic point of view.

A great number of these actions are being promoted by ANQIP - National Association for Quality in Building Installations, an NGO that work on the implementation of water-efficiency certification systems for products and buildings.

1 INTRODUCTION

Water has become a resource of the utmost importance. Demographic growth and, most especially, economic development and today's lifestyles have rendered drinking water scarce, and its status has changed over the past decades from that of a community and national asset to that of an economic one.

Climate change has worsened the situation and it is predicted that in certain countries, such as Portugal, the forecast reduction in rainfall or the alteration of its regime could have a negative effect on situations of crisis in the short to medium term. Because water is a finite resource which is essential to life, its rational usage at all levels is now a priority.

Mankind is already using approximately 50% of the fresh water resources available. In only 15 to 20 years this percentage could rise to 75%. As a consequence the risk of hydric stress will increase significantly across the entire planet and some countries, such as Portugal, might experience very serious problems in a large part of their territory by 2025.

In addition, there is a high level of inefficiency in the water supply system in Portugal (in public and building systems), which amounts to approximately 250 million m³ a year, representing 60% of total inefficiencies in economic terms. The Government aims to rectify this situation and has drawn up and published a National Program for Efficient Water Use, anticipating the support of various non-governmental organisations and non-official bodies to achieve its goals. Amongst the actions suggested in this Plan are proposals for the labelling of devices in buildings (flushing systems, showers, etc.) in order to provide consumers with information as to their water efficiency. The Plan suggests that this measure be made compulsory after a transitional period.

The National Program for Efficient Water Use (PNUEA) [1] also predicts the involvement of companies, management organisations and non-governmental organisations for the implementation of the said measures. ANQIP (National Association for Quality in Building Installations) is the only large Portuguese association which focuses on building installations and it covers the sector of businesses, universities, management organisations and technical companies. Its responsibility is clear in terms of launching the process and its leadership role.

2 WATER EFFICIENCY CERTIFICATION AND LABELLING IN PORTUGAL

2.1 Short description of ANQIP (National Association for Quality in Building Installations)

ANQIP (www.anqip.pt) is a Portuguese non-profit association and was established in 2007. Its members include several universities, firms from the sector, management organisations and self-employed technicians, whose basic aims are to promote and ensure water quality and efficiency in the water supply and drainage fittings and fixtures of buildings [2][3][4][5].

Under its powers and in accordance with the proposals of the National Plan for Efficient Water Use ANQIP decided to introduce a product certification system and a water efficiency labelling scheme in Portugal, starting in 2008.

The model used (described below) was implemented in stages and started with cistern toilets, since these account for most consumption in building systems in Portugal.

2.2 The water efficiency labelling model proposed for Portugal

The water efficiency labelling of products has generally been implemented voluntarily in various countries. In some countries efficiency is not graded, but an efficiency label is awarded when consumption is less than a specific amount. This is the labelling system in use in the US and Scandinavia, for example. In Australia and Ireland (Dublin), however, the label indicates a classification that varies with the product's efficiency [2][4].

ANQIP has opted for a voluntary model of the latter kind for Portugal. Figure 1 shows the labels used. The base colours, which cannot be seen in the Figure, are green and blue.

"A" signifies the greatest efficiency and is considered ideal. It also takes into account the user-friendliness and performance of the devices in question. There is a graphic indication by means of drops, for a better understanding of the symbol, and a small informative bar at the side. The A+ and A++ ratings are meant for special or regulated applications, as explained below.

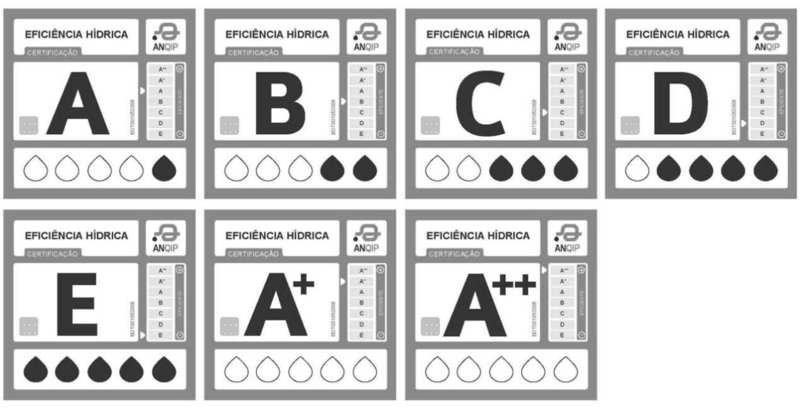

Figure 1: Portuguese water efficiency labels

ANQIP has drawn up Technical Specifications (ETA) for different products so as to create and establish the necessary benchmark values to be assigned to each letter. These Technical Specifications also establish the certification testing conditions.

Firms signing up to the system will sign a protocol with ANQIP which will define the conditions under which they can issue and use the labels. ANQIP controls the process by randomly testing labelled products on the market, from time to time. These tests are performed by accredited laboratories or by laboratories which are recognised by the Association.

2.3 Certification and labelling of flushing cisterns

As mentioned earlier, cisterns were regarded as a priority since toilet flushing cisterns are one of the biggest consumers of water in buildings in Portugal.

As there is a project for a European Standard for WC and urinal flushing cisterns (prEN 14055:2007), it was decided that the labels of water efficiency to be used in Portugal should comply with this Standard, where applicable.

The following mechanisms are also regarded as water-saving devices, under this Standard:

a. Double-action mechanisms (interruptible): one action initiates flushing and a second action stops the flush;
b. Dual-control mechanisms: one control releases the full flush volume and another control releases a reduced flush volume.

The reduced volume cannot be greater than two-thirds of the maximum flush.

Table 1 presents the categories defined in the Technical Specification ANQIP 0804 for flushing cisterns.

The minimum permitted volume or discharge amounts in current facilities are limited for reasons linked to performance, user-friendliness and public health. The use of 4-litre flushing cisterns, for example, has led to problems in the flushing of solids in building and public networks. Therefore, their usage requires an alteration of the usual criteria of the design of the drainage system (which is incompatible with many existing drains). In addition, the European Norm EN 12056-2 does not allow the use of 4-litre flushing systems in building systems whose design comply with System I of the said Norm, and this is precisely the most common system in Portugal, allowed by the General Regulation.

Furthermore, it must be ascertained if the discharge volume is compatible with the other characteristics of the cistern toilet. Product performance is usually ensured by compliance with European norms, meaning that any water efficiency certification must require prior compliance with the existing norms in terms of the product’s respective performance (in the case of flushing cisterns, as mentioned above, it is the prEN 14055).

Based on these facts, ANQIP established low volume flushing cisterns belonging to water efficiency categories A+ or A++, but with the obligation that the label should warn users of the need to guarantee the performance of the system and compatibility of the drainage conditions in the building system (Figure 2).

Table 1: Water efficiency categories for the labelling of flushing cisterns

Nominal volume (litres)	Type of flush	Water efficiency rating	Tolerance (Maximum volume – complete flushing)	Tolerance (Minimum volume for water-saving flushing)
4.0	Dual control	A++	4.0 – 4.5	2.0 – 3.0
5.0	Dual control	A+	4.5 – 5.5	3.0 – 4.0
6.0	Dual control	A	6.0 – 6.5	3.0 – 4.0
7.0	Dual control	B	7.0 – 7.5	3.0 – 4.0
9.0	Dual control	C	8.5 – 9.0	3.0 – 4.5
4.0	Interruptible	A+	4.0 – 4.5	-
5.0	Interruptible	A	4.5 – 5.5	-
6.0	Interruptible	B	6.0 – 6.5	-
7.0	Interruptible	C	7.0 – 7.5	-
9.0	Interruptible	D	8.5 – 9.0	-
4.0	Complete	A	4.0 – 4.5	-
5.0	Complete	B	4.5 – 5.5	-
6.0	Complete	C	6.0 – 6.5	-
7.0	Complete	D	7.0 – 7.5	-
9.0	Complete	E	8.5 – 9.0	-

Figure 2: Examples of water efficiency labels for low volume flushing cisterns

2.4 Certification and labelling of showerheads and shower systems

Shower systems and showers represent over 30% of the daily average domestic water consumption volume in Portugal [2] [5]. At this level, efficiency reduces both water consumption and the consumption of energy required for the production of hot water.

The classification of these devices considers the following:

- Shower heads (showers), individually;
- Shower taps equipped with a hose and a shower head or with a fixed shower head (shower systems).

For shower systems and showers, the model implemented considers the ideal usage (letter A) to represent a water usage of between 5.0 litres/minute and 7,2 litres/minute. The A and A+ labels applied to shower heads with a discharge which is 5 l/min or less must bear the indication "Recommended for usage with thermostatic taps", due to the increased risk of scalding. [6]

In products which can be regulated by the consumer, certification may be awarded on the basis of the most efficient position, as long as the criterion is clear to the consumer, without any risk of confusion, and it must be marked next to the label. Due to the fact that discharge is dependent on residual pressure, the established reference residual pressure for all ratings and for the tests was 300 kPa, which represents the average pressure in Portugal and is the pressure selected by several recognised laboratories for various tests.

The taps for bathtubs were not rated, because hot water consumption depends on the volume of the tub to fill, and not on the discharge of the device.

Table 2 presents the various efficiency categories for showers and shower systems.

Table 2 – Water efficiency ratings for the labelling of showers and shower systems

DISCHARGE (Q) (l/min)	Shower	Shower systems	Shower system with a thermostatic tap or an eco-stop function	Shower system with a thermostatic tap and an eco-stop function
$Q \leq 5$	A+	A+	A++ (1)	A++ (1)
$5.0 < Q \leq 7.2$	A	A	A+	A++
$7.2 < Q \leq 9.0$	B	B	A	A+
$9.0 < Q \leq 15.0$	C	C	B	A
$15.0 < Q \leq 30.0$	D	D	C	B
$30.0 < Q$	E	E	D	C

Note (1): Eco-stop functions are not considered of interest in these cases

2.5 Certification and labelling of taps

The certification and labelling of taps are now being study by the technical commissions of ANQIP. Tables 3 and 4 presents the various efficiency categories for taps, in study.

Table 3 – Water efficiency ratings for the labelling of bathroom taps (in homes)

Discharge (l/min)	Bathroom taps	Bathroom taps with an aerator or an eco-stop function	Bathroom taps with an aerator and an eco-stop function
$Q \leq 2.0$	A	A+	A++
$2.0 < Q \leq 4.0$	B	A	A+
$4.0 < Q \leq 6.0$	C	B	A
$6.0 < Q \leq 8.0$	D	C	B
$8.0 < Q$	E	D	C

Table 4 - Water efficiency ratings for the labelling of kitchen taps

Discharge (l/min)	Kitchen taps	Kitchen taps with an aerator or an eco-stop function	Kitchen taps with an aerator and an eco-stop function
$Q \leq 4.0$	A	A+	A++
$4.0 < Q \leq 6.0$	B	A	A+
$6.0 < Q \leq 8.0$	C	B	A
$8.0 < Q \leq 10.0$	D	C	B
$10.0 < Q$	E	D	C

The certification and labelling systems for urinals and other devices will only be developed by the end of 2010.

3 RESULTS OF THE IMPLEMENTATION OF THE SYSTEM IN PORTUGAL. THE CASE OF THE FLUSHING CISTERNS

The water efficiency certification and labelling system for flushing cisterns was implemented in the last quarter of 2008. Approximately 40% of the companies on the market adhered to the new system from the outset. Initially, 29 flushing models were certified. Many companies and consumers have complied with the system, and it now covers about 70% of the national market. 44 flushing models have been certified, corresponding to 93 commercial references.

Table 5 summarises the certifications awarded per category. [6]

Table 5 – List of certified flushing cisterns according to category

Category	No. of certifications awarded
A++	0
A+	2
A	86
B	5
C	0
D	0
E	0

The situation presented in Table 5 was expected (i.e. no certifications awarded to the less efficient categories). In fact, because compliance with the system is voluntary, manufacturers/importers do not usually request labelling for less efficient categories. This is not negative for the system; quite the contrary. Since so many companies and consumers complied with the system, the lack of certification of the said flushing cisterns will gradually lead to their removal from the market, thus contributing towards ANQIP's goals.

4 CASE STUDY

In the following tables are compared the consumptions in buildings, in Portugal, equipped with conventional products and products with the letter "A". It is assumed an average occupancy of 2.7 persons / building.

Table 6 – Consumption in a building equipped with conventional products

Product	Consuption l/s	Time of use accumulated per day min	Total time (2,7 persons per building) min	Total consumption per day l/day	Total consumption per month m^3/month	Total consumption per year m^3/year
Shower	0,15	5	13,5	121,5	3,6	44,3
Bathroom tap	0,10	4	10,8	64,8	1,9	23,6
Kitchen tap	0,20	-	5	60,0	1,8	21,9
Product	l per use or discharge	Number of uses or discharges (per person)	Total number of uses or discharges			
Flushing cisterns	9	6	16,2	145,8	4,4	53,2
Washing machine	90	-	1	90,0	2,7	32,9
Dishwasher	22	-	1	22,0	0,7	8,0
TOTAL				504,1	15,1	184,0

Table 7 – Consumption in a building equipped with products with letter "A"

Product	Consuption l/s	Time of use accumulated per day min	Total time (2,7 persons per building) min	Total consumption per day l/day	Total consumption per month m^3/month	Total consumption per year m^3/year
Shower	0,10	5	13,5	81,0	2,4	29,6
Bathroom tap	0,03	4	10,8	19,4	0,6	7,1
Kitchen tap	0,06	-	5	18,0	0,5	6,6
Product	l per use or discharge	Number of uses or discharges (per person)	Total number of uses or discharges			
Flushing cisterns	6	6	16,2	97,2	2,9	35,5
Washing machine	45	-	1	45,0	1,3	16,4
Dishwasher	16	-	1	16,0	0,5	5,8
TOTAL				276,6	8,2	101,0

It's easy to observe that the savings can reach 45%.

Considering also the inherent energy consumption for heating hot water, this economy can reach 51%.

5 CONCLUSIONS

Efficient water use is an environmental priority in all countries of the world. However, in some countries, such as Portugal, the development of measures in this field has become urgent because the availability of water could be significantly reduced in the short or medium term.

Special attention must therefore be given to the use of efficient products, and consumers must be able to identify these efficient products, leading to the need for a labelling system which is easy to understand.

In Portugal, ANQIP, a non-profit NGO, has decided to launch a voluntary water efficiency labelling system for products, similar to those developed in other countries.

Over 70% of the companies operating on the Portuguese market have adopted the first certification and labelling system, for flushing systems, and 93 certified flushing systems are available.

This initiative will most certainly provide an answer to the crucial and urgent need for intervention in the field of rational water use in Portugal, aiming to guarantee in the near future the essential sustainability conditions desired.

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Architecture, tourism and sustainable development for the Douro region

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ABSTRACT: this paper deals with sustainable construction and architecture in the douro Region touristic facilities. We claim that this has vital role in achieving the tourism full potential for conservation and development of the region with recognized potential for tourism growth. Buildings that make possible tourism occupation, involve extra consumption of energy and natural resources, when compared to average levels of local communities.

To make progress on this, we are gathering a representative set of tourism compounds that will be evaluated through criteria from evaluation methods of sustainable construction like SBtool, LiderA, LEED and BREEAM. We are gathering data related with the comfort experience of this buildings users, aiming to know the ratio between tourists demands of comfort, and final consumption of resources.

As result of this research, we intend to refine environmental certification criteria in this specific geographical context and building category, and if necessary, define corrective intervention strategies and guidelines.

1 INTRODUCTION

In Europe, "increased demand for sustainable destinations, were nature and local communities play a key role"(ETC, 2006) along with a growing environmental awareness are recognized as crucial factors in the success of tourism products. The Portuguese National Strategic Tourism Plan (MEI, 2006), places "Gastronomic and Wine Tourism" in first of the 10 strategic products. Nowadays, the Upper Douro and Douro International, combine the strands "Wine" and "Nature" with recognized potential for tourism growth. However, architecture and contemporary construction are synonymous with intervention and change of preexisting ecosystems. Moreover, the buildings that are necessary for leisure and tourism activities, imply an extra consumption of energy and natural resources, when compared to consumption levels for regular dwelling.

The original development impetus of the industry associated to the Demarcated Wine Region of Alto Douro, with 250 years of existence, has little in common with the current demands of growth and development of the "Gastronomic and Wine Tourism" concept. In many cases Tourism, understood as "leisure, culture, mobility and knowledge, is just a synonym for unsustainable "(Costa, 2006).

To overcome such problems, in one hand "the policies of destination management should be improved with a more consistent and coherent planning"(ETC, 2006). Tourism growth should follow ecotourism models, understood as a scientific approach to planning, management, development of tourism products and sustainable activities. On the other hand, at a small scale analysis, attention to architecture and construction detail of tourist facilities, is central to "explore the potential for tourism promoting conservation and development, avoiding the negative impact on the ecology, culture and aesthetics"(Lindberg, 2002). In Order to have Tourism contributing to national cohesion, reduction of interior desertification and following the latest theories of Ecology and Nature Conservation, it is also necessary to know the factors that interfere with the comfort feelings of visitors and users of Tourism buildings. The comfort parameters required by visitors should converge with the need to lower the levels of energy consumption and reduce landscape and environmental impacts, such as solid waste, sewage and water use. In a region that is a unique example of the balanced relationship between human activity and nature, visitors will most probably tend to settle in the most sustainable facilities.

Despite that we don't known the ratio between the tourists demands of comfort and final consumption of resources, the result of individual small decisions in architecture to satisfy these requirements are reflected exponentially in the environmental indicators of the tourist region.

2 DOURO REGION

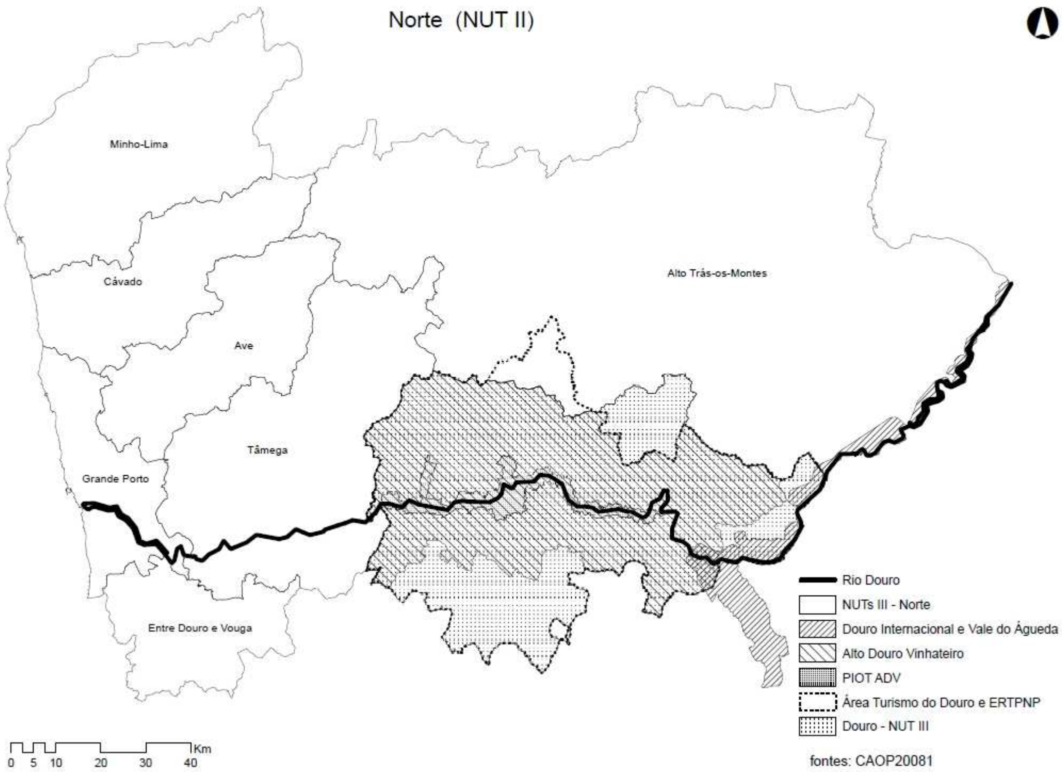

Figure 1. Map of North (classification of territorial units for statistics – NUT II) and Entities: Douro River; North Regions NUT III; International Douro and Águeda Valley; Alto Douro Wine Region; Intermunicipal Plan for Land Use Planning of the Alto Douro Wine Region; Areas of responsibility of the Douro Tourism and Regional Tourism Entity for Porto and northern Portugal; Douro Region – NUTIII.

Much is yet to be done in the Douro Region, regarding the growth of construction for tourism purposes, justified by key factors of Portugal differentiation. There are clear intentions of promoting tourism, in order to stimulate rural development and fight desertification, stated in the National Strategy for Sustainable Development and in all sectoral policies regarding the Conservation of Nature and Biodiversity (Zorrinho, 2005). It is though mandatory to know the specificity of these region and sub-regions to sustain the interventions in the near future. Figure 1 pretends to give an overview to this region in terms of territorial compartment and institutional organization that shares the Douro river as the main common and unifying element. The subregion Alto Douro Vinhateiro, recognized for the Vineyard of Porto Wine, is a Unesco World Heritage Site and one example of a successful relationship between human economic activity, and demanding natural elements. This region has critical characteristics of fragile water resources, though its proximity to an apparently stable river. Further upstream the "International Douro is an orographic enclave formed by the River Douro and its tributary the *Águeda*, natural border between Portugal and Spain, has unique characteristics in terms of geology and climate, affecting communities of plants and animals, including birds, and the actual human activities”(ICN, 2007). This particular area was recognized as Natural Park in 1996 (RCM, 1996) and crosses three NUTIII regions, starting from *Douro,* continues to the Northeast into the *Alto Trás-os-Montes* and stretches Southeast the *Centro* NUTIII region. Several other entities, not listed on *figure 1*, have general territorial management and tourism specific skills for a region that has a wide diversity of landscape, morphology, geology, climate, demographic and socio-economic characteristics. Forestry and agriculture are relevant economic activities in the region, both for its historical and contemporary significance. Though the industrial and tertiary activities and tourism services are sectors that should lead the economic future Douro region, only with all vigorous sectors can the region effectively set the population. Data reveals that Municipalities with positive demographic trends have in common the existence of alternative activities to the primary sector due to the possibility of obtaining better wages and the existence of a greater diversity of employment opportunities, enabling the incorporation of young people with higher education levels more heterogeneous than in rural societies.

Recently published *PROT-N* (North Regional Plan for Territory Planning) recommends the adoption of a wide range of principles and guidelines for strategic options and operational objectives set for the protection, re-qualification, enhancement and management of water resources, especially by its great relevance for regional development. The main goals are to ensure the management of basin water resources, strengthen Iberian cooperation in water resources field, and to promote socio-economic enrichment of riverside areas, through activities related to nature tourism and leisure, taking advantage of traditional hydraulic heritage and cultural values. This document refers to Tourism, as a transversal activity with strong territorial impact, that interacts and depends on several factors for its economic, social and environmental sustainability. Tree fundamental assumptions are identified in the *PROT-N* as guides to ensure tourism regional development – Excellence, Sustainability, Competitiveness and Innovation. Also, regarding the regional model for energy, *PROT-N* recommends the adoption of best practices for monitoring and benchmarking the Region. In order to assess the progress in energy-environmental sustainability each subregion should define its goals and actively measure them. Tourism is to be set under tight rules on energy performance according to the energy certification legislation (SCE, 2006) requiring that the new 5-star ventures must have class A+ and the 4-star tourism developments should have class energy A or A+. Other *PROT-N* recommendations emphasize the need to promote rail infrastructure in the region and improve integration and coordination of public transport offered by the different operators.

The Douro region is currently facing marginalization of its territory in the national and European level. The socio-economic decline seriously threatens territorial cohesion in a region that struggles to maintain minimum levels of territory occupation and access to local public services and amenities. According to *PROT-N*, the main challenges for this region are to increase its critical mass in terms of population, its attractiveness, competitiveness and its capacity of being self supportive. To realize these ambitions it is mandatory to ensure the pursuit of excellence, the promotion of innovation and encouragement of partnerships between public-sector private.

Among the main *PROT-N* Strategic Guidelines for the Douro region is highlighted the need to strengthen key economic and productive vocations of the region, rearranging and qualifying the business areas and promoting tourism that focuses on local vocations, resources and values, as a major vector of development.

3 TOURISTS

Data from the Department of Tourism (DGT - tourism in Portugal, the main source markets, 2001-2004), reveals that the tourists who visited Portugal in recent years are mainly from countries such as Spain, Germany, United Kingdom, France and other northern Europe countries. The environmental and ecological awareness and the importance that ecology has on public opinion, is higher in the visitors origin countries, than in the general populations of the visited regions. The "German tourists have a higher environmental orientation than those of other nationalities, and more than 50% takes into account environmental concerns in their decisions to travel"(Kaae, 2001). Given that Portugal second largest source of tourist is Germany, in terms of overnight stays in hotels (about 16.4% in 2004, according to INE and DGT), it is of extreme importance in the strategic development of Douro tourism to consider the relevance given by this tourists to environmental issues. Moreover, we should note that this market is decreasing the amount of arrivals in Portugal since 2000, which could, among other things, be a reflection of deviation to other destinations with more environmental awareness than Portugal. These tourists are mainly distributed by about 874 *Pensões* (hostels), along many regions of North and Center of Portugal. In terms of number of accommodation category, Hotels appear in second place with 563 units, with the regions of Lisbon, Center and North holding the largest number of units, with about 66% of the total offer (Costa, 2006). It should also be noted that 2004 saw an increase accommodation capacity in Campsites 3.7%, and Rural Tourism, more 5.1% of beds than 2003 (Silva, 2005).

We want to know to what extent is the "eco-efficiency" factor relevant in the satisfaction of tourists visiting the Douro Region?

4 STATE OF THE ART

Architecture and construction, understood as a means for human settlement, represent irreversible transformation of the natural environment. The growing interest in various forms of tourism, in the most recent period of human history, pursued the industrialization and is associated with the development of "spare time" concept. Since recent evidence of growing global awareness of the scarcity of resources, mankind is increasingly committed to redefining processes to reverse the trend of increasing natural resources and energy consumption. It is now required that tourism architecture ensures the sustainability of systems in which they operate. We are looking for models of sustainable development to reconcile economic development, social justice and the efficient management of natural resources. The WTO Global Code of Ethics for Tourism, dedicated the 3rd Article to the Tourism as a factor for sustainable development. It states that " All the stakeholders in tourism development should safeguard the natural environment with a view to achieving sound, continuous and sustainable economic growth geared to satisfying equitably the needs and aspirations of present and future generations"(OMT, 1999). Also a specific reference is made to construction of infrastructure, which “should be designed and tourism activities programmed in such a way as to protect the natural heritage composed of ecosystems and biodiversity and to preserve endangered species of wildlife”.

According to recent reports of WTO, Europe reveals growing interest in activities associated with rural tourism and directly linked with nature. This is also probably related to the fact that the population residing in large urban areas is growing worldwide. The proportion of world's urban population should grow up to 60% by 2030, according to the information services of the United Nations (UN, 2005).

Tourism is now globally understood as determinant to economic and social development. Nations such as Sweden and Finland, already enjoy the results of coherent policies to improve environmental indicators, presenting the world’s highest levels of development (Esty, 2006). In Portugal, we see ambitious presentations of documents such as Guidelines of the National Strategic Plan for Tourism (MEI, 2006) and the Lisbon Strategy. There we can find explicit intentions to "accelerate Tourism growth" and follow a sustainable model, along with the desire to promote "agricultural and forestry policies that reconcile the productive activities, services, nature conservation, the sustainable use of natural resources and protection of the landscape". These political commitments to "accelerate growth" should be replaced by the desire to "consolidate and qualify", not to further underline the divergence with international and European referential contexts. It is increasingly "difficult to support the claim that sustainable development is continuous economic growth" (Partidário, 1997). Doubts as to the proper implementation in the field of sustainable planning policies, are still fed by reports indicating that 63% of all new tourism projects for the Algarve (South of Portugal), will be in Protected Areas. Moreover, these "developments" where only presented as "five-star hotels" (Rosa,2007). If doubts arise at the level of choosing the most sustainable localization, more uncertainties lie on the effective construction of these tourism buildings that are likely to be caught by the Vicious Circle of Blame (Cadman, 2000) represented in figure 2.

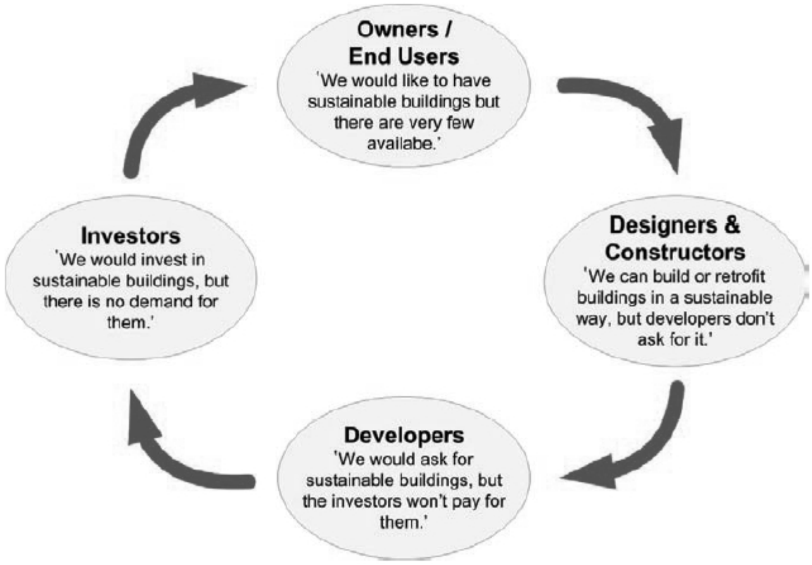

Figure 2. The Vicious Circle of Blame, adopted from Cadman, 2000 (FiBRE,2008)

Parallel to this generic reflection on reasons why buildings are highly unsustainable, in the Portuguese context it is clear that innovative and sustainable products available on the construction industry take too much time to by actually used. To illustrate this fact, the most consensual example can be found in the small number of solar panels for domestic hot water installed in Portugal, when compared to the rest of Europe and locations with less Sun radiation. Even with recent government direct incentives of about 50% of total investment necessary for acquiring a solar water heating systems (Medida Solar Térmico 2009) that significantly raised the number of installations, demand for this efficient proven technology continues very low. Possibly, some other reasons that block innovation and sustainable construction to be applied specifically to Tourism are: stakeholders are insensitive to added value of eco-efficiency and are unwilling to take the risk of innovative solutions, prefering the safety of conventional solutions, architects and designers involved in the construction processes, don’t deal with multi-disciplinary teamwork; architects and designers unable to calculate and communicate the tangible benefits of sustainable building solutions over conventional solutions; high institutional bureaucracy consumes too much time between the start and completion of the project withdrawing the innovation factor; lack of eco-efficiency studies applied specifically to the Tourism buildings and infrastructure to sustain decisions for eco-efficient architecture - though there are several studies focusing on implementation, management and monitoring of eco-tourism facilities, where there is a social, anthropological, environmental or cultural study object, very little focus has been made on construction and architecture solutions; added value and positive differentiation of sustainability certification is not yet demonstrated for tourism services and buildings - at the moment (December 2009), Portugal has only five tourism services certified by the Community eco-label (Label created in 1992 and revised in 2000 by the European Parliament) and three LiderA certified Buildings.

Large investment projects advanced for the Region will hardly change the business model of conventional tourism, despite exhibiting "green" ambitions and applying to higher market levels. While these investments, "normally display substantial quality standards and formally present good sustainability indicators in terms of consumption of water resources, energy or waste management”, most often they neglect singularities of the local context and the region only fulfills the function of support for the tourism activities that are immediately most profitable.

Douro region needs to adopt touristic standards based on the contemporary adaptations of the original Ecotourism model. The term Ecotourism was “coined by Héctor Ceballos-Lascuràin in 1983, and was initially used to describe nature-based travel to relatively undisturbed areas with an emphasis on education”(Rajan, M). Nowadays, Ecotourism is synonymous with models of sustainable tourism development that meets in the present, the needs both of the tourists and visited regions, at the same time protects and ensures equal opportunity for the future. The management of resources must be such that the economic, social and aesthetic needs can be fulfilled while maintaining cultural integrity, ecological processes, biodiversity and all systems of life support.

4.1 *Some examples*

The subject region has no significant or consistent ecotourism projects established, as far as we have been able to perceive, nature oriented tourism accommodations are built in current standards and no innovative solutions are yet explored.

The eco/sustainable/community-based tourism, widely presented as tool for development of pour countries or regions, has its actual benefits and effectiveness progressively questioned and debated. Although there are many early succeeded experiences, only a hand-full of examples have lasted for more than a decade (Luleciler, 2009). In relatively stable Occidental countries, where social and cultural issues aren’t extremely delicate, focus on economic and environmental sustainability allows some space for creativity and experimentation.

In this context, we would like to present a couple of international innovative and systematized solutions to illustrate in what extent ecotourism models can evolve and be reinterpreted to incorporate value in areas with similar problems and opportunities as the Douro region. The examples where chosen only for the simplicity and small scale and innovative approach, though are not to be seen as a best practices or “how to do” solution for the Douro region.

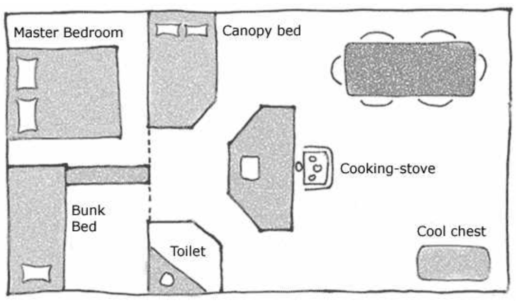

Figure 3. Feather Down Farm tent layout www.featherdownfarm.com

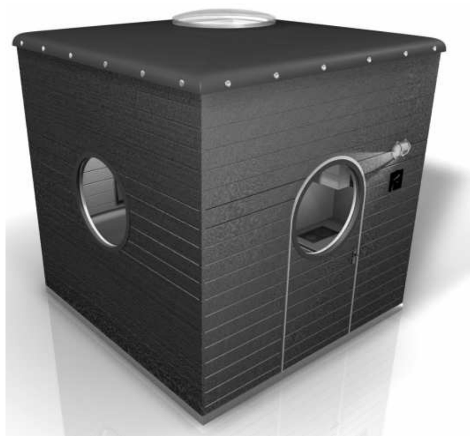

Figure 4. *Carré d’étoiles* 3D CAD simulation www.carre-detoiles.com

Figure 3 is available on the internet site of “Feather Down Farm®” which is a farmers' alliance in the United Kingdom, Holland, Belgium, Germany and United States of America. This on-line tourism business structure is located in selected farmland and rural areas. The Feather Down farms pretends to recreate the rural experience, in harmony with the rhythm of such life. Operating only on working farms where the farmers are passionate guardians of the countryside. Every Feather Down farm has its own speciality: one might specialize in beef; another in organic products; one might be dairy; another might combine cattle with horses or sheep. Not entering in architectural or marketing value judgments, the model Feather Down farm tent, is described as "incredibly spacious and comfortable", with a "traditional interiors" recreating ancient rural life. Tough this business is not globally presented as independently eco certified franchising structure, it aims to emphasize site historical significance and rural conservation is high on the agenda. Some farms are into a Higher Level Environmental Stewardship Schemes, aiming to encourage many aspects of conservation. This work includes restoration of old ponds, ditches, fences and hedges as well as constructing new ponds and lakes to encourage wildlife habitats of rare and endangered plants and animals.

Figure 4 is the key image of a totally different approach to what promoters name as "get away from it all tourism". This "*Carré d'étoiles*" is also on-line tourism business structure which proposes the rediscovery of night spent in the open air, through a forward-thinking innovative type of accommodation. It is a portable and reversible structure set to be placed in any compatible environment. The concept is declared to be based on wisdom and perfection, daring architecture cube shaped accommodation embodying stability and probably a spaceship like experience. Each "cube" is hi-tech equipment and is prepared to proportionate superb sky gazing experience. Each module comes with a sky observation kit, including telescope, stellar chart and pedagogic astronomy games. Some construction details are declared as environment friendly, namely bio-ethanol chimneys and recyclable wood structure.

5 THE APPROACH

Within the Douro geographical context, these research focus is to analyze the architectural features of region's most representative tourism buildings, identify what defines and determines comfort and satisfaction of buildings visitors and users and finally, promote corrective strategies for the analyzed buildings along with organized information to support future building projects.

The fieldwork is being prepared with the objective of gathering architectural surveys on each chosen touristic facility. Tough Christian Baumgartner (Costa, 2006) states that "visitors are not interested in staying in a sustainable hotel in a non sustainable region", we feel that the sustainability isn't yet assessed nor guaranteed in the building lever and so, the regions sustainable balance can be irreversibly compromised.

The World Tourism Organization (Inskeep, 1998) recommends that the principles of sustainable tourism development should undergo a careful analysis of the tourists satisfaction levels so that destinations retain their popularity and attractiveness. Tracking this recommendations in the architectural perspective, means that primary fonts in the shape of data gathering near visitors and users of buildings, is necessary to minimize environmental damage and promote the use of eco-efficient techniques of construction and design. This detailed data, collected from visitors and direct users complies with the principle of "participatory tourism, which argues that" sustainable tourism is reflected in a strategy to convert the traditional model and the incorporation of new parameters management (Fraguell, 1998). This will permit a solid setting of standards for "environmental comfort" in the region.

The ambitioned result, will not create another assessment system of sustainable construction, the aim of this research, is to find concrete solutions, starting from the existing systems available and the new data collected on site, in order to develop indicators to assess sustainable construction in the context of the Douro region. This research aims to provide specific data to improve existing methods such as SBTool, LiderA, LEED or BREEAM in the specific analysis of tourism buildings.

6 CONCLUSIONS

The potential conflicts or benefits that arise from local versus global construction standards is one of the key factors to determine the outcome of the region touristic success extremely dependent on territorial landscape identity. Conflicts can arise due to scarce resources abuse and misuse, whereas in this sense buildings and particularly those related to tourism use have incontestably responsibility if not properly conceived and managed. Benedicts can be found if small scale, locally integrated touristic facilities which are in harmony with the local landscape and where tourists share space with hosts and social exchange occurs (Luleciler, 2009).

Sustainable tourism is an extensively proclaimed strategicall goal for the Douro region, this ongoing work and other related and critical investigation is indispensable to provide valid input for local governance decisions and territorial management tools.

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Life Cycle Assessment of constructive materials – a qualitative approach

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ABSTRACT: This work concerns with the Life Cycle Assessment (LCA) of constructive materials starting from the analysis of a steel construction building. The aim is to find a LCV representation which will be able to communicate the environmental performance in a more effective way the constructive systems for designers. Some methodologies and possible tools of LCA were studied and one of them was adapted concerning communicability of the results. The result is an organigram that indicates the material environmental performance for each constructive system, considering the covered aspects in the Life Cycle Assessment of the ABNT NBR ISO 14040: 2004.

1 INTRODUCTION

The LCA is a technique that evaluates the inputs and outputs of raw material and emissions in each step of the material life, adding the resource extraction impact and the emission of pollutants. Its origin is the immediate products industry (Sonnemann, G., 2003) and it was adapted to the environmental building evaluations. However, the construction process, use and demolition of the buildings, is still artisanal, and there is no precise information on the inputs and outputs of resources and emissions. The absence of database of Brazilian materials makes the use of LCA software, created in other countries difficult, because these are supplied by local databases or similar. Considering this difficulty, the question is how to transform the results of an LCA as prescribed in ISO 14040 series in data understandable to architects, responsible for the selection of building systems. The facility of using the system and understanding of the results are considered crucial in the use of the LCA for selecting building systems.
To answer this question, it was selected a building which was prepared an organigram of perceived environmental impact.

2 DEVELOPMENT

Nowadays, the use of LCA in the construction industry is based on the analysis of each material used in the construction system. The result of this evaluation is the sum of partial results of each material. However, a building is formed by constructive systems that are connected, forming the whole. As a human body: each system works through the functioning of organs and their connections, and the whole is formed by all the systems and their interfaces. The failure of one of them interferes in the whole function. Likewise is the building: its operation depends on the integrity of each building system, which consists of materials, connections and interfaces. For this reason, the positive outcome of the evaluation of materials does not guarantee that a building system composed of these materials is also positive. The application, assembly form and use of equipment in the building system modify its environmental performance.

There are researches focused at the evaluation of the impact of the manufacturing of the materials in Brazil, but data are scarce when it comes to materials used in construction (Soares, S. R., et al, 2006). The creation of a national database of the life cycle of products is the goal of several research groups, but it is an extensive work for the urgency in the selection of sustainable building systems. The aim of this work is to show clear results of the environment performance of the materials and constructive systems to construction industry professionals, in the project step or during the execution of the work.

2.1 *Materials and methods*

The chosen building is the basis for defining the parameters, limits and boundaries of the functional unit to be used. Thus, the limit of the functional unit is a building with a total area of 1575.00 m², deployed in Lagoa do Piau, an environmental protection area, located in Caratinga, Minas Gerais, Brazil.

The initial choice of Piau Building as the basis for the functional unit is justified by the discourse of sustainability, where the architect, Sylvio de Podestá, acts using the concepts of reducing, reusing and recycling to select the constructive systems and concepts of bioclimatic architecture, as ventilation and natural lighting (Fig. 1).

The architectural project with this deployment defines the limits of the functional unit. To define the parameters it was observed the constructive systems that take part of the original building, which are:

- internal sealing system: drywall;
- external sealing system: autoclaved aerated concrete panels;
- cover system: metal tile with polyurethane sandwich + crate of cold-formed steel;
- structural system: cold-rolled + slab with embedded metallic mold.

Based on the characteristics of these systems, substitutions can be made. The defining characteristics of the parameters were based on standards set by ABNT NBR 15.575:2008 for each of the constructive systems. These requirements are described below:

- internal sealing system: fire fighting performance, thermal performance, acoustic performance, durability and maintainability, functionality (interaction with doors and windows) similar to drywall;
- external sealing system: structural performance (production of cracks), airtightness, fire fighting performance, thermal performance, acoustic performance, maintainability and functionality (interaction with doors and windows) similar to autoclaved aerated concrete block;
- cover system: structural performance (strength and deformability), fire safety, safety in use (slip and displacement of parts), airtightness, thermal performance, acoustic performance and maintainability similar to sandwich tile, having very similar weight to sandwich tile with polyurethane core;
- structural system: stability and structural strength and functionality (interaction with sealing) similar to the laminated profile and slab with embedded metallic mold.

Figure 1 – South Facade with glazing and protected plans

The boundaries of this study are from the transportation of raw materials to the construction site to the disposal or dismantling of components. The useful life of the systems is according to the durations provided by ABNT NBR 15575:2008. According to this rule (Fig. 2), the structural and internal sealing systems must have a minimum useful life of 40 years, but the internal vertical sealing and the cover systems must have a minimum useful life of 20 years. Thus, it will be provided two life cycles of internal vertical sealing and of cover to get the compatible result of the building system as a whole. The assessment will be made from the production of components stage, through the use and operation, and ending with the disposal of the building.

The proposed method starts in the planned building, which should be evaluated in two ways: the history of constructive systems and the dismantling of this building (Fig. 3). Thus, it is dismembered in constructive systems and components arising the dismantling of this building, in other words, the past and the future of the building is investigated.

In the historic, or “cradle” of the building, each one of the constructive systems is formed by components that are descendant of processes. These are manufacturing, transportation, assembly, disposal processes - shown in figure 3 as “Process yn” - where each one requires resources (inputs) and emissions (outputs). These inputs and outputs are linked to the process by dashed arrows that indicate the amount used (little, reasonable or very). In each case, the emissions and the use of resources, whether material or energy, are identified by inputs and outputs arrows.

Observing the figure 3, it is noticed that in the way of the history of the constructive system, the last frame of the organigram refers to the inventory of the “X Component”, the inventory of a constructive material, which is outside of the limits of the evaluation proposed in this paper.

In the step of use and operation will be assessed requirements related to the bioclimatic strategies, which are described through the use of energy resources, use and management of water and energy, maintainability of constructive systems, described by the consumption of material resources for repairs and replacement and the performance of the constituent materials of the system, regarding the issue of air pollutants harmful to human health, the thermal performance and airtightness.

System	Expected useful life years
Structure	≥ 40
Internal Floors	≥ 13
External vertical sealing	≥ 40
Internal vertical sealing	≥ 20
Cover	≥ 20
Sanitary	≥ 20

Figure 2: Useful life of the project provided by NBR 15575. Adapted: ABNT NB 15575:2008

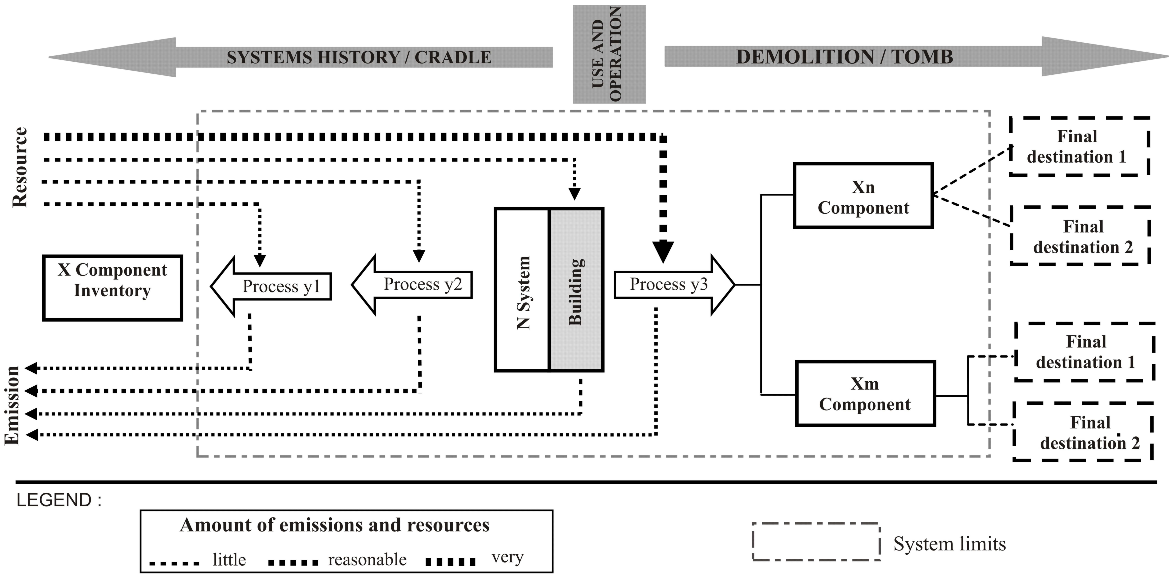


Figure 3 – Methodology model based on LCA - new proposal

For this purpose, the architectural project, solar orientation and direction of the dominant winds will be observed. Strategies for reuse of water will be considered and counted positively if they exist. As for maintainability, thermal performance and airtightness, it will be used as a reference to NBR 15575:2008, which describes procedures for assessing these requirements.
In the disassemble, or “tomb”, there is the possibility of dismantling the building into components and the final destination of each one. These components can, in turn, split into two destinations simultaneously or have two choices of destination. In figure 3, the representation of the output lines of the “Xn Component” indicates that this may have the “final destination 1” or the “final destination 2”. In the case of “Xm Component”, the output line of this frame indicates that this had the “final destination 1” and the “final destination 2”, simultaneously.
The result of this proposed methodology is an organigram where the quantities of emissions are indicated by thick that relate to little, reasonable or very. It is still a subjective classification, but trying to present simple results to be used by the professional who does not have any knowledge of the categories of environmental impact proposed by international organs.
Thus, it is believed that the format of chart facilitates intervention by the designer, because it is easy to identify the location of the heaviest possible environmental impacts and it is possible the replacement of building systems to minimize these impacts.

2.2 *The life cicle assessment of the building piau*

According to the methodology described above, the assessment of Building Piau began at the building in use and operation toward its history (limited to the transport of raw materials to the construction site) and its demolition (limited to the transport of demolition components for disposal, recycling and reuse). Therefore, it has been divided into External Sealing System, Internal Sealing System, Cover System and Structural System. Each of these systems lead to a history and a disassemble, as shown in figure 4.
In use and operation, the building requires an average amount of water for everyday use, toilets and general cleaning, and it does not have box attached or water reuse systems. The request for electricity is small, because the ventilation and natural lighting strategies will reduce the demand for active providing energy. The autoclaved aerated concrete and drywall have adequate thermal inertia to a hot and humid place. As for its maintenance, the sanitary and electrical systems and logic are inspected under the stilts to avoid the dismantling of part of the sealing for maintenance. The materials used do not emit volatile organic compounds (VOCs) that cause damage to human health.

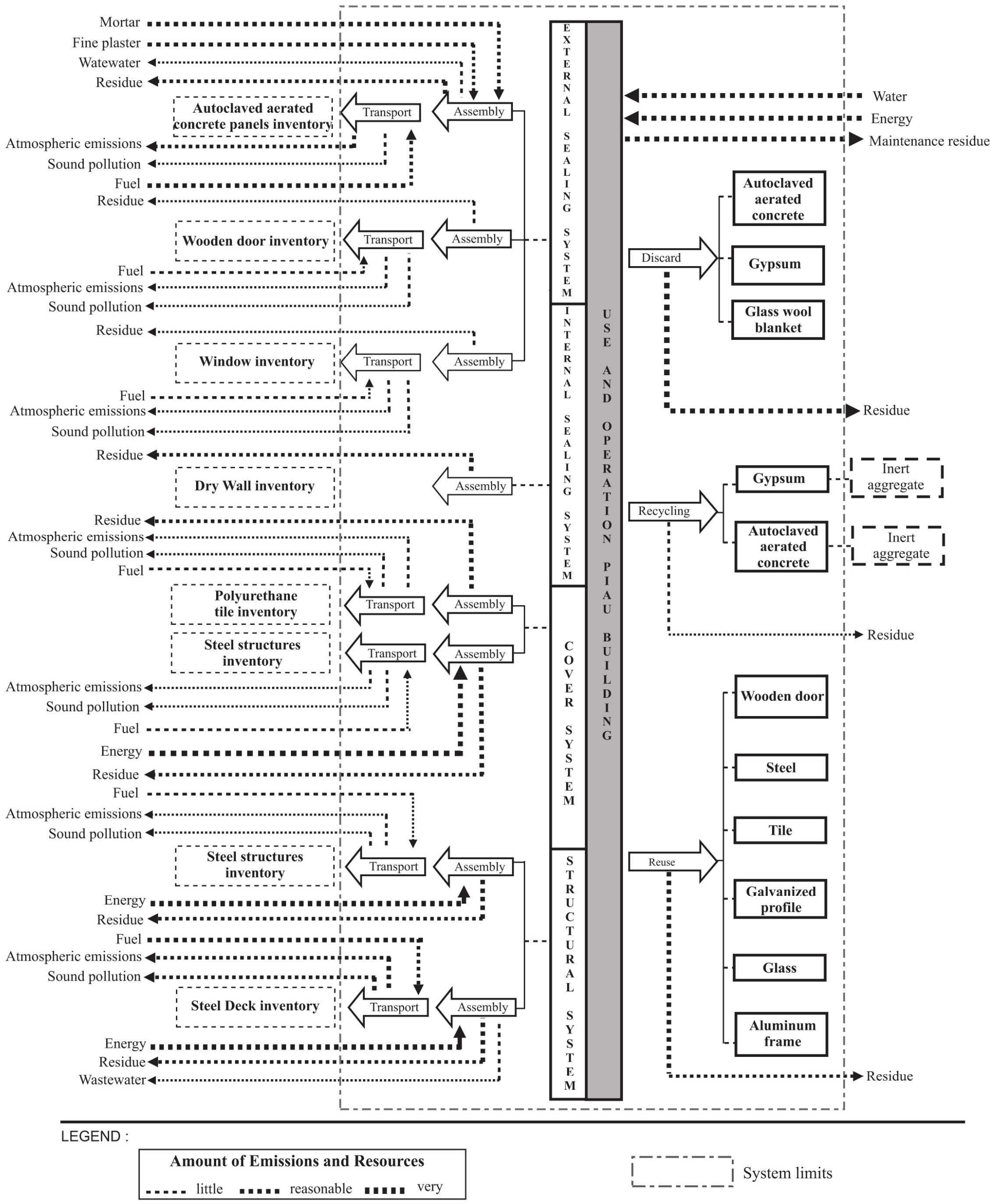
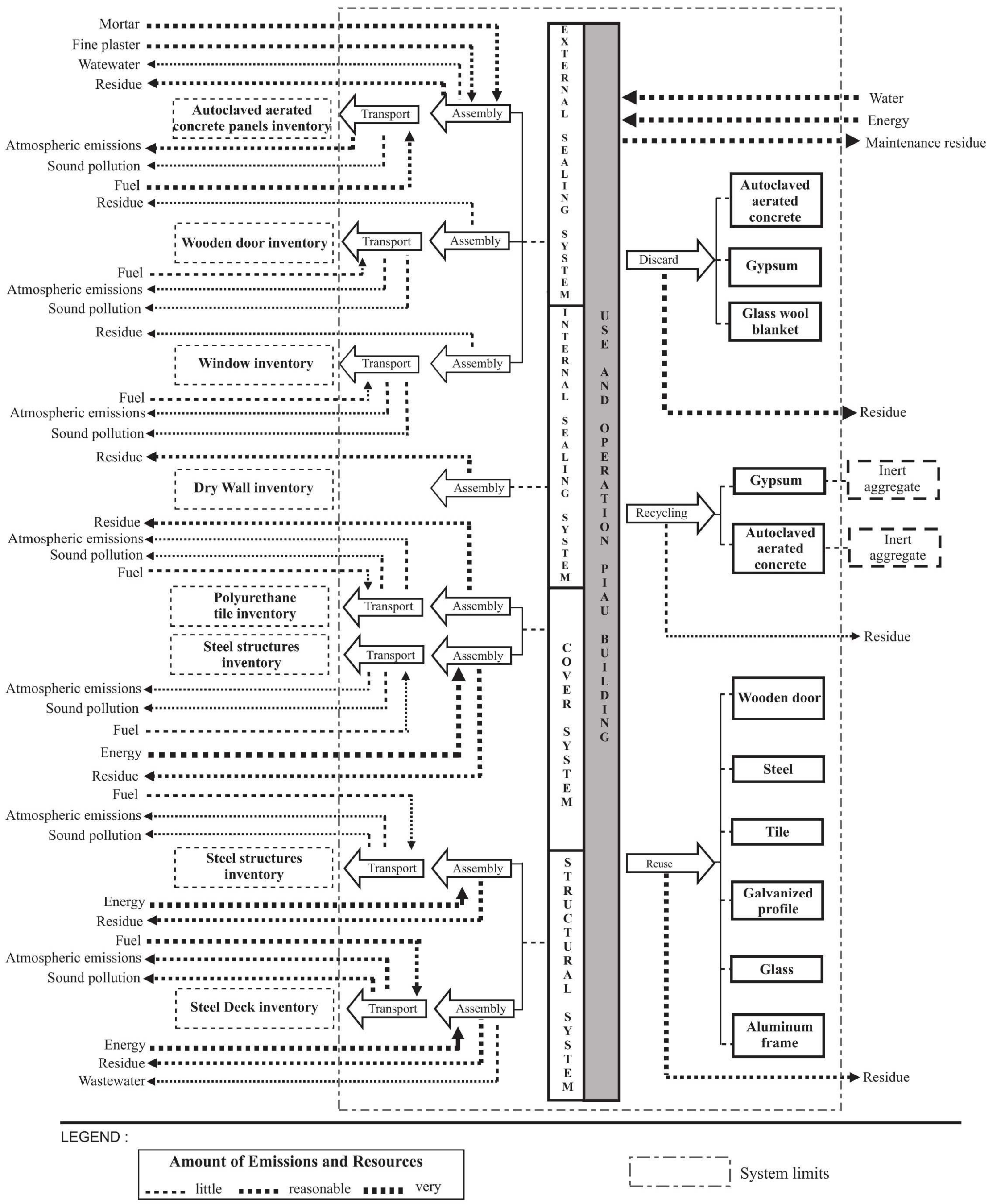


Figure 4 – Organigram of general constructive systems of Piau Building

At the demolition of the building can be verified the possibilities of disposal, recycling and reuse (Fig. 4). The autoclaved aerated concrete and the plaster may be discarded or recycled as inert aggregates in concrete and mortar. In this case, the impact will depend on a decision at the time of demolition. The glass wool can not be recycled and its disposal has to be in special landfills, because of its toxicity. The wooden doors, the metal tile, the aluminum frames and the glass can be reused with less waste if the reuse project considers the existing dimensions. The laminated steel profile, the cold-formed profile and the galvanized profile can also be reused, but with a greater generation of waste, especially in the laminated steel profile and the cold-formed profile that have undergone a process of welding. In the case of galvanized profiles, which are screwed, the generation of waste will be less.

Among the processes of transport and installation of systems that take part of Piau Building, it can be verified that the greatest impacts are in the energy used for assembly of steel structure,



Portuguese Thermal Building Legislation and Strategies for the Future

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ABSTRACT: Portugal must evaluate, according to the Energy Performance Building Directive, the national requirements for energy performance of new buildings until 2011, which can be an opportunity to devise a national strategy that tightens the minimum energy performance requirements. The present study intends to analyze the changes that should be introduced in the Portuguese Regulation to achieve highly energy efficient buildings. The objective consists on evaluating the relevant improvement of thermal envelope performance such as walls, roofs and floors thermal insulation (maximum U-values), air tightness (ventilation strategies) and windows (minimum shading requirements), heating and cooling systems, as well as wider use of integrated renewable energy. The study considers apartments with different shape factors located in different climatic zones. The optimizing methodology makes use of a genetic algorithm for the estimation of primary heating and cooling energy indexes through a simplified calculation methodology established by Portuguese Regulation.

1 INTRODUCTION

The reduction of greenhouse gases emissions, namely carbon dioxide (CO_2), and security have been identified by the European Commission as priority areas for action in order to comply with the Kyoto Protocol. And about 50% of the energy related to CO_2 emissions derive from energy use in buildings.

The studies carried out in the nineties concluded that if any action was taken in 2020, Europe would import about 80% of the energy consumed and the energy use in buildings represents 40% of the total energy consumption in Europe, furthermore, implementing a set of economically sustainable efficient measures, the potential of energy savings is more than 30%.

To overcome this situation, in 2000, the European Commission identified the need to introduce specific measures in the building sector, namely with the Energy Performance Building Directive (EPBD) - 2002/91/EC - was published on 16 December 2002. This Directive proposes the adoption of common methodologies for calculating energy consumption, quality requirements for new and existing buildings, periodic inspection of boilers and central systems air conditioning, as well as the buildings energy certification.

Portugal must evaluate, according to the EPBD, the national requirements for energy performance of new buildings until 2011, which can be an excellent opportunity to draw up a national strategy tightening the minimum energy performance requirements. Reviews of national building regulations should always be seen as an effective instrument for achieving highly energy efficient buildings.

The present study aims at analyzing the changes that should be introduced in the Portuguese Regulation, "RCCTE – Regulamento das Características de Comportamento Térmica dos Edifícios" for different scenarios in order to achieve very low energy demands in buildings.

This study is based on the RCCTE methodology where the energy performance sustains the building energy classification and, therefore, energy labeling. For an optimized analysis a genetic algorithm is used for a large number of parametric variations, in order to fix up the best solutions in terms of primary energy needs, heating and cooling energy indexes.

2 METHODOLOGY

2.1 *Optimization method*

Instead of calculating all possible combinations, which can easily reach thousands of possibilities (for the parameters of this work, all combinations would be more than 5,000,000 for each case study), a genetic algorithm is used. The methodology consists of generating a population with *n* individuals, which characteristics ('genes') are randomly generated within defined intervals. At each iteration, for all individuals, a fitness value – ζ – is calculated and the best solutions are saved.

Afterwards, genetic cross-over or mutation, according to the probability associated to each event, is applied for the 'best' individuals within the population. Genetic cross-over of each new individual ('child') consist of combining part of the genetic code between two individuals ('parents') randomly selected. Mutation is obtained by a randomly changing one of the 'genes'.

The genetic code of an individual is a vector with parameters, such as, walls, roof and floor thermal insulation (U-value), walls and roof color (surface absorptance), windows glazing (single or double), type of shading devices (internal or external), building inertia, air tightness (infiltration), existence and type of solar panels for domestic hot water (DHW), type of heating and cooling systems and, finally, type of DHW system.

2.2 *Case studies*

It is noteworthy that the case studies presented in this paper, as well as the parameters, are used to exemplify the application of the optimization method. The same methodology could be applied for other cases whereas they are residential, under Portuguese climate conditions and following Portuguese thermal calculations for the energy index, even if generalizing the method for other countries is effortless.

The base case study is a small apartment with 53.5 m^2 of floor area, occupied by two people, located above a parking area. The apartment main façades are south and east orientated. The study covers also the same apartment but located in different positions inside the building, varying the shape factor (FF). The base case have a shape factor equal to 0.50; the other cases consist of an intermediate apartment between two residential apartments (FF = 0.34), in the last floor (FF = 0.74) and as a unique floor (FF = 1.14).

Walls are double brick, middle insulated with expanded polystyrene. In this study, thermal insulation thickness varies from 0.03 to 0.08 m (U-value from 0.57 to 0.34 $Wm^{-2}K^{-1}$). Floor slab is also thermally insulated by 0.03 to 0.10 m of expanded cork agglomerate (U-value from 0.88 to 0.40 $Wm^{-2}K^{-1}$); 0.03 to 0.08 m of expanded polystyrene is used for roof slab (U-value from 0.77 to 0.39 $Wm^{-2}K^{-1}$).

Windows are single or double glazed, externally shaded by roller blinds or internally shaded by semi-transparent curtains; sliding frames are in aluminium without thermal-breaking.

Variations are carried out on heating and cooling systems efficiency (or coefficient of performance for heat pumps) such as electric resistance, heat pump, gas or fuel boiler, absorption and compression chillers. For DHW, gas boiler, as well as electric and gas storage water heaters are considered; in some cases, standard solar panels (2 m^2) also contribute for DHW production.

2.3 *Parametric variations*

This study aims at searching for the optimum solutions among several possible combinations, enabling the variation of a large number of parameters, as synthesized in Table 1.

Table 1. Parametric variations.

Parameters	Possible solutions						
Wall thermal insulation, U-value ($Wm^{-2}K^{-1}$)	0.34	0.40	0.50	0.57			
Roof thermal insulation, U-value ($Wm^{-2}K^{-1}$)	0.39	0.45	0.53	0.66	0.77		
Floor thermal insulation, U-value ($Wm^{-2}K^{-1}$)	0.40	0.47	0.57	0.75	0.88		
Window U-value * ($Wm^{-2}K^{-1}$)	4.1/5.2 (single)	3.1/3.9 (double)					
Position and type of shading devices, $g_{\perp}$ †	0.10/0.07 (external)	0.47/0.46 (internal)					
Building inertia, coefficient a	1.8 (light)	2.6 (medium)	4.2 (heavy)				
Air tightness, infiltration (ACH)	1.00	1.05	1.10				
Wall color, absorptance	0.4 (light)	0.5 (medium)	0.8 (dark)				
Roof color, absorptance	0.4 (light)	0.5 (medium)	0.8 (dark)				
Heating system efficiency and energy source	1 (el.)	4 (el.)	0.87 (gas)	0.87 (liq.)	0.60 (sol.)		
Cooling system efficiency and energy source	3 (el.)	0.8 (el.)					
DHW system efficiency	0.87	0.82	0.80	0.75	0.70	0.65	0.50
Solar panels contribution to DHW (kWh/year)	0 (without)	794 (forced circulation)	944 (kit)				

*U-value depends also of the shading device (external roller blinds/internal curtains)

† $g_{\perp}$ is a function of the glazing type (single/double)

Furthermore, a sensitivity analysis to each one of these parameters is carried out in order to evaluate their influence in the primary energy index (Ntc/Nt), heating energy index (Nic/Ni) and cooling energy index (Nvc/Nv), given by the ratio of apartment energy needs (Nxc) and the standards established by Portuguese legislation (Nx), see Table 2. An eligible solution should verify legislation requirements for heating energy index (Nic/Ni $\leq$ 1), cooling energy index (Nvc/Nv $\leq$ 1), DHW energy index (Nac/Na $\leq$ 1) and primary energy index (Ntc/Nt $\leq$ 1).

In terms of climatic variability, Portuguese legislation defines three severity index values (from 1 to 3, where 3 is the most severe) for both winter (I) and summer (V) seasons. Therefore, three locations are chosen representing those climatic zones: Lisbon (I1,V2), Portalegre (I2, V3) and Montalegre (I3,V1).

Table 2. Standard heating, cooling and DHW according to Portuguese legislation

kWh/(m^2.year)	Ni				Nv	Na
Climatic zone	FF 0.34	0.50	0.74	1.14		
Lisboa (I1, V2), South	51.5	51.6	62.1	77.4	32	44.2
Portalegre (I2,V3), North	73.2	73.4	88.7	111.1	26	44.2
Montalegre (I3, V1), North	115.9	116.2	141.0	177.4	16	44.2

3 RESULTS ANALYSIS

3.1 *The 'best' solutions*

The first goal of this paper is searching for the best solution in terms of primary energy needs for the base case study and respective shape factor variations. The fitness coefficient ζ corresponds to the minimization of the primary energy index, Ntc/Nt.

After some generations for different climatic zones, we conclude that the best solution in terms of construction options for all of them should be:

- high insulated walls, roof and floor (U-values of 0.34, 0.39 and 0.40, respectively),-
- walls and roof light color (absorptance of 0.40),
- double glazing windows with external roller blinds (U-value of 3.1 and g of 0.07),
- heavy inertia (coefficient a equal to 4.2) and
- minimum air infiltrations (ACH of 1.00).

In terms of systems for heating and cooling production, the best solution is a heat pump (COP equal to 4 for heating and 3 for cooling) or a compression chiller for cooling (COP of 3). For DHW energy production instead, solar panels of kit type system should be selected, as well as a heat gas boiler ($\eta = 0.87$) as backup.

It can also be observed that the primary energy index of the best solutions is almost invariable for the different geometries considered (apartment shape factor) and climate conditions; in fact, primary energy index lies between 0.24 and 0.31.

Analyzing the case of the apartment with FF equal to 0.50 (no external roof) at Lisbon; Ntc/Nt of the optimum solution is 0.24, i.e. a building that only consumes 24% when compared to a standard building (A^+ in terms of building labeling). However, some other possible combinations are also very close to that value, as shown in Figure 1. Building characteristics, such as walls color, inertia, walls insulation and air tightness are the less sensitive elements; primary energy index varies less than 3%. The glazing type and shading devices have a small influence of less than 8%.

On the other hand, the type and efficiency of the energy systems (heating, cooling and DHW) cause high variations. For example, the use of certified solar panels for DHW reduces the primary energy index by 48%, and the selection of a heat pump instead of an electric resistance for heating reduces primary energy index by 25%. Nevertheless, the most influential parameter is the DHW system where the worst solutions are the electric storage water heater with different level of thermal insulation.

Therefore, one of the first conclusions of this study is that systems efficiency and the existence of certified solar panels are determinant on the primary energy index, and all the other parameters have a minor influence.

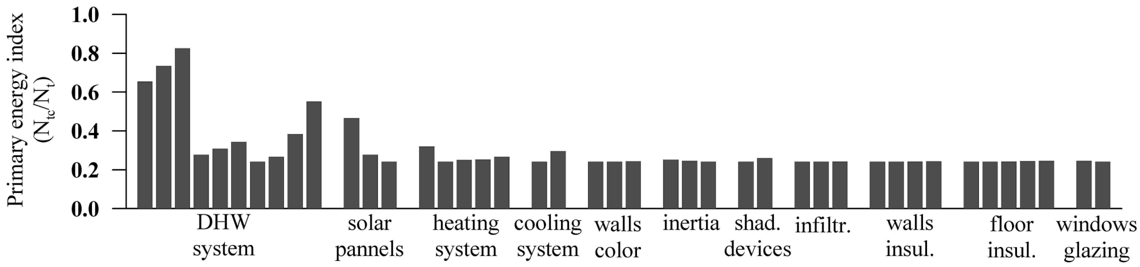

Figure 1. Primary energy index calculated to the best solution varying only one of the parameters for base case apartment (FF=0.50) at Lisbon.

3.2 *Heating energy index*

Systems efficiency, unlike construction characteristics, has a major impact on the primary energy index. However, construction characteristics are extremely important for heating and cooling energy index values. In this section, the same study is performed but establishing as fitness coefficient the heating energy index.

From the variables summarized in Table 1, only the first seven have a direct impact on this coefficient. Note that walls and roof absorptance are not considered for the heating index calculation.

Running the genetic algorithm for apartments with different shape factors in the three climatic zones, heating energy index increases with climate severity and varies with shape factor as shown in Figure 2. The sensitivity in one of the points (FF=0.50 and I1) is tested by making variations to each of the parameters (Fig. 3).

The most sensitive parameter is the building inertia; changing from light to heavy construction reduces the heating energy index (Nic/Ni) by 38%. Floor insulation is also an important element because an increase of the thermal insulation thickness (from 0.03 to 0.10 m) reduces Nic/Ni by 19%. Moreover, increasing the wall insulation thickness from 0.03 to 0.08 m reduces Nic/Ni by 9%. Infiltrations also play an important role on decreasing Nic/Ni, namely, the worst tested solution (1.1 ACH) has a Nic/Ni 8% higher than the best tested solution (1.0 ACH).

Selecting double glazing reduces the heating energy index by 11% compared with the single glazing solution. Adopting external shading devices reduces the heating energy index by 18% due to its additional thermal insulation for night time periods.

Some of these parameters can also be crucial for Regulation verification. For example, the same apartment (FF=0.50) located in Montalegre (I3) may have a floor insulation higher than 0.04 m, as well as external roller blinds that reduce the windows double glazing U-value from 3.9 to 3.1 W/(m^2.K).

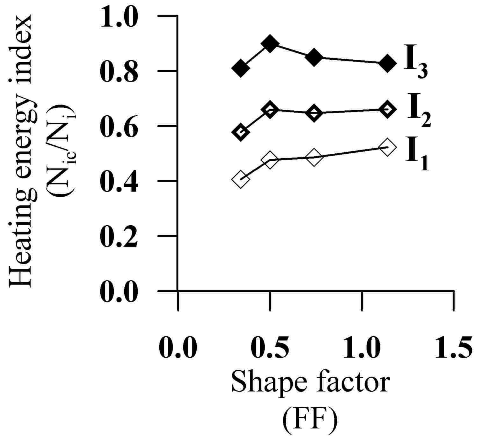

Figure 2. Heating energy index calculated to the best solution for different geometries and climates.

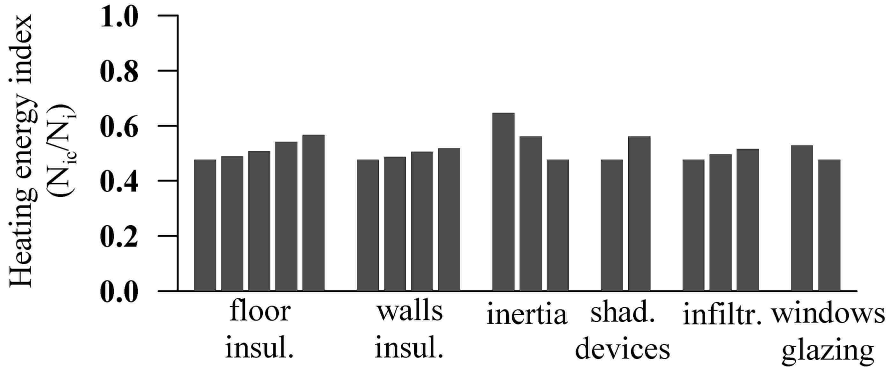

Figure 3. Heating energy index calculated to the best solution varying only one of the parameters for base case apartment (FF=0.50) and for Lisbon.

3.3 *Cooling energy index*

Some of the building characteristics are also important in terms of summer performance, which is here analyzed in terms of the cooling energy index (Nvc/Nv). The sensitivity analysis reveals the dominance of the shading devices position relatively to others parameters (Fig. 4). The cooling energy index for the single glazing solution is 10% higher than considering double glazing. Selecting lighter instead of darker colors for roof and walls decreases Nvc/Nv in 19% and 13%, respectively. Increasing roof thermal insulation is also decisive, as well as thermal inertia. Walls insulation and infiltrations has a minor influence on Nvc/Nv, which is less than 4%.

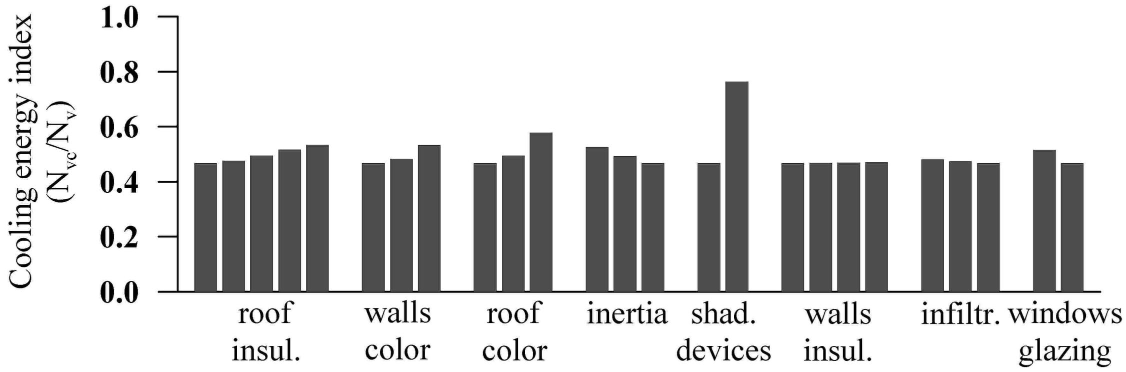

Figure 4. Cooling energy index calculated to the best solution varying only one of the parameters for the last floor apartment (FF=0.74) at Lisbon.

3.4 *Defining a target value*

For a given case study, another common problem consists of knowing what characteristics an apartment should have in order to be in classified by a certain label, i.e. Ntc/Nt should be less than a target value.

Taking the base case apartment (FF=0.50) with the following building characteristics: heavy inertia, walls medium color, 1.0 ACH of infiltrations, the method is applied to define the systems type or how much insulated should be building walls, so that Ntc/Nt ≤ 0.5 (A or A+ label in building certification).

In this section the standard solution for systems is a gas boiler for DHW with efficiency of 0.87 and a heat pump of COP 4 and 3 for heating and cooling, respectively.

3.4.1 *Standard systems and no solar panels*

After running the genetic algorithm in search of solutions with Ntc/Nt of less and close to 0.5, it is possible to know the minimum of wall and floor insulation for different cases:

A - double glazing (DG) and external shading devices (ESD);
B - double glazing and internal shading devices (ISD);
C - single glazing (SG) and external shading devices and;
D - single glazing and internal shading devices.

These results are presented in Table 3 which shows that 0.30 m of thermal insulation (expanded polystyrene in walls and expanded cork agglomerate in floors) is enough for I1 climate, except for D case (SG/ISD) where 0.40 m of thermal insulation should be used inside walls. For I2 climate, 0.30 m of thermal insulation is enough when double glazing is used, otherwise, walls should be insulated with 0.60 m and floors with 0.80 m. For D case of I2 and I3 climate, there are no solutions performing as required.

Table 3. Maximum allowed wall and floor U-value for a **A** building (Ntc/Nt ≤ 0.50) with standard systems and no solar panels.

	I1 (Lisbon)		I2 (Portalegre)		I3 (Montalegre)	
Case study	wall	floor	wall	floor	wall	floor
A – DG/ESD	0.57	0.88	0.57	0.88	*	
B – DG/ISD	0.57	0.88	0.57	0.88	*	
C – SG/ESD	0.57	0.88	0.40	0.47	*	
D – SG/ISD	0.50	0.88	*		*	

* there is no solutions for the defined condition.

3.4.2 *Double glazing, external shading devices and 0.30 m of thermal insulation*

Another possibility is to evaluate different systems solutions keeping the same level of thermal insulation on walls and floor (0.30 m). In this study it is assumed that an electric or gas/fuel system can be used for heating . For cooling, an electric system with COP equal to 3 is always selected and for DHW a gas system is always used. Table 4 shows the minimum of system efficiency to assure that Ntc/Nt is less than 0.50 for two climatic zones, I1 and I2.

Table 4. Minimum system efficiency (COP for heat pump) for heating and DHW systems for an **A** building (Ntc/Nt ≤ 0.50) with double glazing, external shading devices and 0.30 m of thermal insulation. Cooling COP is always 3.

	I1 (Lisbon)		I2 (Portalegre)	
Solar panels	Heat	DHW	Heat	DHW
A – no	0.80 (not elec.)	0.87	* (not elec.)	
	4 (electric)	0.87	4 (electric)	0.87
B – forced circulation	0.60 (not elec.)	0.65	0.80 (not elec.)	0.65
	1 (electric)	0.70	1 (electric)	0.87
C – kit	0.60 (not elec.)	0.65	0.60 (not elec.)	0.65
	1 (electric)	0.65	1 (electric)	0.82

* there is no solutions for the defined condition.

The results evidence different possible combinations. When certified solar panels are not installed, it is necessary to choose systems with a higher efficiency, such as, for heating, a fuel heat boiler (η = 0.80) or an electric heat pump (COP = 4) and, for DHW, a gas heat boiler (η = 0.87). In terms of climate severity, higher efficiency is generally required when the apartment is located in I2.

4 FINAL REMARKS AND CONCLUSIONS

In this study, a genetic algorithm is used to calculate the energy indexes of a large number of parametric variations, with the goal of searching for the best solution according to different criteria, namely the lowest primary, heating or cooling energy index. This optimization method is useful for the identification of the parameters which exert most influence on those indexes.

The main conclusion is that the primary energy index (the index used for certification labeling) is mainly established by the systems efficiency, as well as the use of certified solar panels (or other renewable energy sources, not here considered). Passive strategies, like adequate thermal insulation or windows dimensioning, have a small influence on building labeling.

This influence is, however, disguised on heating and cooling energy indexes, which are quite restrictive in terms of the quality of the building envelope. For the apartment studied at the more severe winter climatic zone (I3), solutions according to Portuguese legislation are hardly found. In fact, the heating energy index is close to 1 for the best solution and any small variation in one of the parameters makes the solution impracticable. For winter thermal performance, thermal inertia, thermal insulation, infiltrations and windows characteristics are elements that play an important role on the heating energy index. It is noteworthy, however, that this study does not cover all the possible parametric variations in a building, such as air tightness window frames and mechanical ventilation.

Instead, for summer season, windows shading devices position are crucial for cooling energy index. But roof thermal insulation, surfaces color, thermal inertia and windows glazing are no less important. Due to the monthly dependence on the average temperature in the methodology to calculate cooling energy needs, heat transfer by ventilation, conduction and convection always contribute for building losses. However, thermal gains trough the envelope are considered by the sol-air temperature concept, which is not true for infiltration gains. In fact, the 'best' solution for minimizing cooling energy needs corresponds to infiltrations increasing. So, summer methodology should be rethinking, besides minimum shading requirements, in order to prevent overheating periods.

The optimization method applied in this paper is a good contribution for common case studies analysis. However, this study intends to go further and raise questions for the Energy Performance Building Directive revision at national level. According to ours point of view, building characteristics differentiation should have a greater impact on building labeling. As shown is the paper, it is possible to have an A^+ apartment with windows single glazed, since it has solar panels for DHW and efficient systems. Is that a real contribution to energy consumption reduction?

Another issue is that related to the climatic zones where buildings are located, for the more severity winter climatic zone (I3) it was not possible to achieve, for the solution adopted of no solar panels and standard systems, any combination where Ntc/Nt ≤ 0.50, however this was possible for I1 and I2, trough the increase of thermal insulation. The parity of criteria should not be the same?

These raised questions direct the problem to the definition of standards indexes and the possibility of their reduction, which for certain cases could lead to impracticable solutions. Other important issue would be minimum requirements for A and A^+ building in terms of envelope thermal quality, such as double glazing, as well as the use of renewable energy production (certified solar panels, for example), in order to standardize buildings labeling throughout climatic zones.

The SURE-Africa Project: Sustainable Urban Renewal – Energy Efficient Buildings for Africa

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ABSTRACT: This paper summarizes the results achieved by the 3-year E.U. SURE-Africa project. The project aims at strengthening knowledge and its application in practice, contributing to a sustainable development through the vital area of energy efficiency in buildings and cities, and, ultimately, to reduce poverty. Academic and professional expertise from three E.U. Universities - namely the Higher Technical Institute (IST, Coord, Portugal), the University of Cambridge (UK) and the University of Lund (Sweden) - was organised to set up a data-base of information, in cooperation with Academic Institutions in Portuguese-speaking African countries (Angola, Mozambique, Cape Verde and Guinea), with information about tools, case studies and teaching material in the field of sustainable, energy-efficient building and urban design. Seminars, workshops and conferences were carried out, and best-practice Manuals are also being published as a final outcome of the project.

1 THE SURE-AFRICA PROJECT: INTRODUCTION

The project aimed at strengthening knowledge and its application in practice, contributing to a sustainable development through the vital area of energy efficiency in buildings and cities and, ultimately, to reduce poverty. The situation found in the participant countries was representative of many other countries in Africa, with developing economies often scarred by long-term armed conflicts. Building and urban renewal have an urgency that requires a different approach to the incorporation of renewable technologies from that in Europe. This is due to the scarcity of resources, the pressing demand for social housing and refurbished or new public buildings such as schools and hospitals, and the difficulties of implementing building and town planning regulations (often deficient or even non-existent).

It is important to consider energy conservation through passive building design as a proven equivalent to renewable energy power generation. The project adapted well-established knowledge in this area to the economic and climatic context. Emphasis will be on net demand reduction rather than generation; this approach making less downstream demands for maintenance and replacement, and being more compatible with traditional life-styles. In non-domestic buildings, a high priority was the avoidance of air-conditioning. In the case of housing, it is important that basic comfort performance criteria are met, since failure in this respect will prompt the occupants to purchase package air-conditioners if and when reduced costs and improved finances allow.

The project has also drawn from existing areas of expertise in post conflict reconstruction, trying to resolve inevitable conflicts between the short-term need, and the longer-term imperative of sustainability. It recognised, that in the area of housing in particular, there is much self-build, and it was acknowledged that the support materials must not only be accessible to the design professional but to the layman as well.

The overall objective is to create a network of practical and scientific knowledge between African and European Universities, in the field of energy-efficient building and urban design. Training workshops, Seminars and Conferences were held in each of the African countries involved (Cape Verde, Guiné-Bissau, Angola and Mozambique). Within this programme different target groups (local politicians, teachers, professionals, students, self-builders) were addressed at appropriate levels.

Academic and professional expertise from three E.U. Universities - namely the Higher Technical Institute (IST, Coord., Portugal), the University of Cambridge (UK) and the University of Lund (Sweden) - was organised to give the lectures at all training courses and workshops, and to contribute to documentary material. A data-base of information was set up, in cooperation with Academic Institutions in Africa, with information about tools, case study exemplars and teaching material in the field of sustainable, energy-efficient building and urban design. Best-practice manuals are also being published as a final outcome of the project. The basis for long term collaborative research on energy efficient and sustainable construction were developed during this 3-year E.U. COOPENER project.

2 RESULTS

The main, long-term, objective of the project was to establish a network of practical and intellectual knowledge between African and European Universities in the field of sustainable, low-energy building design and construction. The project has enhanced the communication and information exchange between higher education institutions in the EU and Lusophone African countries in the field.

Several steps were taken for this purpose, following the initial workplan, mainly:

- Development of a website, which is updated regularly as a central resource for information and communication (http://www.sure-africa.org).
- Organisation of Project meetings and production of Reports.
- Planning, organisation and realization of Seminars and Workshops that took place in Cape Verde, Angola, Mozambique and Guinea-Bissau, with participation of the various institutions involved. The Seminars and Training Workshops were designed based on the identification of the specific needs and constraints existing in each of the African countries involved, and successfully delivered.
- Development and completion of the Best-Practice Manuals and teaching material. The Best-Practice Manuals are pioneer publications in this area (a reference not only for Portuguese-speaking countries but also for other African countries), and are one of the main outcomes of the project.

2.1 *The Seminars and Training Workshops*

Together with the publication of the Best-Practice manuals, the realization of the various Seminars, Training Workshops, and Conferences were one of the most important achievements of the project. Theses three types of events were distinct in nature. The Seminars consisted on series of presentations, with moments for queries between each presentation, and audiences involved a diversity of attendees, from Government and Local Authorities Representatives, to Professionals of the Building Sector (Architects, Engineers, Builders, Representatives of the Professional Orders and Associations), Academics and Students. In general, attendance was made by Invitation (from the Local Team Coordination). The Training Workshops were mostly directed to University Students and Professionals (mostly Architects and Engineers), and took place generally after the Seminars (where various presentations were made); in these, discussions were encouraged on various topics, questions (of a practical nature) were posed and answered, and case studies were analysed. The Conferences were opened to the general public, including a broader audience, and were generally opened and closed formally by important personalities (Government, Dean of the University).

The Seminars in Angola took place between the 26-29th May 2009. The Seminars, Training Workshops and Conference took place in the premises of Faculty of Civil Engineering and Architecture of UAN. The seminars took place in the first days, to an audience of mostly students, academics and professionals.

Figure 1 (right): Photo of the SURE-Africa Seminars in Luanda (May 2009)

Informal workshops were realized after the end of each day, mostly with students, where a number of issues were debated. The final event was a conference, opened by the Minister of Environment and the University Dean, where a series of presentations were made, both by Local (e.g. Town Hall Architects and Engineers, University Staff) and EU experts.

In Cape Verde, two series of Seminars and Workshops were carried out, one in Praia Island (City of Praia, Capital of Cape Verde) and another in the Island of S. Vicente, at the M_EIA premises (City of Mindelo). Attendants were mostly professionals (Architects, Engineers), Academics, and representants of local Government (Town Hall) and the Order of Architects and Engineers. A final conference was also realized in Mindelo (in collaboration with other institutions), at the Town Hall, opened to the general public.

Figure 2: SURE-Africa Seminars in Praia (left) and Mindelo (Right), Cape Verde (March 2008).

In Guinea-Bissau, the final Seminars took place in between 07/12/2009 and 09/12/2009. Both the Seminar and the Conference (at the Franco-Guineese Institute' Auditorium) had a high-profile attendance, including representants of a number of Official and Private Institutions.

Figure 3: Photos of the SURE-Africa Conference (left) and Seminars (right) in Bissau (Dec. 2009).

In Mozambique, the Seminars and Training Workshops were carried out between 04/06/2009 and 07/06/2009. The Seminars' audience in Mozambique was about 90-100 people, mostly representing State Institutions, Academic Staff, and students. Some NGO's were also present. A special presentation was made for students only on the 7th, at the Faculty.

Figure 4: Photos of the SURE-Africa Seminars in Maputo, Mozambique (June 2009).

2.2 *Publications*

A series of publications were produced by the project, being the most important ones the Best-Practice Manuals and Teaching Material (Brochures and Slides). A number of other publications were also produced, namely press releases and advertisements made during the Seminars in Cape Verde, Angola, Mozambique and Guinea-Bissau including TV and radio news and interviews, web postings, posters, flyers, etc.. However, the bulk of the publications were the Best-Practice Manuals - a reference not only for Portuguese-speaking countries but also for other African countries, and are one of the main outcomes of the project.

One Manual – "Manual of Sustainable Architecture"- was produced for each country involved: Angola, Cape Verde, Guinea-Bissau and Mozambique, with approximately 300 pages each. They are destined to be used by professionals, academics, and general public. The Manuals include a general overview of the local context (social-economic, climatic, cultural, local resources and technology, etc) and present a set of design recommendations, applicable to most types of buildings – from self-construction to more complex buildings, such as offices or touristic infrastructures. They also include recommendations on other critical issues, such as urban planning, the use of water, and the use of renewable energy systems. A number of local case studies are presented.

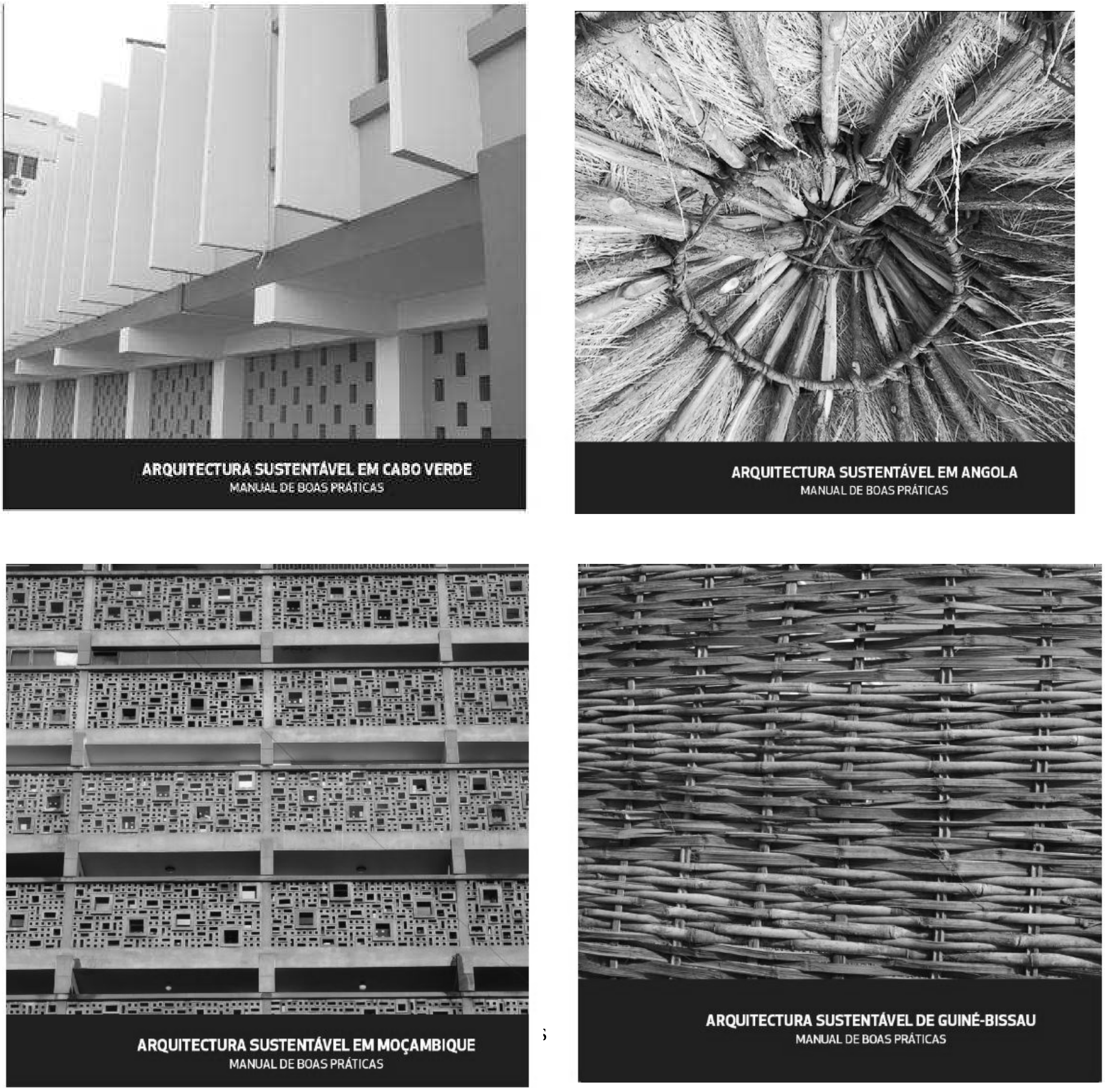

Figure 5: The Best-Practice Manuals: Covers

3 FUTURE ACTIONS

There is no doubt that the project was the "embryo" for a long-lasting future collaboration. Various research and student exchange protocols are being formalised between E.U. and African Institutions as a direct result of SURE-Africa. A Network of Sustainable Architecture and Urban Design is also being created for Lusophone countries (including Brazil), which is now on the process of being extended to Universities existing in other E.U. and African counties (Francophone and Anglophone).

The consortium is also considering candidacy for new joint projects in the line of SURE-Africa. The E.U. team is at the moment preparing another funding candidacy for a new project, a continuation of SURE-Africa for other Lusophone countries such as S. Tomé e Príncipe and

Timor (local colleagues have already shown great interest in joining in), as well as other Francophone and Anglophone countries in Africa. The existing E.U. team will also be dilated to include other EU universities.

The results of the Project are now going to be further disseminated, both in terms of the distribution of the manuals, the maintenance of the website, the participation in International meetings (e.g. SB10, PLEA and WREC), and publication in peer-reviewed magazines. An International Conference on Sustainable Construction in Africa, planned for February 2011 in Lisbon is being organised.

4 CONCLUSIONS

The general opinion of all teams is that good work was made, with enduring impact. This project was the starting point for future projects, so necessary in the area. The most valuable deliverables were the Seminars, Training Workshops and Conferences, and very importantly the Best-Practice Manuals, which are a pioneer publication in this field of studies.

One is certain of the creation of future long-time links between the various teams of the SURE-Africa project. The project is achieving one of its most important aims: being the embryo for a future extended network of information between EU and African Institutions.

Rehabilitation of rural houses as a contribution to Sustainable Construction

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ABSTRACT: Relevant data about Portuguese housing stock are presented in this paper, according to Census 2001 and the 4th General Housing Census, particularly in Beira Interior and Cova da Beira. These data show that the percentage of single family housing in Portugal is very high. In addition, the index of building ageing indicates the situation is worrying if there is no investment in maintenance and rehabilitation.
It is also presented characterisation and evaluation work and proposals of immediate intervention on a set of houses placed in rural areas, in Cova da Beira (Portuguese centre countryside region).
Houses' external and structural conditions and other aspects related to occupation and use were evaluated. Noticing the need of immediate intervention, a graduated list of conservation conditions of the buildings was established. Finally, obtained results are discussed, and rehabilitation proposals for rural houses are presented, jointly with some ideas of research, so that the interventions may aim the promotion of Sustainable Construction.

1 INTRODUCTION

The statistic indicators show that the percentage of single-family buildings is very significant in the European countries and especially in Great Britain and Portugal. For example, in Germany it is 56%, in Spain, 33.3%, in Italy, 45.5%, in France 69.1% and in Portugal, 86.9%. In the case of Centre Region of Portugal, the percentage is 94%. There are areas of statistical analysis, such as Pinhal Interior Sul, where the percentage is 97.1%.

Before this numbers, it is necessary to give special attention to individual housing if the global objective is to stop depopulation in rural areas and contribute to the sustainability of the territory.

On the other hand, considering the age of the buildings, the situation in Portugal starts to be quite worrying. The statistical data related with the age of the buildings usually show good information in what concerns to their physical characteristics, since the buildings are the result of the appliance of building techniques common at the time of construction. At the same time they give information about their quality, when compared to the present parameters. The evaluation of present thermal quality is one of those examples. According to Census 2001 and the 4th General Housing Census, the percentage of buildings over 31 years in Portugal was 43.2% and the percentage of buildings over 56 years (higher than their life expectancy) was almost 20%.

It is a valuable patrimony that has resulted mainly from the financial effort of families and to whom the public authorities have given little attention. There is much concern about the new construction, social housing programmes, rehousing, but the single-family buildings are degraded and the maintenance of this Particular Cultural Patrimony must be considered as a national priority.

In the case of the subregion of Beira Interior, in Portugal, the situation is even worse, reaching the percentage of 46% of buildings over 31 years and 23.4% over 56 years. The number of buildings that have overcome their life expectancy is higher than 25%.

From a more global perspective, the index of building ageing of Portuguese housing presents worrying values and these values are especially high in the countryside. It is a statistical reality, but one just has to observe attentively the general state of housing constructions from the countryside and from the historic centres of big cities to confirm this worrying reality.

2 HOUSING IN BEIRA INTERIOR AND COVA DA BEIRA

In the regions of Northern Beira Interior (counties of Almeida, Celorico da Beira, Figueira de Castelo Rodrigo, Guarda, Manteigas, Meda, Pinhel, Sabugal and Trancoso), Southern Beira Interior (Castelo Branco, Idanha-a-Nova, Penamacor and Vila Velha de Ródão) and Cova da Beira (Belmonte, Covilhã and Fundão) the housing stock is worrying as well, in what concerns to its ageing. In these three regions, which are located in the countryside of the Centre Region of Portugal, there are 154.352 buildings, according to Census 2001, from which 36.288 were built before 1995 and 23.884 after 1991. The index of ageing of buildings in these three regions is 152, being 92.5% of the buildings constituted of single housing buildings.

Considering that these three regions are markedly rural and taking into account the index of ageing of the building stock, it is estimated that, from the 142.764 single-family buildings existing there, a great majority is rural housing (or have been built in rural areas).

There are several places and historic villages identified in these regions, whose rural housing has been characterised and some of them have been recovered due to its cultural, historical, architectural and constructive value, such as, for example, the villages of Sortelha, Almeida, Castelo Novo, Idanha-a-Velha, Monsanto, Piódão, among others.

3 CHARACTERISTICS OF RURAL HOUSING IN COVA DA BEIRA

Rural construction is normally very diverse, from Region to Region and inside the same Region. It varies in its characteristics and materials, as well as in its quality. For example, in Minho, Trás-os-Montes, Beira Baixa and Beira Alta the appliance of apparent stone, the construction of verandas, sheds and roof-edges is very usual. In Baixo Alentejo, Ribatejo and Algarve the application of adobe, pug, brick (and later, cement block), lime washing of walls, coating of the ceilings with reed, artistic tracery of the chimneys, among other aspects predominates (Machado, 2002)

The most used stone in Cova da Beira is granite. Normally stiffer stones and with a better appearance are chosen and laid on one of the faces. The corners are built using bigger stones (bond stones) to help the fixing of the walls. The external walls are plastered first with clay and after with lime and sand mortar, and may be lime whitened or painted in the outside finishing. Brick masonry is also used to build the external walls of the first floor and the mud wall, both for external and partition walls. Another common material used in this kind of houses is timber. It is used in the construction of wooden floors, supported by wooden beams, and attics and roofing that are coated with ceramic tiles.

In Paul, a village located in Cova da Beira, 12 km distant from Covilhã, there are rural houses (Figure 1) with a particular form of construction of external walls. Near the local stream bed there exist very stiff granite pebbles (cobble stones), with spherical or ovoid shapes. These materials have been used to build the walls of the old houses in the village and also sidewalks, laid with mortars of sand of red clay, which predominates in place. Pebbles were broken in middles to compose the walls, which finally get an original shape, marked also by the application of schist or granite flagstones, forming the windows frames. The common tile of roofing is Portuguese tile and the timber that is used for wooden floors and roof structures is chestnut or pine, which are abundant materials in this region.

In the village of Casegas, 20 Km distant from Covilhã (near Paúl), the elected building material for walls is schist, which predominates in the place, where, due to their geological constitution, very ancient schist fields prevail. In these houses (Figure 2), the stability of the schist walls is reinforced with lintels and corners of granite inserted in current masonry. Only in some privileged places is it possible to extract a stone for a door or window frame from a piece of schist. This difficulty has imposed the using of thin-grained granite in this area. Although the use of granite in the windows and doors frames is the most common situation, timber is also used instead. The roofing is made of ceramic tile, fixed to a timber structure, and stones are put on them in order to avoid the wind effect.

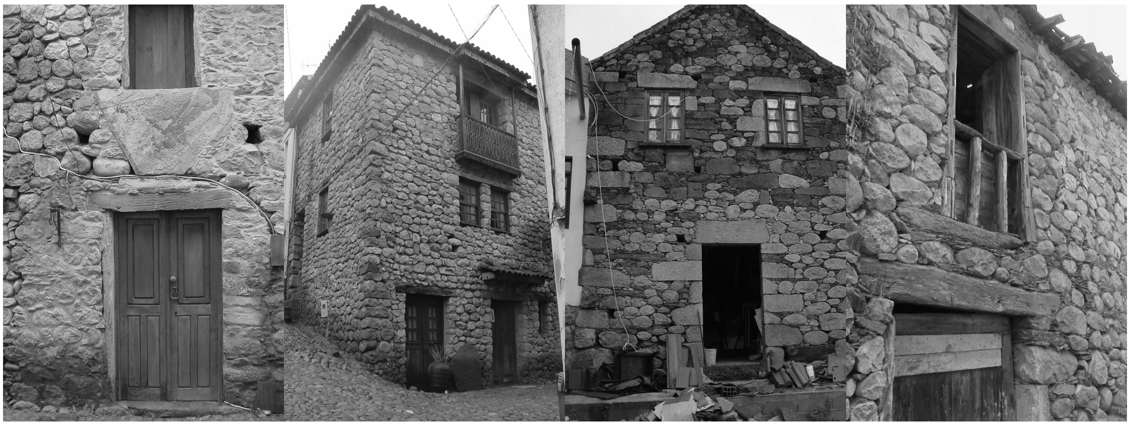

Figure 1 – Examples of rural housing in Cova da Beira – Paúl.

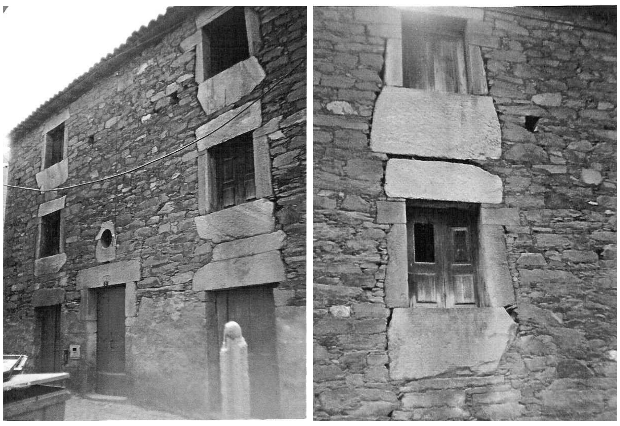

Figure 2 – Examples of rural houses in Cova da Beira – Casegas.

Figure 3 – Other examples of rural houses in Cova da Beira

Another example of rural housing in Cova da Beira can be seen in the village of Sobral de São Miguel. Most of the constructions are in schist masonry (dominant in the geologic composition of this place), and the roofing is made with slate flagstones. Schist replaces granite because it is easier to stock it locally being granites only used for the richest houses in the village.

Schist is used almost exclusively in its extraction natural forms, in masonry walls, much less stable than the granite ones, or in simple roofing of poor buildings, being the flagstones fixed to a timber structure. The lintels of the doors and windows are made of solid and lasting timber, almost always chestnut timber, which looks very similar to schist, throughout the years. Others examples of rural houses may be found in rural agglomerates in the region of Cova da Beira. Unhais da Serra, Sarzedo, Barroca or Janeiro de Cima are some of this examples.

4 STUDY ON THE STATE OF DEGRADATION OF A SET OF RURAL HOUSES LOCATED IN COVA DA BEIRA

The development of this multidisciplinary social-housing project involved the study of a group of 74 families distributed by 7 villages of a council with rural characteristics, located at the interior centre of Portugal. One of the main axes of the project was to intervene in the buildings with the objective to provide basic living conditions.

To accomplish such objective, a study was made by the technical team of the Architecture and Civil Engineering Department of University of Beira Interior (UBI) participating in the project with the priority of evaluate and make the characterization of the houses' internal and external conditions and establish a house ranking that would fundament the intervention priorities.

4.1 *Adopted Methodology*

4.1.1 *Inspection and Diagnosis*

The preliminary visit to the places and houses object of study demonstrated that the group of houses had diversified characteristics. The houses presented a low level of construction quality and of living conditions. For that reason, a methodology to pick up data oriented specifically for the sample study object was developed. Obviously, this methodology is very different from the other methodologies that are usually adopted for buildings of medium quality (Lanzinha et al., 2001a,b, 2002). It was also concluded that most of the houses under analysis were single-family houses, having a mainly rural architecture, and built by using the local building materials and that are not usually subject to periodic maintenance works.

During the development of this new methodology (Lanzinha et al., 2002b) it has been established the necessity of organising the data gathering in order to get three information levels:

- HOUSING SURVEY – This inquiry "picks up" detailed information on the house type. It collects elements for characterization of the house, occupation regime, infrastructures and available equipments and main internal and external anomalies. The objective of this inquiry was, fundamentally, to know the houses general conditions and to provide the statistical treatment of this type of information.
- OPINION SURVEY – Its objective was to gather the opinions of the residents regarding their house. It intends to confront their opinion relatively to the general requirements of comfort and living conditions that are defined by regulations and to detect eventual anomalies or systematic disconformities in respect to that. This inquiry can help to define intervention priorities based on resident's expectations in respect to their comfort and living conditions.
- DIAGNOSIS SURVEY – Through this last indicator it was intended to get a technical evaluation of the situation. Having as an objective the quantitative study of the quality of the houses and of their conservation / degradation conditions, the filling form that has been created predicts the existence of 33 observation points. The defined structure permits to know the building in three main aspects: external conditions, structural situation and interior living conditions. It is predicted then the possibility of not being possible to evaluate the house in its totality, remaining, even so, the possibility of a partial evaluation. In this diagnosis filling form, the external evaluation has been subdivided in 4 main areas: roof, external walls, window system and pluvial drainage system, in a total of 14 observation points.

The evaluation of the structural situation system includes 5 observation points.

The evaluation of the internal situation includes the observation of 14 points, including evaluation of constructive anomalies, safety's conditions, living conditions, basic sanitary infrastructures available and occupation conditions.

The survey of house detailed construction considers the graduation of all inspected points (elements) in 4 levels, being accompanied of an auxiliary record of graduation created for the effect, describing the evaluation conditions of each one and the respective classification. It is intended with this auxiliary document that the analysis is rigorous and technically based, being avoided subjective appreciations.

Since this kind of inspection has a remarkable technical character it is obvious that its completion should be made by qualified and technically informed personnel.

4.1.2 *Evaluation and production of complementary information*

The application of the house detailed conditions survey resulted in two main documents: a record of house individual analysis and a record of global analysis for the group of houses.

These two records were specifically created to give the inter-disciplinary project intervenient partners a working document, easily understandable, that objectively help the intervention decisions for each house.

4.1.3 *Record of individual house analysis*

The record of results relative to each inspected house, as presented in figure 2, includes an identification code and a picture for each house. In this record, the treatment of collected data is organized in such way that gives the possibility to analyse needs of immediate intervention and state of house conservation.

4.1.3.1 - *1st Analysis - Needs of immediate intervention*

The 1st analysis is the primary "screen" of the detected anomalies. It has the objective to evaluate an immediate intervention to be done, whenever people's and goods safety is at risk or whenever minimum living conditions are not guaranteed.

The 1st analysis gives clear indicators of risk alert. These indicators are organized in 4 levels, which reflect the degree of severity of the conditions found in each house, for decreasing order of importance, as follows:

- Level 1.1 - Structural safety (5 checking points): To intervene whenever the ruin is eminent;
- Level 1.2 – Use safety conditions (3 checking points): To intervene whenever conditions of safety related to gases extraction or electrical system are serious deficient;
- Level 1.3 – Water penetration (1 checking point): To intervene whenever serious problems of water infiltration exist;
- Level 1.4 – Living conditions (3 checking points): To intervene whenever public water supply, domestic sewers and sanitary facilities are inexistent as well as in cases where the house is over occupied (more than one family or inadequate bed room sharing).

Whenever one of these checking points is registered by the inquirer, an alert and intervention information is immediately available and highlighted. For example, if risk of eminent ruin is indicated in the checking point corresponding to the diagnosis of the structural elements, this will highlight the respective alert indicator.

Furthermore, as complement of each one of the alert indicators, the respective corrective actions are immediately presented.

4.1.3.2 - *2nd Analysis - Level of conservation of the house*

A resulting graphical analysis of the state of conservation of the building is supplied, in agreement with 3 evaluation levels: Level 2.1 - Quality of the interior; Level 2.2 - External and structural quality; Level 2.3 - Global quality (external, structural and internal).

The graphical analysis results are estimated based on weight factors, considering the different checking points of survey and diagnosis phase. The weight factors were established in an empirical way, based on the number of inspection points and the consequences of different house construction anomalies and its expected effect on the evolution of the conservation conditions and global behaviour of the house. The weight factors give more importance to the consequences of the eventual problems on the roof, the defects of pluvial water drainage and the structural anomalies in the evolution of the state of degradation of the house, as thus have higher relative weight in respected to other aspects.

As it can be verified this methodology of individual house analysis is progressive. It considers the inspection points and it depends on the possibility of visiting or not the interior of the house. In this last case, the external situation of the house prevails.

4.1.4 - *Record of global house analysis*

As it was referred previously it is intended that intervention decisions would be objective and based on documents of easy interpretation and use, although essentially technically based.

To accomplish this objective a global analysis record was produced, which allows comparison of all studied houses and gives relative graduation between them. This makes possible the definition of the intervention priorities.

The elaboration of this record, that establishes the ranking of the houses in the same way, considers the levels of 1st analysis of immediate intervention as well as the levels of 2nd analysis.

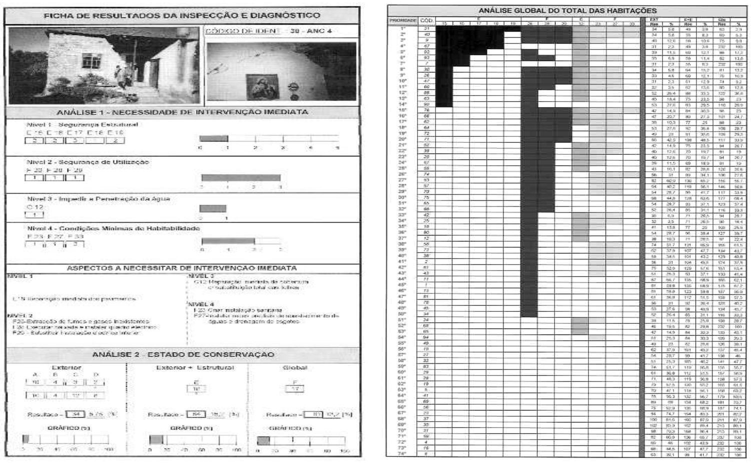

Figure 5 – Example of an individual filling form (left)
and of the global filling form of the 74 houses (right)

4.2 - *Results*

After analysing the global filling form of the 74 inspected rural houses it has been concluded that 54 of them (73% of the total) has immediate intervention needs, which reveals the high state of degradation of the group of houses and shows that the care with the definition of the most adequate methodology have been adequate, before the expected results.

The main problems detected in the using of houses are the inexistence of any sanitary installation (43% of the cases) and to the handicaps detected in the kitchens (42% of the cases). In the case of kitchens, the inexistence of chimneys or domes to extract smokes and gases is common.

The opinion survey has shown that humidity, thermal comfort conditions and, mainly, the non-efficiency of warming systems are the main worries of the residents. It has not been detected any kind of sensitivity to noise or bad-smell problems.

This methodology has also been successfully applied in the project of rehabilitation of houses developed some years ago in the parish of Cantar Galo, Covilhã.

5 THE INTERVENTION ON THE REHABILITATION OF RURAL HOUSES AS A CONTRIBUTE FOR THE SUSTAINABLE CONSTRUCTION

The results obtained reflect the need to further study the global situation of the rural type of houses. It seems evident that, besides natural degradation of the constructive elements, great deficiencies in the use of the houses were verified, above all for lack of the residents´ information. It will be opportune to develop some activities that would complement the simple actions of constructive rehabilitation, such as: Creation of a guide to use correctly the house; Give basic notions on use of kitchens and sanitary facilities; Explain the causes of more common degradation of the houses; Develop awareness of hygiene habits; Implementation of integrated housing pilot program destined to study new house solutions to the aged rural populations.

In Portugal a very significant number of this type of houses exists, usually in bad state of conservation and for that reason it is necessary to develop in the future this kind of measures that may have a great impact on the populations.

The investigation on the field of rural houses' rehabilitation must also be a priority. It must contemplate, among others, the study of new solutions to improve the quality of this kind of construction and, particularly, improve the hygrometric and thermal comfort of these houses.

Some ideas follow, as a conclusion of this work, so that the investigation and intervention on the rehabilitation of rural houses may be done under a perspective of Sustainable Construction:

- To improve the thermal and hygrometric comfort of these houses must be one of the main priorities of investigation and intervention.
- To study new solutions to improve the thermal behaviour of ground floors, masonry walls and timber roofing structures. Obviously, those solutions must be cheap so that the rural population may adopt them and they must be adequate to this kind of construction. To study their combination with the traditional heating systems and with new heating solutions, more ecologic and with renewable power supply (particularly geothermal and solar power).
- To study new constructive and architectural solutions so that the heat losses are less importance but thermal inertia and the solar gains be improved, namely with more openings in the south quadrants.
- To take advantage of the existence of trees in the rural environment to ventilate and cool the houses must also be a theme to develop.
- To study solutions to rehabilitate the houses in order to prevent the infiltration of water through the roofing, walls and pavements, in a lasting way, in particular to eliminate the ascensional humidity and the problems of infiltration through the door and windows frames, which are very common in this kind of house.
- To promote the use of the traditional materials, as far as possible, in the rehabilitation solutions.
- To act carefully in the demolitions. Many rural houses may be demolished, due to its state of deterioration. Thus, the existence of adequate municipal infrastructures must be promoted, to reuse and increase the value of the wastes produced in the demolitions. (Guia 1999)
- To study solutions to separate the waste produced during the demolition and store it accordingly to its origin. To use deconstruction and disassembly techniques instead of making massive demolitions. (Guia 1999)
- To forbid the incineration of construction wastes or the deposition of contaminant substances in the general sanitation infrastructures and control the harmful emissions: noise, dust, water (leakage or waste water), etc. to minimize the environmental impact in the demolition phase. (Guia 1999)
- To execute rehabilitation works by accomplishing the duties, regulations and environmental laws, guarantee the taking of safety and health measures predicted by the regulation and make the actions of quality control needed to guarantee a good final quality.
- To have specialised personnel in the assembly of pre-fabricated or industrialised building systems to guarantee their good functioning and durability.
- To plan and control the execution of the works so that the product wasting may be avoided.

- To take advantage of the existence of demolition materials and smashed petro wastes to do drainage works or under-basis pavements. To separate the waste produced during the demolitions and store them in different boxes, accordingly to their origins. (Guia 1999)
- To respect the rural environment, obliging the contractor to declare the volume of waste produced and to specify its final destiny, as an indirect way of promoting the elimination of wastes, the adequate management of the wastes and avoiding the deposition of wastes in non-controlled places.
- To promote the use of equipments and reusable auxiliary execution elements, and with low gases or noise emission levels and to control the harmful emissions in the phase of construction.
- To avoid the application or production of work materials waste potentially dangerous: welding products, bitumen or asbestos mastics, preserving biologic agents (germicides, antioxidants, creosote), paintings and varnishes (waste), lead-based paints, diverse chemical products (anticorrosion, fungicides, insecticides, solvents, diluents, acids, abrasives, detergents, etc.) (Guia 1999)

Figure 6 – Examples of rehabilitated rural houses in Portugal

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Arquitectura Enquanto Interface Dinâmico com o Mundo Natural

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ABSTRACT: O modelo conceptual que melhores resultados práticos consegue a todos os níveis no domínio da arquitectura enformada pelas questões ecológicas é de preocupações bioclimáticas. As principais orientações arquitectónicas da actualidade concebem todo território como paisagem (construída ou não construída) numa atitude integradora que esbate a velha separação dicotómica entre natural e artificial. Desta simbiose entre o natural e o artificial, nasce o conceito de ecomonumentalidade que entende, em última instância, a sensibilidade para com o Mundo Natural. Desta feita, a arquitectura começa a incorporar o apelo à Natureza e às preocupações ambientais, na qual se fundem os ensinamentos vernáculos com os tecnológicos que resultam numa concepção técnica anti-despesista e com profundo respeito pelo valor lugar.

1 PROPOSITO

Ganha crescente destaque na nossa vida quotidiana a maneira como nos relacionamos com o mundo natural, matéria de estrema importância porque a todos concerne o estado desta “Grande Casa que Vivemos”. Este artigo pretende rebater o actual posicionamento da Arquitectura com o Mundo Natural que a contem, com especial enfoque na relação estabelecida entre estas duas dimensões e incluindo a nossa agenda problemática: a questão da sustentabilidade. Neste sentido, convém traçar um quadro cultural e tecnológico do presente momento para discernir do impacto destes na biosfera e quais as mais valias de uma construção sustentável acessível a todos.

2 NATURAL

2.1 *Espaço e tempo*

São irrefutáveis, hoje, os argumentos que apontam uma causalidade antropogénica para as transformações ocorridas na Ecosfera. O apelo para a problemática ambiental faz, hoje em dia, parte do nosso interesse colectivo. Paradoxalmente, todos os sectores da sociedade já perceberam que existem alternativas viáveis para este impasse. A actual tecnosfera encontra-se suficientemente desenvolvida para produzir soluções capazes de responder satisfatoriamente às nossas prementes necessidades e vontades. Prova disso mesmo foi a recente intervenção do ex-Vice Presidente dos Estados Unidos da América, Albert “Al” Gore, em que corajosamente lançou um repto a todos os seus compatriotas:

"Today I challenge our nation to commit to producing 100 percent of our electricity from renewable energy and truly clean carbon-free sources within 10 years. This goal is achievable, affordable and transformative. It represents a challenge to all Americans - in every walk of life: to our political leaders, entrepreneurs, innovators, engineers, and to every citizen". (Gore, 2008)

Um auspicioso discurso pois a confirmar-se esta intenção, seria a mais rápida transição tecnológica de toda a história da Humanidade. Sem dúvida que este discurso inspirador conseguiu canalizar as atenções para a necessidade, capacidade e vontade de uma efectiva mudança de paradigma. Já anteriormente tinha conseguido mobilizar toda a sociedade global para a problemática da ecologia e sustentabilidade introduzindo-nos didacticamente nas questões sistémicas relacionadas com as mudanças climáticas, suas origens, efeitos e riscos associados. (Gore, 2006) Importa, no entanto, desenvolver um posicionamento crítico relativamente ao modelo de desenvolvimento desta problemática, isto é, reflectir sobre as principais opções tecnológicas e as suas eventuais repercussões no Mundo Natural pois a construção de edifícios é o processo com maior impacto na ecosfera a qual emprega cerca de 60% dos recursos utilizados pela Humanidade. (Edwards, 2004) Paradoxalmente, os pequenos contributos tecnológicos, tais como automóveis mais eficientes, com menores consumos e emissões, processos industriais mais limpos e seguros, tentam mitigar os efeitos negativos dos anteriores e, desta feita, minorar o nosso sentimento de culpa perante as questões ambientais. No campo da arquitectura a situação acompanha esta tendência generalizada para apetrechar os edifícios com artifícios tecnológicos transformando-os em objectos pretensiosamente mais 'verdes', mais ecológicos, eco-eficazes, eco-eficientes e interactivos com os elementos naturais, destacando-se apenas pelos seus atributos tecnológicos.

Torna-se evidente, portanto, que são necessárias reorganizações estruturais das colectividades, em particular das ocidentais, para minimizar os riscos decorrentes das tecnologias que surgiram com o advento da Modernidade, isto é, com o processo de modernização da sociedade. Para o sociólogo Alemão Ulrich Beck a Modernidade, ou Primeira Modernidade, relaciona-se historicamente com o período correspondente ao nascimento da Sociedade Industrial, momento em que se desenvolve o modelo de modernização da sociedade europeia. Caracteriza-se, portanto, por um forte incremento e predominância da actividade industrial, baseada na exploração de recursos humanos e naturais, que subtraiu as colectividades humanas do jugo do sistema feudal e as introduziu na frenética tecnosfera das sucessivas invenções tecnológicas que culminaram na chamada Revolução Industrial do século XVIII. Por sua vez, a Segunda Modernidade compreende temporalmente o período entre a segunda metade do século XX e o momento actual. A Segunda Modernidade, ou Modernidade Reflexiva, é entendida como um processo de crítica e reflexão contínua dos modos postulados pela Sociedade Industrial. Durante este processo as antigas instituições científicas e tecnológicas, fiéis depositárias da verdade e progresso da modernização, são desacreditadas pela falência ou inoperância dos seus postulados na construção de uma sociedade industrial mais equitativa e segura. São ainda ponderados os efeitos colaterais e/ou inesperados, nomeadamente os desequilíbrios no ecossistema e a agressão ao meio ambiente. (Beck, 1998)

O momento particularmente problemático que atravessamos, as sociedades contemporâneas encontram nas potencialidades da globalização, da comunicação em rede, e da crescente individualização os instrumentos necessários a produzir a necessária massa critica para confrontar os problemas introduzidos pela própria Modernidade. A superação das antinomias e insuficiências da Modernidade, ou antes, a Modernidade Reflexiva, origina a formação de uma nova postura e consciência do processo de Re-Modernização da sociedade, cuja expressão máxima vai de encontro aos princípios de sustentabilidade.

A questão da segurança e controlo, em particular ecológico, são temas recorrentes quando se elabora acerca dos principais desafios da Segunda Modernidade. Os registos e resultados anómalos produzidos pela ciência e tecnologia ocidental representam um acréscimo significativo no nível e percepção dos riscos. A Sociedade de Risco de Beck entreve toda a tecno-ciência como intrinsecamente perigosa e potencialmente fatal pela imprevisibilidade dos seus efeitos e pela incapacidade de domesticação do futuro. Em reacção, a Modernidade Reflexiva, através do processo de reforma e reorganização da Sociedade Industrial, desenvolve uma estratégia baseada em princípios capazes de reduzir a vulnerabilidade ou sobreexposição aos efeitos negativos da actividade humana: Sustentabilidade. Esta assume-se então como um novo modelo paradigmático de desenvolvimento que toma forma num pacote de medidas de segurança e controlo ambiental, tentando diminuir os riscos associados aos desenvolvimentos científicos que proporcionaram um entendimento do estado do Mundo Natural. Por outro lado, traduz, também, a necessidade de um melhor relacionamento do Homem com o Meio Ambiente.

2.2 *Arquitectura de limites*

A celebre definição de sustentabilidade ou desenvolvimento sustentável (* "[…] development that meets the needs of the present without compromising the ability of future generations to meet their own needs." - World Comission on Environment and Development, *Our Common Future*. Oxford: Oxford University Press, 1987) proposta pelas Nações Unidas em 1986 aquando da elaboração do relatório da, comummente denominada, Comissão Brundtland, nasce precisamente da necessidade de compreender os limites e regular a acção humana à escala global sobre os sistemas naturais. (WCED, 1987)

Neste relatório reafirmaram-se velhas questões relacionadas com o crescimento e, principalmente com os modos da acção humana, e suas implicações na demografia, economia, tecnologia, postas a descoberto uma década antes pelo denominado Clube de Roma. Através de uma abordagem holística tentam compreender a influência do ambiente no desenvolvimento social, económico, politico, psicológico e cultural mas também com o intuito de compreender a verdadeira amplitude dos efeitos anómalos produzidos e manifestados à escala global, ao nível dos sistemas ambiente-população-economia.

A investigação foi conduzida pelo System Dynamic Group do MIT, liderado pela investigadora Americana Donella "Dana" Meadows, do qual resultou o polémico relatório intitulado *Limits to Growth*, tendo sido publicado em 1972. Através de uma analise escatológica, colocou-se a descoberto o conflito latente entre o modelo de crescimento económico e o mundo natural. Os modelos computorizados utilizados na investigação permitiram fazer um estudo especulativo sobre os futuros desenvolvimentos dos sistemas naturais e humanos mantendo-se inalterados os presentes níveis e formas de actuação sobre o mundo natural, nomeadamente ao nível do crescimento demográfico e económico. Em todos os cenários, mesmo os mais optimistas, indicavam uma falência iminente dos sistemas naturais. Este facto traria constrangimentos de uma escala e intensidade nunca vividos esperando-se uma escassez de recursos (incluindo os mais básicos), resultantes da poluição e do mal estar geral do planeta.

Volvidos 30 anos, este mesmo grupo de investigadores relançou o polémico tema dos limites de crescimento fazendo um ponto de situação do actual momento. Apesar das significativas mudanças na tecnosfera, nas instituições e nos hábitos humanos, todo o mundo desenvolvido continua sobre a ameaça de um abrupto e definitivo colapso entre estes os sistemas naturais e artificiais. A mensagem é bastante clara e explícita. Os avisos de 1972 e de 2002 propõem ferramentas eficazes na transição para um sistema sustentável. Apesar de não avançarem com uma solução concreta para a problemática da sustentabilidade, nem referenciarem os moldes e parâmetros de um desenvolvimento sustentável, apresentam um conjunto de medidas preventivas no sentido de limitar ou controlar o uso dos recursos. (Maedows, 2004)

As implicações destes na Arquitectura resultaram contenções de ordem material e, principalmente, energética pela dependência das energias e materiais provenientes de uma única fonte, protagonizada pela hegemonização das bases tecnológicas propostas pela economia de mercado global. Estes eventos colocaram em causa o velho modelo económico e social operando uma verdadeira viragem paradigmática à qual a arquitectura não ficou isenta, prevendo sérios constrangimentos.

A noção de limites de crescimento sempre esteve associada a ideia de sustentabilidade e cujo conceito se foi esboroando ao longo destes últimos duzentos anos. Nos assentamentos humanos da Grécia Antiga, quando ultrapassado o limite demográfico estabelecido como aceitável para uma determinada cidade, os habitantes eram incentivados a procurar ou fundar novas colónias prevenindo uma instabilidade ecológica (mas também económica e social) no biótopo em que estavam inseridos. Para uma cidade na Idade Média, a noção de limite de crescimento era imposta fisicamente pela cintura de muralhas que, com o seu constrangimento físico e tecnológico condicionava o consumo de recursos à mesma velocidade com que se regeneravam. Desde a Revolução Industrial que o mundo dito "desenvolvido" se afastou deste idílico cenário de equilíbrio onde comungava do infindável poder regenerativo da Natureza, enveredando, perigosamente, por um caminho de incautos consumos proporcionados e estimulados por uma indústria transformativa poderosa. Na Contemporaneidade tornam-se evidentes as consequências destrutivas deste irresponsável modo de vida causando problemas ambientais bem conhecidos de todos nós: desperdício, poluição, desflorestação e aquecimento global. Apesar de, aparentemente, compreendermos a origem e funcionamento destes fenómenos pouco ou nada se tem feito para alterar a matriz de acção e desenvolvimento.

Tomando em consideração estes factos, a Arquitectura vê-se na necessidade de, a curto prazo, reelaborar as suas práticas para níveis de actuação mais sustentáveis fazendo um uso sensato da escassez de recursos e materiais disponíveis. Em última instância, uma das medidas que poderá servir de apoio para esta transição pode passar, eventualmente, pela necessidade de limitar o ímpeto construtivo, facto que colocaria o sector económico e profissional em cheque. Porém, os constrangimentos relativamente ao uso de materiais e a inviabilidade de uma politica limitativa das novas construções pressupõem a procura de medidas que entrevejam na reutilização de alguns elementos construtivos uma solução viável que compatibiliza a necessidade de crescimento com necessidade de limitar e controlar o uso dos recursos.

2.3 *Reparadigmatização*

Podemos encontrar no campo das Ciências Naturais e Humanas as directrizes que podem reformar os parâmetros de uma nova forma de desenvolvimento da arquitectura e construção e, em última análise, a própria sociedade ocidental. Encontramos no filósofo francês Edgar Morin a vontade de enformar este paradigma emergente – a Complexidade – pela necessidade de reorganizar e religar o pensamento transdisciplinarmente para responder e enfrentar as preocupantes questões do nosso tempo. (Morin, 2003)

A arquitectura, imbuída deste pensamento e vinculada pelos recentes avanços na Biologia, desenvolve uma empatia pelos sistemas ecológicos e naturais incorporando as metáforas e analogias biológicas e, em particular, a referência ao orgânico. A arquitectura procura, assim, uma identificação a um organismo vivo em pleno diálogo com o entorno num claro esforço de compatibilização dos sistemas naturais com os artificiais, isto é, ameniza o emprego extensivo da máquina com profundo respeito pelo uso de materiais locais. (Montaner, 2002)

No seguimento disto, atentamos na dinâmica recursiva da relação natural/artificial, e as recíprocas ressonâncias endógenas que em constante ajuste tentam reequilibrar o sistema ecológico. Segundo o filosofo Norueguês Arne Naess a existência de uma perspectiva ecosóficas, isto é, de uma sabedoria ecológica em detrimento de uma filosófica ecológica, permite ‘aprofundar’ o nível das relações do homem e das suas produções com o mundo natural entendendo o homem numa relação de reciprocidade e interdependência com o mundo natural (Naes, 1995). Na óptica de Naes o resultado arquitectónico do seu egalitarianismo biosférico só se pode manifestar na produção de estruturas vernáculas e no uso de tecnologias tradicionais típicas de um lugar. (Naes, 1995) Por outro lado, a visão fragmentada das esferas ecológicas e o pensamento rizomático que o filosofo Francês Félix Guattari defende encontra afinidades com as estruturas móveis, ligeiras e de baixo impacto, colocando grande ênfase nas novas tecnologias e tipologias. (Guattari, 2000)

3 ARTIFICIAL

Ao longo da história da humanidade, várias foram as civilizações que se depararam com situações de iminente colapso e outras que atingiram elevados graus de desenvolvimento técnico. Porém, nenhuma foi capaz de produzir tão fortes e irreversíveis danos na ecosfera ou ficar profundamente influenciado pelos métodos e técnicas. As ferramentas essenciais para a concretização de qualquer objecto passam, invariavelmente, pelo conhecimento profundo das diferentes técnicas e tecnologias com o intuito de articular pensamento e prática projectual (construtiva). As técnicas ditas modernas, herdadas da Revolução Industrial, produziram efeitos catastróficos no globo. Em momento algum da longa evolução humana, existiram civilização que atingiram elevados graus de excelência técnica mas, curiosamente, nenhuma foi capaz de produzir tão fortes e irreversíveis danos na ecosfera ou que fossem profundamente influenciados pelos métodos e objectivos das tecnologias e técnica. A discussão em volta dos avanços da técnica e dos desenvolvimentos tecnológicos enfatiza a necessidade de um retorno à harmonia ecológica entre as produções humanas e a Natureza. (Mumford, 1950)

Parece que é totalmente inviável como improvável que neste preciso momento haja lugar a retrocesso tecnológico para patamares primitivos mas, pelo contrário, (re)evolucionar o actual quadro tecnológico. Assim, a Arquitectura enformada neste mosaico tecnológico, dispõe de novos dispositivos que tomam como referência os próprios modelos e sistemas orgânicos no que concerne, particularmente, ao uso e gestão dos recursos materiais e energéticos. Para tal, ponderamos acerca da qualidade e forma de interacção dos sistemas tecnológicos e tipologias arquitectónicas com os elementos naturais de maneira a prover soluções alternativas para a produção energética. (Mumford, 1950)

É precisamente sobre este último factor, a energia, que a problemática da sustentabilidade e da construção sustentável encontram os seus maiores desenvolvimentos e as mais acesas discussões. Existe uma extensa produção teórico-prática bem como um largo quadro de dados técnicos que legitimam a vertente tecnocrata da sustentabilidade. É um vasto e pertinente campo de acção, pois a instabilidade dos mercados energéticos, nomeadamente dos combustíveis fósseis, está a captar o interesse de órgãos políticos, corporações, investidores e profissionais para os benefícios dos edifícios energeticamente eficientes e para o potencial das energias alternativas de origem orgânica. Por estas razões, o arquitecto Espanhol Luiz Fernandez-Galiano, atento ao evoluir desta problemática, recupera atempadamente o tema da energia no discurso da arquitectura defendendo a sua importância simbólica e funcional mas, também, o necessário desenvolvimento estético das novas construções em consonância com o presente tempo. (Fernandez-Galiano 2005)

Neste contexto adquire importância, o pensamento pró-activo, que faz uso do profundo conhecimento dos sistemas naturais e dos métodos de produção industrial para conceber uma Arquitectura que se enquadre dentro do ciclo orgânico do Mundo Natural. Este pensamento procura ponderar os efeitos do objecto arquitectónico em todo o seu ciclo de vida, desde a sua concepção até ao seu desmonte, com o objectivo de produzir o mínimo impacto ambiental. O arquitecto Norte-Americano William McDonough, procura transladar as dinâmicas e ciclos de nutrientes na natureza para a sua investigação e pratica profissional desenvolver uma arquitectura que se assemelhe ao metabolismo circular presente na natureza e, assim, eliminar a noção de desperdício. Assim, elabora o conceito de nutriente técnico para explicar a circularidade dos materiais e componentes do objecto arquitectónico. Isto é, no entender de McDonough (McDonough, 2002), no final do ciclo de vida de um edifício, todos os componentes empregues na sua construção podem (e devem) ser reconvertidos ou reaproveitados para produzir novos elementos de construção sem perdas das qualidades e características intrínsecas de cada um dos referidos objectos,

Esta concepção leva o pensamento arquitectónico mais longe mergulhando o objecto arquitectónico na teia ecológica do mundo natural. Igualmente importante para esta perspectiva é a importância da experiencia sensorial dos espaços internos ser positivamente qualificada pelo que a arquitectura deve procurar criar espaços permeáveis aos elementos da natureza contribuindo para um ambiente confortável e salutar.

4 INTERFACE

Com os desenvolvimentos das Ciências Naturais e do entendimento dos seus sistemas operativos a arquitectura é hoje um elemento dinâmico no ecossistema. O universo das propostas de arquitectura ecológica abrangem um largo espectro de aportações desde as de carácter telúrico, fruto das ideias primitivistas dos anos 70 do século XX e dos impactos da crise energética, até aos mais recentes exemplos de arquitectura com alta performance tecnológica como o High-tech. Uma posição intermédia entre estas duas posições aparentemente opostas, porém não contraditórias, parece ser o modelo conceptual que melhores resultados práticos consegue a todos os níveis no campo da arquitectura enformada pelas questões ecológicas.

A postura bioclimática funde os pressupostos vernáculares com os tecnológicos permitindo conceber o objecto arquitectónico como um ecossistema no qual se articulam componentes orgânicos e inorgânicos. Apuramos que a produção teórica e prática do arquitecto malaio Ken Yeang traduz magistralmente este pensamento pela inclusão dos referidos sistemas nos edifícios permite esbater a tradicional dicotomia entre natural e artificial. (Documento audiovisual: *Architect Ken Yean speaks on EcoDesign*. Disponível em http://br.youtube.com/watch?v=tYONQW78qbE ; acedido em 2008-08-15). A aplicação dos principios bioclimaticos não estão unicamente destinados a tipologias ou programas particularmente mais ‘modestos’ como, por exemplo, a habitações unifamiliares, mas podem ser aplicados, virtualmente, em toda a extensão das construções e forma arquitectónicas. O trabalho de Yeang é a prova viva da sábia apliação de princípios bioclimáticos a uma tipologia tao dificil e improvavel como as dos edificio em altura, promovendo uma melhoria no rendimento energético mas também social através da inclusão de elementos e soluções naturais.

Para Yeang, a arquitectura vernácula é o modelo conceptual a seguir pois, argumenta, nela reside a base material com que a arquitectura contemporânea se deve reger. O conceito de ecomimetismo que, tal como se depreende da formação etimológica da palavra, se prende com a imitação dos processos ocorridos na Natureza. Tal como num organismo na natureza, tenta perceber e prever o ritmo metabólico dos edifícios com o intuito de fornecer dispositivos capazes de optimizar os níveis de conforto de acordo com as necessidades do momento. Esta é a base da aplicação dos preceitos bioclimáticos à tipologia em altura. Yeang alude à metáfora de edifício permeável para caracterizar a forma como os elementos naturais – a luz, o vento e a vegetação – penetram nos edifico. As propostas de Yeang integram estes elementos em toda a sua extensão horizal e vertical do plano através do um complexo sistema de rampas que interconectam os diferentes pisos, dando lugar a espaços abertos para o exterior. Estes permitem a expansão do habitat e o contacto com o exterior criando lugares de encontro e ócio dentro do proprio edificio, um cordão verde no sentido vertical.

O interesse pelas questões da técnica e da ecologia não esquecendo o mesmo entusiasmo para com o estudo dos sistemas é o que identifica o pensamento e prática dos arquitectos espanhois Iñaki Ábalos e Juan Herreros mas, também, a mesma preocupação com os novos desafios impostos pela realidade contemporânea deste início de século na arquitectura. Este colectivo acredita nas potencialidades e no desenvolvimento da técnica como forma de resolver os problemas relacionados com o papel da tecnologia na mediação das interacções entre Natureza (ecologia) e fruidores (humanos). Neste sentido, reconhecem que o presente momento cultural concebe todo o espaço público como paisagem (construída ou não construída) numa atitude integradora que esbate a velha separação dicotómica entre natural e artificial.

O conceito de ecomonumentalidade nasce da simbiose entre o natural e o artificial, entendido como um processo intemporal que ressalva em última instância a sensibilidade para com o Mundo Natural. Desta feita, num processo retroactivo, a arquitectura começa a incorporar o apelo à Natureza e às preocupações ambientais, quer seja pela inventividade dos processos técnico-construtivos quer pela composição e organização do plano. (Abalos & Herreros, 2002)

Mais ainda, constatamos com a ecomonumentalidade de Ábalos & Herreros que a transformação dos lugares em paisagem coloca um entendimento global do território e, por conseguinte, todos os seus elementos são ponderados sob o ponto de vista cenográfico. Daqui resultam espaços e edifícios híbridos que pressupõe um discernimento dos limites de actuação da arquitectura e paisagismo (e, com isto, o urbanismo) pela similaridade dos objectos de estudo e áreas de intervenção. As totais potencialidades deste novo modo estão ainda por revelar.

5 APROPRIAÇÃO

As preocupações com o estado do Mundo Natural estão cada vez mais presentes nas nossas vidas pelo agravamento dos fenómenos ambientais à escala global. Apesar destes últimos terem, inequivocamente, uma causalidade antropogénica, isto é, gerada como subproduto da actividade (industrial) humana, não é um acontecimento inaudito no decorrer da História da Humanidade. Apesar deste cíclico colapso entre estes dois sistemas, a Modernidade Reflexiva, através do processo de reforma e reorganização da Sociedade Industrial contemporânea, desenvolve uma estratégia baseada em princípios capazes de reduzir a vulnerabilidade ou sobreexposição aos efeitos negativos da actividade humana: Sustentabilidade.

A arquitectura, enquanto produto do processo de humanização, encontra-se entre os principais visados pelo novo modelo paradigmático de desenvolvimento que toma forma num pacote de medidas de segurança e controlo ambiental para travar a contínua degradação do ambiente.

A indústria da construção é responsável pelo uso de cerca de 50% dos recursos disponíveis o que a torna numa das actividades humanas que mais degrada o planeta. Portanto, a viragem para um paradigma alternativo socialmente responsável e acessível a todos é, sem dúvida, moralmente desejável como economicamente necessária.

A incapacidade do planeta para absorver todos os resíduos da actividade humana e a instabilidade dos mercados energéticos, nomeadamente dos combustíveis fósseis, está a captar o interesse de órgãos políticos, corporações, instituições, agremiações, investidores e profissionais para os benefícios dos edifícios energeticamente eficientes e para o potencial das energias alternativas de origem orgânica.

Parece oportuno, hoje, informar conscientemente os diferentes grupos alvos para as mais-valias que uma perspectiva ecocentrada pode trazer para a arquitectura e para os diferentes níveis de actuação na sociedade como forma de democratização. Nesta perspectiva, os desenvolvimentos das Ciências Naturais e do entendimento dos seus sistemas operativos e os seus reflexos no corpo de saber, colocam a arquitectura contemporânea numa dialéctica dinâmica com o ecossistema.

Assim, o modelo conceptual que melhores resultados práticos consegue a todos os níveis no domínio da arquitectura enformada pelas questões ecológica é de preocupações bioclimáticas. As principais orientações arquitectónicas da actualidade concebem todo território como paisagem (construída ou não construída) numa atitude integradora que esbate a velha separação dicotómica entre natural e artificial. Desta simbiose entre o natural e o artificial, nasce o conceito de ecomonumentalidade que entende, em última instância, a sensibilidade para com o Mundo Natural. Desta feita, a arquitectura começa a incorporar o apelo à Natureza e às preocupações ambientais, na qual se fundem os ensinamentos vernáculos com os tecnológicos que resultam numa concepção técnica anti-despesista e com profundo respeito pelo valor lugar.

Neste sentido, encontramos o ponto de contacto com que iniciamos este artigo onde se tentou deslindar as relações do objecto arquitectónico com o mundo natural onde aludimos à nossa qualidade de simples inquilinos desta grande casa. Apesar de estar longe a resolução da problemática ambiental e ecológica verificamos que possuímos actualmente as competências necessárias e suficientes para operar uma viragem paradigmática e iniciar uma nova fase de Modernidade cujos frutos serão igualmente ricos em desenvolvimentos tecnológicos, esplendor filosófico e metafórico como em períodos anteriores.

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Comparative approach to energy behavior of contemporary urban buildings in Greece

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ABSTRACT: This study examines the particular characteristics that define the energy and environmental behavior of urban residential and commercial buildings in Greece, where both the climate and other factors that shape these characteristics are specific and well defined. Based on the available statistical data, the study evaluates the energy behavior of corresponding buildings and compares them with similar data of other countries, where prevail different climatic conditions. From this comparison, indications are obtained, and reflect the exploitation of the available energy potential in the country. Furthermore, this study examines the basic methods and practices, which are applied in the design and construction of urban buildings in Greece and contribute to their energy and environmental behavior.

1 INTRODUCTION

Greece, with an overall land area of approx. 132,000 km^2, consists, by the four-fifths of its mainland, of mountainous terrain. Greece is also a maritime country with numerous islands and a coastline of over 15,000 km in length. The bulk (i.e. about 59%) of the country's population according to the last census (2001), stands at about 11 million, lives in urban areas [4]. Most urban centres and the largest of them, including the conurbation of the capital, Athens, with its population of about 4 million, and the second largest city, Thessaloniki, with its population of about 1 million inhabitants, lie on the coast.

Greece has a Mediterranean climate [6]. According to the relevant climatic data, the annual cycle can be divided into a cold and rainy season (October to March) and a warm and dry season (April to September). Temperatures on the Greek mainland present intense contrasts mainly due to geographic factors. Greece is between the average annual isothermal of 14.5 and 19.5 °C. The extreme temperatures are close to -25 °C (during winter in the mountainous and northern regions) and +45 °C (during heatwaves on the mainland). The mean relative humidity ranges from 65% to 75%, according to location. It displays a simple annual fluctuation, with the maximum occurring during the winter months, and depends on the proximity of natural concentrations of water. In Greece, the general circulation of the atmosphere and the prevailing synoptic systems in the wider area contribute to the prevalence of western and northern wind components and fairly moderate speeds. However, in interaction with them, the complex relief of Greece plays an important role in determining the prevailing wind direction and speed in many regions. Greece is a very sunny country. The average annual rates of incoming solar radiation, moving from north to south, range from 5000 to 6100 MJ/m2/yr [3]. The climatic data above relate mainly to the countryside. In urban environments, in which the majority of buildings are situated, these data change as a result of the influence of the factors which make up the urban climate [9].

2 THE CONTEXT OF THE ENERGY BEHAVIOUR OF URBAN BUILDINGS IN GREECE

In Greece, the vast majority of buildings in urban environments, about 75%, are residential buildings. Second in terms of frequency comes the category of buildings housing productive activities, which are commonly known as commercial buildings (housing commercial operations, services, businesses etc.). In constructional and architectural terms, this category displays many similarities to the previous one. The smallest group includes buildings housing social services or functions (schools, hospitals, meeting halls etc.) and buildings serving special uses. In this category the greatest variety of architectural forms is to be found, despite the fact that the basic constructional characteristics of buildings in this category are the same as those in the other two categories.

An important piece of legislation with provisions relating to the health and comfort of occupants, the protection of the environment and energy saving in the building sector in Greece is the Construction Code for Buildings [13]. This Code deals specifically with the natural lighting, ventilation, damp protection, sound insulation and fire protection of buildings, amongst other things. In the recommendations that it contains, the Code uses mainly qualitative criteria; wherever quantitative criteria are used, these relate indirectly to the physical magnitudes of the phenomena being examined (e.g. the dimensions of openings for natural lighting or ventilation).

The EU Directive 2002/91 on the energy performance of buildings would have been transposed into Greek legislation by the end of 2006. The government had decided to launch a program to limit CO_2 emissions from the building sector by replacing existing regulations for the thermal insulation of buildings with more stringent ones. This would establish minimum energy standards for new and renovated buildings, energy audits, and energy labeling of buildings according to EU Directive 2002/91/EC. So far, no auditors have been trained [8]. This directive will replace the current legislation that concerns the energy behavior of buildings in Greece, the Thermal Insulation Code, which has been in force since 1979 [7].

During the last decade, the Greek energy system is undergoing significant changes. The penetration of natural gas, the construction of trans-European energy networks, the promotion of renewable energy and energy saving and the release of the electricity market are the new features.

In Greece almost all urban residential and commercial buildings take the form of multi-storey apartment blocks. The great majority of these buildings consist of a ground floor and a series of higher floors usually between three and five in number and very rarely more than seven. An analysis of building statistics for the period 2002-2006 reveals that the average volume of buildings in Greek towns is around 1500 m^3 [5]. This volume works out at about 120-200 m^2 per floor.

In Greek urban areas, buildings are constructed on site with a supporting structure of reinforced concrete and non-load bearing walls of perforated bricks. The external walls are built with a double row of bricks, each 9 cm wide, with internal insulation consisting of a 5 cm-thick layer of expanded or, at best, extruded polystyrene. Such a wall, if the layer of plaster on each side approx. 2 cm thick is included, is over 27 cm thick, while the mean thermal transmittance coefficient is approximately 0.45 W/m^2K. Thermal insulation is applied to the vertical elements in the envelope of the supporting structure by fastening 3 or 4 cm thick tiles of expanded or extruded polystyrene onto the external surfaces. In this case, the mean thermal transmittance coefficient of a typical wall 30 cm thick with a 3 cm-thick insulation layer is approx. 0.74 W/m^2K. Thermal insulation is also applied to the flat roof, as well as the floor of the first storey, if this lies above an open-sided parking area. The external openings in Greek buildings, i.e. windows and balcony doors, usually consist of two leaves, with each leaf consisting of a pane of glass set within a frame. In the past, frames used to be constructed of wood. In the 1970's wood began to be replaced by aluminium. Indeed, at that time aluminium frames used to be made to order by small cottage industries which could not guarantee good quality of construction or good behavior in their products. Typical aluminium frames consist of parallel sliding units. Nowadays, aluminium continues to be used as a construction material for external doors and windows, although at the same time greater use is being made of plastic. Typical modern synthetic door and window units consist of two leaves, with double glazing, which open or tilt around a horizontal axis in the bottom section of the frame [12].

In Greece, natural ventilation systems predominate as a result of the climatic conditions, which favour their use. All residential buildings in Greece are ventilated naturally. Mechanical ventilation systems can be found in other categories of buildings in cases where natural processes are unable to cover the increased or special ventilation requirements (e.g. meeting halls and conference rooms). As for the control of natural ventilation in internal areas, this can be achieved by using the doors and windows in the envelope, which in Greek buildings are generally sufficient in number and easy to use. As for infiltration, brick-and-concrete constructions generally imply airtight envelopes. Thus, most cases of infiltration appear to be related to external doors and windows, whose improvement in quality in recent years is leading, according to the current evidence, to even more airtight envelopes [10].

An important element that plays a decisive role in the interaction between buildings and their environment in Greece is the balcony. Balconies are an essential feature of all residential buildings. Apart from their functional role and their active contribution to the external appearance of the buildings to which they belong, balconies also play a dynamic role in shaping a series of environmental influences that are exerted on buildings. Such influences concern numerous aspects of building physics, like sun-control, day lighting, heat transfer, damp protection, sound insulation, wind-loading, natural ventilation etc [11]. These influences are essentially either directly or indirectly connected with the energy behavior of the building to which the balcony belongs.

All building interiors possess a heating system. In most apartment blocks this takes the form of a two-way oil-fired central heating system. The burner, distributor and fuel storage tank lie in the basement, whence a network of pipes, which are usually not insulated, carry the water to all floors and apartments.

3 THE FACTS RELATING TO THE ENERGY BEHAVIOUR OF BUILDINGS IN GREECE

Buildings in Greece are wasteful in energy terms. According to statistics for 2007, the energy sector that they represent (Households and Services) consumes about 8.56 Mtoe or 39% of the total annual energy consumption [2], while, of this amount, the energy use for heating of buildings is estimated to be about 61%. In addition, it is characteristic that, apart from the increase in absolute values that the energy consumption sector for buildings understandably shows as a result of the increase in the number of buildings and the energy-consuming applications in them (66% between 1990 and 2000 and 13% between 2002 and 2007), in recent years, there has also been a sharp rise in the proportion of total energy consumption that it represents. Thus, this has increased by about 10% in 12 years and also by about 11% in the last six years (from 29% in 1990 to 39% in 2002, ending with 50% in 2007). This increase has been partly caused by the wide use in recent years of air conditioning systems in buildings [8].

These figures, although they are not directly comparable, appear to approach those of countries in central and northern Europe, where, however, the climatic conditions are clearly worse. Though in the last six years, for the majority of the European countries, the amount of energy consumed for residential needs has reduced in contrast with the Greek residences [2].

In Germany, the mean temperature is about 8.2 °C. The total energy consumption for Households and Services in 2007 is 90.53 Mtoe or 43% of the total annual energy consumption. While, of this amount, the energy use for heating of buildings is estimated to be about 74%. This amount of energy has decreased by about 10% during the last six years [2].

In Switzerland, the mean temperature is about 4 °C. The total energy consumption of the buildings in 2007 is 9.77 Mtoe or 46% of the total annual energy consumption, while, of this amount, the energy use for heating of buildings is estimated to be about 69%. This amount of energy is decreased by about 13% from 2004 to 2007. Finally, in another Mediterranean country, Spain where the climate appears similar to Greece, the mean temperatures in winter is about 2 °C and in summer 35 °C. The total energy consumption for Households and Services in Spain is 29.90 Mtoe or 30% of the total annual energy consumption, while, of this amount, the energy use for heating of buildings is estimated to be about 80%. The amount of energy consumed for residential need from 2004 to 2007 appears also in Spain slightly decreased of 0.3% [12].

As can be assumed with this comparison with the other European countries, in all the analyzed countries (Germany, Switzerland and Spain) during the last three years, the total energy consumption for buildings has reduced regardless to the new buildings that are constructed. This reduction rate in some appears to be quite weak and in some it is more evident (Figure 1). Greece not only has not improved the total amount of energy consumed for residential uses but also the total percentage of energy consumed from the building sector appears similar with countries with much more severe climates such as Germany and Switzerland.

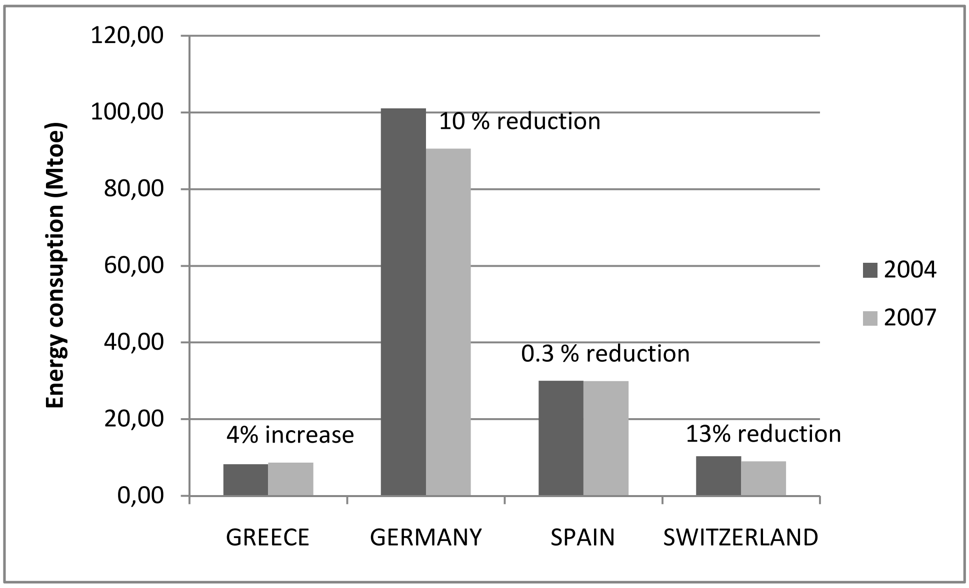

Figure 1: Energy consumption in Mtoe in 2004 and in 2007

The main factors responsible for the low performance of buildings with regard to energy behavior may be the following, in no particular order of importance:

a. A large proportion of these buildings were built before the Thermal Insulation Code (1979) came into effect and do not possess thermal insulation of any kind. In this respect, it has been estimated that the average annual heating energy demand of Greek apartment buildings built before 1980 is about 96 kWh/m^2, while for those built after 1980 the demand is estimated to be between 75-94 kWh/m^2 [1].

b. On the basis of modern scientific approaches, the present Thermal Insulation Code does not successfully deal with the matter of energy losses in buildings. On the contrary, in a dubious attempt to simplify matters, it excludes or reduces the significance of parameters that play an important role in them. As an example, it does not take account of infiltration losses or losses from thermal bridges in its calculations.

c. The practices followed in the implementation of thermal insulation studies are not always suitable. It is quite usual for inferior, and therefore cheaper, thermal insulation materials to be used, just as it is fairly common to see poor workmanship in their application, the most characteristic example of this being the laying of such materials on broken surfaces.

d. Energy design is ignored. The number of urban buildings in Greece in which serious attempts at energy design have been made is small, just as there is only a small number of design teams that possess the experience to undertake and carry out such works.

Apart from these factors, a significant share of the responsibility for the high consumption of energy in buildings in Greece belongs to the residents, with their generally low sensitivity to energy-saving matters [14].

On the basis of 2007 statistics, oil (which is used as a fuel for heating buildings), accounts for 43.2% of the total amount of energy consumed in the buildings sector in Greece [2]. Electricity, with 39.7% of the total, represents the second most used energy form. It is used for lighting and the operation of domestic appliances (including air conditioning systems) and, more rarely, for heating buildings (electric fires and storage heaters). Natural Gas began to be used in buildings in 1998, mainly as a fuel in central heating systems. Despite its rapid spread, it accounts for just 3.3% of the total amount of energy consumed in the buildings sector throughout the country. This percentage is larger in urban buildings, since only these are supplied by the existing network. In contrast, renewable forms of energy, which account for 11.0% of the total amount of energy consumed in the buildings sector in Greece, represent a smaller proportion of the energy used in urban buildings, since most of this category consists of the burning of wood and woodwaste in order to heat buildings in agricultural areas. In urban buildings, this proportion of energy use relates mainly to the exploitation of solar energy through glazed solar collectors, which are placed on the flat roofs of apartment blocks in order to heat water for domestic use.

Although in 2002 the total consumption of renewable sourced energy in the building sector was relatively high compared with other countries in Europe, in 2007 some countries seem to have adopted a large variety of measures for energy efficiency in buildings even though their energy potential is poorer compared with Greece. For example in Switzerland renewable forms of energy account for 11.7% of the total amount of energy consumed for buildings. In addition, Greece owns this high percentage more in heating from biomass and lacks of the ability to exploit other sources which are equally beneficial judging from the region's available potential. Whereas countries like Spain, where almost all the percentage of the renewable energy consumed by the building sector (7.6%) comes from the exploitation of the solar energy and the implementation of PV panels on residences.

CONCLUSIONS

The basic factors that determine the energy behavior of buildings in Greece can be briefly divided into three categories:

- The most important and obvious category is the local climate. The mild characteristics of this climate, combined with the way in which these characteristics fluctuate widely during the climatic cycle, create a complex set of conditions and also challenges which the concerced buildings have to meet.
- The second most important category is the building construction methods. The concrete, perforated bricks and other building materials, as well as the building practices that prevail in the construction of urban buildings in Greece, have a direct impact on their energy behavior. Thus, the great heat capacity of the building materials, the low air permeability of the envelopes, the presence of thermal bridges, the high levels of fire resistance and mechanical resistance, as some of the typical properties of the particular construction model used, of course play a role in shaping important parameters in the behavior of the buildings concerned. So, too, do those properties relating to thermal conductivity, moisture permeability, sound-insulating power and other parameters of the construction elements.
- The quality of construction of buildings in Greece, at least during the last few decades, has, by and large, been average. The building materials that are used and the practices that are applied, with regard mainly the invisible surfaces of buildings (such as layers of insulation) are often governed by a rationale of low cost and ease of application. The underlying causes of this reality can be sought in different areas. Its consequences, however, are reflected in building pathology issues and of course in the low performances of the buildings in terms of their energy behavior.
- The last category concerns the Greek people. In particular, it concerns the way they behave in the buildings in which they live or work. One aspect of this behavior includes the attempt by constructors to exploit the weaknesses of the existing system of building construction in order to make financial gains at the expense of the quality of construction. Another very important aspect of the user's behavior concerns his active intervention in processes that influence the behavior of the buildings they live in. In this area, although no available data exists, it can be assumed that the Greeks are by and large insufficiently sensitized. The way in which they face their role in the energy behavior of buildings is rather superficial and their conduct in this respect could be described as being based on reflex actions. For example, the actions they take to control the parameters of the internal environments of their buildings rarely go beyond using the available electro-mechanical installations.

The similarities in the energy behavior of different urban buildings in Greece allow us to form an overall picture of this behavior. This picture is also improved by the comparison of the data that represent it with similar data from countries in different climatic zones. According to what has been stated above, this behavior presents certain weaknesses, various causative factors of which have already been identified. One of the main reasons that could explain these weaknesses is the fact that many of the crucial choices that play a part in forming the overall picture are determined by other parameters and priorities. This finding, insofar as it reveals a wrong approach, indicates how useful it would be to encourage attempts to give greater emphasis to energy parameters in the design, construction and use of buildings.

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The importance of the external envelope within energy certification of residential buildings in Portugal

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ABSTRACT: The certification of the energy performance of residential buildings in Portugal is well implemented. However, the specific calculation method that leads to the determination of the energy class does not consider adequately the main aspects of energy performance. It is possible to obtain an excellent certification class in a dwelling where its inhabitants will have to spend more energy to obtain the nominal comfort conditions, when compared to a dwelling where the external envelope is thermally optimized and where therefore the heat loss will be much smaller. This paper addresses this issue, analyzing the existing method and proposing an adapted methodology that is thought to better reflect the external envelope of the building. From the standpoint of public policies, the priority should be put into promoting the quality of construction to ensure a potential of reducing energy consumption. Information provided by the energy class as determined by this proposal is more accurate in terms of the end user, allowing therefore a more precise comparison of different dwellings.

1 INTRODUCTION

Energy certification of buildings is intended "*to make it possible for consumers to compare and assess the energy performance of the building*" (Directive 2002/91/EC). Energy performance is related, among others, to architectural design strategies (including materials and construction elements), lighting equipment, heating and cooling systems, domestic hot water systems, the quality of construction, final and primary energy sources and to use patterns of inhabitants.

The overall objective is to achieve comfortable and healthy indoor environments in a cost-effective way. Improving the energy performance of existing and new buildings is therefore a complex but determinant task. It encompasses a sometimes difficult compromise between end users and the need to reduce the energy dependence of countries. Anyhow, one side of the problem should not prevail.

The certification of the energy performance of residential buildings in Portugal is well implemented. People in general are sensitive to this issue and public authorities have been putting quite an effort in assuring the viability of the whole system.

However, the specific calculation method that leads to the determination of the energy class does not consider adequately the main aspects of energy performance. This paper addresses this issue, analyzing the existing method and proposing an adapted methodology that is thought to better reflect the external envelope of the building.

2 THE PORTUGUESE REGULATIONS FOR ENERGY CERTIFICATION OF RESIDENTIAL BUILDINGS

2.1 *General considerations*

The energy certification of residential buildings in Portugal depends, in general terms, on two regulations. First, on a regulation concerning the thermal comfort and the domestic water heating. Secondly, on a specific regulation that defines how the energy certification is implemented.

The first one, that will be called in this paper by its initials, RCCTE, defines the method for calculating the annual nominal energy requirements for heating, cooling and domestic water heating and, based on these, the annual primary energy requirements. The method is to be applied to each dwelling.

The second regulation (and related regulatory documents), SCE, defines that the energy class of a dwelling depends on the quotient between the respective annual primary energy requirements and the maximum allowed value.

2.2 *Primary energy requirements and energy class*

The calculation of the annual primary energy requirements (N_{tc}) of a dwelling considers the annual nominal values of the energy requirements for heating (N_{ic}), cooling (N_{vc}) and domestic water heating (N_{ac}). Despite this general principle, energy for heating and cooling is reduced to 10 % of its annual nominal values (Eq. 1).

$$N_{tc} = \frac{0.1\, N_{ic}\, F_{pui}}{\eta_i} + \frac{0.1\, N_{vc}\, F_{puv}}{\eta_v} + N_{ac}\, F_{pua} \qquad [\text{kOe/m}^2\text{.year}] \qquad (1)$$

where η_x = nominal efficiency of the system (for heating or cooling); and F_{pux} = conversion factor for primary energy.

In what concerns the nominal efficiency of equipments, actual values from the producers may be used. Typical values are also mentioned in RCCTE. The conversion factors for primary energy to be used are 0.290 kOe/kWh for electricity as final energy source and 0.086 kOe/kWh for other solid, liquid and gas final energy sources.

On the other hand, the maximum allowed value for primary energy (N_t) is calculated according to Equation 2:

$$N_t = 0.9\left(0.01\, N_i + 0.01\, N_v + 0.15\, N_a\right) \qquad [\text{kOe/m}^2\text{.year}] \qquad (2)$$

where N_x = maximum values for annual nominal energy requirements (for heating, cooling and hot water).

The maximum value for heating energy (N_i) is calculated with one of four possible equations depending on the form factor of the dwelling and on the degree days of the respective climatic region. The maximum value for cooling energy (N_v) is indicated in RCCTE in a list of six possible values according to the respective cooling season climatic region.

In Equation 2 the equipment nominal efficiency and the conversion factors for primary energy are implicit in the 0.01 and 0.15 factors. Although there is no official document explaining these numbers, in the case of heating and cooling it is believed that they arise from the following assumptions. For heating (Eq. 3), the consideration of a gas boiler with η_i = 0.87 (typical efficiency mentioned in RCCTE); for cooling (Eq. 4), the consideration of an equipment with a COP of 3 (also mentioned in RCCTE as a mandatory system in the case there is no other system yet defined in a design stage).

$$0.01 = 0.1 \times \frac{0.086}{0.87} \qquad (3)$$

$$0.01 = 0.1 \times \frac{0.290}{3} \quad (4)$$

The energy class is determined according to the result of the quotient N_{tc} / N_t as defined in table 1.

Table 1. Determination of the energy class.

Energy class	R = N_{tc} / N_t
A^+	R ≤ 0.25
A	0.25 < R ≤ 0.50
B	0.50 < R ≤ 0.75
B^-	0.75 < R ≤ 1.00
C	1.00 < R ≤ 1.50
D	1.50 < R ≤ 2.00
E	2.00 < R ≤ 2.50
F	2.50 < R ≤ 3.00
G	R > 3.00

Energy classes C to G are intended to existing dwellings that have to be certified under certain conditions and may not have to comply with RCCTE. In new buildings the condition N_{tc} / $N_t \leq 1.00$ is mandatory.

This calculation method has significant implications in how the thermal quality of the building external envelope is considered. In fact, the disregard of 90 % of the heating and cooling energy requirements neutralizes, in terms of primary energy requirements, the contribution of well thermally designed construction elements. It may be argued that nominal values do not have an exact math in the inhabitants consuming patterns. This is indeed accurate in what concerns Portugal in general. However, since the energy class is only dependent on primary energy requirements, energy certification is not favoring the quality of the external envelope neither the contribution of passive solutions. Moreover, if the assumptions of Equations 3 and 4 are correct, the certification process is favoring specific systems, especially considering the discrepancy between the values of the conversion factors.

In the following sections of this paper an evaluation of this method will be presented and some principles for improvement will be suggested.

2.3 *Evaluation of the method for the determination of the energy class*

In order to better understand the meaning of the above comments regarding the external envelope, an assessment was carried out determining the energy class, varying several parameters. These include form factor, degree days, cooling season climatic region, heating and cooling systems and equipment for hot water.

The maximum annual nominal energy requirements for heating (N_i) were calculated for three form factors – 0.5, 1.0 and 1.5 – and four degree day values – 1000, 1500, 2000 and 2500. The choice of these values is related to the specific equations for N_{ic} and to the interval of degree days in Portugal (the interval 1000 to 2500 covers 90 % of the municipalities in the mainland). Each one of the six possible maximum annual nominal energy requirements for cooling (N_v) was also considered.

In the scope of the above mentioned favoring of specific systems for heating and cooling, this assessment also considered three alternatives for heating: an electric domestic device (η_i = 1.00 and F_{pui} = 0.290 kOe/kWh); a system based on water heated by a gas boiler (η_i = 0.87 and F_{pui} = 0.086 kOe/kWh); and a heat pump (η_i = 4.00 and F_{pui} = 0.290 kOe/kWh). For cooling, equipment with COP of 3 was considered in every calculation. These are typical values mentioned in the regulation.

The three types of equipment to heat domestic water included in this assessment were a gas boiler (η_a = 0.87 and F_{pua} = 0.086 kOe/kWh), an electric boiler (η_a = 0.95 and F_{pua} = 0.290 kOe/kWh) and a gas heater (η_a = 0.50 and F_{pua} = 0.086 kOe/kWh). It was also considered the contribution of thermal solar collectors to support the heating of domestic water, using the default regulatory procedures.

The main concern in this paper is related to the quality of the external envelope. Therefore, three quality levels (*QL*) were used, through the relationship between annual nominal values and maximum values for heating and cooling energy requirements. Quality levels are defined in table 2.

Table 2. Quality levels used to simulate different external envelopes.

QL	N_{ic} / N_i	N_{vc} / N_v
1	0.9	0.9
2	0.5	0.5
3	0.1	0.1

2.4 *Assessment results and discussion*

For each quality level 648 possible combinations were calculated and the energy class determined. Results are presented in Figures 1, 2 and 3, in terms of the percentage of combinations that fall under each of the energy classes, for each type of equipment for domestic hot water (DHW). In these figures, "nc" means that RCCTE regulation is not complied with.

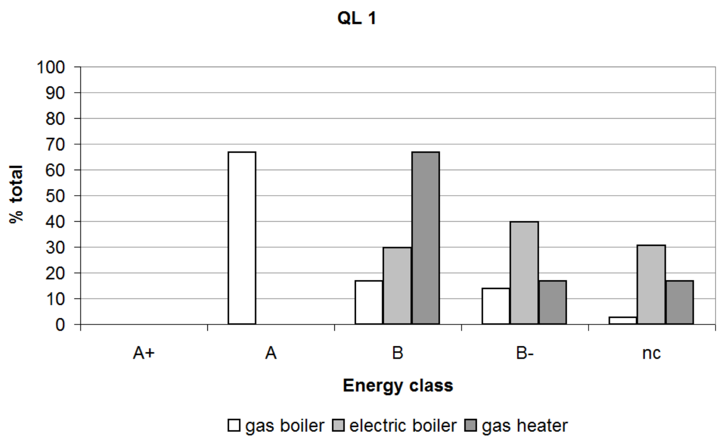

Figure 1. Energy class per DHW equipment, *QL* 1.

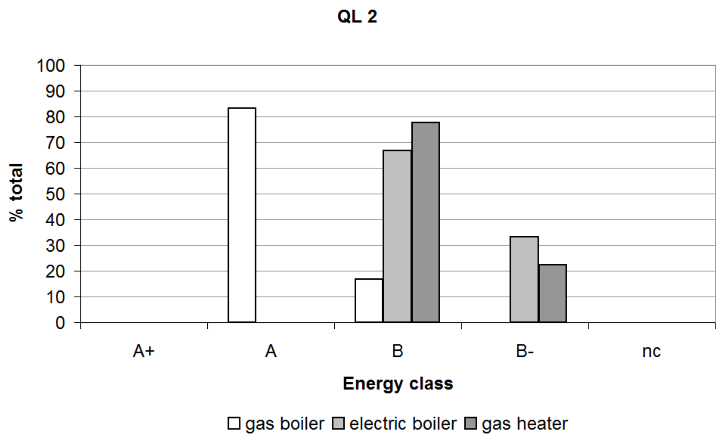

Figure 2. Energy class per DHW equipment, *QL* 2.

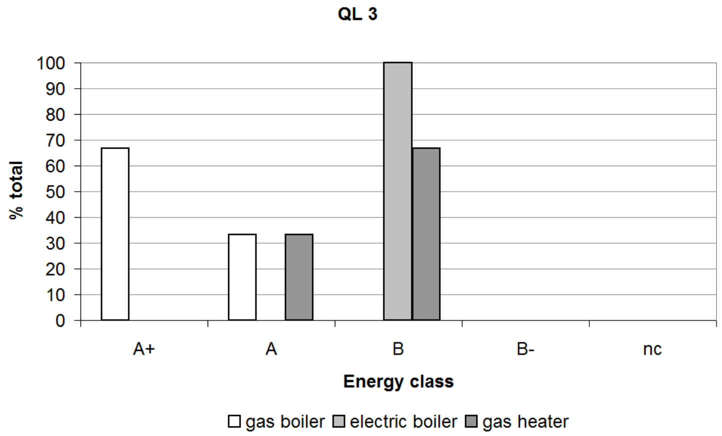

Figure 3. Energy class per DHW equipment, *QL* 3.

For *QL* 1, there are combinations that do not comply with RCCTE because $N_{tc} > N_t$. In every one of these cases, the heating system is an electric domestic device. Most of *QL* 1 combinations have a *B* or B^- energy class. With the gas heater for DHW a majority of the cases have a *B* class, while with the electric boiler there are more cases with a B^- class. This arises from the significant difference in the conversion factors to primary energy (0.086 kOe/kWh and 0.290 kOe/kWh, respectively) despite the also significant difference in the nominal efficiency considered (η_a = 0.50 and η_a = 0.95, respectively). Another important observation is that with the gas boiler the majority of the combinations obtain an *A* class, despite the bad quality of the external envelope.

For *QL* 2, there are no cases of non-compliance. Another difference from *QL* 1 is that with the electric boiler the majority of the combinations fall now under a *B* class. However, with the gas heater there are more *B* classes than with the electric boiler.

For *QL* 3, all the combinations with the electric boiler have a *B* class. The majority of the cases with the gas heater have a *B* class although some fall under an *A* class. Finally, with the gas boiler, most of the combinations have an A^+ class.

These results clearly show that the quality of the external envelope (as simulated by the relationship between nominal and maximum heating and cooling energy requirements) have some influence in the energy class. However, DHW systems and primary energy have the main role in this certification process. This is why it is possible to obtain an *A* class with a bad quality external envelope (*QL* 1); this is also why a DHW equipment with nominal efficiency of 0.50 leads to better results than another with nominal efficiency of 0.95. These results arise from the fact that 90 % of the heating and cooling nominal energy requirements are disregarded when determining the energy class, thus giving predominance to the DHW system. These results also arise from the conversion factors to primary energy actually regulated.

This way of considering the energy efficiency of residential buildings and dwellings does not properly considers the day-to-day use and the effort that inhabitants must put to have thermal comfort and DHW. It is possible to obtain an excellent certification class in a dwelling where its inhabitants will have to spend more energy to obtain the nominal comfort conditions, when compared to a dwelling where the external envelope is thermally optimized and where therefore the heat loss will be much smaller. In simple terms, it may be said that with efficient DHW and heating equipments using gas as final energy source and with the installation of thermal solar collectors, the energy class will be very good, even if the external construction elements have high U-values.

This predominance of gas as final energy source is of course related to the energy mix considered in this regulation package. As far as it was possible to search, there is no official information about the date of this energy mix.

It is believed that the energy class of a dwelling should not only reflect the way its energy efficiency influences the global energy dependence of the country, but it should begin to reflect efficiency itself.

In the following section an adapted method is proposed. The main objective is to allow for more adequate information to the general public when analyzing energy certificates of different dwellings.

3 PROPOSAL TO ADAPT THE DETERMINATION OF THE ENERGY CLASS

3.1 *General principles*

On the basis of what has been previously presented in this paper, an adaptation of the method to determine the energy class of a dwelling should consider the quality of the external envelope, the systems to produce domestic hot water as well as primary energy requirements. In a first approach, these parameters are taken into account equally.

The energy class is dependent on the result of a proposed index (R^*) and considers the intervals shown in Table 1. A new equation to calculate maximum primary energy requirements is also proposed in order to account for the heating and cooling systems actually being specified.

3.2 *Adapted equations*

Equation 5 proposes a new method of calculating maximum annual primary energy requirements (N_t^*):

$$N_t^* = 0.9\left(\frac{0.1\,N_i\,F_{pui}}{\eta_i} + \frac{0.1\,N_v\,F_{puv}}{\eta_v} + 0.15N_a\right) \quad [\text{kOe/m}^2\text{.year}] \quad (5)$$

Equation 6 describes a proposed index (R^*) which result defines the energy class:

$$R^* = \frac{f_{iv}\left(N_{ic} + N_{vc}\right) + f_a\,N_{ac} + f_t\,N_{tc}}{f_{iv}\left(N_i + N_v\right) + f_a\,N_a + f_t\,N_t^*} \quad (6)$$

where f_x = weighting factors to account for heating, cooling, DHW and primary energy requirements.

Using these proposed adaptations, the calculations have been repeated for all the variables previously mentioned. Results are presented and discussed in the next section.

3.3 *Results and discussion of the proposed adapted method*

The results of the adapted method are presented in Figures 4, 5 and 6. The weighting factor used was 1/3, that is, in these calculations the same importance was assigned to heating and cooling (and therefore to the external envelope), domestic hot water and primary energy.

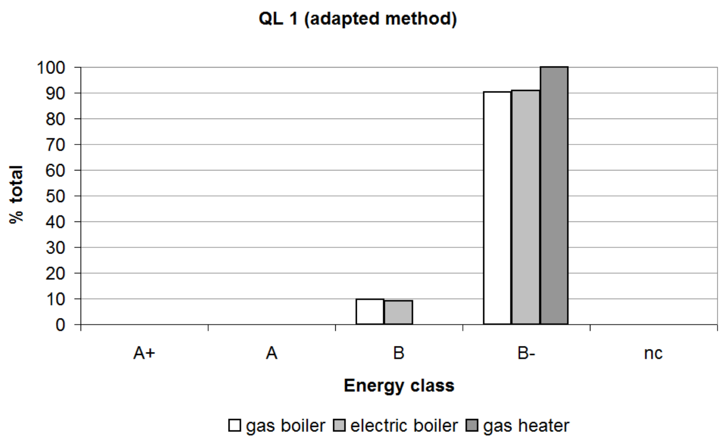

Figure 4. Energy class per DHW equipment, *QL* 1 (adapted method).

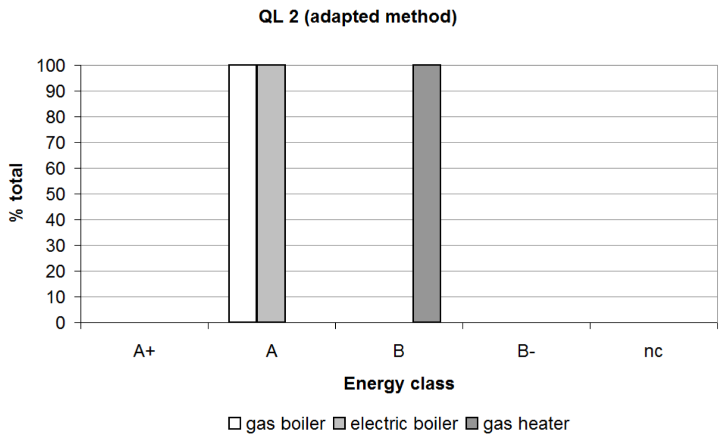

Figure 5. Energy class per DHW equipment, *QL* 2 (adapted method).

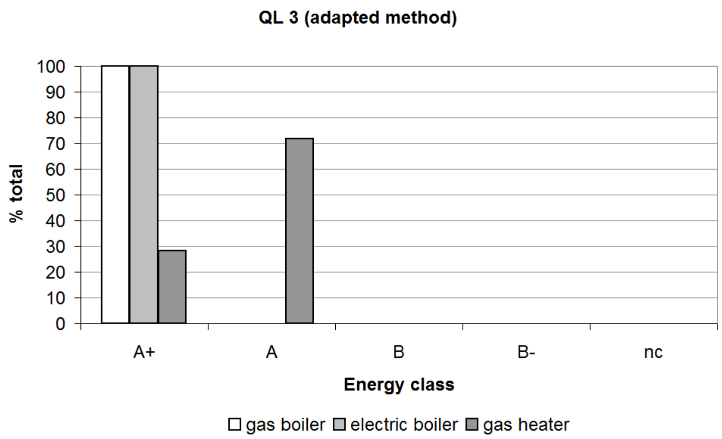

Figure 6. Energy class per DHW equipment, *QL* 3 (adapted method).

The results show that the proposed adapted method allows for what is believed to be an adequate consideration of the external envelope and the energy efficiency of the building. The importance of the primary energy requirements is diluted but, with well designed construction elements, final energy requirements are much smaller and thus the negative effect of some final sources of energy also loses significance.

For the cases with *QL* 1, the *B* class is obtained with low values of the form factor and of the degree days. Otherwise, the energy class is always B^- reflecting high thermal loss through the external envelope and ventilation. The poor efficiency of the gas heater considered does not allow any *B* class.

For the cases with *QL* 2 and *QL* 3, the improvement of the external envelope leads to a progressive increase in the energy class.

This method seems to provide more credible information to non-specialized persons willing to decide on the basis of energy performance.

From the standpoint of public policies, the priority should be put into promoting the quality of construction to ensure a potential of reducing energy consumption. Without this potential assured, every action taken to improve energy dependence, on the side of primary energy, will not have much effect or at least will have a much smaller effect than what could be expected.

4 CONCLUSIONS

The existing methodology to determine the energy class of residential buildings in Portugal privileges domestic hot water (DHW) and primary energy requirements. The quality of the external envelope is neglected and primary energy prevails over the efficiency of the equipments. Therefore, this method does not reflect properly all the issues related to the energy performance of the building.

The adapted method proposed in this paper seems to better balance heat loss and gain, DHW, systems efficiency and the implications of these energy requirements in terms of primary energy. Information provided by the energy class as determined by this proposal is more accurate in terms of the end user, allowing therefore a more precise comparison of different dwellings.

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Sustainable Mediterranean Urban Development Affordable to All, a Morphological Approach

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ABSTRACT: By 2030 the Mediterranean cities will count 100 million new inhabitants. This new urbanization will be mostly informal and in the Southern part of the Mediterranean region. Moreover, it will have to meet with the challenge of sustainable development and with a more and more arid climatic situation due to Global Warming. On the other hand, the Mediterranean region presents a huge potential for solar energy and has a long tradition of bioclimatic urbanism. To cope with those challenges and to seize these opportunities we propose to analyze urban morphology, which is an influential factor on the energy performance and livability of a city. We will question what lessons are to be learned from traditional vernacular dwellings.

1 METHODOLOGY

1.1 *Different scales and different layers in the city*

Urban morphology describes the city with the help of different interdependent layers:

1) Human interactions and activities are the first level studied, it corresponds to the upper part of the scheme below.
2) Streets network and urban pattern are the second center of focus; they imply means of transportations in the long run and are the first choice to be made to design a city or a district.
3) The third layer is the plot. The administrative and historical divisions of the city are a constraint that often induces a certain type of houses. For example, small plots discourage the construction of high rise buildings.
4) Then topography and relief are studied, they also influence flows in the city along with the urban form.
5) The fifth layer comprises the activities and land use. This is very important for the flow of people, the equilibrium, and dynamic of the city. It is crucial on a financial point of view as well as on a social point of view.

1.2 *Measuring the city to limit GES emissions through the urban form*

Research at the CSTB[1] Urban Morphologies Laboratory measures the city – street lengths, building heights, green areas and so forth – and uses geometric data to describe its morphology and spatial organization. The data are used to construct urban parameters that affect energy consumption and environmental performance. We can compare the performances of cities across the world by integrating their morphological parameters into energy and environmental

[1] *Centre scientifique et technique du bâtiment*

equations, in order to help decision-makers organize cities so they consume the fewest resources possible while remaining attractive places to live.

Acting simultaneously on urban form, building technology and systems, and people's behaviour would help reduce GHG emissions in successive, cumulative steps. By itself, well-thought-out bioclimatic design of urban morphology would cut GHG emissions in half. Optimizing building technology would further divide emissions by 2.5, while optimizing systems would halve them again. Finally, residents adopting "sober" or low-carbon-consuming behaviours would again divide energy consumption by 2.5. Ultimately, combining all of these factors would have a multiplicative effect, reducing energy consumption by 90% to 95%.

2 MORPHOLOGY, CONTINUITY, CONNECTIVITY

2.1 *Morphological discontinuities*

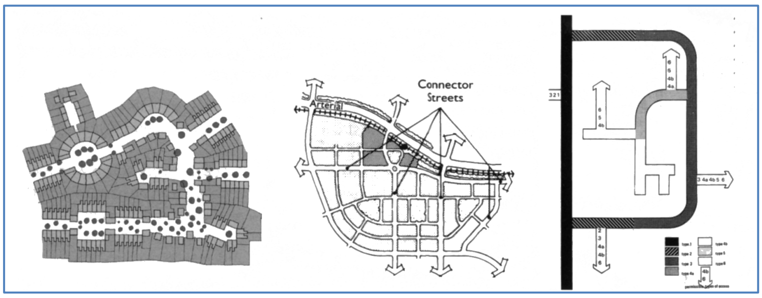
Whereas in Europe urban morphology of cities changed slightly along time for centuries, the South of the Mediterranean Sea experienced a huge morphological discontinuity between the colonization and the creation of new cities as in Morocco. Barcelona is a typical example of a smooth change in its urban morphology between the old, medieval Barri Gothic and the new, modern extension designed by Cerda during the 18th century. In Fes, the old medieval city (the medina) is closed by high walls and the French created a new city a few kilometers away from the medina with typical French urbanism.

Today, both North and South shores of the Mediterranean Sea are experiencing a new morphological change with the international modern urbanism inherited by Le Corbusier's theories. The morphology is characterized by high rise skyscrapers with no connection to their environment, and urban sprawl. With the same population (2.1 million) the Great Tunis is 25 times bigger than Paris.

2.2 *Our approach*

The Laboratory of Urban Morphology uses mathematical theories, like the graph theory, to analyze different urban textures and their connectivity. In order to analyze street patterns, three levels of analysis must be distinguished with different degrees of abstraction.

- **Composition** of the street network. This is the first impression anyone has, when he comes into a new city. The connection between the human being and its environment are the core part of the composition: how does the space physically or visually impact the man? For example, to describe Torino the narrowness of streets, the relative heights of buildings, the impression of surprise created by the sudden discovery of huge places around the corner of a small street, must be discussed on a composition point of view.
- **Configuration.** The form is taken out of the analyzis and the focus is put only on topologies, that is to say the connections between the different elements of the city. Ratios are calculated, indicators of continuity and connectivity.
- **Constitution**. The structure of links and nodes is then the center of focus. Hierarchy and constraints are the two central topics discussed in this part. Typologies of street patterns are built and used. This part helps to understand the fundamental choices of urban designers.

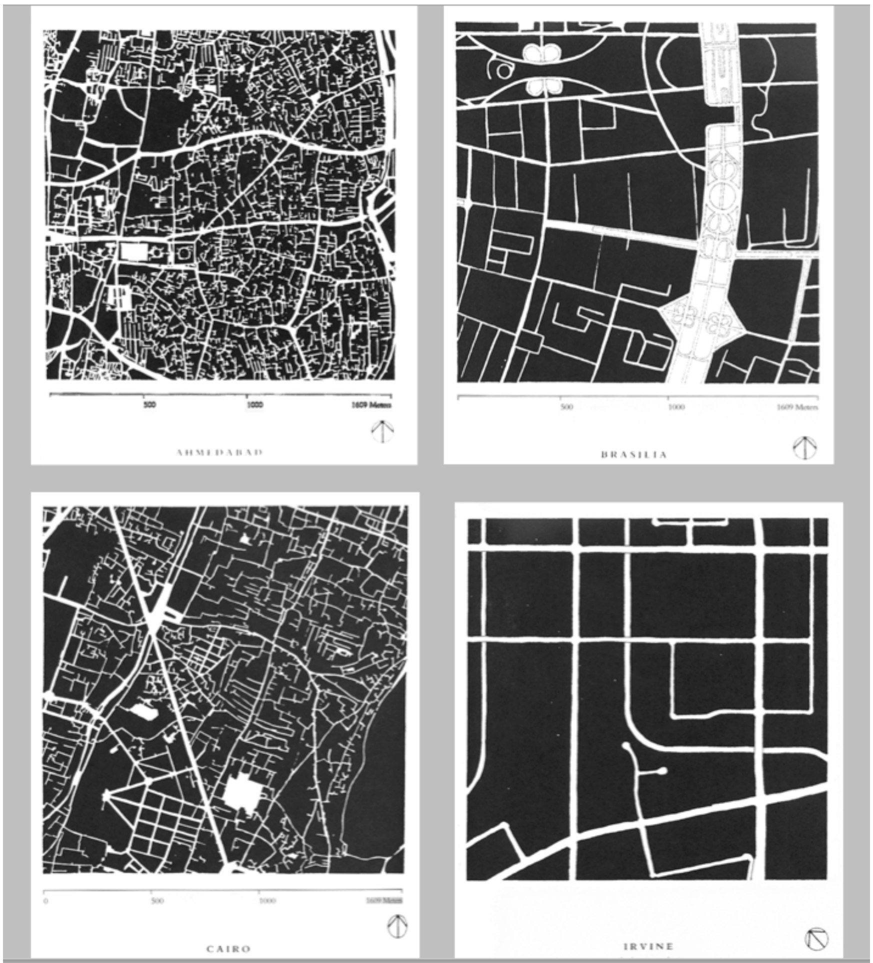


Our approach implies the definition of indicators, such as the cyclomatic number. Cyclomatic numbers, which count the number of circuits in a network, prove very useful to measure a city's degree of connectivity based simply on its block organization. A cyclomatic number gives us an idea of the number of possible routes between one point to another: the higher the cyclomatic number is, the more diversified the possible routes and the less congested the city will be. Moreover, route diversity allows various forms of transport – such as walking, bicycling, or taking the bus or tram – adapted to different activities. The cyclomatic number, combined with the average distance between two intersections, has been used to study several cities in different regions of the world, allowing comparisons of their urban block forms.

The Urban Morphology Lab studies showed that traditional urban forms, such as those in the historical centre of Kyoto or in Paris, have many more alternative routes and much shorter distances between intersections than modern tower-block cities, such as Le Corbusier modernist archetype City of 3 Million inhabitants. The first two cities have layouts that allow movements on foot or by bicycle, subsequently adapted to trams. Both cities were built before motorized vehicles, while modernist cities develop solely to suit the needs of cars. This clearly creates problems: cars tend to exclude other people, occupy a great deal of space and concentrate high pollution levels. A sustainable city must allow individuals to choose their transport modes and to adapt them to their activities, giving priority to soft, non-polluting means of transport – means that are more beneficial to health, accessible to all types of people, and independent of unproven and costly technological advances intended for less-polluting cars. A sustainable city must allow individuals to choose their means of transport.

2.3 *Measuring the connectivity of Mediterranean urban forms: the example of Fes, Morocco*

Islamic patterns can easily be set apart from other patterns. Below are represented Islamic Patterns in comparison with a modernist pattern (Brazilia) and a new urbanism of sprawl in the US.



Moreover these specificities can be mathematically proved and analysed. That is the object of the very interesting work of Kubat & Asami, who created a mathematical function to discriminate Islamic patterns. Their work outlined the following characteristics of Islamic patterns:

- Numerous cul-de-sacs
- Huges urban blocs
- Few X-junctions
- Narrow and curved streets
- An opaque network that cannot be apprehended totally easily.

We applied our metrical method to four samples of urban morphologies in Fes, Morocco.

Traditional Islamic patterns are characterized by a very thin urban grid. You can measure this by looking at the mean distance between intersections. It is 10 meters in Fez, 40 meters in Toledo and almost all European medieval cities, which are very closed to the medina type, whereas the mean distance between intersections is 150 meters in Paris, Melbourne and Hong Kong. It is a first morphological change in the urban form, from the medieval type, with a very thin grid, and the first extensions of this grid. Then another huge morphological change appeared in the second half of the 20^{th} century with the new modernist urban forms and the urban sprawl. The distance between intersections in Brasilia is 400 to 500 meters. We can find this kind of typology in Fes, with the old medina, the new town built by the French settlers, and new developments.

This multiplication by more than ten of the basic size of the city, creates a city made for the car and not for the pedestrian. It produces a city which doesn't reach the density required to protect itself from the sun through the clumping of housing units with each other. The cyclomatic number is also very important. It is an indicator of the number of different possible paths through the city. The cyclomatic number is crashing down in the modern town, creating a monotonous repetitive city from a pedestrian point of view.

The old medina
- cyclomatic number : 200
- density of intersections : 6 per ha
- mean distance between intersections : 10m

The French colonial city
- cyclomatic number : 40
- density of intersections : 1,4 per ha
- mean distance between intersections : 50m

New project
- cyclomatic number : 40
- density of intersections : 1 per ha
- mean distance between intersections : 75m

Informal settlement
- cyclomatic number : 6
- density of intersections : 0,3 per ha
- mean distance between intersections : 100m

3 MORPHOLOGY AND VERNACULAR BIOCLIMATIC CITIES IN THE MEDITERRANEAN AREA

3.1 *Introduction*

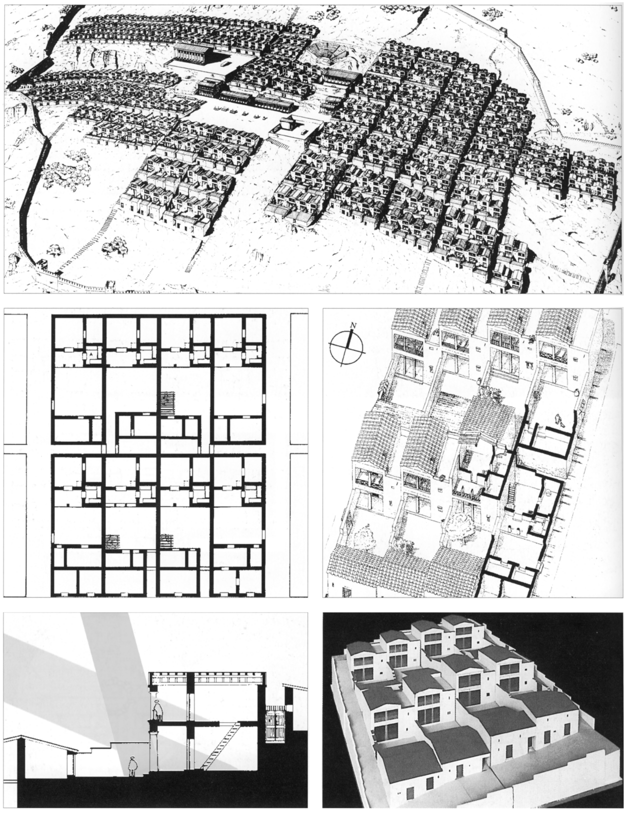
Current design guidelines used in Northern Europe do not apply to the Southern shore of the Mediterranean Sea, where the main question is to deal with hot and dry climate. Lessons for the design of urban forms can be found in traditional organization of human settlements, which were very efficient to protect from light and to use wind to refresh the city at different scales thanks to a very porous urban texture (with the traditional courthouse for example) which creates a dense (not compact) city. This peculiar texture manipulates the climate to create a more livable and sustainable city, and it could be used to design new urban developments.

The ancient Greeks, as well as Mesopotamians and Egyptians, designed their towns as tools able to organise symbiotic exchanges with their environment. Ancient Thera, now Santorin, which we have chosen, formed part of a national identity whose cosmogonic centre was Delphi, which in Antiquity represented the pivotal point in Greek urban planning. Delphi supervised the planning for siting new towns. This centralised planning entity, using oracles and placed under the aegis of Apollo, made decisions concerning the dispatching of expeditions and controlled the growth of the urban population which otherwise would have led to overcrowded cities and uncontrolled migration.

3.2 *Greek and Roman development of the "bioclimatic housing" concept*

In Greece, it was above all the Economics by Xenophon (born around 340 BC) that led to the birth of "bioclimatic housing". He saw the need to orient buildings and make nature and land bend to production requirements while continuing to respect their natural characteristics and potential. Around 350 BC, Aristotle made a number of observations concerning the relation between the healthiness of the air and the prevailing winds, reconciling the need of defence and harmony with nature. One of the most important treatises by Hippocrates, Treatise on air, water and places, formulated basic public hygiene concepts linked to the choice of where to build and urban planning: "there is a need to orient streets and buildings in such a way as to avoid the summer sun and take advantage of cooling winds, to build away from mosquito infested areas and unhealthy places and have sources of clean water". This became a town planning standard in the creation of Greek cities and the same principles were subsequently used by Vitruvius. These characteristics continue to remain strongly anchored in innumerable examples of ancient architecture and in today's towns around the Mediterranean Sea. Given that they were designed to provide a maximum level of comfort in a world without fossil fuels, they provide examples of complete urban complexes based on zero energy bioclimatic urban morphologies.

Priene was developed in Western Asia Minor in 400 B.C. as a new, entirely Hellenistic city. At the centre of the city grid are the expected municipal buildings and the market place. The southern section of the city was designed for recreational activities, with a *stadion*, or racetrack, and a *gymnasion*, an open court for sports. Recent excavations have shown that almost all buidings at Priene were the same, with almost identical plans, sections, and elevations and similar orientation. The plans and axonometrics show this simple structure. Every unit was organised around a courtyard. The buildings to the north were used for living. The main room had a shaded porch facing south.

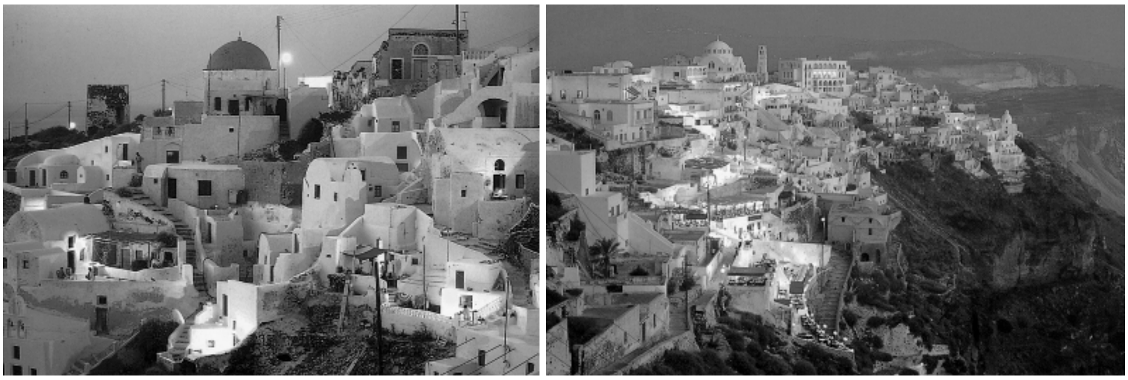


Priene. Source: Sophia and Stefan Behling, Solar Power, Prestel

The citizens of Santorin have transformed the forces of nature into groups of shapes designed to defend and provide protection. They have made use of the climatic specificities of their island to insulate their houses. On Santorin, each house is oriented to take full advantage of the wind. All towns, from Pirgos to Thera, from Emporeion to Ia, make use of the predominant onshore winds, which run parallel with the street networks in the towns and provide natural ventilation. Each house uses the breeze provided to ventilate its rooms through a basic system of openings and/or connections to the streets. In the Cyclades, the street represents the main bioclimatic element used by the houses. All new buildings built by the islanders are designed to assure the passage of fresh air and avoid creating any physical barriers that might block the wind.

3.3 *The sustainable town is a complete and organic bioclimatic unit: the example of Santorini, Greece*

The organic functioning of the towns on Santorin results in the creation of informally shaped built masses that provide an unbroken continuity between the houses. Each housing unit is organically connected to its neighbours, resulting in an air filtered by the preceding houses being introduced to circulate through the rooms and beyond. The formal consequence of this bioclimatic orientation is that the urban grid is given a unitary appearance: houses interpenetrate like organic cells, creating a dense, tight fabric amalgamated by its own heterogeneity.



Santorini, Greece

The urban layout of the towns on Santorin gives them the appearance of being a single large structure. The widths of the streets are designed to prevent the walls of the houses from overheating during the summer. The continuous house elevations act as wind tunnels and their configuration, using the Venturi effect, increases the speed of the onshore wind along the steep streets.

As in many other old Mediterranean cities, bioclimatic design underlines the construction of the urban groupings on Santorin. The relationship between the urban morphology and the sun, wind and the use of local materials, the interaction of the houses with the ground and the urban morphology results from an attentive design approach that has always been closely linked to local environmental resources.

3.4 *Conclusion: the sustainable bioclimatic town is naturally cooled without any energy cost.*

The houses are equipped with underground air conditioning, as each house has “roots” in the basement formed by small rooms dug out of the rock and equipped with a well in which rainwater is stored. These cavities, which create an environment where the temperature remains cool and constant throughout the year, have connecting passageways leading to the house’s upper levels. The higher temperature of the rooms resulting from the daily sunlight sets an internal ventilation level thanks to exchanges with the air currents provided from the underground chambers.

The cooling is based on three physical laws:

- the natural thermal inertia and insulating quality of the rock,
- the heat exchange between water and air,
- the slow endothermic evaporation of the water.

This process is able to maintain the temperature of the environment and the air at a satisfactory level throughout most of the year without any energy cost: during the winter, the high thermal inertia of the thick walls retains the heat while, in the summer, it cools the rooms. This phenomenon is facilitated by the natural movement of the air inside the house.

Thermal mass in vernacular Mediterranean architecture, Mykonos, Paraportiani Church, Greece.

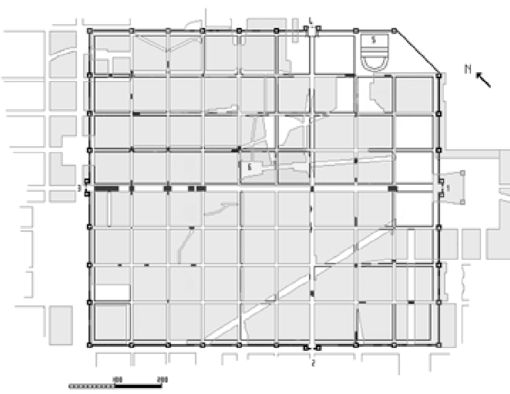
In harmony with Mediterranean traditions, the external skin of the buildings also has an influence on the climate of the rooms in the house. The interaction of a mixture of mud and straw has a very good thermal coefficient and the natural very pale colours form a sort of skin that protects the architecture from extremely high and low temperatures.

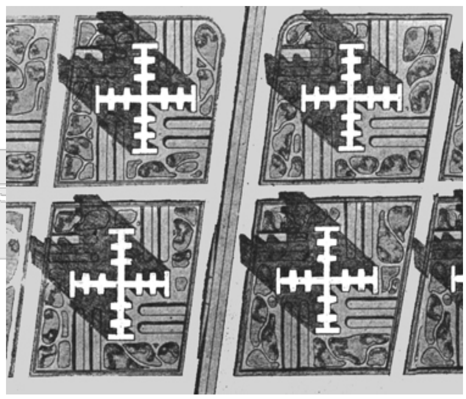
3.5 *Traditional vernacular city versus high rise*

Are new High Rise Sustainable in the Mediterranean Region?

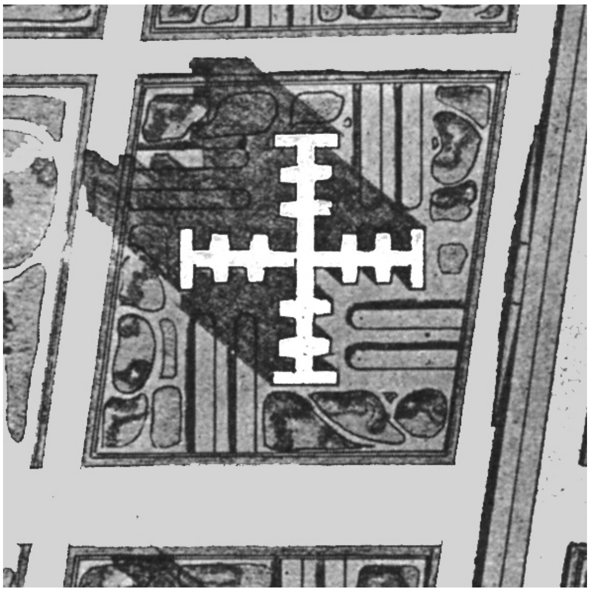
The recent years have seen the multiplication of Dubai style towers in the southern part of the Mediterranean Sea. The claim that the towers are vertical streets needs to be qualified. Streets offer shops, open spaces and places for meeting, strolling and relaxing. In very tall towers, elevators are needed to take people from one place to another. Circulation in such a context necessarily involves a destination – a beginning and an end – which leaves little room for the changing paces, movements and spur of the moment shifts in direction that characterize human circulation. Streets are places of meeting and exchange. They are public spaces. Elevators are not. In addition, elevators are a mechanical mode of transportation that consumes a lot of energy, closer to motor vehicle transportation than to other forms. In our opinion, due to the energy cost of creating green spaces in towers, designing ecological towers that offer the advantages of the street is unfeasible.

In actual fact, these towers do not replace the streets but rather groups of urban blocks comprising many streets. The analysis can and must be conducted comparing towers to the urban fabrics that they replace. For this purpose, it is interesting to compare 4 Corbusian towers placed on a square of 800 meters between axes and the center of Turin corresponding to the layout of the Roman city covering 710 by 770 meters.





Comparison between the urban fabric of the Roman city comprising 74 blocks and the urban fabric of Radiant City comprising only 4 towers on the same scale.



On the left, a district of Turin presents a development model made up of square blocks with spacious interior courtyards (some built up) and a hierarchy of different streets and plazas, all of which creates a fabric informed by a scheme but also endowed with complexity and diversity. In contrast, on the right, the Radiant City, on the same scale, consists in a clean slate and a single sculptural object that has no connection to its environment.

In Turin, nearly all the ground floors are occupied by shops and the linear length of the façades facing the street is significant: nearly 30 km in the square of 800 meters being studied as against 0 in the Corbusian district. The linear length of façades facing the courtyards is also quite significant: 16 kilometers as against 0 in the Radiant City. The street in Turin is a place of intensive exchange, commerce and human activity. In a natural way, this type of street life creates social bonds that contribute to a better quality of life, unlike modernist forms that dehumanize streets, eliminating the human factor and giving pride of place to cars. Courtyards are semi-private, open spaces that are reassuring by their human scale and that lend themselves to interactions between residents – exactly the opposite of the oversized and disquieting empty spaces in the Radiant City from which courtyards have been eliminated. Topologically, Corbusian streets are a series of dead-ends without the slightest human interface. An extremely rich model, architecturally and socially, was replaced by a monotonous organization that breaks down social bonds.

4 CONCLUSION

This analysis aim at encouraging new researches and quantitative evaluations to invent new urban forms as sustainable as the old medina, but suited to the modern way of life and which can cope with the 100 billions new inhabitants in the Mediterranean area.

Given the urgent need to reduce resource consumption and to house a growing number of people in the world’s cities, adopting urban development and planning strategies becomes crucial. They must take into account the drawbacks of private cars: not everyone can afford them; they consume major shares of urban space, pollute directly and indirectly, and tend to exclude other transport means. The keywords remain density, mixed usage, and sober energy use through passive building design. We have shown the tools available for comparing and measuring these criteria in cities. It now becomes vital to develop the city inside the city or as an extension of the urban fabric – providing spaces for all kinds of activities and all residents, and thinking about connecting these spaces from the outset. All participants and all aspects of urban life must be assessed as a whole, before starting to build— to integrate forms and flows, so ensuring that cities develop along a harmonious and sustainable path.

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From low cost buildings to eco neighborhoods – possibilities and contradictions in affordable housing refurbishment

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ABSTRACT: Renovation of existing building stock presents significant environmental benefits when compared to demolition or new construction, although it presents several constraints and structural specificities. In particular, public social housing – or affordable housing - is characterized by a common framework of very complex resolution. Some experiences were attempted challenging the theory of an apparent contradiction between the refurbishment of low cost housing blocks and the establishment of sustainable buildings/communities.

The aim of the research is to suggest a system of regenerative strategies, identifying the major issues that impend on the transformation of low cost public housing neighborhoods into eco neighborhoods, and highlighting the need of working simultaneously on local ecosystem and community balance to guarantee a strong sustainability. In order to assess the proposed methodology, its opportunities and constraints, a theoretical approach was applied to a case study (Bento Jesus Caraça neighborhood, in Oeiras municipality).

1 INTRODUCTION

Considering the environmental assessment of building sustainability, rehabilitation of existing building stock presents significant benefits when compared to demolition or new construction options. Among these benefits, stands out the reduction of material's embodied energy, resource consumption, pollutant emissions and waste production, as well as site preservation.

The importance of existing building stock refurbishment, in Portuguese context, is significant, where it was observed that the number of existing/built housing units exceeds the effective population housing needs (Bragança. 2007; INH/LNEC. 2006). However, according to Euroconstruct, in Portugal, the retrofitting/rehabilitation works represents about 8% of the total construction market, while the average percentage for the retrofitting/rehabilitation operations in western Europe is 45% (Bragança. 2007). This observation strongly points out the urgent development in this work field.

Currently, the Portuguese housing stock consists mainly of buildings constructed over the past fifty years (76% of total households), with greater expression to those built in the decades of 1960, 1970 and 1980. In fact, the dwellings built from 1961 to 1980 represent 31% of the total of national existing households (INH/LNEC. 2006). In Europe, it is commonly observed that residential buildings from the second half of the 20th century present several repair needs, demanding intervention at a social, energetic, technological, environmental and constructive level (Giussani. 2007). In Portugal, 40% of the housing units built from 1961 to 1980, also present a diverse range of repair needs (INH/LNEC. 2006).

Considering the surplus of available housing units, it is therefore an essential strategy of sustainable development policy the possibility of integrating these buildings into closed loops of resources and materials, improving its performance through environmentally regenerative strategies. However, the refurbishment of these existing buildings often presents several constraints, of technical, social and economic order, adding to these factors, constructive and structural specificities. In particular, public social housing – or affordable housing - is characterized by a common framework of very complex resolution, including socio-demographic, housing and typological organization questions (INH/LNEC. 2006).

Public social housing typologies, built in Portugal, with great expression over the previously mentioned decades of 1960 to 1980, besides the obvious repair needs, show generally some of the following problems to be taken in consideration in rehabilitation works:

1. Socio-economic and cultural uniformity.
2. Existence of large families with similar age composition.
3. High number of children and young people contrasting with isolated and aged households.
4. Low levels of education and low socio-professional integration/employability.
5. Weak accessibilities and isolation of the neighborhood, relatively to central urban areas.
6. Predominance of residential function.
7. Conflictive use of common or collective spaces, subject to divergent forms of occupancy.
8. Building degradation and inadequate housing conditions.
9. Inadequate flat size and spatial organization to the inhabitant's occupation.
10. Difficulty in implementing regular maintenance of the building, even after the completion of rehabilitation works.

Adding to this already difficult framework, the lack of energetic and water efficiency of the buildings itself, and poor indoor air quality, worsen the low overall environmental performance of these housing units.

On the other hand, high performance sustainable buildings and communities, like eco neighborhoods, have been long conventionally related to high cost solutions for high class population. However, some experiences were already attempted to challenge the theory of an apparent contradiction between the refurbishment of existing low cost housing blocks and the establishment of high performance/sustainable neighborhood communities. Sustainable refurbishment of low income housing blocks was already put into practice at 20th Street Apartments (Santa Monica, USA), or at eco neighborhood scale in Augustenborg (Malmo, Sweden), while in Portugal the building complex Ponte da Pedra proved the possibility of sustainable low cost housing development.

2 SUSTAINABLE REFURBISHMENT STRATEGIES

In building refurbishment, as in the design of new buildings, the implementation of an integrated approach is more valuable than a prescriptive of fragmented approach (Lyle. 2004; CEA. 2001). Similarly, on the path of a strong sustainability, it is intended to achieve progressively restorative and regenerative built environments, co-evolving with nature (Reed. 2007). Therefore integrated refurbishing strategies require an adjustment of the boundaries of the built system concept (Cole. 2005).

The perception of architectural intervention/rehabilitation at the level of *context* or *place* (including site + building + community), and not just the building itself, allows the expansion of the intervention opportunities, at the same promoting positive possible mutual influences on these three spheres (Figure 1). Several environmental and sustainability assessment methods are increasingly approaching this perception (Pinheiro. 2006). A methodological frame combining (site+building+community) was drawn upon LEED, LiderA, CASBEE and SBtool considering different criteria such as surface water, waste management, energy and transport, biodiversity, local employment, community development and welfare.

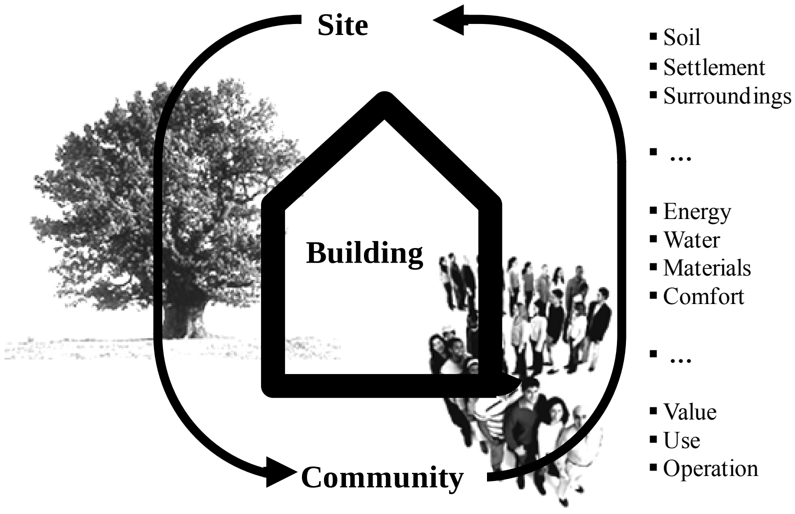

Figure 1. *Context/Place* built system concept: the building acts as interface between site and community.

As part of the built system, the involvement of the population in the rehabilitation process is essential to guarantee the sustainability of the building retrofit work, promoting:

a) Proper adjustment of the rehabilitation options to the tenant population needs.

b) Participation and power sharing in decision-making and project process.

c) A truthful understanding of the building/site operation and a greater commitment to constructive and environmental maintenance issues.

3 CASE STUDY APPLICATION: BENTO JESUS CARAÇA NEIGHBORHOOD

3.1 *General description, building system and sustainability assessment*

Bento Jesus Caraça neighborhood, located in the municipality of Oeiras, is a building complex of affordable rental housing, built by local initiative, between 1972 and 1984. The neighborhood is located in a consolidated urban area with favored accessibility to Oeiras town center, and to Lisboa-Cascais highway. The area is characterized by the predominance of residential function.

The housing complex is composed of 2 buildings of Type 1 (Tp1), 3 buildings of Type 2 (Tp2) and 1 building of Type 3 (Tp3). In 2003, a survey was conducted on the degradation problems already found in these buildings (Mesquita. 2003). Regarding building systems and materials, it is possible to observe a transition, through the buildings chronology, from structural load-bearing walls of masonry (Tp1 buildings) to reticulated structure of reinforced concrete (Tp2 and Tp3 buildings).

It was also registered that Tp2 and Tp3 buildings have considerably more problems than Tp1 buildings, which can be attributed to a decrease in construction quality. While the degradation problems identified in Tp1 buildings are located on secondary elements such as coatings and finishes, Tp2 and Tp3 buildings show diverse levels of degradation on primary structural elements, despite the fact that they are built after Tp1 buildings.

Considering the life cycle of the buildings, the main indirect causes of the observed degradation problems may be assigned, to errors at project conception (40%) and building execution (35%) stages (Mesquita. 2003). Regarding building degradation direct causes, moisture problems are common to all buildings, manifesting particularly in the form of:

- Branched cracking and efflorescence on the interior coating of exterior walls;
- Patches of mold on the indoor surface of exterior walls.

The building elements most affected by degradation are: exterior walls, due to the action of humidity and shrinkage of the coating materials; windows and other exterior secondary elements, due to lack of regular maintenance, inadequate building solutions or inadequate materials. On Tp1 and Tp2 buildings, there are also effects of moisture condensation at the ceilings/slabs (Figure 2).

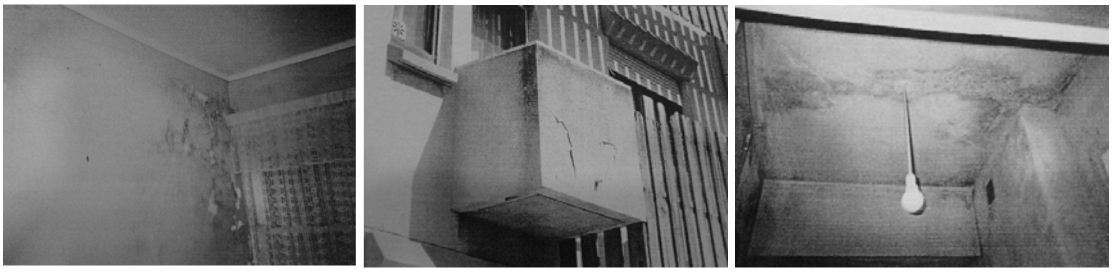

Figure 2. Degradation problems: (a) branched cracking and efflorescence, (b) concrete balconies degradation, and (c) ceiling condensation mold.

Between 2003 and 2009, the building complex had some repair works, including exterior wall painting, yet such action was less a building renovation than an upgrade of exterior spaces and amenities. In the first quarter of 2008, the neighborhood was covered by a municipality strategic plan designated by "Áreas Plano"; which included the improvement of urban infrastructures and green spaces, and the installation of a playground. This action had as guideline the promotion of the neighborhood's sustainability, providing green areas with native species and water saving irrigation systems, and increasing the proximity to solid waste and recycle bins (CMO. 2008).

3.2 *Sustainable strategies and priorities definition*

Improved public space and urban cohesion are referred as a vital strategy in the promotion of the quality of life in recent housing areas (INH/LNEC. 2006). In this neighborhood, public space presented reasonable conditions although some sustainability enhancements may be required. Priorities were directed preferentially to the buildings overall repair, since indoor degradation problems presented severe health and wellbeing consequences to the dwelling community.

Considering the buildings environmental assessment, the following related problems were highlighted on preliminary diagnosis sketch (Figure 3):

- Poor quality of materials and poor execution/selection of building systems.
- Low energy performance, and poor indoor air quality and comfort.
- Inadequate size flats and dwellings over-occupation.

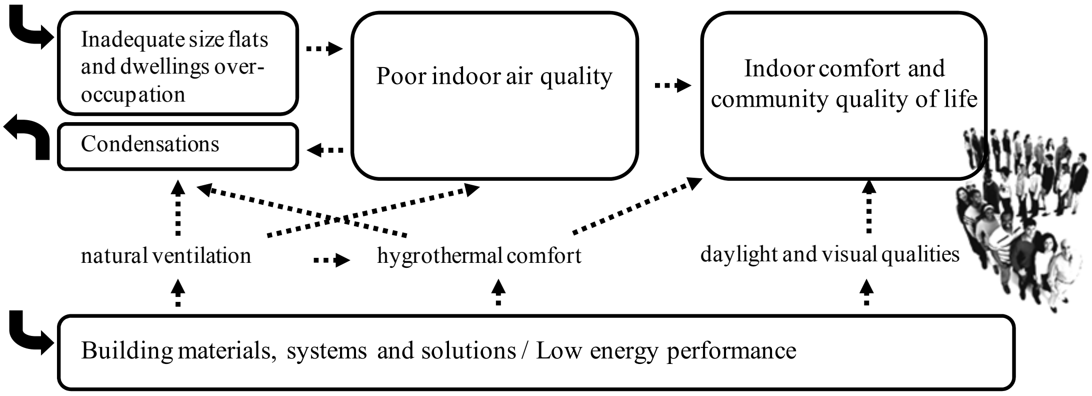

Figure 3. Priorities definition: preliminary diagnosis sketch.

Most of the identified building degradation problems, associated with moisture/surface condensations, have their cause on the combination of the factors described. So, regarding the buildings sustainability and bioclimatic performance, were addressed the following priority areas:

- Inadequate thermal and acoustic insulation of the buildings envelope.
- Existence of thermal bridges.

• Lack of vapor barriers, on walls and on roofs.
• Natural lighting and ventilation poor conditions due to window downsizing.
• Unfavorable conditions for senior citizens or disabled people, particularly in Tp2 buildings.

Considering the whole built system sustainable refurbishment, further intervention criteria were highlighted on (site+building+community) methodological frame. Opportunities and constraints most relevant to the case study were selected as briefly shown on Table 1.

Table 1. Intervention criteria (site+building+community) methodological frame.

Area		Intervention criteria
Site		
soil	+	location in urban area, with built infrastructures availability
	-	soil infiltration capacity or replacement high potential of the surrounding area
settlement	-	buildings with favourable solar exposure
	+	buildings with favourable wind exposure
	+	urban landscape integration
surroundings	-	accessibility to public and alternative transportation
	+	availability of public green areas
	+	reintroduction of vegetation native species and local biodiversity
	-	integration of regenerative local processes
Building		
energy	-	existing building with integrated passive solar strategies
	+	envelope and indoor thermal mass increase possibility
	+	thermal bridges insulation possibility
	+	available roof and wall area for solar active or other renewable energy
	+	introduction of efficient lighting and electric equipment prospects
water	+	rainwater catchment system for non-potable water reuse possibility
	+	introduction of flow reducers and water efficient equipment prospects
	-	wastewater reuse and recycle conditions
materials	+	buildings structural and non-structural degradation problems repair
	+	high percentage of building reuse
	-	high recycled content of refurbishment materials
	+	storage and collection of recyclable materials
	-	deconstruction systems and components
	+	re-use and recycle construction and demolition wastes
	-	renewable materials usage
comfort	-	availability of high ceilings and/or room for comfort maintenance infrastructure
	-	air volume and floor space ratios per tenant
	+	natural lighting and ventilation potential accessibility
	-	south facing windows and solar gain area availability
	+	prospect of operable window and louvers supply to all rooms
	-	exterior accessibility for passive solar vegetation or kitchen gardens
Community		
value	+	buildings' social significance to the community
	-	building's aesthetic and architectural relevancy
	+	economic, cultural and social improvements derived from refurbishment
	+	multigenerational and multicultural population
use	-	mixed use urban area or within walking distance
	-	flat size and functional settings adequacy
	-	buildings' and site potential to universal accessibility
operation	+	operation and maintenance information supply
	+	sustainable behaviour and consumption promotion prospect
	-	local food production and organic waste composting conditions

+ Opportunities; - Constraints

3.3 *Refurbishment proposal*

Among the most effective strategies for sustainable repair are regular maintenance, preventive strategies and corrective intervention, acting on causes rather than on building degradation effects (Appleton. 2003). Examples of these strategies are windows adjustment in order to promote natural ventilation, or the extension of eaves or overhangs to prevent walls from direct exposure to rain water, thus providing long durability sustainable performance.

The typological/functional adjustment of the flats is also a possibility to consider when working on existing affordable housing. This strategy promotes mixed uses and social diversification (multigenerational, multicultural and multisocial communities), along with improvements regarding indoor comfort and thermal performance of the building. Considering these observations, the following measures were suggested for sustainable rehabilitation of Tp2 buildings:

1. Exterior wall insulation, with ETICS system, and introduction of vapor barrier - in order to avoid thermal bridging and moisture infiltration.
2. Functional and spatial rearrangement of flats, to ensure natural ventilation and prevent damp condensations, improving indoor air quality.
3. Re-use and recycle C&D wastes, resulting from refurbishment work, particularly plaster in the formation of new mortar.
4. Window revision and addition of louvers to promote natural lighting and air ventilation indoors.
5. Walls and ceilings coatings repair, with no-voc painting finish.
6. Repair and replacement of degraded window frames and metal elements.
7. Passive or mechanical ventilation systems, in kitchens and bathrooms.
8. Network repair, particularly electricity and water, with introduction of more efficient equipment and flow reducers.
9. Installation of solar water heating system, with solar thermal collectors on roof.
10. Rainwater catchment system for non-potable water reuse.
11. Installation of double facade structural system, allowing solar gains and additional living space.
12. Installation of vertical shading elements, on the West facade, ideally integrating PV panels for microgeneration and/or deciduous vegetation to provide shadow, particularly during summer period.

3.4 *Opportunities and constraints of the case study*

The location of Bento Jesus Caraça neighborhood had brought this housing complex into a positive social dynamic, avoiding the segregation symptoms of other affordable rental housing in more peripheral areas. However, mobility and transportation issues demand a wider intervention, requiring a distribution of jobs, shops and public facilities within walking distance.

The implementation of a set of sustainable refurbishment actions could contribute positively to the quality of life and comfort of the population, allowing families to effectively reduce the economic costs associated with water and energy. Moreover, this refurbishment could also act as a catalyst for the community awareness regarding consumption patterns and site's ecology, as well as to promote other positive changes in the neighborhood surrounding area.

Energy and water eco-efficiency payback should be clearly put in evidence, as well as the improvements in indoor air quality and comfort, in order to gather the attention of the communities and municipality and obtain complementary funding.

Regarding the refurbishment constraints, funding depends almost exclusively on municipality initiative, with possible contributions of the central government, therefore the feasibility of effective refurbishment potential remains very limited. As partial solution to this question some possibilities may occur:

- Raising funds through neighborhood committees.
- Development of particular building stages with the help of the tenant population.
- Allocation of vacant flats into the real estate market in return for municipal investment.
- Sponsorship from building materials/systems producers and contractors.

• And presently, applying for specific programs such as Eco-bairros, promoted by CCDR-LVT (Comissão de Coordenação e Desenvolvimento Regional de Lisboa e Vale do Tejo).

On the other hand, the possible demand for huge changes in flats size and organization, as well as exterior appearance of the buildings, may raise authorship questions, as extremely recent projects are being analyzed. The promotion of *charrettes* or workshops with all the stakeholders may provide solutions to the mentioned questions, as well as achieve better design/refurbishment options to the resident population.

Further investigation on cost-benefit analysis will be needed in order to establish a more accurate prioritization of possible refurbishment actions, and to gather data to and from community participation sessions.

4 DISCUSSION AND CONCLUSIONS

Sustainable refurbishment of affordable rental housing requires simultaneous social, economic and cultural management, being this combination essential to the success of all interventions (CMO. 2006; INH/LNEC. 2006). From this point of view, the proposed methodology allows the balanced treatment of the various components of *place*/*context*, contributing to the overall sustainability of the refurbishment action.

Affordable rental housing, built from 1950, in Portugal, presents technical, social and economic constraints, adding to these factors building degradation problems and structural specificities. To its sustainable renovation is essential an integrated strategy, supported by rigorous surveys and community participation, as well as fund raising and technical resources to its execution.

Regarding sustainable refurbishment of affordable housing built from 1950 to the present day, we are not facing so much technical impossibilities to achieve an environmentally sustainable built system, but rather social, legal and economic constraints. Some of these issues regard essential questions to this theme: funding, community participation and commitment, and authorship questions.

However, sustainable refurbishment of these neighborhoods is feasible, considering the requests and possible solutions in each case, highlighting durability throughout the buildings life cycle. Considering the number of families dwelling in affordable housing, especially in large metropolitan areas, the development of specific studies and research on the sustainability of these housing typologies, reveals to be of utmost importance, taking into account its positive impact on the building segment and on global urban environment.

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Material flow analysis for reaching a sustainable model of the building sector

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ABSTRACT: The construction industry, where building sector is included, consumes 50% of the natural resources, 40% of the energy and is responsible of 50% of the total wastes generated in Spain. To reach the required habitability standards we are consuming more materials than ever. This big volume of materials produces a big impact in the environment in all the life cycle of the materials, from cradle to grave. But there are physical limits in natural production of required resources as well as in the final sinks (air, water and soil). Required construction materials in buildings are subject to these physical limits which are gradually closer to saturation. Construction materials management in the building sector is a key point in order to preserve the environment.

The final objective of this paper is to define a global strategy in the use of building materials to reduce the environmental impact of the building sector. This paper will focus on the development of a methodology of work to analyse the movement of building materials between the environment and the anthroposphere, taking as a basis the recently developed methodology of "Material Flow Analysis" (MFA). MFA is a systematic assessment of the flows and stock of materials within a system defined in space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material. Because of the law of the conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of a process. This methodology allows getting indicators for reducing the environmental impacts of the building sector and check out the points where it is possible to reduce the material requirement. The analysis is focused on the flow of materials for building sector in the region of Lleida for the highly productive period from 2000 to 2008.

Results show that building sector has to reach a stationary flow model by decreasing of the input flows through the reduction of the total material consumption, the low increase of the existing building stock and the decrease of the output flows (wastes to the soil, water and air). This model should be achieved taking measures from the beginning of the chain. Controlling the materials flows through the total system is more efficient than separating management of wastes from the management of production supply and consumption. Making of Lleida a locally self-sufficient region allows controlling the total flow of materials from cradle to grave and achieving measures to reducing the environmental impacts of the building sector.

1 ENVIRONMENTAL IMPACTS OF THE BUILDING SECTOR & PHYSICAL LIMITS

The construction industry, where the building sector is included, consumes 50% of the natural resources, 40% of the energy and is responsible of 50% of the total wastes generated in Spain (Arenas 2007). The energy demand is linked to the activity of the construction sector. Considerable amount of energy is spent in the manufacturing processes and transportation of building materials. Conservation of energy becomes important in the context of limiting greenhouse gases emissions into the atmosphere and reducing costs of materials. The building sector is responsible of one third of the total emissions that are attributed to Spain, accounting the total emissions of greenhouse gases produced by all the activities used for building plus the energy consumed during the useful period of the building (Cuchí & Pagès 2007). All gas emissions produced by the manufacturing processes of the construction materials, either generated in Lleida or in other countries, affect all Earth. Therefore, every gas emission generated to produce construction materials for building in Lleida should be accounted in the Lleida total emissions, even when materials are imported, making responsible of the gas emissions to the country which uses the material and not only the one which produces it.

The current building sector is exceedingly inefficient. In order to reach the required habitability standards we are consuming more materials and using more natural resources than in other previous period. The evolution of the construction industry -growing or decreasing- is linked to the economy of the state. In Spain, about 75% of the total flow of materials is linked directly or indirectly to the construction sector. 90% of raw extracted materials in Catalonia are minerals. From this amount, 94% are used in the construction sector (Sendra 2008). This big volume of materials produces a big impact in the environment in all the life cycle of the materials: from the extraction of raw materials, the manufacturing and the transport of construction materials, to the execution of buildings, the use phase of the buildings and the final disposal at the end of life of the building with its demolition (Arenas 2007).

There are physical limits in natural production of required resources as well as in the final sinks (air, water and earth). Required construction materials in buildings are subject to these physical limits which are gradually closer to saturation. The actual access to the materials resources also depends on old biogeochemical cycles. But nowadays, resources are being used at a pace much faster than the production, and are not being replaced (Brunner & Rechberger 2004).

The growth of the building sector is linked to population and economic growth. Is there a limit on the area of new constructed housing every year? In the last decades, the big growth in housing has not considered neither the real need of housing for the growing population nor the physical limits of the Earth. The building sector has grown because of economic factors. The growth of material flows is closely associated with the economic growth. The economic progress is defined in a way that causes an increase in the material turnover. It is important to develop new economic models that decouple economic growth from material growth, thus promoting long-term welfare without a constant increase in resource consumption (Brunner & Rechberger 2004, Martínez-Alier 2008, Daly 1991).

2 OBJECTIVES

The objective of this paper is to analyse the flow of materials in the building sector of Lleida, with the aim of understanding the key points where to act in order to get a more efficient material system for building sector. This analysis pretends to get indicators for reducing the environmental impacts of the building sector and to check out the points where it is possible to reduce the material requirement. The final goal is to define a global strategy in the use of building materials.

This paper will focus on the development of a methodology to analyse the flows of building materials between the environment and the anthroposphere, taking as a basis the recently developed methodology of “Material Flow Analysis” (MFA).

3 METHODOLOGY: MATERIAL FLOW ANALYSIS AS A TOOL FOR ENVIRONMENTAL MANAGEMENT

MFA is a systematic assessment of the flows and stock of materials within a system defined in space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material. Because of the law of the conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of a process (eq. 1). It is this distinct characteristic of MFA that makes the method attractive as a decision-support tool in resource management, waste management, and environmental management (Brunner & Rechberger 2004, OECD 2008). Material Flow accounting is moved by the aspiration to relate the use of natural resources to the capacity of the environment to provide the materials and absorb waste materials (Adriaanse & Bringezu 1997). The analysis is focused on the flow of materials for the building sector in the area of Lleida for the period from 2000 to 2008.

$$\sum \dot{m}_{input} = \dot{m}_{storage} + \sum \dot{m}_{output} \tag{1}$$

Where: $\dot{m}_{input}$ *is the material flows input,*
$\dot{m}_{output}$ *is the material flows output,*
$\dot{m}_{storage}$ *is the material flows storage.*

4 SYSTEM DEFINITION

4.1. System Boundary: space and time

Material Flow Analysis starts with the definition of the system. The system comprises the flows of materials involved in the analysis as inputs or outputs of it, the process and activities, and the accumulation of materials as stocks within a defined boundary. The system boundary is defined in space and time (Brunner & Rechberger 2004). The spatial system boundary is determined by the scope of the project. In this analysis it consists of a geographical border which is the region of Lleida. It is a wide territory (12,167.7 km^2) with a low density of inhabitants (35 inhab/km^2 in 2008). The area of Lleida is the environment where the economic processes take place. There is a strong interrelation between the economy and the environment.
The temporal system boundary is *one year*. It is considered that one year is a period of time appropriate for making a balance of the construction materials in a region mainly for reasons of data availability. A *year* is also the unit used to determine the using period of a building and the residence time of materials within stocks. The analysis considers a period of study from 2000 to 2008 which is subjected to the availability of statistical data. This period of time comprises a very high production period of building in Lleida. The material requirement is the highest of the history. The year of analysis will be the most representative one from all the period, as an average of all the period.

4.2. Determination of activities and processes

The main activity in this analysis is *to inhabit*, and in a more precisely way the *habitability*. The *habitability*, from an architectural point of view, is the part of this discipline dedicated to assure some minimum conditions of health and comfort in the buildings. Especially, the habitability is occupied of the heat and acoustic insulation, and of the health conditions. The activity *to inhabit* includes all the buildings for housing, the new constructed ones and the existing ones. This analysis will focus on the required materials to produce new habitability; it means the new constructed buildings.

4.3. Selection of materials

The main materials used in buildings for housing are represented in Table 1 (Cuchí 2005). Due to the current methods of building, which are based in concrete structure and ceramic walls, the most used materials, in weight and volume, are the components of concrete for structure (aggregated stones, cement, water, and steel), and ceramic and lime for façades and interior partitions. Precast mortar and concrete are also highly required materials and, in a smaller measure, wood. The rest of materials that form a building are used in minor volume. In spite of representing just 5% of the total weight, some of them, like aluminium or plastics, represent very high energy consumption and are even more environmental damaging than the rest of materials.

Material	kg/m^2
Aggregate Stone	1,490.50
Ceramic	557.70
Cement	192.70
Water	138.60
Precast Mortar	131.90
Lime	51.20
Precast concrete	38.20
Steel	34.90
Wood	16.90
Other	140.20
TOTAL	**2,792.80**

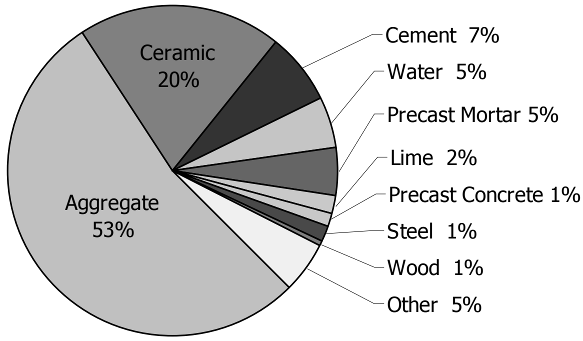

Table 1. Main materials used in Catalonia (Spain), kg per inhabitable square meter of useful area and percentage. Source: Cuchí, A. *Arquitectura i sostenibilitat, 2005.*

4.4. Flows and stocks

Processes are linked by *flows* (mass per time) of materials. When a material crosses the system boundary of region of Lleida we are talking about an *imported* or *exported material*. Flow and fluxes of materials entering to the process of building are named *inputs*, while those exiting are called *outputs*. The unit used for quantifying the material flow is *tonnes per year* (T/yr). It is necessary to identify the shift of material stocks from "natural" reserves to "anthropogenic" accumulations (Brunner & Rechberger 2004). All these movements of materials have the aim of producing the habitability for the population.

4.4.1. Input Flows: Direct Material Inputs, Domestic Extraction and Imports

The inputs to the system are *consumption of materi*als. Material inputs consist primarily of extracted raw materials. The material inputs have its origin inside or outside of the system, which are represented as *local (domestic extraction)* or *imported* materials, respectively. Both origins have in common that are extracted from the environment -more precisely the lithosphere and pedosphere- and they finally are used in the anthroposphere. Therefore there is a flow of materials from the environment to the anthroposphere. The environment loses materials while the anthroposphere earns them. That means a depletion on the natural resources, which implies a loss of richness and damaging in the ecosystems (eq. 2).

$$\sum \dot{m}_{input} = \text{TMI} = \text{DMI} + \textit{unused}\ \text{DE} = \text{DE} + \text{Imports} + \textit{unused}\ \text{DE} \quad (2)$$

Where: *TMI is the Total Material Input,*
DMI is the Direct Material Inputs,
DE is the Domestic Extraction,

4.4.2. Stock: Building stock in Lleida

The total amount of materials stored in a process is designated as the "stock of materials" in the process. Stocks are defined as material reservoirs (mass) within the analyzed system, and they have the physical unit of tones (Brunner & Rechberger 2004). The materials that are entering to the process are stored in form of buildings. Therefore, the stock of buildings is the accumulation of materials in the system (eq. 3). From the total amount of throughput of materials, just a part is finally accumulated in form of building in the system, the rest will flow back from the anthroposphere to the environment in form of wastes. These wastes and emissions are the outputs of the process of building, also named environmental impacts. Both the mass of the stock and the rate of change of the stock per unit time (accumulation or depletion of materials) are important parameters for describing the process of *building*. These parameters allow to analyse the growth of the building stock, and to compare it with the need of housing in function of the growth of population in Lleida.

$$\dot{m}_{storage} = \text{Stock of Buildings} \quad (3)$$

4.4.3. Output Flows: Wastes to the Air, Water and Soil

The materials going out from the system have lost their utility in order to become wastes. They are not useful anymore in the anthroposphere and therefore they are coming back to the environment. The environment comprises four compartments: atmosphere, hydrosphere, pedosphere, and lithosphere. The output flows imply that materials are accumulated in the also called “final sinks”. A “final sink” is a process where materials have very long residence times (tR>1000 years) (Brunner & Rechberger 2004). There are 3 main outputs: construction wastes accumulated in the pedosphere, emissions of gases to the air accumulated in the atmosphere, and wastes to the water accumulated in the hydrosphere. These materials have lost quality and they are neither useful for the environment, so then they become a problem in the moment that accumulation in these final sinks increases till the limit of supporting of the environment (eq. 4).

$$\sum \dot{m}_{output} = TMO = TDO + Exports = DPO + \text{disposal of unused domestic extraction} + Exports \quad (4)$$

Where: *TMO it the Total Material Output,*
TDO is the Total Domestic Output to nature,
DPO is the Domestic Processed Output to nature.

4.5. The System

Summarizing, the boundary of the system is *the region of Lleida* for the period of *one year*. The first and main process is *building* and the accumulation of materials in the process is the *building stock*. The inputs to the process are *domestic extracted* and *imported building materials*, and the outputs of the process are *construction wastes to landfills*, *emissions to the air*, *wastes to the water* and *exported building materials*. Besides this, it is necessary to consider the flow of *unused domestic extraction* and *indirect flows of imports* which comprises overburden and parting materials from mining, wood harvesting losses, as well as soil excavation and dredged materials from construction activities. The materials analysed are based on the main materials required for building housing in Lleida as components of concrete (aggregated stone, cement and water), steel, ceramic, lime, and wood. According to the mass-balance principle, the mass of all inputs into a process equals the mass of all outputs of this process plus a storage term that considers accumulation or depletion of materials in the process (eq. 1).

A methodological approach of Material Flow Analysis has been developed for the building sector in the region of Lleida. The graphic system shows the movement of materials as inputs and outputs from the process of building and offers and overview of the function of the system (Fig. 1).

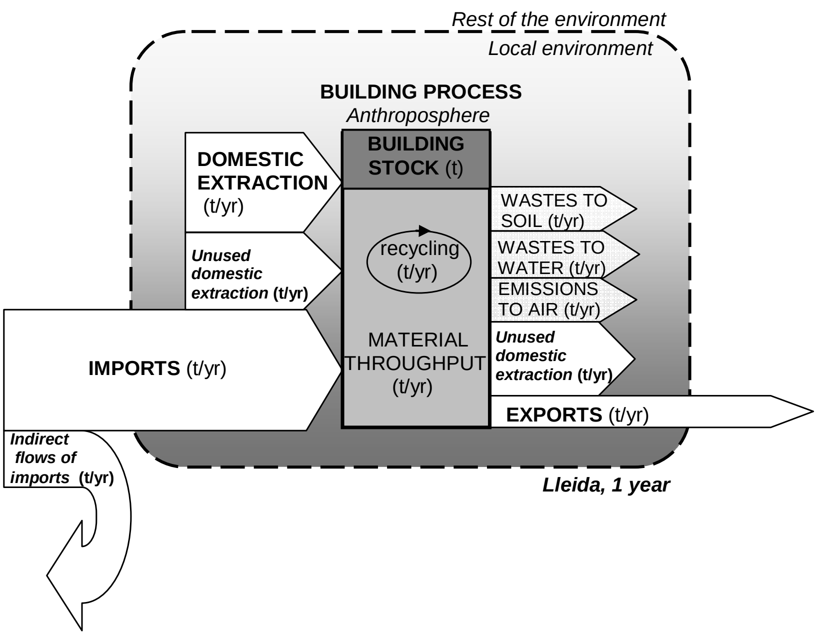

Figure 1. Model of the flow of materials for the building sector in Lleida (EUROSTAT 2001).

5 DISCUSSION OF FIRST RESULTS

The amount of required materials for building in Lleida is shown in Figure 2, where statistical data about the average of constructed area for housing among 2000 and 2008 and the weight of the main used materials per square meter of useful area of building have been taken into account. In total, building housing in Lleida requires a flow of materials extracted from the environment (both local and rest of it) of more than 3.25 millions of tones of materials every year that are stored in the anthroposphere in form of buildings. The most required material is aggregated stone and represents almost 1.75 million of tones per year. Aggregated is mainly used in the structure of the building since is one of the components of concrete.

The output flow "wastes to the atmosphere" is shown simultaneously in Figure 2. Emissions of CO_2 generated by all the processes necessary for the production of each building material required for new housing in Lleida every year are shown. The processes required for making possible the materials extraction imply the emissions of about 1 million tones of CO_2 per year. The material that heads the ranking of emissions is ceramic and cement, which signify the 23% and 20% of the emissions of CO_2 but 20% and 7 % respectively of the total mass. Remarkably, the third material is steel, which just means less than 1% of the total mass but more than 17% of the emissions. Aggregate suppose just 1.5% in spite of being the major mass of required material.

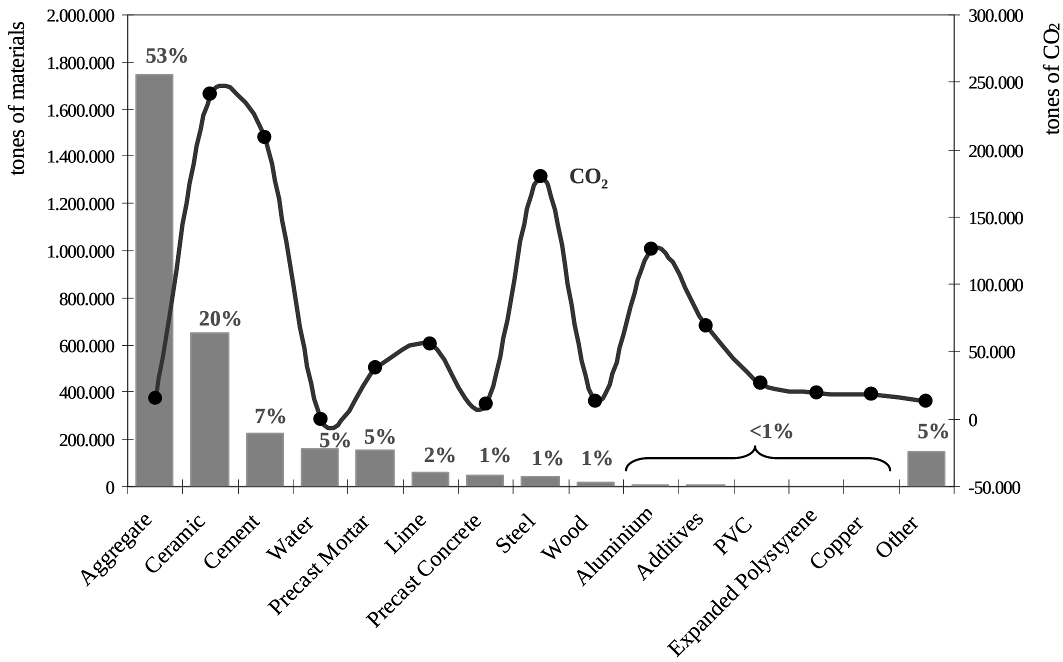

Figure 2. Total mass of required materials for new housing in Lleida (inputs) and total generated emissions of CO_2 for producing the building materials per year (outputs, average 2000-2008). Source: own compilation (IDESCAT 2008, Ministerio de Fomento 2008, Cuchí 2005).

Concerning the building stock, first it is necessary to know the rate of accumulation of materials, and the time of residence in the stock (Figure 3). The building stock in Lleida in 2008 was nearly 30 million of square meters. Among 2000 and 2008, the average of net addition to the stock of building was 1,240,000 m^2 per year, which means an average of 5% of annual increase, higher than the increase of population with an average of 1.9%. The building stock per capita reached the maximum of 70 m^2 per inhabitant in 2007. Therefore the rate of accumulation of materials in the stock of building has been growing every year from 2001 to 2007, from 2.3 million tones of new materials added to the stock in 2001 to the 5.5 millions of materials in 2006. In 2007 and 2008 the rate of accumulation decreased, with 3.9 and 1.3 millions of tones, respectively.

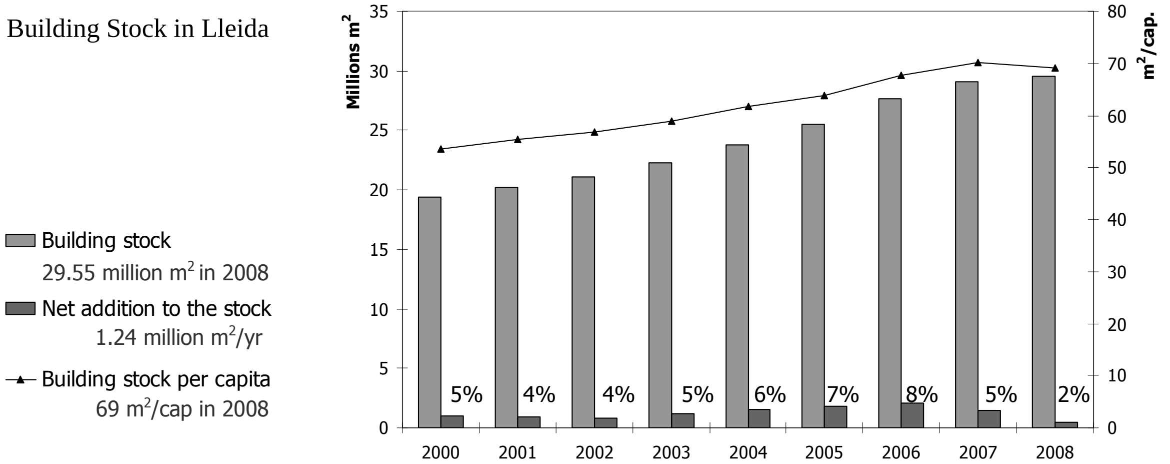

Figure 3. Total stock and net addition to the stock of housing in Lleida every year (m^2), and building stock per capita (m^2/cap). Source: Own compilation (Ministerio de Fomento 2008, Ministerio de Vivienda 2008, IDESCAT 2008).

6 CONCLUSIONS: TOWARDS A STATIONARY FLOW MODEL

The defined system for Lleida allows a transparent understanding of the building material flows. The direction of the general flow consists in the extraction of raw materials from the environment to the anthroposphere and back to the environment as wastes to the earth, air and water (Figure 1). All these flows of materials produce the depletion in the natural resources from the environment, damaging in the ecosystems and saturation of the final sinks in the environment. From the total amount of throughput of materials, just a part is finally accumulated in form of building in the system.

Only for housing in the province of Lleida 3.25 million tones of construction materials are required every year (Figure 2). The addition of new materials to the building stock has been growing in major or minor percentage in all the studied period (Figure 3). Is it possible to supply the building sector and at the same time reduce the mass of required materials? A dematerialization of the building sector is required and can be achieved working on four key points.

First, it is necessary to decrease the input flows for reducing the total materials consumption. It means dematerialization by reducing the material intensity (t/m^2) of buildings and infrastructures, extending the useful life of the buildings and its components and producing lighter materials. The longer the materials are in the stock, the later they become outputs to the environment as wastes.

Second, the stock balance should tend to zero or at least reach a low increase of building stock linked to the real need of housing. In Lleida the rate of accumulation to the building stock is a 3% higher than the growth of population. This results in a high inhabitable area per capita (about 70 m^2/capita). This accumulation is also restricted by the physical limits of extraction of materials from the environment. Therefore, this limit should be quantified for each region.

Third, it is necessary to decrease the output flows by decreasing the input flows in order to reduce the wastes and therefore the environmental impacts of building. The reutilization and recycling of the output wastes as input resources can help to mitigate this problem. However, because of the entropy law, the materials that can be re-used from output flows is much lower than the material required in input flow. Even with high rates of recycled and reused materials there would not be enough materials for substituting the domestic extraction. Therefore, waste management should be replaced by materials and resource management. To promote this tendency, new policies must be defined to reduce the use of primary natural resources for minimizing both extraction inputs and waste outputs.

The fourth point is to decrease the import flow by making of Lleida a locally self-sufficient region. Future development of strategies and measures will be necessary for improving the material flow systems of building in Lleida. This model should be achieved taking measures from the beginning of the chain. Controlling the materials flows through the total system is more efficient than separating management of wastes from the management of production supply and consumption. Globalization makes possible that the materials required for building in Lleida come from the extraction of the natural resources in the environment of another country, often are transformed into products in a second one, and finally are consumed in Lleida. The extraction and harvesting of primary natural resources for building materials requires transporting and processing large mass of materials. The country which takes benefit of the materials consumption should be responsible not only of the environmental impacts that are generated in its own environment but also in the rest of it. This key point is difficult to achieve if the processes required for obtaining the building materials are taken in other countries. A total control of the material flow model, from the beginning of the chain to the end of pipe, can be reached if the materials used for building are extracted, processed, and finally treated as wastes inside the own country. Making of Lleida a locally self-sufficient region allows controlling the total flow of materials from cradle to grave and accomplishing measures to reduce the environmental impacts of the building sector. The next given question is if there are enough natural resources in the region for satisfying its total needs of building. If this limit has been already achieved, then the sustainability of the building sector in the future is not guaranteed. Sustainability requires a change of the current building model to a material flow system that remains constant in a stationary state in flows of materials and energy. A stationary flow model would provide the equilibrium needed to reach sustainability.

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Chapter 3

Low cost sustainable building solutions

Low cost sustainable building solutions: A study in Angola

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ABSTRACT: Aiming a sustainable development through the vital area of energy efficiency in buildings, strategies of bioclimatic architecture will be set in order to provide housing accessible to people in need, giving attention to environmental and cultural aspects.
The work aims to study architectural and constructive solutions to housing at affordable rates in southern Angola (provinces of Kunene and Namibe), analyzing traditional models previously applied and proposing solutions within the existing socio-economic and environmental context.
It seeks to contribute to the resolution of socio-economic and environmental problems in our days. Examples of these problems include the cultural uprooting as a result of migration from rural to urban places (mainly during the 30 years of armed conflict), poverty levels of the poorest people, poor living conditions (lack of quality in construction and basic support infrastructure), and the excessive use of energy in buildings as an alternative to the lack of bioclimatic architecture strategies correctly oriented. Aiming a sustainable development through the vital area of energy efficiency in buildings, strategies of bioclimatic architecture will be set in order to provide accessible housing to people in need, giving attention to environmental and cultural aspects.

1 STATE OF THE ART

Angola is a country with developing economies marked by armed conflict in the long term, like many African countries. Sustainable Construction and Urban Development become urgent in a context where demand for housing and basic support equipment is constantly increasing, where lack of resources and lack of construction and urban planning are frequent.

The absence of basic comfort performance criteria in the construction involves increasing use of air-conditioning, making it more expensive. Moreover, for much of the population, such a system is unaffordable, making the interior spaces conducive to unhealthy concentration of mosquitoes (malaria) and other insects. The lack of adequate ventilation, overheating, the appearance of fungi on the walls, are problems easily solved by the implementation of passive architecture strategies.

The buildings and construction sector is one of the key sectors for sustainable development, both in terms of the important benefits it contributes to society and the considerable negative impacts it may cause if appropriate considerations are not given to the entire life span of buildings" - UNEP-SBCI (Sustainable Buildings and Construction Initiative, United Nations Environment Programme).

The aim of this work is to find solutions for sustainable passive architecture and building with the inclusion of renewable technologies, through research on models of vernacular housing built to respond to the climate in which they operate, using local materials available. For example, the use of earth on walls gives them thermal inertia, making the house cooler during the day and warmer at night, an important condition in places with high temperature difference between night and day. The use of "stick-to-peak" structures with straw roofs allows ventilated and shaded spaces, comfortable during the peak hours. These kinds of strategies should be analyzed in order to propose methods adjusted to the development of sustainable housing with controlled costs, responding to environmental and socioeconomic needs, and inserted in the Angolan context.

This issue was raised in Angola before independence, with no definitive solutions and without making studies about buildings environmental performance. There is, in spite of this, a great body of literature on Angola which gives to the attention, among cultural and socio-economic issues, facts about the construction of vernacular housing, to be considered in this work, such as Carlos Estermann, 1961, Maria Lima, 1977, Ramiro Ladeiro Monteiro, 1994, Garcia da Orta, 1996, René Pelissier, 1986, José Redinha, 1973 e 1975.

Also good examples of solutions in other countries should be referenced, in response to the growing need to adapt the building to local contexts, reducing energy costs and minimizing the environmental impact, such as the work of Laurie Baker, 1986, Joo-Hwa Bay and Boon-Lay Ong, 2006, Samuel Cougey and Jean-Pierre Oliva, 2006, Peter Van Dresser, 1996, Wolfgang Lauber, 2005.

The development of this proposal is supported by the work done under the Sure-Africa Program (Sustainable Urban Renewal: Energy Efficient Building for Africa), of which I belong, and which is currently taking place in Portugal at the Instituto Superior Técnico, co - funded by the European Union. This program aims to develop a network of practical and intellectual knowledge between African and European universities, about energy-efficient building and urban design.

2 MAIN OBJECTIVES:

1. Gather information about the Vernacular Housing model, its evolution and current framework in the urban space, of two southern Angola regions;
2. Analyze the construction methods and environmental performance of these models and other models of existing housing within the urban space, comparing the results;
3. Propose solutions for passive architecture construction development, including renewable technologies, with a view to its future implementation in dwellings at affordable rates.

In order to achieve these objectives, it is necessary to:

4. Increase knowledge in the areas of spatial and constructive organization, assessing levels of comfort, by the analysis of thermal, acoustic and lighting performance of the building;
5. Understand the influence of two different cultures in defining their models of vernacular housing;
6. Understand the way traditional housing models developed over the years, identifying some characteristics of those same models in urban spaces or cities;
7. Combine the study of traditional housing with tools of environmental comfort analysis (monitoring and computer modeling) in order to rate the performance levels and compare them with contemporary housing models. This will allow having technical and measurable conclusions to be applied in future solutions;
8. Across all the information obtained, resulting in an organized data system, allowing the definition of constructive and project strategies for housing at affordable rates, with application in everyday practice.

The following proposal falls under the PhD in Architecture that I am developing at the Instituto Superior Técnico, about "Low cost Housing in southern Angola”.

Angola has seen 30 years of armed conflict, resulting in great human and material damage. Today it is growing at a fast rhythm, with the creation of new urban centers, residential areas, business, shopping, etc.. However, not always is the city planning or building construction appropriate to the local climate and, often, to the social environment: glass towers are raised in a tropical climate; the buildings have large glazing areas without any shading or natural ventilation. The result is an uncomfortable interior, making the use of air-conditioning and involving unnecessary spending of energy.

Angola is a country of contradictions - the lack of housing conditions and the unsustainable construction clashes strongly with the economic potential of the country.

It is urgent to have an answer, a contribution so that the urban growth can be conducted in a sustainable manner, helping to reduce poverty levels and assigning sufficient housing conditions to everyone.

The study of traditional contexts concerns the search for constructive answers for examining the behavior of vernacular housing models, given the geographic and climatic context in which they operate. It will be essential to understand how those housing models behave, evaluating their best abilities and their main weaknesses, to propose improved solutions.

In order to base the work in specific contexts, and given the great diversity of cultures and ethnic groups in Angola, the scope of this PhD is limited to two peoples of southern Angola. The case studies focus on two sub-ethnic groups, the Kuanhama belonging to the group Ambó [10], and Kuvale, belonging to the Herero [17], both of Bantu origin. The option comes from the particularity of both Kuanhama and Kuvale being two sub-major groups within each group above (in number or influence). It was also a fundamental criteria of choice that they are two peoples who only would later give in to the colonization by the Portuguese, keeping deeply, even today, typical qualities and characteristics of its cultural roots, which will certainly allow a more specific and targeted study.

Figure 1 –Illustration of the geographic location of the Kuanhama and Cuvale ethnic sub-groups belonging Provinces.

Figure 2 – Aspect of Kuanhama's traditional models of housing and cultural traits

3 METHODOLOGY

3.1 *Collect literature in various libraries and institutions*

The work have a basis for further research on the various issues surrounding it (traditional Construction, Architecture and Urbanism).

3.2 *Local data survey*

Starting from general to detail, it is vital to understand all the procedures in terms of legislation and its local applicability, at the current state of vernacular housing in both rural and urban areas and, finally, at the construction processes and economic implications. In this sense should be made on site:

- Survey about how applies or implements legislation and policies to promote housing and urban and territorial development in the study area;
- Survey of architectural typologies and design features;
- Monitoring and analysis of the environmental performance of buildings (involving the use of Data Loggers)
- Queries to the population (rural and urban), in order to understand the criteria and expectations.

Monitoring the environmental performance of buildings through the use of Data Loggers is essential since it allows the measurement of levels of comfort, namely, identifying and assessing existing environmental comfort problems. The results are then used in comparisons with analysis of computer simulation, also indispensable.

3.3 *Computer simulation of the environmental performance of the building:*

Both studied buildings (existing) and final project proposals computer models will be carried out, using Ecotect software for the environmental performance simulation (see figure 3).
Ecotect allows the integration of the 3D visual aspect with a wide range of environment analysis and simulation and has the feedback results of both calculation and design. These results will allow the evaluation of the buildings behavior, identifying key issues and pointing out some solutions to them.

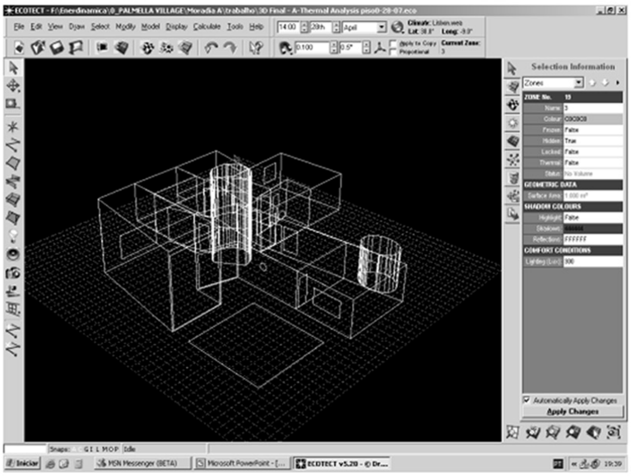

Figure 3 – Aspect of the Ecotect Software' sketchpad

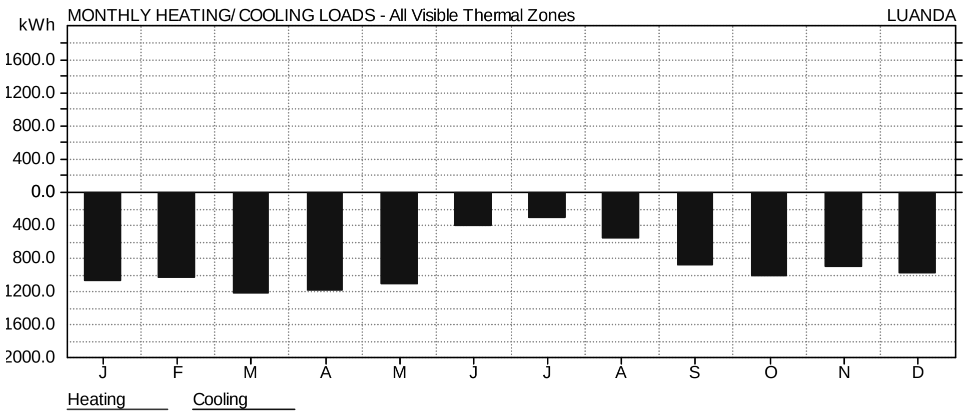

Figure4 – Output example – Chart Energy Consumption

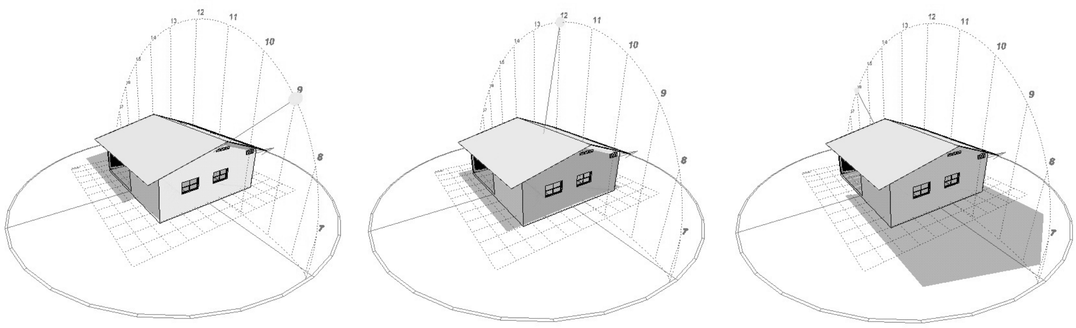

Figure 5 – Output example – Solar projection on the building às 9h, 12h e 16h de Verão, for a building in Luanda

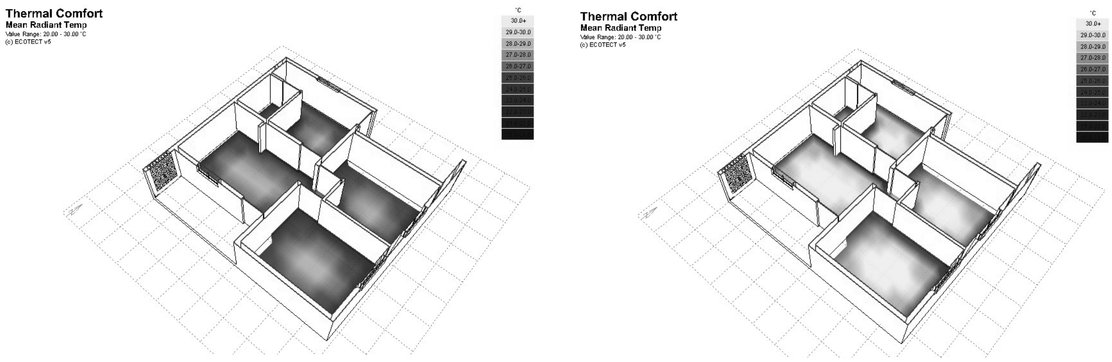

Figure 6 – Output example – Mean radiant temperature distribution on the building interior

The intersection of all obtained information during the study and research will result in a organized data system, allowing the development of strategies for constructive and project housing at affordable rates, with simple application in everyday practice.

Strategies as a result of the whole process of research and analysis will be presented, finally, showing in practice feasible solutions, which should not, however, represent limited and unique model applications in terms of housing.

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Defining eco-efficiency solutions useful during maintenance activities of existing buildings

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ABSTRACT: This research is aimed at defining innovative guidelines and building components for introducing eco-efficiency principles into maintenance activities of real building stock.
This goal is justified by the awareness that nowadays the building sector is one of the main responsible of the environmental burdens especially during its lifespan. This issue is true, in particular, in the Italian context where most of the existing buildings are generally out of date and not fit to minimize the energy consume.
On these assumptions, adopting the Design by Components (DbC) approach, which has been conceived at DIPRADI for developing environmental-friendly industrial products, the study is going to transfer this approach also in the building sector in order to demonstrate that recurring on sustainable components maintenance and replacement is a direct strategy for improving the environmental performances of building lifespan and at the same time it is indirect way for improving the environmental performances of building life cycle.

1 GOALS OF THE RESEARCH

The research is aimed at defining innovative guidelines and building components which introduce eco-efficiency principles into maintenance activities of real building stock adopting the Design by Components methodology, which has been conceived at DIPRADI Department in order to develop environmental-friendly industrial products and services.

This know-how transfer is justified by the awareness that nowadays several building components and products can be taken into account as industrial products, because they are produced by manufacturing industries, delivered to construction sites and finally assembled as an industrial product. In this way the construction products could be considered the real link between industrial ecodesign and the building renovation and maintenance sector by which the Design by Component approach could be put into practice in the Building Sector. In other words the building components could be a common field of study where is possible a critical confrontation between these two cultures, which look so distant but are both aimed at planning cultures and process.

2 BACKGROUND ANALYSIS

Starting from this assumption, the research has began with a background analysis on the state of the art of the existing building blocks in relation to the renovation and maintenance procedures and the influence of the sustainability and zero energy principles in these activities in the Italian context.

Nowadays the existing buildings can be considered as one of the most responsible for resource consumption and environmental impacts. Therefore the main sustainability goals such as the minimisation of resources consumption (materials and energy) and the reduction of emissions into the environment (solid waste, air and liquid emissions) along the product life cycle have to be translated also in the building sector.

This issue is true in particular in the Italian context where the most existing constructions are generally out of date and are made of materials and technological systems which are not fit to minimize heat losses in the winter and overheating in the summer with a consequently high energy consumption for the heating and air conditioning plants . As indicated in a CRESME (Centro Ricerche Economiche e Sociali di Mercato per l'Edilizia) Report of 2006, if 40 years is assumed as the critical age of a building when could be identified an high level of obsolescence of building technical plants and components, it will be possible to estimate that in 2020 more than 80% of the Italian real estate will be out of date. Specifically in the real estate are included the following kind of buildings such as block of flats, office block and school buildings which are generally built of a concrete framework with a building envelope made of bricks or pre-concrete panels.

As a consequences the Italian Legislative Decree (at national and regional levels) has implemented the European Directive (2002/91/CE) with the adoption of building energy labels for improving the eco-efficiency level of buildings during their life span, as it is for the energy label in electronic and electrical equipment.

At the same time in our country in order to face a progressive obsolescence of the building stock in conjunction with a contraction of the new building market (due to a high rate of constructed and the considerable costs of new buildings) it is possible to underline that renovation and maintenance activities and cultures have been playing a central role over the years with an evolution from being simple repair works, when the damage has already happened, to a system of preventive and planned activities aimed at preserving the quality performances and the economic value of buildings in time. As a consequences the maintenance procedure have been gradually undertaken as a service strategy and new advanced real estate management companies have arisen in the property market with an increase of the renovation investments. These companies have specialised in building or in facility management services when the building is in usage phase.

In relation to this context, from a sustainable point of view along with a Life Cycle Thinking Approach, a suitable building maintenance regime can be an indirect strategy for reaching sustainability goals, because it extends the operating lifetime of a building, thereby postponing the time of its end of life (including its demolition and the following waste production and disposal), and at the same time deferring the consumption of new resources for the construction of a new one. However, if eco-efficiency is really the main issue, these maintenance and renovation activities do not have to focus exclusively on the preservation of the current quality, but also on the improvement of the energetic and environmental performances during the building life span. In this way, the renovation/removal operation complying with a high level of eco-efficiency could be the right solution to improve the building environmental performances not just during its lifetime but along the whole building life cycle.

As a result, we can conclude that the main "scenario" of this research has been the existing energy consuming buildings and the correlated maintenance and renovation activities with the components replacement for improving their energetic performances during the winter and summer season.

3 IDENTIFICATION OF COMMON WEAK POINTS INTO THE EXISTING BUILDINGS

Following this background analysis, the research has been carried out through the analysis of several thermal imaging surveys on existing buildings in order to identify the common weak points (building components or subparts) where heat losses are unusual.

The Infrared Thermography is a non-invasive diagnosis technique, thanks to which it is possible to detect the radiations of an object in the infrared range of the electromagnetic spectrum and produce images of its radiation. Using this technique for the building analysis it is possible to detecting the emissivity and the temperature variations linked to the materials of the building components and structures and identifying anomalies in temperature distribution. These anomalies generally mark some problems which prejudice the transmittance performances of the building envelope. Nowadays this technique in used in the building analysis in order to identify the heat bridges of the structures and envelope, verify the regular functioning (working) of wall thermal insulation, check breakdowns (damaged or failure) of electrical, plumbing and heating systems and identify damp infiltration in the building envelope. In other words the 4 main factors which can be compromise the building transmittance performances.

Thanks to the reading on several thermal imaging of existing buildings, the research has been able to identify the recurring weak points corresponding to the following building components or parts (Figure 1): part of the external wall under/over windows, windows and doors (including ledges, fasteners, shutters and frames integrated into the wall), drain gutters and pipes of the rainwater collection system, roof ledges and string-course bands, balconies and terraces, internal connections between walls and attics, smokestacks connected to the heating system.

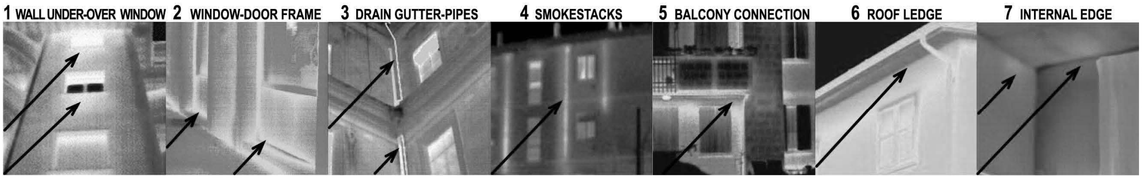

Figure 1. Common heat bridges corresponding to building components or parts

These identified points are coincident with winter heat bridge losses and with the way by which the heat go inside easily with a consequence overheating of the rooms during the summer. In other words, these are building components where the transmittance performances are compromised by construction mistakes or bybuilding materials subject to wear (damaged or insufficient insulation layer, worn out window frame gaskets).

As a result, these critical building components/parts will be the specific objects of study and design activities of the research in the following phases.

4 ADOPTION OF DESIGN BY COMPONENTS METHODOLOGY FOR OUTLINING INNOVATIVE BUILDING COMPONENTS AND SOLUTIONS

After a close analysis of these weak points stressing the recurring problems for each selected element, the traditional and environmental requirements to be met, the most common maintenance or replacement activities, in this research it has been finally possible to set new requirements for each elements not just regarding energy efficiency, but also in favor of the inhabitants well-being by the adoption of the Design by Components.

4.1 *Design by Components*

Design by Components (DbC) is a methodology that was developed at DIPRADI Department in order to design really innovative and environmentally-friendly products, where the man is at the centre of the project (Figure 2).

By adopting this method, the design pathway starts from a critical analysis where the product is dismantled (concretely or abstractly) so as to better understand its constituent parts (both materials and components). A follow-up analysis is then carried out, including several kind of analysis and scheme in order to obtain an essential scheme of the object under study.

Specifically the DbC approach has been conceived through subsequent analysis and abstractions such as: the macro-components and components scheme, the functional scheme explaining the relation between the composition and the functionality of the object under study, the analysis of the correspondence between its function and shape, a its sensory and perceptual scheme, a components lifetime scheme illustrating the principle replacement and maintenance activities of the different components, an analysis of emotional relationship between the user and the object and a background analysis of the other similar products with the same function. Thanks to these several analysis schemes, an essential scheme of the studied object has been achieved by which defining the project needs of a new product.

Adopting an holistic point of view, as suggested by the DbC, with these several studies and analysis the designers are able to understand mutual relationship between the main functional groups and to define the essential scheme in order to point out the problems and strengths, priorities and emergencies and consequently to identify the different groups of problems to be tackled.

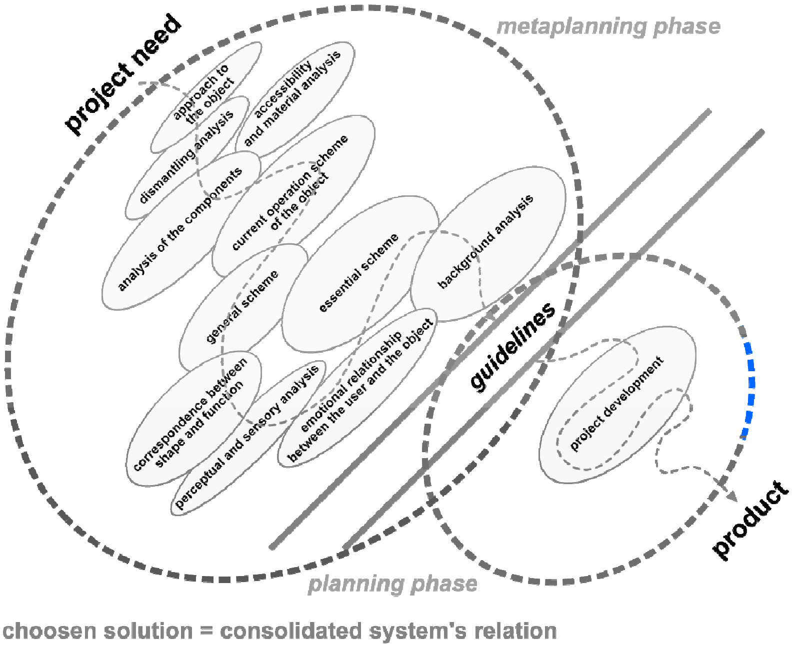

Figure 2. Design by Components (DbC) scheme

As a result from this analysis process of the product, which is not linear, but starts from the definition of a complex relational scenario, it could be possible define the main guidelines and the subsequent needs and requirements system which have to be satisfy in the development of new concepts for the new product in the following planning process phases of the design pathway.

In the same way it is possible the adoption of the DbC approach into the building design process because also in this context the planning and designing process requires to outline an answer through a process, not necessarily linear one, but which starts from the definition of a complex relational scenario, as it is made for an industrial product, concerning the specific relationships involved in the thematic area we are going to act in.

As it was said before, the DbC can be transmitted because it is based on a new consideration implying that the existing houses and their components are equal to any other sophisticated serial product. They are therefore regarded as complex systems, which are decomposable into functional and then essential schemes, to be analyzed afterwards using the same methodology adopted for the industrial product. Consequently the architects will be able, as designers do, to outline new concepts that exemplify the objectives that the following planning process phases will focus on.

For this reason, this research could be an opportunity to put into practice into and test the DbC method in order to achieve planning and designing solutions for the selected weak points in a building structure and envelope, as identified before.

4.2 *Application of DbC to the selected building components*

Since the main goal of this research is the re-consideration of these problematic parts/components focusing on sustainable maintenance activities, as suggested by DbC, the most important requirements that design concepts should meet are solutions able to be produced outside the building site, then installed in the most easily and fasten way, without invasive or destructive interventions on the different buildings structure and walls.

The respect of these requirements will not be possible for all identified critical building parts because elements such as balconies and terraces, roof ledges and string-course bands and the internal connecting edge between walls and attics require invasive interventions on the building structure which are possible in case of whole building renovation/reconstruction or new building constructions. As a result for these weak points it could be possible only to define guidelines useful in case of these invasive works.

While building parts such as external walls parts (under/over the window), windows and doors (including ledges, fasteners, shutters and frames integrated into the wall), drain gutters and pipes of the rainwater collection system and the smokestacks of the heating system could be tackled using this method, as it will be explained in the following paragraphs.

4.3 *The wall under/over the window: an application of DbC for designing innovative solutions*

According to the DbC methodology, the first step of the design pathway is the identification of the main problems of this building part which compromises the energetic performance of the whole building and the internal inhabitant well-being as well and an analysis of the requirements able to gather the main function of this elements.

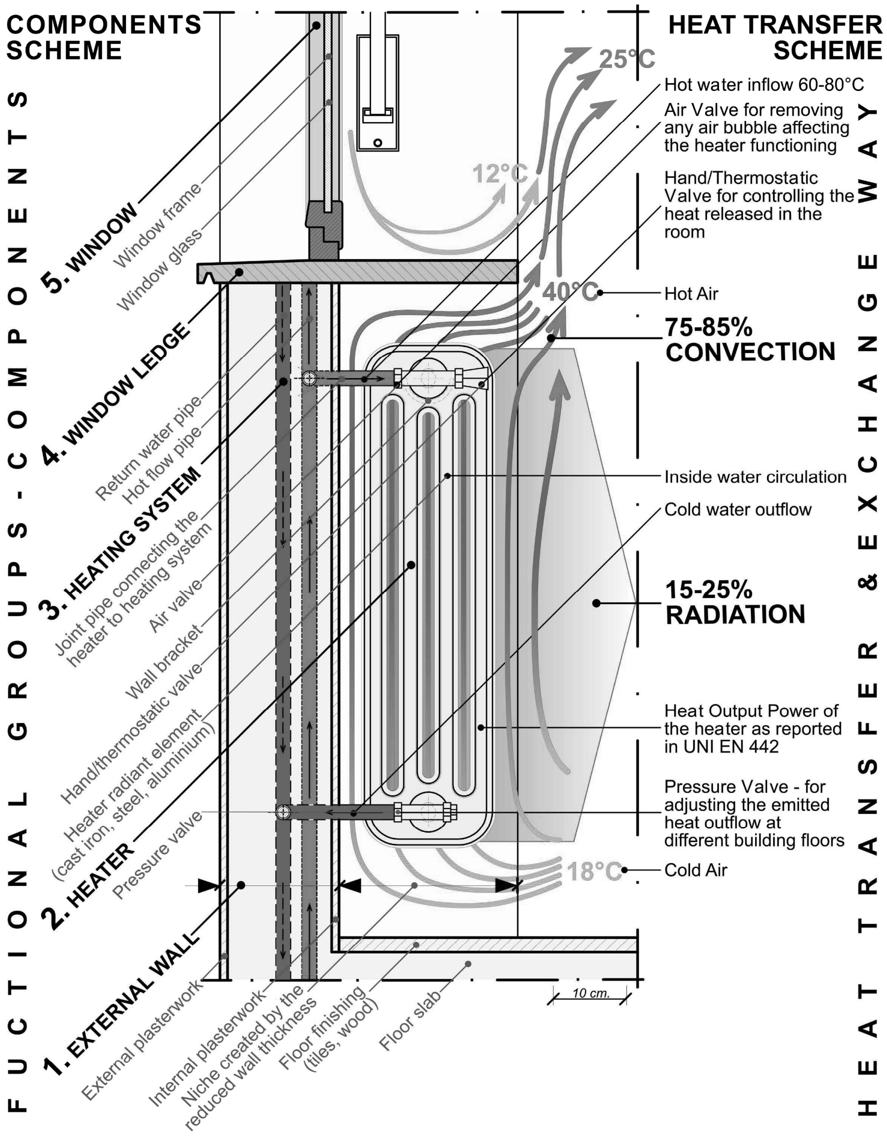

Figure 3: Example of functional scheme concerning the incorporated components and the heat transfer and exchange functionality

Specifically the main problems recurring on this building portion are:
- heat loss bridge in the area of the rolling shutters box and in the wall portion under the window, where the wall has a reduced thickness generally in conjunction of an insufficient thermal insulation layer,
- cold air infiltration and hot air losses through the windows frame due to air tightness of gaskets in the windows frame
- damp infiltration due to atmospheric elements and consequently building up of condensation inside the wall materials, are the main underlined problems.

Concerning the main function of building portion such as separating interiors from the outside elements and at the same time ensuring a fixing temperature and a good level of thermal inertia in the interiors (during the winter and summer seasons), several requirements have been satisfied for gathering this function such as: safety, usability, healthiness, perceptual comfort, building life cycle management and inhabitants well-being. The last two points, building life cycle management and inhabitants well-being, have the most influence on the building eco-efficiency performances.

After these preliminary analysis, the next phase of design process, from an abstract point of view, is the dismantling of the building envelope which involve this weak point, in order to better understand its constituents: building macro-components and product where to concentrate the project proposals and attention.

In this way we can identify three main macro-components: the wall under the window, where generally a heater is located, the window frame and the rolling shutters box.

Concerning the first macro-component, the wall under the window, it is possible to pinpoint some functional groups and the system of mutual relationships which will influence the performances and the functionality of this macro-component (Figure 3).

Therefore the research project has investigated these relationships between the main components by means of various schemes which investigate aspects such as: the expressive features of the different kinds of existing heaters and the current trends into designing new heaters, the different ways heaters connect to the hot water central heating system, the operating modes of heat

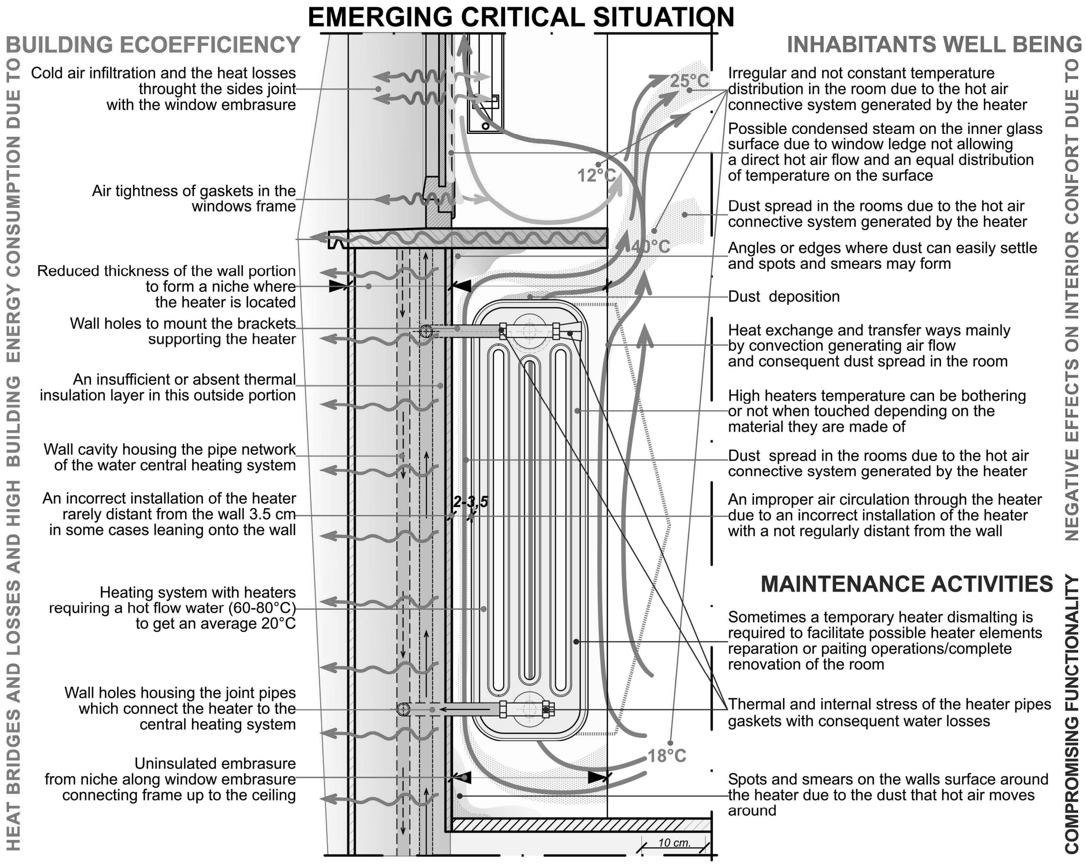

Figure 4. Emerging critical situation derived from the analysis of the different functional schemes

transfer and exchange of a traditional heater (Figure 3), the analysis of the hot air convective circulation in a room and the consequently temperature distribution in function of the different heater positions in the room, the method to calculate the heat output power of heaters, the life-span of the parts composing this macro-component with an indication of the different kinds of maintenance activities to keep it functional.

Thanks to the object analysis carried out through these functional schemes, we are able to identify the mutual relationship between its parts and then stress the main critical situations by outlining new concepts for an innovative building component.

In this case the emerging critical situations (Figure 4), are related three groups of critical factors related to:

- heat loss bridge and energy consumption, such as the reduced thickness of the wall, the presence of holes in the walls, an insufficient thermal layer and so on, which influence the whole building eco-efficiency during its lifespan;
- negative effects on interior comfort, such as the dust deposition and spread in the room and others, which influence inhabitants well-being;
- aspects compromising the building functionality, which will influence the maintenance activities.

Starting from this identification of the emerging critical situations, by the adoption of DbC we are able to define a need and requirements system, which have been met during the design process of a new component. From each identified need derived different guidelines and solutions for these specific point (wall under the window) (Figure 6).

NEEDS	REQUIREMENTS	GUIDELINES
1. Reduction of heat losses due to irradiation through the wall	- Improving the wall insulation	- Using further insultaion layer such as thermo-reflective slim insulation or other form of insulation with thermal consuctivity low value - In case of building renovation (destructive intervention) ensuring a correct stratification of wall elements
	- Reducing the gaps in the wall contributing the heat losses bridges	- Avoiding screw anchors for securing new component into the wall and using components self-supporting - Avoiding heater installation directly into the wall - Avoiding continoues window ledge, using solutions for thermal shearing perfomances - Arranging a correct thermal insulation of the wall embrasure - Improving the airtightness of the primary and secondary frames of the window
	- Substituting the heater	- Opting for an element granting a better output against a lower flow temperature - Respecting the minimum distance suggested of 3,5 cm. form the wall
2. Preservation internal comfort of the room	- Ensuring a uniform temperature distribution on the room	- Locating the heatre in acorrect position in the room
	- Preventing the condensation steam form building up in the inner window surfaces	- Avoiding positioning ledge or other elements which deviate hot air flows - Locating the window in the correct middle position of the wall embrasure
	- Avoiding dust deposition which is spread in the room by the hot air flows form the heaters	- Reducing or rouding the edge niche where the heater is positioned
3. Foreseeing an easy and quick installation and maintenance activities	- Preserving yhe exiating heating system	- Avoiding to change the position of joint pipes connecting the heater to the heating plan
	- Adapting to the different shapes and size of the wall niche	- Using a system of components to be adapted to the different shapes - Adopting reversible joints nd fastening system easily assembling/disassembling
	- Facilitating component disassembling	- Using reversible joints and fastening system which facilitate disassemblu and materials separation
	- Facilitating maintenance and cleaning activities	- Using reversible joints and fastening system - Planning to move the heater without disconntecting it form the heating system
4. Reducing environmental impact	- Selecting components with a low environemnatl impacts along the whole life cycle	- Using materials derived from renovable resources - Adoping materials whose manufacture processes include a fraction of recycled resources
	- Reducing environmental impacts during the production, distribution and installation phase	- Reducing manufacturing and installation scraps and waste - Using local materials in order to reduce the transport emissions - Foreseeing easily stackale packging in order to optimize the trasnport and delivery

Figure 5. Main needs, requirements and following guideline that should be satisfy during the planning process elaborated as suggested by the DbC approach.

In this way, on the basis of needs system elaborated as suggested by DbC, at the present the research is focusing on outlining new concepts for an innovative building elements able to solve these needs and in conclusion combining the sustainability and maintenance needs (Figure 6).

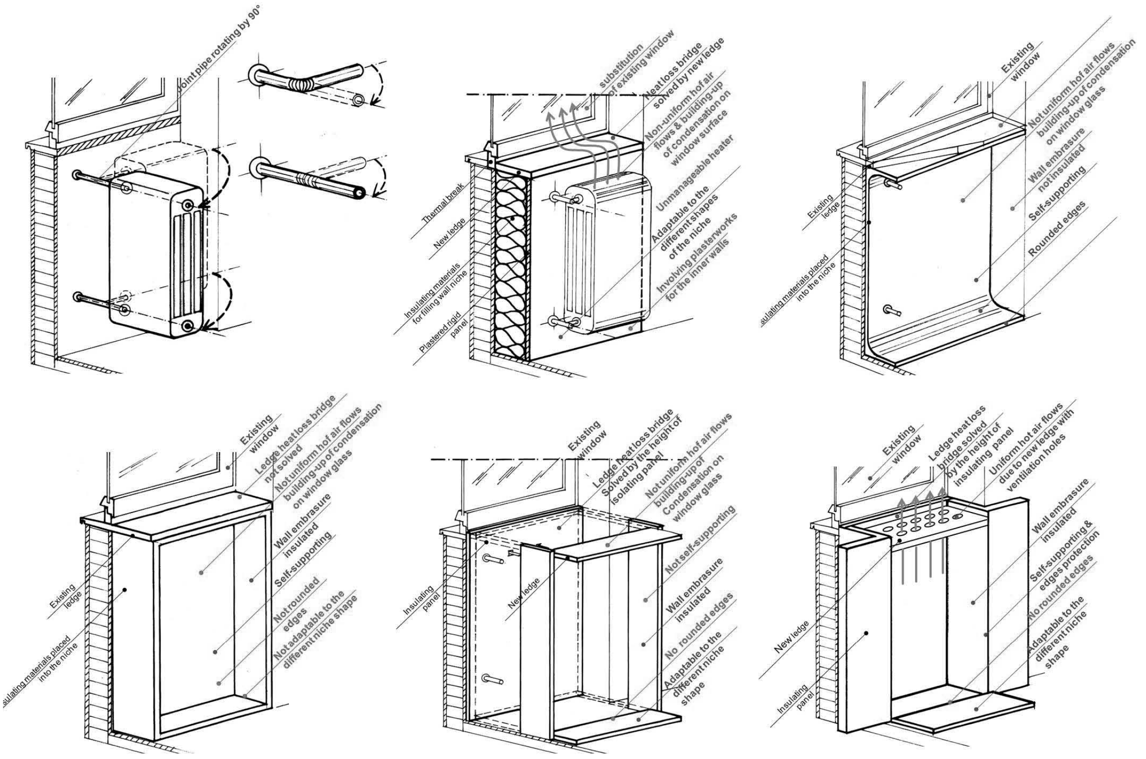

Figure 6. Meta-project sketches under development in order to outline innovative building components for building part wall under the window

5 CONCLUSIONS

As a result, adopting the Design by Components methodology it has been possible defining the families that the previously outlined objectives are bound to, and then after the analysis over their nature and mutual relationships, the architect will finally choose the most appropriate meta-planning configuration and face planning definition and execution phases.

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Lighting Design in Workplaces: A Case Study of a Modern Library Building in Sheffield, UK

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ABSTRACT: Using natural light has always been a desirable building feature and a hallmark of a good design. With a considerable design, daylight creates an ambience of well being and visual comfort. Daylighting design has recently taken up a role among the whole design process, beyond the aesthetic and psychological aspects, with the sustainability and the energy efficiency. The alternative to daylighting is to use artificial lighting in workplaces in buildings; however there is a significant amount of energy use when compared with the consumption levels in residential buildings. The paper focuses on a recently completed modern library building in Sheffield, UK and examines its open plan offices in connection with lighting design in workplaces. Effective use of daylight in such a modern library design is both an art and a science. The aim of this study is to present the principle concepts of lighting design used for the workplaces and a case study to demonstrate if a modern library building is fulfilling some of the lighting design guidelines, and to discuss the findings of the preliminary lighting analysis.

1 GENERAL INTRODUCTION

This section of the paper is aiming to provide general information about lighting design in Architecture with a particular focus on daylighting, energy efficiency, people and workplaces.

1.1 *Lighting Design in Architecture*

Using natural light has always been a desirable building feature and a hallmark of a good design. With a considerable design, daylight creates an ambience of well being and visual comfort. Daylighting design has recently taken up a role among the whole design process, beyond the aesthetic and psychological aspects, with the sustainability and the energy efficiency. The alternative to daylighting is the use artificial lighting in workplaces in buildings however there is a significant amount of energy use when compared with the consumption levels in residential buildings.

The workplaces built-in various buildings such as open plan and traditional offices, industrial and educational buildings including library buildings. Today, in modern libraries, the main purpose is no longer limited with reading, but also incorporated widely with IT based workplaces, which makes the main function very similar to most office buildings. In such cases, lighting design therefore should be considered more like in offices rather than in traditional libraries.

Daylighting in buildings do not necessarily lead to energy efficiency. Even well daylit buildings may have high energy usage if artificial lighting is constantly on due to improper controls in place. Lighting should be switched on only when required and to the level require and therefore, the integration of daylighting and artificial lighting requires considerable planning including the appropriate choice of light source, easy controls and a strategy for energy efficiency.

1.2 *People, Lighting and Workplaces*

Whether in industrial or office settings, proper lighting makes all work tasks much easier. People receive about 85% of their information through their sense of sight. Appropriate lighting, without glare or shadows, can reduce eye fatigue and headaches. It also reduces the chance of accidents and injuries from 'momentary blindness' while the eyes adjust to brighter or darker surroundings. Millions of people spend a significantly large part of their lives working or studying, and lighting is provided at their workplaces to ensure that they can see to do their work quickly, accurately and easily. Therefore, people's satisfaction is an important factor when it comes for lighting design in workplaces.

The studies completed by Weston in 1945 have served to demonstrate the general form of the relationship between lighting conditions, task characteristics and visual performance. Accordingly, luminance level and task can form a link to each other so as to determine the work condition. People rarely change the task when working, like the size and contrast of the print. In another words, luminance level is a key point for working efficiency. Improving illuminance levels can enhance working efficient, but this is easy to get its 'saturation' (Weston, 1945).

With regards to daylight requirements, the luminance level is not enough for working situation, light quality is more important for human being. Lighting quality can be the brightness contrast, potential for glare, and colour rendered. Ignoring quality always reduce visual performance so as to reduce the productivity. Normally, natural light is considered with the best quality. The fact that daylight is desired can be shown by quite a few evidences. From research, comes the fact that almost any study which asks office workers about which light source they would like to illuminate their work area reveals a strong preference for daylight; or occupied worked near windows have higher production compare with the ones sitting further of the window (Cuttle, 1983).

Given that daylight appears to be strongly desired by most people, it is reasonable to ask what happens when people are asked to work without daylight, while it is available outside. Observation of almost any multi-story office building will reveal that people are willing to give up daylight when it causes visual and thermal discomfort. Measurements of the use of window blinds in multi-story office buildings have shown two trends. The first is that window blinds are increasing to be shut down when the sunlight through the windows cause solar glare or extra. Another trends is that many of these blinds are kept down even after the sun has disappeared on the window; and this, in some areas, the blinds are left in the down position for ages, this probably because the eyes' adoption and occupies lack of responsibility. These appearances suggest that the desire for daylight, or at least direct sunlight, is limited when it causes discomfort (Heerwagen and Orians 1986).

People also tend to increase the amount of electric lighting as the increase amount of daylighting in the office. The cause of this behaviour might be the desire to balance the luminance of the window and working area; or the surfaces brightness near the window and deep in the room. It also implies that the whole light distribution in the room is more important than the purity of daylight (Begemann, 1994). Accordingly, this suggest that the reason why daylight is so desirable as a main part of lighting from the point of people' satisfaction. This again implies that while considering the lighting design, people' psychological requirement are important, even sometimes people can not realise this themselves. Potential behaviour should be considered while designing, or the certain devices and systems can not achieve the expected result.

2 LIGHTING STUDIES IN A CASE STUDY BUILDING

This section of the paper is dedicated for lighting analysis and the studies carried out using a case study of a modern library building in Sheffield, UK in order to demonstrate some of the principles behind lighting design in relation to daylighting analysis in workplaces.

2.1 *Using Ecotect Programme*

Special computer programmes can calculate the light quantity and light distribution, and with the required computing input, able to also simulate the quality of the light atmosphere. In this study, the computer programme Ecotect is used for several lighting analysis focusing on Daylight Factor (DF) calculations.

Ecotect is a comprehensive and innovative building environmental analysis tool with a vast range of functions to help understand how a building design will operate and perform. The geometry of a space is composed of a few simple basic volumes of any number and at every scale. Any shape can be produced at the required degree of detail. The programme uses sky models that are employed to represent the light source from each situation from different locations across the world. Ecotect offers a range of lighting analysis and whilst its main focus is on natural lighting analysis, it also performs some rudimentary artificial lighting design functions. For more comprehensive lighting analysis, it also allows the user to output native files to other lighting applications such as Radiance (Autodesk, 2009).

Most natural lighting calculations are based on daylight factors. The Daylight Factor (DF) is simply a ratio of the daylight illuminance at a particular point within an enclosure to the simultaneous unobstructed outdoor illuminance, expressed as a percentage. Thus an unobstructed view of the sky would result in a 100% daylight factor. A point in the middle of a football pitch surrounded by stands may receive 70-80% whilst points in a room with only one window would receive considerably less, possibly as low as 1-5%.

The programme uses the Building Research Establishment's (BRE) Split-Flux methodology which is a widely recognised and very useful technique for calculating daylight factors. This method is based on the assumption that while ignoring direct sunlight, there are three separate components of the natural light that reaches any point inside a building; (1) Sky Component, (2) Externally Reflected Component and (3) Internally Reflected Component.

Using the daylight factor methodology, it is also possible to calculate the illuminance levels at any time of the day, any day of the year. Thus, it is possible to determine how often each point will be above a certain value. This is known as 'daylight autonomy' and is given as the percentage of time throughout the year that each point will need no additional light to maintain the selected level. Sky illumination at any time is calculated using the diffuse sky formula proposed by Tregenza in 1989 (Tregenza, 1989).

2.2 *Information Commons – A Case Study Building*

The Information Commons (IC) building is located in the heart of the University of Sheffield's urban campus. This 11,500 square metres building provides a 24/7 integrated learning environment for undergraduate and postgraduate students with 1,350 new study spaces where students can study individually or in groups, using print and electronic materials. It takes into account of current and future learning methods and technologies.

The IC building was designed as a modern style library and delivered in 2 phases through a design and build procurement route, and was completed in April 2007 by RMJM Architects. The main concept demonstrates the University's commitment to developing new styles of learning, teaching and research, and represents the biggest investment in learning support by the University since the opening of the Western Bank library in 1959, which was a traditional style library.

The footprint of IC building is a simple 'L' shape - west and east facade is longer than south and north. There is a central atrium which is located in the centre along with the circulation area going through first to forth floor with the top light full spans the length of the roof. The ground floor includes the reception and service area, VDT screens on the searching table, combine with a cafe. The cafe behaves as a buffer zone separates the library inside form outside, avoid the disturbing from the main road, keep the service and searching area quite and clean. The store and learning area start from the first floor, with offices and double height conference room around the building. Natural light from the roof window penetrates to the atrium in the middle of the building.

The building layout is arranged around a central rectangular atrium with open spaces located either side of atrium from second to forth floor. From the second to the third floor, the central atrium also separated the general learning space with VDT screens and quite study areas where is double floor height with the gallery. The atrium is provided with daylight via a rooflight that spans the length of the atrium; daylighting being allowed to penetrate downwards through the atrium to illuminate lower floors.

The learning area has a ceiling height of 3.8 meters and display the space in a daylight atmosphere similar to that outside, where one would expect to stay and work. The facade with large or ribbon windows lets filtered daylight into the building, the view and landscape out side the library recedes into a backdrop for the viewing. The main glazing areas are mainly facing north; this means the interior would receive most diffused and indirect daylight, which is better for working environments compare with more direct sunlight of south facing. However, this also means the building may not have enough daylight to support the certain brightness standard, and the artificial light may be used, which is not necessarily energy friendly for a building opening 24 hours and 7 days.

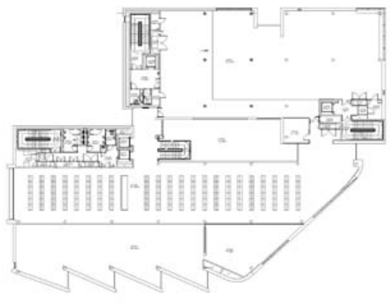

Figure 1. Information Commons building (left) and an Ecotect lighting modelling (right).

Figure 2: Typical floor plan of IC building

2.3 *Daylight Analysis in IC Building*

Generally, the reflectance of internal surfaces in IC building are quite low; one of the reasons behind this might be that there are direct and more diffuse light available, which also means decrease in direct light as means to reduce potential visual problems.

The calculation of daylight factors (DF) as well as the illuminance distributions is established on horizontal layers (working planes) across the study area on each floor using the height of 1 metre from the floor at 11:00 am on 21st August as the suggested hottest day average for Sheffield to illustrate the extreme situation under an overcast day (with 8500 lux sky illuminance). The climatic data and the daily conditions graph shown below (see figure 3) is clearly illustrating that there is clouds covering most of the day, and diffused solar is much higher than direct solar, also considering the fact that overcast situation takes nearly half proportion in Europe. Hence, the overcast sky model is chosen for the simulation.

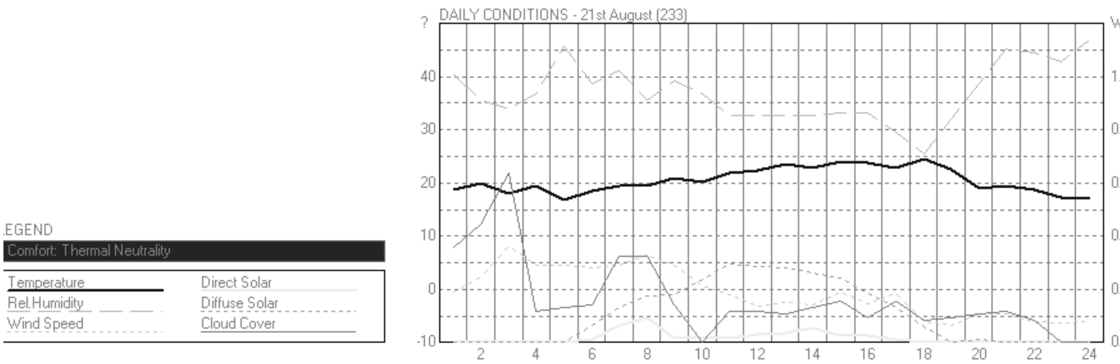

Figure 3: Climatic data for Sheffield, hottest day average, 21st August

The reflectance is one of the important aspects in lighting performance that also influences calculations during the computer simulation process. According to CIBSE guidelines, the internal reflectance range in ceilings, walls and floors are somewhere between 0.6-0.9, 0.3-0.8

and 0.1-0.5. The ceilings in IC building are different on each of the floors; normally with grey or white but matte (with texture) using low value of 0.6; the walls are mostly white but matte (with pattern) surface, so using the neutral value of 0.5; the floors mostly in dark blue carpet, therefore a lower value of reflectance 0.1 is used.

The daylight simulations have been carried out for all floor and also separated into each side of atrium space due to the different functions and window systems used within the building. East part area of atrium has mainly north facing windows with large glazing area; this large glazing area on the south facade is shaded by louvers. West part of the building is mainly designed as a quite study area, similar with the general open office layout, but the glazing area is more on the north and west facing facades, and again limited on the south. The typical floor plan is shown above (see figure 2).

2.4 *Floor by Floor Analysis*

The first floor is the bottom of the atrium with skylight on the roof as the function of general study with computer workstations. It also includes double height general study area in the east with large north facing glazing area, and small open general study area in the west. The analysis is completed separately for each of the floors as follows (see figures 4-9):

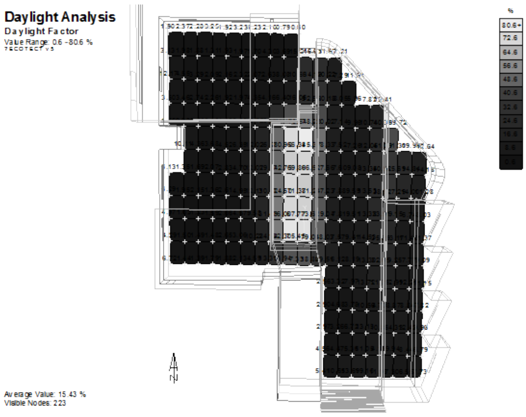

Figure 4: Daylight factors on the first floor

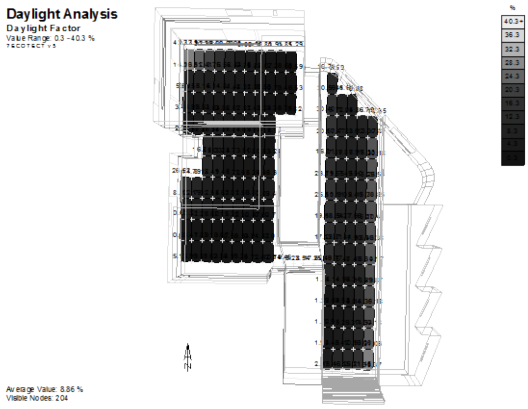

Figure 5: Daylight factors on the second floor

Figure 4 is showing the daylight factors on bottom of atrium which is extremely high compare to the surrounding area, with about 70% due to the skylight on the roof. This is the main problem of the skylight during summer season with high angle direct sunlight, and again this may cause visual discomfort, and therefore proper shading devices are needed. The area in the east with large north facing windows has higher daylight levels than in the west area with normal windows and limited south glazing (see figure 6, left and right).

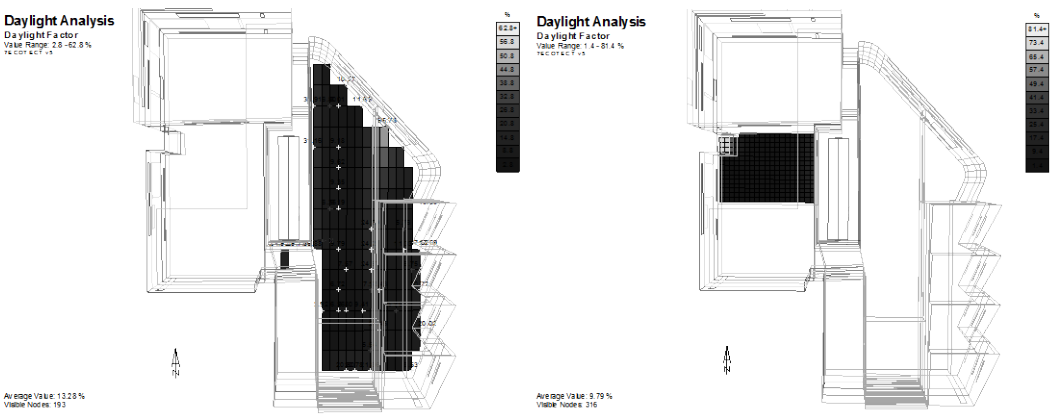

Figure 6: DFs in east part (left) and west part (right) of the building on first floor

The average daylight factor in east area with north light is 13.3% (see figure 6, left). Clearly, double height floor area near the windows has the higher brightness and distributed quite evenly. Brightness level reduced in single height floor in deeper area which is the store shelving located, the DF mostly around 6-9% which is still higher than the CIBSE guidelines (5%). The layout of shelving is parallel to the lighting source (east to west) allowing the light penetrates through the shelves. The light level in deeper area can be compensated by near the atrium space. On the first floor, only central part of west area is the general study area with storage shelving adjacent to the atrium space. The rest of the spaces are used as offices and circulation area and was not taken into account for the calculations. The average DF is 9.79% with illuminance of 832 lux. Natural light source comes from windows facing west and atrium, however due to non-shaded west windows, there may be a possibility of glare during afternoons (see figure 6, right).

The second floor has fairly even illuminance distribution compare with the first floor (see figure 5). General study area in east of atrium has the average illuminance of 1080 lux and DF of 12.7%. The shelving is located parallel to the light source also allowing the natural light to penetrate through (see figure 7, left).

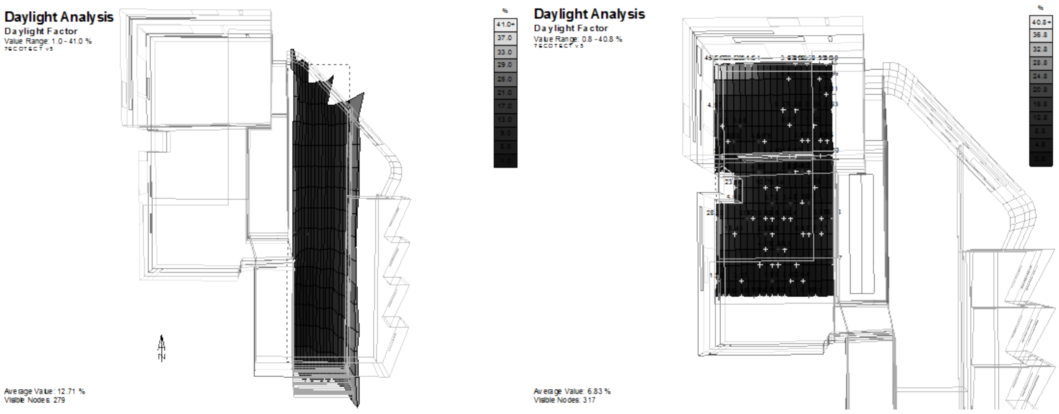

Figure 7: DFs in east part (left) and west part (right) of the building on second floor

Figure 7 is showing the quite study area facing west which has double height floor with gallery with the average illuminance of 580 lux and DF of 6.8%. Apart from the area adjacent the window, the DF is around 3-5%, rarely below 3%, just in the range of the CIBSE guidelines (see figure 7, right). Because of the fact that a quite environment was required in this space, the atrium was blocked, but the light still can go through in from the ribbon window on the atrium wall and compensate natural lighting into the area (with DF of about 8%).

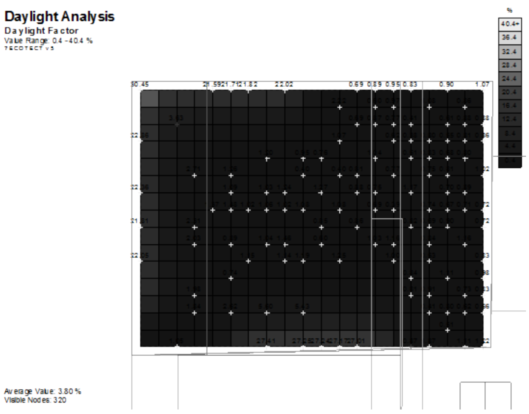

Figure 8: Daylight factors on the fifth floor

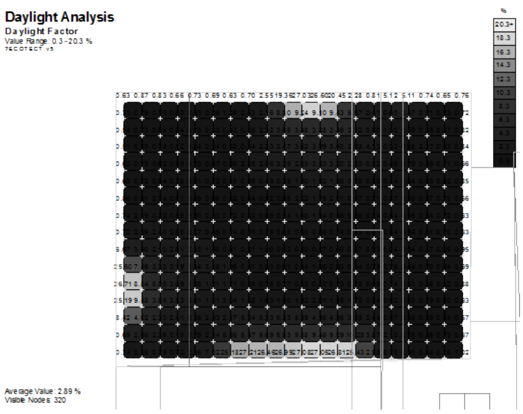

Figure 9: Daylight factors on the sixth floor

The fifth floor has a general open plan space and the calculations have shown the average DF of 3.8% with illuminance of 323 lux; one difference is that it has a bright ceiling (with reflectance of 0.9) instead of a matte one, and the DF has increased about 0.1% (see figure 8). This is also similar within the sixth floor space where the average DF is of 2.89% with illuminance of 245 lux, and the DF has increased about 0.06% (see figure 9). Hence, the inertial reflectance is important when performing such lighting simulations. In addition, although the average DF and illuminance level on fifth floor met the CIBSE guidelines, the large areas on both fifth and sixth floors are slightly below the 3% guidelines and therefore artificial lighting is needed. Daylight autonomy on sixth floor is only 27% and 31.5% on fifth floor.

2.5 *Walk-round Observations in IC Building*

In the double height area in IC building, an uplighter is used which is very smart technique. The luminaries are mounted on the wall, indirect lighting reflected off the reflector on the ceiling (see figure 10, left). Furthermore, the reflectors have a curved specular finish and it is spreading the light over a large part of the ceiling, and avoiding direct light into eyes. It also minimises the problem of casting excessively bright and direct light. In addition, from the maintenance point of view, the ceiling of double height floor is hard to reach but using this uplighter, it is much easier for people to only change the luminaries on the wall, and do the cleaning of the reflectors.


Figure 10: The uplighter used in double height floor area (left); dark grey and deep textured surfaces, which resulted in the 'hot spot' and the dark appearance of ceiling (right)

Most of the study areas in IC building use direct/indirect lighting system where its indirect lighting reflected off the ceiling and walls. It is a diffused even and soft lighting, and creates a comfortable ambience. However, the ceilings in IC building are dark grey and deep textured surfaces, and as a result, it creates the 'hot spot' and the appearance of ceiling being quite dark (see figure 10, right).

OVERALL CONCLUSIONS

In the Information Commons building, the brightness is reduced significantly as we go further away from window. The atrium can compensate and increase the central brightness levels by channelling through natural light. Some of the findings as a result of the lighting analysis undertaken during the study are summarised in the following:

- The arrangement of shelving in storage area is better placed parallel to the main lighting source like windows. This allowed the light to go through the deep areas.
- Double height floors have higher brightness levels due to the larger glazing areas.
- Clerestory windows can increase the lighting quality within the space, even though the thermal aspects should also be considered. However, in long term, it can be considered more important for improving the ambience which has more benefits for people and their satisfaction working in the building and using such workspaces created.

- Skylight on top of the atrium increases the brightness levels on the bottom area significantly, however due to reflectance glare effect may happen, and therefore proper shading devises may be also required.
- According to the simulations on third floor, the solely north light are not able to achieve sufficient daylight conditions to meet the CIBSE guidelines during overcast days, even with large glazing areas. This can be compensated by considerable planning, such as increasing the floor height, using a double height floor, or opening more windows facing other orientations.
- Most of the surfaces (walls and ceiling) in IC building are matte (with texture) or grey; this allows more diffused light in spaces, reducing glare and also other potential visual discomfort conditions. Although the grey ceiling seems too gloomy in some areas and reduces the whole brightness in spaces, the electrical lighting is needed at all times.

To conclude, human factor is the most important aspect in lighting design, the lighting quality and energy efficiency that can not be achieved without considering such conditions. Although the computer lighting analysis can simulate the light distribution with close accuracy and easy to use, lighting design guidelines can be more sophisticated and flexible, the design process should be based on the 'people's requirement' and fully understand the lighting design principles.

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An integrated approach to products and their environment

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ABSTRACT: Due to the current crisis, the production type approval of competing firms, but first of all the new environmental urgency, is rising the need of reconsider new production systems.
The methodological approach of the Design by components (DbyC) (Luigi Bistagnino, 2008), appears as one of the possible open paths to successfully face the on-going change; thanks to this approach, that critically analyses all the parts of a current industrial product, it's possible to redesign new typology of products/production chains as well as the system they are introduced in.
This approach, consequently, involve the redesign of the industrial structure that evolve in a more flexible, glocal, ethical , economical and environmental model.
Such strategies must be urgently met, because the lack of even only one of them could compromise the entire policy implementation and its own reaction to change.

1 INTRODUCTION

The research underlines the possibility to redesign new type of products, production chains and the system in which they operate.

The actual energy consumption claim new structure of product and system of production that have to be more efficient and environmental friendly.

The methodological approach of Design by Component, seem to be one of the possible paths capable to deal successfully with the on-going change, thanks to this approach all the elements of a current industrial product are critically analysed. At the same time the holistic approach, which the designer/design should never forget, explore at 360 degree all the possible implications, causes and consequences of the detected problem.

2 ACTUAL SITUATION

2.1 *Environmental analysis*

In the last years the environmental field and economic crisis have been the two main topics of our daily discussions. Someone says that these two matters are caused by the globalization, others attribute the responsibility to businesses, but there are those who say that the problem is much broader, it's social, and the cause now ingrained in our lifestyle.

"Sustainability, in a broad sense, is the capacity to endure. In ecology, the word describes how biological systems remain diverse and productive over time" (see wikipedia). But today, our society is facing a new situation; from the bought consumer goods to the industrial production is vanished the concept of level / limit.

Our society is consuming more than what we have at our disposal and we are producing more waste than the biosphere is able to absorb. The catabolic (Greer 2008) collapses we are witnessing not include a single system, but as in any system involving a network and impact on other causing a general collapse.

Even if recent European studies have shown that industrial output in electronic equipment over the past 15 years, has devoted special attention and investments to reduce consumption, conscious use of materials and improve performance, much has still to be done. The data published in "Energy and Environment Report 2008" by European Communities clearly disclose that the household appliances sector helps to produce 10% of greenhouse gases.

Although the environmental initiatives carried out by individual manufacturers over the years have allowed a limited improvement in the impact on the environment, the constant technological developments are no longer able to provide concrete reductions in the consumption and emissions that commodities produced. Data submitted by the Design Council in the annual Review of 2002 show that 80% of the environmental impacts of products or services that we use is determined in the planning stages. Materials, technologies, processing methods, systems of transportation, use, and waste products are estimated even before the object is produced.

Due to the current crisis of the macroeconomic scenario, the production type approval of competing firms, but first of all the new environmental urgent needs, is rising the need of reconsider new production scenarios.

The redesign of these scenarios is due to designers' key figure because [...] positioned at the crossroads between changes in technology and consumer proposition "(Argate, March 2009), the designer's task is to summarize the industrial requirements, consumer and marketing, but also must plan and this implies a social responsibility.

2.2 *The household: from tool to machine*

“Hitherto it is questionable if all the mechanical invention yet made have lightened the daily toil of any human being "(John Stuart Mill in Principles of Political Economy). Following up the industrial revolution, the proliferation of mechanical and automatic machinery has been unstoppable. The overview of product enriched crowded by tools designed to limit human labor, or to celebrate the realization capacity of their builders, those are defined as "machine celibitaire”.

Considering only those machines useful to alleviate the workforce of operators, it can be seen how the industrial revolution has forced a shift from tool to machine, the driving force has been transformed from energy produced by man to other kind of energy. In this new scenario the production of mechanical devices and machines continue to maintain the link with human beings seeking to satisfy their needs, even if sometimes, they are influenced and corrupted by pure marketing operations.

Looking at the manufacturing evolution from a semiological point of view two key changes are detected as related to the product machine, the social sphere and consequently to the machine communicating value In the period prior to the production of the first domestic machines, the job action was convivial, it was used to gathered to complete a job (washing, drying clothes, ...) and where was possible to develop social relationships.

The introduction of household implies the transformation of work, the shared places on the work lose their intended use, but the distinguishing feature of these sites remain in popular consciousness. The forerunner of the current appliance converts the work to be undertaken as private action in the home, undoing the social aspect of sharing.

Technological change has introduced elements of efficiency and safety for the use of machinery, but it also removed those signs that could be explanatory of the operation. The transition from an instrument (Marx, 1867) to a machine (Marx, 1867) imposed a physical detach from the appliance that involves a progressive loss of knowledge and relationship with the appliance and know-how . This relation has been left to the maintainer depriving the user from it.

2.3 *Methodology*

Nowadays the appeal of the product is mainly related to the outside shell and to marketing concept of innovation, but if we analyze these ideas it’s clear that are insubstantial. The aesthetic value is dependent on the fashion fluctuation and the innovation is limited only to the 20% of the whole product (Dieter, 2000), for two main reason:

- the firm have to write off the cost of the plants
- the interface is considered by the user the product (Raskin, 2000), for this reason it's common to redesign only this component.

Those two factor cause of the semantic obsolesce of the object combined with the difficulties to maintain the product at cheap price are the cause of the huge quantity of products sent to the landfill.

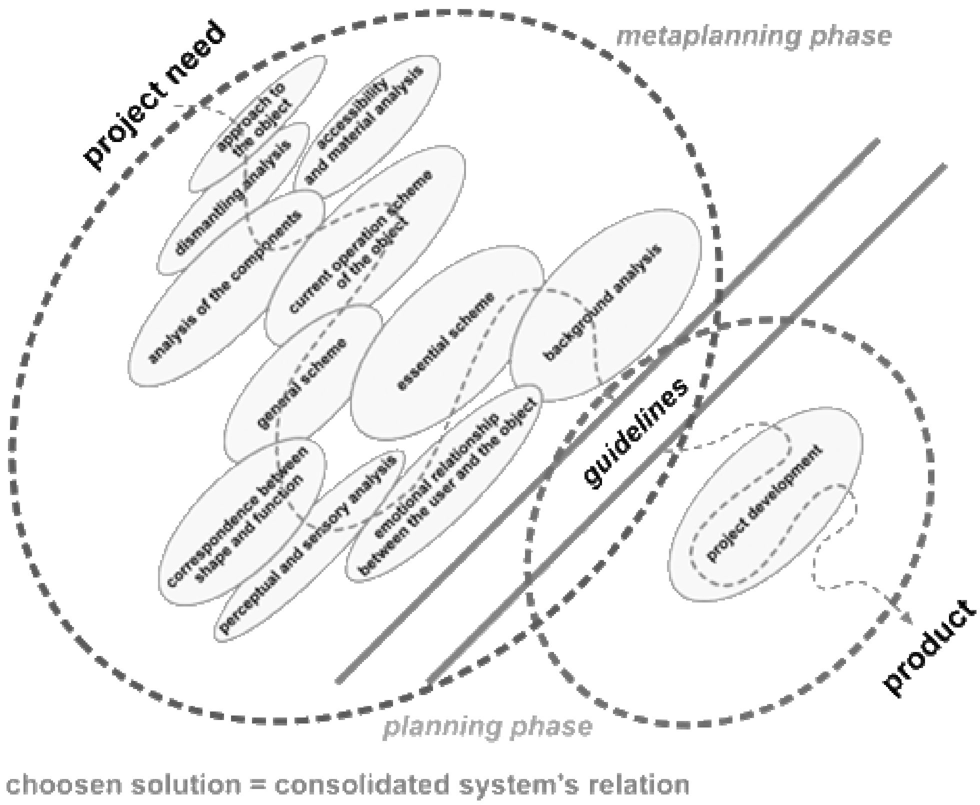

Figure 1: schema of the Design by Components methodology developed by the Industrial Design research team at Politecnico di Torino.

The path proposed by Design by Components in a systemic vision implies a design where the external shape of the object is determined by the internal placement of its own components. This type of design starts from the analysis of disassembled objects belonging to the same semantic category (so as to be able to understand all their constituent parts: materials and components), considering the relationships and connections between components, production technologies and physical-mechanical laws that characterize the product. It is important to consider the approach users could have to the analysed product, taking into account the different levels of accessibility the user, maintenance technician and manufacturer will have.

Each component must be considered as a final product with its own independent life cycle, and must be considered in relation to the other components.

It is subsequently analysed according to a functional scheme, where its composition is revealed by aid of follow-up abstractions, firstly in accordance with an operating scheme, and afterwards with an essential one, allowing for the isolation of the necessary and sufficient functional groups.

Acting on the basis of this criterion, it is possible to comprehend the complexity of the relationships which exist between functional groups and the system as a whole, and to recognize the various different types of problems which need solving.

On the basis of the complexity of these relationships we can affirm that Design by Components intends to focus primarily on the system of which it is a part, and to which it belongs.

Design by Components is, to all intents and purposes, the up and downstream conception/planning existing behind and throughout a more complex process that looks at the finished product as the concrete exemplification of ideas, thoughts and the more diverse strategies, all entangled and interrelated into one with the others, in strict connection with the life cycle of the designed item.

Last but not least, is the concept of shared responsibility, also promoted by the 2002/96/EC *WEEE-Waste Electrical and Electronic Equipment* directive. The protagonists who contribute to the ideation, design and manufacture are designers, industrialists, law-makers, economists and final users. They will be asked to collaborate responsibly.

New products created thanks to this mental path represent the execution of relations and functions of the appliances. Being aware that all household electrical appliances are part of an integrated system (with the territory, the society, the environment, the residential units, …) and not only of the individual production chain, will entail a new product design conception.

3 APPLICATION OF THE DbyC METHODOLOGY TO THE WHOLE SYSTEM

The environmental system, as Lewis Thomas suggests in his book "The Lives of a Cell: Notes of a Biology Watcher", is composed by living creatures related to the whole environment; if this web of life is compared to all the production system, it is possible to assert that these combined elements create a complex network, correlated with the flow of knowledge, information, materials, energy, etc..

Looking forward the beginning of the next industrial revolution, where the industry will try to emulate the natural cycles, rather than hope in increasing production of the earth, we must learn to do more with what the earth provides. All the outputs of firms can be converted into value added or used as feedstock for other industries or processes, doing so industries will have to reorganize in clusters. The elimination of waste represents the last solution to the problem of pollution, which threatens both locally and globally (l. Bistagnino, 2003).

Before handling the actual production system according an holistic point of view, it's necessary to analyze the industrial model evolution. This historian path underlined the awareness of the industry in the importance of cost reduction, but it also stress out capacity to evolve or create new type of production model. All the analyzed model highlight the ability to increase: the economic efficiency, time reduction, dead time in the supply chain, quality, innovation,…Unfortunately all this element are only to the price factor that means a limited solution of the problems (linear approach).

Nowadays most of industry are used to buy the element of their product from component producers usually located in emerging countries, that means that the main company follow the principle of reducing cost to the detriment of quality, sustainability and ethic.

The product is produced, delivered and after a certain time dismantle, the cost of maintenance are too high therefore also the repairable object are thrown away.

The application of the Design by Component methodology combined with the positive extrapolate from the production model evolution (from taylorism to hondism) generates a new holistic manufacturing model.

The new model induce all the actors to operate according ethical value, the componentist are actively involved in the design phase, all the production are local and the component repaired can foment the second hand market.

This Sort of revolution of the industrial mentality will certainly be neither easy nor immediate. In the year to come, it will be necessary to predict and plan all the constituent part of a product, their material, duration, replacement and all there is to know about the life cycle of an object..

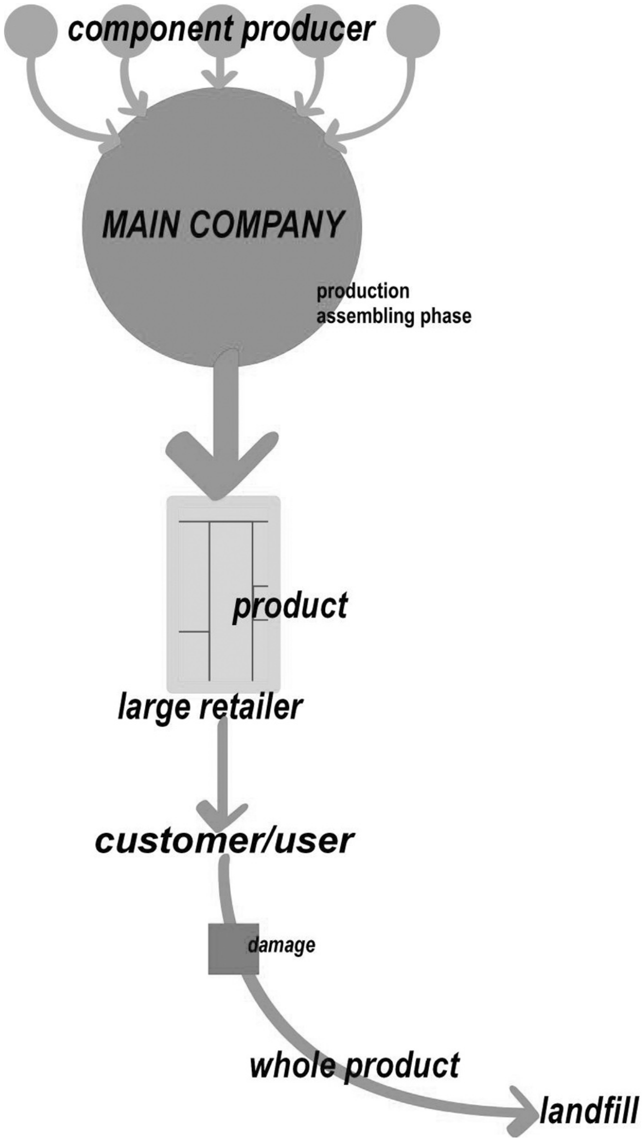

Figure 2: Actual production systems (linear approach)

Facing the infinite opportunities offered by technological innovations, industrial culture and design will point out the need to assume our own responsibilities, as being able to choose forces us to plan at the same time all the variables that are part of production and dismissal of the object on many level.

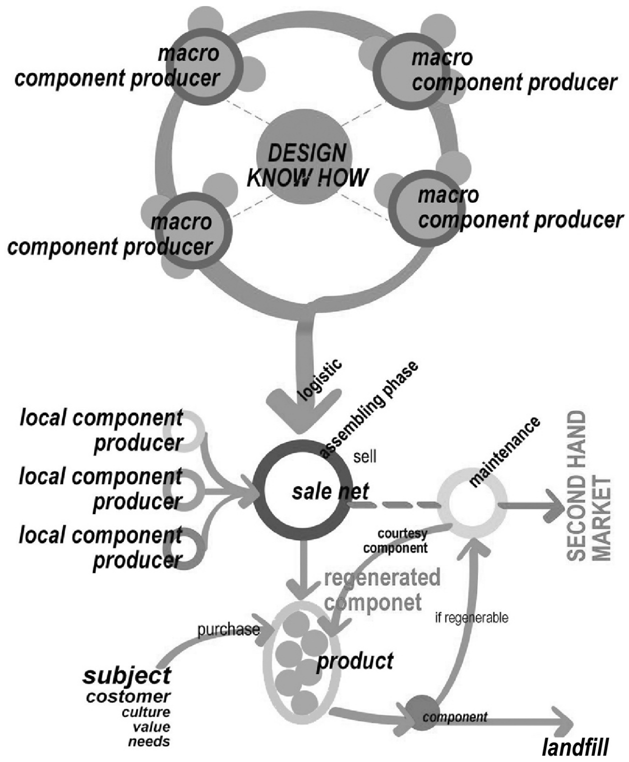

Figure3: New production systems (systemic approach)

4 CONCLUSIONS

In conclusion, it is mostly up to large size industries to make the sharpest change and to drift away from logics of goods designed for the end markets, by focusing on the technical and quality evolution of components and by changing the production rules in favour of systemic strategies deeply integrated with their own territorial, social and economical contexts.

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FGD Gypsum Based Composite for Non-Structural Applications in Construction

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ABSTRACT: There are many by-products created in industry that can be recovered or valued for the creation of new products allowing, in this way, the decrease of environmental damages caused by its disposal in landfills. This research work aims at the valuing of several industrial by-products, such as: flue gas desulfurization (FGD) gypsum from exhaust gases of thermoelectric power plants; granulate cork from insulation black cork boards; and textile fibres from the recycling of used tyres.

The composite materials that come from the mixture of these products may be produced according to two different procedures, moulding or pressing, and the result will be products with different features. Through moulding one gets a lighter composite and through pressing one gets a thicker composite with higher mechanical strengths and better surface's finishing. These composites may be used to fabricate masonry blocks for non-structural inner walls of buildings. Therefore, one has done several lab tests in order to obtain the mechanical behaviour of the referred composites so as to confirm the possibility of using it in construction.

1 INTRODUCTION

Knowing that, nowadays, just about 10 % (in weight) of everything what is extracted from the planet by industry will be transformed in an useful product and the remaining can be considered a residue, a sustainable management of the existent natural resources that take us to a sustainable consume too appears to be urgent.

So, the need of a sustainable world demands that more and more alternative products should be used in construction, such as materials that include in their composition industrial wastes. These materials conventionally have been referred to as “green materials”.

Several are the by-products generated by the industry that can be recovered or improved to a new product generation, that this way, can minimize the environmental damage resulting from the laying on landfill.

The gypsum is a material largely used in building construction due to its diverse applications. The building sector consumes about 95% of the total gypsum produced. It is calculated that about 80 to 90% of finishing interior work and partition walls in buildings are made of gypsum products, such as plaster and card gypsum (wastebook, 2007).

According to those thermal and acoustical properties, these products contribute significantly to the comfort of millions of persons. Having an extraordinary resistance to fire, the gypsum products contribute to the buildings' security, particularly in the public ones.

FGD Gypsum is a synthetic product derived from flue gas desulfurization (FGD) systems at electric power plants. It is chemically identical to mined natural gypsum and provides more environmentally friendly applications. There are many uses for FGD gypsum, including gypsum panel products, highway construction, agriculture, mining applications, cement production, water treatment and glass making (fgdproducts 2009).

The world availability of FGD gypsum is considerable. Approximately 18 millions of FGD gypsum tons were produced in 2008 in the USA, 60 % of which were reused (acaa-usa 2009). In the European Union, according to 2007 data referring to the 15 European countries (ecoba 2009) 11 millions FGD gypsum tons were produced about, 89 % of which were reused.

Some surveys show that the actual annual world production of FGD gypsum reaches values near the 225 millions of tons and in 2020 will be around 500 millions of tons per year (Malhotra, 2008). The developing countries, namely China (the biggest world producer of FGD gypsum, exceeding the 100 millions of tons in 2004 and India (about 20 millions of tons per year), will decisively contribute to this increase. It is expected that in India the productive capacity of electrical energy coming from electric power plants will double until 2010, what will result in an increase of FGD gypsum production that will reach the 40 millions of tons by then.

The FGD gypsum is also very cheap and rather affordable material, turning it especially attractive in economic terms.

Cork (bark of the plant Quercus Suber L), a substance largely produced in Portugal, is a material whose characteristics are of considerable interest for the construction industry. It is regarded as a strategic material with enormous potential due to its reduced density, elasticity, compressibility, waterproofing, vibration absorption, thermal and acoustic insulation efficiency (Gil 2005 & Hernández-Olivares, 1999).

The cork is a natural and ecological product, odourless and it is considered imputrescible and unalterable, maintaining its efficiency for quite a long time.

The cork industry consumes worldwide about 280 000 tons of cork per year. However, about 20% to 30% of the raw cork used at the processing unit is discarded, mainly cork dust and granules which have low granulometry with no industrial interest (Carvalho 1996).

Thus, it has economical and environmental interest to find alternative uses for this industrial by-product from cork transformation, mainly in Portugal, since it is the world's leader producer.

In this research work it was used granulated cork with the aim of lightening the mass of gypsum based composite and, at the same time, providing an improvement of the thermal and acoustic efficiency.

In Europe tyres are produced at a rate of 250 million units per year (www.specialchem4polymers.com, 2004) and nowadays, there are recycling companies that proceed to shredding of used tyres, obtaining separated materials such as crumbed rubber particles, steel fibres and textile fibres from the tyre beads and reinforcement. The textile fibres can be reused, such as in insulation materials or as fibre reinforcing in concrete products (www.wastebook.org, 2007). In this research work the recycled used tyres textile fibres were used with the purpose of providing reinforcement for gypsum composites.

The main purpose of this research work was to develop new mixtures of FGD gypsum incorporating these by-products to value them and to turn the gypsum products more lightweight and sustainable, giving continuity to others studies that aimed at the development of eco-efficient products based on gypsum for construction applications (Eires et al. 2008, Eires et al. 2007a, Eires et al. 2007b, Eires et al. 2006).

Therefore, the characterization and improvement of the compositions was carried out. So, one has done several lab tests in order to obtain the mechanical behaviour of the referred composites so as to confirm the possibility of using them in construction.

2 MATERIALS, COMPOSITIONS, MANUFACTURE AND CONSERVATION

2.1 *Materials*

The FGD gypsum formed in the system of treatment gaseous effluents of a Portuguese electric power plant, is presented under the shape of calcium sulphate bi hydrated ($CaSO_4.2H_2O$) with 7% of humidity. In order to be reactive with water it should be changed to calcium sulphate hemi hydrated ($CaSO_4.0.5H_2O$). Based on the test of differential scanning calorimetry and thermo-gravimetrical analyses (DSC-TGA), it was selected the temperature of 105 ºC to the dehydration, changing the material as the equation 1:

$$CaSO_4.2H_2O \rightarrow CaSO_4.0.5H_2O + 1.5H_2O \tag{1}$$

In table 1 it can be seen the chemical similarity of FGD Gypsum with the conventional gypsum, available at the market and usually known as plaster gypsum.

Table 1 – Chemical composition of FGD and conventional gypsum

Gypsum	CaO	SO_3	F	Fe_2O_3	SiO_2	Al_2O_3	MgO	Na_2O	K_2O	TiO_2	P_2O_5	SrO	ZrO_2
FGD	40.1	54.4	1.61	0.28	1.58	1.11	0.418	0.261	x	0.0134	0.106	0.001	0.001
Conventional	41.3	56.0	x	0.22	1.11	0.395	0.696	x	0.0567	x	x	0.183	0.024

It was achieved the granulometric distribution of the FGD gypsum and a conventional gypsum and it was verified that the first had a bigger fineness, resulting in a small percentage of the retained material on the sieve 100µm (about 2%) opposite to the conventional gypsum (54 % of material retained in sieve 100 µm).

One has also determined the compressive strength resistances of FGD and conventional gypsum, according to EN 13279-2. The FGD gypsum presents a superior strength resistance, achieving 17.4 MPa, while the conventional gypsum reached a resistance of 9.2 MPa.

The used granulated cork was a regranulated of expanded cork, a by-product of a Portuguese industry of black agglomerate cork boards, being the material constituted by different particles sizes: 2/4mm, 2/9mm and 4/8mm. The density is respectively: 166, 182 and 198 kg/m^3 and the bulk density is 65, 73 and 72 kg/m^3.

The used tyre fibres are a material obtained by a Portuguese recycling company of used tyres shredding. These fibres are generally composed by wires and polymeric cords and some rubber residues, being the main element the polyamide 6.

Some dimensional analyses of the fibres were done that consisted of determining the length and the diameter, using an optic microscope with photographic record. It was verified a large dispersion of the fibres length, being the minimum value obtained of 108.2 µm and the maximum value of 12469.1 µm. The average value was 20.69µm with a standard deviation of 1993.2 µm. The fibres diameter is also variable, being the minimum value obtained the 7.2 µm and the maximum 34.1 µm with an average of 20.7 µm.

In the compositions it was also used a setting time retarder for gypsum: citric acid. The incorporation of this material was essential since it was verified that FGD gypsum reacts quickly with water, solidifying the mixture, hindering the maintenance of the working time at reasonable levels during the necessary time to handle the composite at wet state.

2.2 *Compositions, manufacture and conservation*

Aiming at the final composition selection of the composite material to be used in the manufacture of blocks for interior building walls, it was realized an experimental campaign with the objective of characterizing, under a mechanical point of view, the produced compositions.

Thus, a pressed composition (P) and three moulded compositions (M) were studied. The P composition was constituted only by FGD gypsum, water and citric acid, and in the M compositions, with cork incorporation, the amount of granulated cork was varied from 5, 7 and 9 % (M5, M7 e M9) related with the gypsum weight used. The tested compositions are presented at Table 2.

Table 2 – Mixture compositions (at % of gypsum mass)

	Typology	water	Retard.	Cork	Fibres
M5	moulded	80.0	0.05	5.0	3.0
M7	moulded	87.5	0.05	7.0	3.0
M9	moulded	93.75	0.05	9.0	3.0
P	pressed	22.5	0.05	–	–

The water content of moulded compositions was determined experimentally so as to check an adequate working time, which consisted of assuring a flow spread comprised between 140 and 150 mm according to EN 13279-2.

The added water amount in the pressed mixture also resulted from an experimental procedure, done with the objective of manufacture the compositions with the minimal amount of necessary water for gypsum hydration. One has done several tests of pressing with different water percentages in the mixture until obtaining an optimal solution that assured a good superficial finishing, that was admitted as guarantee of a good compactness.

The used retarder dosage was fixed after experimenting several mixtures, containing different acid citric dosages. The tests revealed that the setting time increased with the retarder rise, the same occurred with the flow spread. However, it was verified that the mechanical resistances (compressive and flexural strength) diminished with the retarder dosage increase. So, according to the described, it was adopted a acid citric dosage of 0.05 % of gypsum mass, since that assured the obtaining of paste with enough setting and working time without affecting significantly the mechanical resistances.

The textile tyres fibres dosage was selected based on the product availability and on the fibres effect in the mechanical resistances. Considering the two aspects, it was adopted the dosage of 3 % of gypsum mass.

Regarding to the pressed composition, one has decided not to include the cork in the mixture neither the textile fibres, since this incorporation has revealed adverse, both the mechanical resistances point of view and the superficial finishing.

The mixture process and the samples manufacture were accomplished according to EN 13279-2.

To evaluate the behaviour and the mechanical properties (compressive and flexural strength and elasticity modulus) of the compositions M5, M7 and M9 6 cylindrical samples with 50 mm of diameter and 100 mm of height and 6 prismatic samples with 40x40x160 mm^3 were moulded.

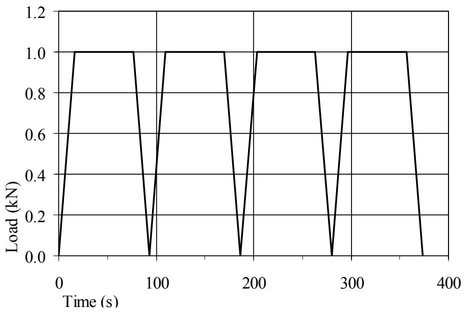
The samples of composition P, shaped by pressing, result of moulding of boards with 35x300x600 mm^3 that were submitted to a pressure of 5 MPa after, diminishing the thickness from about 13 to 14 mm. From these boards, through the cut by damp way, 6 samples with 13x14x27 mm^3 and 6 with 13x40x160 mm^3 were produced.

After manufacture, all the samples were kept in the laboratory at room temperature (about 22 ºC) during 7days. In relation to the samples resulting of pressed board, obtained through cut by damp way, immediately after the cut, they were placed in a drying oven at a temperature of 100 ºC during about 2 hours.

3 TEST PROCEDURES

3.1 *Compressive behaviour*

The elasticity modulus in compression of moulded and pressed material was obtained based on the LNEC specification E 397.



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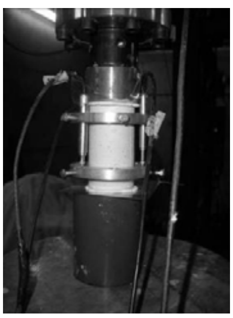


b)

Figure 1 – Elasticity modulus tests: a) loading load; b) general setup for moulded samples

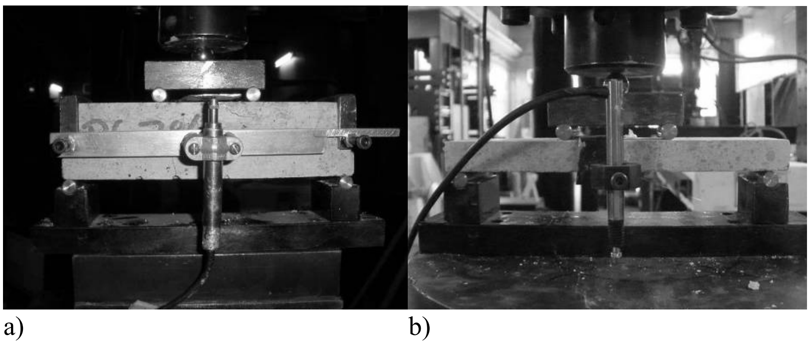
The samples were submitted to 4 load and unload cycles with constant velocity of 0.06 kN/s. The maximum and minimum values of applied load were determined through preliminary tests of uniaxial compression in order to assure that the applied stress was not superior to 30 % of compressive strength. It is generally accepted that the elastic material behaviour in compression is developed just for load less than 30 % of that corresponding to compressive strength (Choi e Shah, 1998; Vasconcelos, 2005). After the maximum load of 30 % of average compressive strength was reached, the samples were maintained under the load action during 60 second, period after which the unload was initiated. The loading law followed in the elasticity modulus tests can be founded at Figure 1a. The load application on the sample was carried out using a thick steel board so as to be sufficiently rigid to uniform the vertical load (Fig. 1b).

In order to minimize irregularities of side samples, these were previously rectified and after covered at the base and top side with a polyester resin of rapid cure. The covering material was always applied before beginning of the test, with the sample vertical aligned and slightly compressed so as to assure the perfect adjust between the load application elements and the sample. In the moulded samples, the vertical displacement was measure through of 3 LVDTs fixed at the sample and positioned according to three equidistant generatrix lines, distanced of 120 º. The used LVDTs have a measure field of ± 2.5 mm and a precision of 0.01 %. The measured distance by the LVDTs was approximately 45 mm. Due to the reduced height of pressed samples, the vertical displacements were pointed out turning to an external transducer, that measured the displacements between the metallic side boards in contact with the sample.

The behaviour under compression of the studied compositions was analyzed based on uniaxial compression tests realized through vertical displacement control. The used loading velocity was 5 μm/s, assuring the maximum load was achieved in a period of time comprised between 2 and 15 minutes. Simultaneously, the adopted velocity had as objective the registration of the complete stress-strain diagram and, allowing this way to characterize completely the behaviour of each material after reaching the maximum stress. The vertical displacements registration was made using the same LVDT configuration used for measuring elasticity modulus.

3.2 *Flexural behaviour*

For the moulded samples, the flexural behaviour was evaluated based on the EN 13279-2 and on the ASTM C1018. The application load scheme was the 4-point flexure test. The used samples for flexural test were prismatic with dimensions of 40x40x160 mm^3 and 13x40x160 mm^3, for, moulded and pressed samples respectively. The tests were carried out with displacement control, through a LVDT placed at sample middle-span. The load velocity for the moulded samples was determined according to the recommendations of ASTM C1018, which indicates that the rupture must occur after a period of 45 s (10 μm/s). The load velocity for the pressed samples, due to the lower thickness and the high rigidity, was fixed to the minimum velocity permitted by the test equipment in order to allow a period of time near to the anterior (1 μm/s). The vertical load was applied through a metallic rigid beam supported in two steel rollers that transmitted punctually the load to the sample. The flexural test setup is illustrated at Figure 2.



a) b)

Figure 2 – Flexural test: a) moulded sample; b) pressed sample

4 PRESENTATION AND DISCUSSION OF OBTAINED RESULTS

Table 3 shows the average values of the densities, γ_m, and the mechanical properties, coming from experimental results, namely the elasticity modulus, E_m, compressive strength, f_m, and flexural strength, $f_{tm,fl}$. The coefficients of variation are presented in brackets and are in percentage.

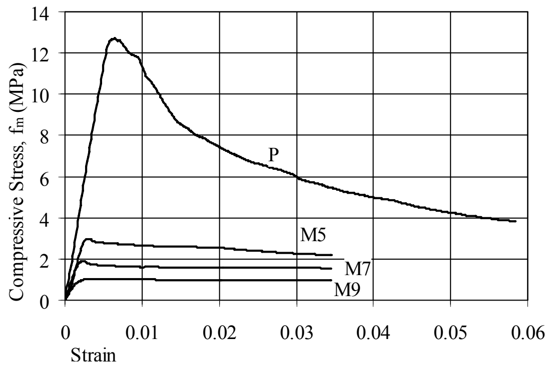
In Figure 3a it is possible to observe the behaviour in compression for the different compositions, expressed by the correspondent average stress-strain curve. Figure 3b shows the same average curves, but referring only to the moulded compositions.

Figure 4 shows the average diagrams stress vs. displacement at middle span obtained at flexural tests for the studied compositions. The flexural stress corresponds to the installed values in transversal section considering that the stress distribution along the section is elastic and linear. It is noted that the procedure for stress calculation is only approximated considering that in the pre-peak regime, and particularly in the post-peak regime, the behaviour is obviously non linear.

The global behaviour in compression and flexure of the pressed and moulded material is significantly different. The pressed material is considerably more resistant, but more brittle than the moulded one. The post-peak at the stress-strain diagrams of the pressed material expresses a stronger reduction of the stress to the same deformation than the verified at moulded material.

Table 3 – Experimental results

	M5	M7	M9	P
γ_m (kg/m^3)	825	760	675	1575
E_m (MPa)	1899.6 [4.7]	1311.8 [12.1]	823.3 [1.5]	2196.9 [17.1]
f_m (MPa)	3.1 [2.7]	2.0 [13.4]	1.1 [5.8]	13.3 [18.2]
$f_{tm,fl}$ (MPa)	0.58 [5.4]	0.68 [4.9]	0.55 [6.3]	1.47 [10.0]



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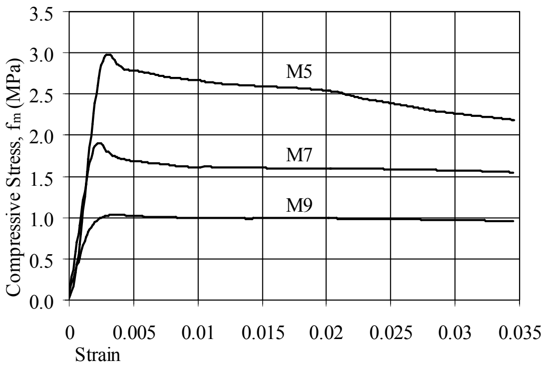

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Figure 3 – Compressive behaviour (stress-strain curve): a) all compositions; b) moulded compositions

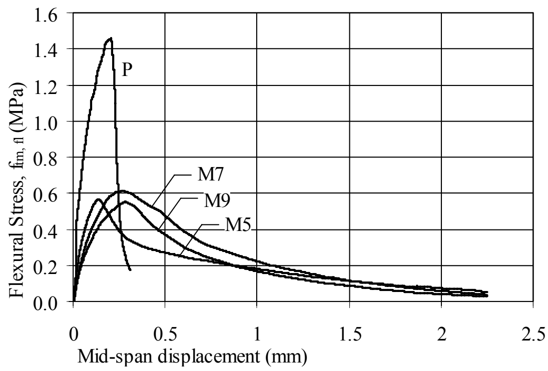
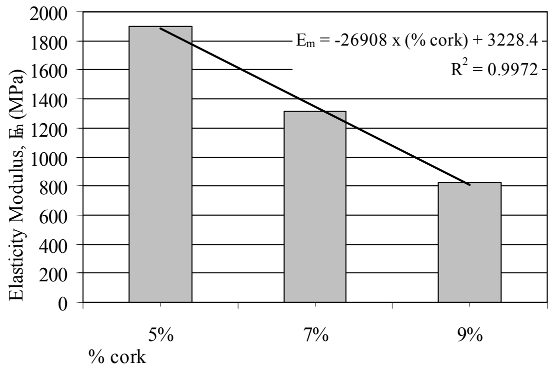


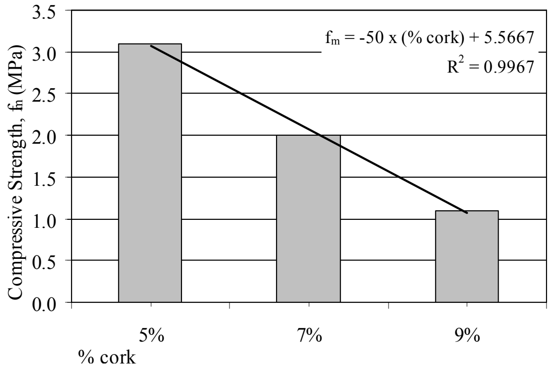
Figure 4 – Flexural behaviour: stress vs. at middle span displacement curve

In compression, the post-peak behaviour of moulded material is characterized by a slight resistance reduction for considerable displacement, expressing this way a much more ductile material. It is verified a resistance increase and a ductility reduction of the moulded material with diminish of cork percentage, in spite of not being registered a considerable difference in the flexural strength. On the other hand, it was verified that the pressed material reveals to be more brittle, with a very quickly resistance loss (without displacement increase) after achieving the maximum resistance. In terms of rupture it is verified that in moulded material the rupture developed through the base or the top, where a level of the sample is crushed and after developing gradually with the crushing of near successive levels. The appearance of the rupture in the base or top is related to the border effect on these areas. In the pressed material the rupture occurs with the development of vertical cracks that were propagated from a sample side to other. The diagrams stress-displacement analyses for the moulded mixtures makes it possible to conclude that important differences in the global flexural behaviour were not verified.

In Figures 5a and b it is possible to observe the cork dosage influence at the elasticity modulus of the composite and at the compressive strength, respectively.



a)



b)

Figure 5 – The cork dosage influence: a) at the elasticity modulus; b) at the compressive strength

In general terms, based on the obtained results, showed at Table 3 and Figures 3 to 5, it is possible to notice that:

- The mechanical characteristics of the pressed composition are, as predicted, quite superior to the moulded compositions;
- The compressive strength of pressed composition is about four times superior to the moulded composition;
- The flexural strength of pressed composition is, also, superior to the verified in the moulded compositions. However, the difference was not so strong, achieving about the double of the resistance of the moulded composition;
- The elasticity modulus of pressed composition is superior to the moulded compositions. However, the difference of the moulded composition with biggest elasticity modulus was only about 15 %;
- In the moulded compositions, the decrease of the elasticity modulus with the rise of the cork amount was nearly linear. To an increase of 1% of cork corresponded a decrease of the elasticity modulus superior to 30 %;
- In the moulded compositions, the decrease of the compressive strength with the rise of cork amount was, also, nearly linear. To an increase of 1% of cork corresponded a decrease of the compressive strength superior to 35 %;
- The results of flexural tests didn't reveal sensitive to the cork amount variation of the compositions;
- The capacity of energy absorption of moulded compositions, whether in compression or in flexion, was really superior to the pressed composition, showing a better ductility behavior.

5 CONCLUSIONS

According to the results obtained, one can conclude that the use of a mixture containing FGD gypsum, granulated cork and textile fibres is viable for several applications in construction, since it is regarded as constituent material of a product with non structural functions. At this context, the initial applicability premise of this kind of material in not resistant masonry blocks seems practicable and can be a very interest way of valorisation of these industrial by-products.

The obtained results of the realized tests allow to verify that there is a clear decrease of the compressive and flexural strength with the cork incorporation related to the pressed gypsum mixture.

Furthermore, it is verified that there is a linear relation between the elasticity modulus and the compressive strength with the cork percentage at the moulded mixtures, meaning that the bigger the cork percentage, the smaller the elasticity modulus and the compressive strength.

The mechanical performance of the material based on FGD gypsum can be considerably improved if one doesn't use the incorporation of cork and tyre fibres and if one uses shaping through pressing. However, this solution is significantly heavier, the manufacture process is also more expensive and the potentialities, in shape terms, are much more limited. Nevertheless, the combined use of these two solutions (moulded and pressed), can result in an interesting product once the pressed solution presents a smaller porosity and consequently an inferior permeability.

6 ACKNOWLEDGMENTS

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Materic character of constructive dry systems for prefab-House. Research and didactics experience.

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ABSTRACT: The evolution of the housing models and the constructive process, recognizes in the light sustainable prefabrication, a sector in answer to the demands of energetic and materic reduction in the constructions sector.
Among the typologies of prefabricated systems, the research focuses the attention on the study of the catalogue houses, realized through "Kit" detachable, with dry technology, with a logic transferred by the industrial sector and particularly developed by the North-European Countries.
The study objective is a critical analysis of meaningful examples, to individualize some remarkable characters of it:
- The materic character: on materials mostly used and on their characteristics.
- The performance character: the common performances of residences, about energetic efficiency, and the yard's management.

The document makes reference to the research and, actually, didactics activities, developed by the authors inside the operational unity STOA of the DASTEC Department, to the Faculty of Architecture of Reggio Calabria, Italy.

1 LIGHT PREFABRICATION AND TEMPORARY LIVING

The cultural issues of sustainability, has shifted attention to the need to limit the consumption of material resources and energy, introducing the concept of useful life and recycling and reuse, modifying the processes of transformation, construction and traditional living patterns.

The temporary prefabricated housing units, the "machine for living" that embodies all the characteristics of contemporary living, is one of the themes explored since the advent of industrialization construction. The temporary housing is a major technological challenge for the future and a field of experimentation and innovation still largely to be explored.

The evolution of the housing models and the realized trials recognizes in the light prefabrication revolt to the sustainable, a sector in answer to the demands both of the housing contemporaneity , both to the application of energetic and materic reduction in the constructions sector.

The light prefabrication as a means of achieving a high level of industrialized production in construction, has always, historically, been a fascinating constructive technique from the theoretical point of view (consider the examples designed by Fuller, Prouvé, etc. ..) but very often associated with living models impractical and technological and environmental benefits of low quality.

The idea of prefab construction as insecure and emergency gives way to an evolution in form and content increasingly attentive to the needs of the consumer who is concerned with safety and sustainability. While there are many possibilities for building customized, they increase rapidly to motions serialized and standardized which adds to the already numerous advantages of mass production that come even closer to the world of prefab design, creating a system that thought forms, environments, furniture and techniques that fall within an established chain. There is thus confronted with standard models and simultaneously studied for specific locations, often 'turnkey', complete with service elements and furnishings.

In recent years, in fact, the prefab building industry has developed enormously moving by leaps and bounds on comfort, environmental sustainability, and pollution, flexibility and technology, belying the stereotipe prefabricated house, short-lived and lack performance. Prefabricated residence begins to represent as demonstrated by examples throughout the world, a model of architecture with character design methods and achieving precise, able to provide outputs high standard of quality, tailored solutions for the buyer, who hopes to have a unique residence, modern, sustainable, durable and, not least important, lower cost, both as regards the purchase maintenance. The different modes of implementation are represented by the house containers, the prefabricated house, modular or systems construction. The latter are particularly interest of this document, in close relation experience teaching and research, still in place, conducted by the authors at the University Mediterranea di Reggio Calabria, Faculty of Architecture.

2 NEW STANDARDS OF LIVING

The requirements of the system construction, environmental and technological, that express these characteristics are partly known and tested and are in part the consequence of recent developments in the overall requirements defined upstream. He highlighted the most significant ones related to the time component of the project and the architectural construction:

- Design flexibility: with it’s to be understood both flexibility type (attitude of the building system to allow different configurations of size, shape, correlation and distribution of space in use phase) and the technological flexibility (ability of the system to allow construction functional and constructive integration between the technical elements, substitutability, adaptability and interchangeability of elements or components providing the functionality and performance appropriate use). Make changes in a prefabricated home, both with respect to the basic layout of the house, and after the installation of this, they become, therefore, possible operations through technological systems, characterized by areas for plant additions and demountable systems which facilitate the variability and maintainability.
- Adaptability: can be considered a re-configurability not instantaneous, immediate, but delayed in time. The independence of the location is based on the requirements for mobility and portability of the object that can provide organs for handling integration, or must rely on the means of transport. The movements can not be separated from the dimensional control of the shape of the unit load, which is used to compact systems (or expand during operation) or removed and replaced.
- Reversibility: as characteristic of a building system to be de-constructed so that the technological elements (materials, parts, components or systems), which is yet to be considered as real resources (and not residues, discards, refusals) from reintroduced in a subsequent manufacturing process or to reintegrate into the wild. The building system may have different degrees of reversibility depending on the performance level that products derived from its disposal compared to retain the original conditions of employment or in relation to new uses. Predicting the destination of the waste from the de-construction is related to the requirements of recyclability and reusability.
- Economic affordability: in the Italian property market, a prefabricated house costs definitely less of a traditional real estate.
- Ease and speed of installation: for structures equipped with facilities for automation technology, ranging from an average of four to six months of the yard.
- The efficiency of plan: Plans for the installation allows to quickly meet codes and regulations through the approval of building permits and provide the purchaser with a fully custom home.

The need also to ensure versatility in any condition of employment, meaning flexibility in performance of the components, is being pursued with the technique of "dry stratification", according to which the required performance is achieved with the juxtaposition and integration of layers or specific items. In this sense, the technological choice of "dry stratification", becomes synonymous with hybrid technology where the performance expectations are achieved through various construction techniques and materials, but more appropriate to the specific use.

3 STATE OF THE ART: RESIDENCES AND FACTORY

The increasing interest toward the development of highly prefabricated evolved, sustainable, implementable, light and to dry, prefab-system is bringing, through a technological transfer from the industrial sector, to the development of projects of Kit catalogue houses. A matter, for the time being, particularly developed by the North-European Countries, both in industrial circle and scientific. To show it, are different companies that are investing the proper Know how for realize cutting and detachable Kit, through the use of low environmental impact materials and dry technologies, as:

Figure 1. IKEAS' Boklok house installation.

- Ikea that, in collaboration with the Swedish building colossus Skanska, has realized the wood prefab-system, Boklok. The project borns in 1997, in answer to the necessity to purchase a residence in Sweden, to more economic prices, emerged through a study realized from the founder IKEA in 1996. The BoKlok houses , based on the strengths client's needs, are smart residences, of high quality, with a flexible plan type open-space, ample lengths and ample openings, guaranteeing visual and bright comfort. The construction/assemblage is realized by specialized workers in less than a month. The residences, follow plain of industrial workmanship entirely similar to those of an integrated chain. A constructive wood framed system, with wood insulated panels sandwich, developed by the Peace Timber Systems of Milton Keynes, to climb on the yard, to reduce the times of construction maintaining the quality allowed by an industrial production. The system, allows the maximum flexibility in the addition of housing unity, in the choice of different typologies of coverings and in the fittings integrations for the energetic saving as solar panels or other.
- Toyota: employed from over 20 years in the building sector, using the same technologies used in the construction of motorcars but, suiting theme for the realization of modern prefab-buildings resistant to the earthquakes. The new ecological necessity compared to the auto market with the design of hybrid motorcars allows the Toyota to invest in ideas that allow a mutual exchange of energy between the residence and the motorcar; Toyota interacts with the electric system allowing the motorcar to enter to the panel of recharge but, at the same time, to act in generating of energy. Of the steel framed houses, exist 12 versions. The steel frames in the houses are painted with anticorrosive paint using methods adopted from its car production. The windows of the houses are made from the same shatter-resistant glass that Toyota uses in his cars to deter burglars.

Toyota engineers are also experimenting with using solar panels as house siding and powering homes with fuel cells, which combine hydrogen and air to produce electricity.

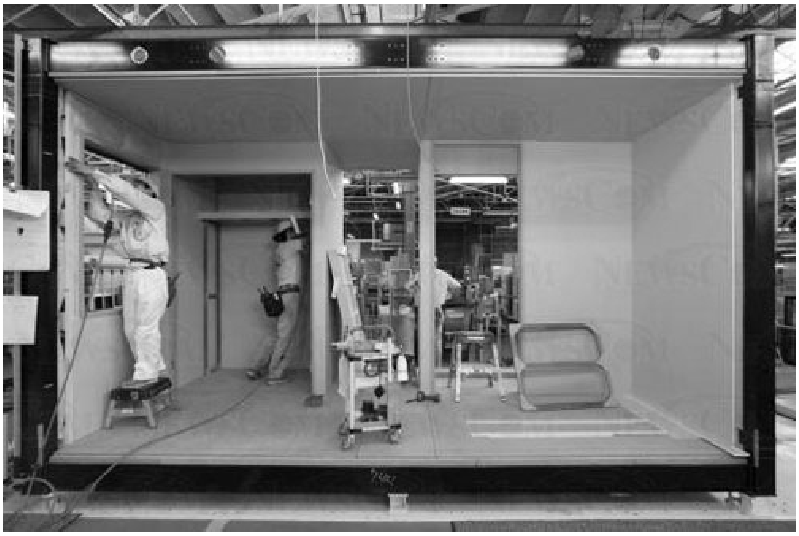

Figure 2. Japanese housing production (Toyota). Font: Getty Images

- Bosch: the system of profiles in aluminum league 6060 - T5, born for different uses in comparison to that architectural, it has been more times experimented for the realization of "Kit" residences, in which the system acts from carrying structure. The screw connections among the profiles, allow a laying fast work and simplified, also furnishing a good quality of resistance for the big loads. Among the principal examples of realized residences:
- Loblolly House, designed and realized by the KTA study (Kieran-Timberlake Associate). It's a construction prefabricated on component, in which a "Kit" of parts can be dismounted and reconstructed with different configurations for different places or residences. Besides the framed aluminum structure, the principal parts are: attics and prefabricated ceilings with integrated wiring and cartridges, pre-assembled bath and kitchen modules and infill panels in wood of cedar. Not having been designed for architectural use, the Bosch system has been integrated by architects from a group of five necessary connectors to satisfy the structural requisite of a building with three floors.
- The TK iT House, planned by the Californian study Taalmankoch, it's a prefabricated residence, already realized in different versions in USA, in which the Kit of assemblage is constituted, besides the framework in Bosch's aluminum profile, from a steel coverage in steel and photovoltaic roof, from a glass façade and screen panels in vinyl material, from a radiant floor, furnishes and equipments to be chosen to catalogue.
- Lignotrend: system of modular prefabrication constituted by a heart in wood, with high characteristics of seismic resistance and thermal- hygrometric performances that respects the European legislations in subject of statics, antiseismic, thermal-acoustic insulation, prevention fireproof and energetic saving. The panels are glued with glue of polyurethane deprived of formaldehyde and certified in class of issue E0, that doesn't exude polluting substances. The wood glued layers guarantee the stability in the form, the absorptive capacity and the regularization of the damp. The system Lignotrend allows a rapid assemblage so that to reduce the times of yard of around 70%. The elements are multifunction and it's possible to integrate electric cables and installation tubes. Differently of the constructions in masonry a profit is around the 10% of habitable surface in more, thanks to the reduced thickness of the panels. The ecological cycle is respected by the choice of the materials up to the disposal.
- LOQ kit: it’s a system of Kit prefabricated components, interchangeable for residences, easy to assemble and customizable. LOQ kit it's based on a technical revolution in house-building, proposing a model of circular progress, in which the actors of the trial are tied up from an only common objective: that to start an orchestrated plan, for realize more houses through sustainable technologies, to accessible prices.

Figure 3. LoqKit different configurations. Font: www.loq-kit.com

When a client purchase a house LOQ Kit, their house will be included in a maintenance program of the life cycle. The life cycle of the reusable components is submitted to careful controls of the Loq-kit society, guaranteeing the reliability of it.
In the moment in which it lowers the performance level of the same, the society withdraws the components and divide them in single parts, profits to be recycled in new components. It deals with a sustainable economic program of reuse, that assures that the components don't finish in the dumps, contributing to the reduction of the C&D wastes. The components, of different dimensions and the connections, are geometrically coordinated. The connections are characterized by the system "snap-lock", that allows to the single parts to be removed, substituted or even to be used in another residence. The Kit of assemblage is formed from three types of components: modular frame structure (in recycled steel), modular infill and modular covering "snap".

Among the principal manufacturing of prefabricated residences, are underlined:

- Envision Prefab: it realizes a sustainable prefabricated to zero impact , using container with systems of energetic provisioning and resources that combine solar and photovoltaic panels and LED illumination .
- Echo-Steel Homes: it's based on a rationalized design, using the 76% of recycled steel coming from autocars, industrial equipments and metal wrecks. Their models in fact don't use wood making them resistant to mold and bugs and insulating them in effective way.
- International Homes of Cedar: it's in contrast with the modern innovative design of the most greater part of prefabricated, proposing a rustic style, through the use of cedar coming from checked forests. The material offers a good durability, resistance to the parasites and thermal resistance.
- Modern Shed: it directs the design on the modularity, creating working spaces directly connected to the residence allowing the integration of a module for the garage. The Modern Shed aims to the design and to a sustainable architecture that makes to choose to own clients thermal insulation in recycled denim, cork floors and other sustainable finishes.
- New System House: it proposes a bioclimatic prefabricated residence, to low energetic consume, that has the tendency to reduce to the minimum the environmental impact exploiting the renewable energetic sources. The residence has an elevated energetic performance that is attested with a thermal requirement (heating) equal to 20 KWh/m2 per year; it has a compact volume with the purpose to have the minimum dispersant surface, with ample and bright inside spaces, rationally distributed. On the north side , a volume is risen to use garage, with function of filter, necessary to mitigate the thermal dispersions (colder façade). On the south side it is foreseed that it's possible to close in the winter months with flowing glass door, creating in this way a solar greenhouse of heat's accumulation. The inside vol-

ume is articulated so that to create a natural ventilation, guaranteeing a correct microclimate and a good air quality both during the winter and during the summer.
- Rubner House: The Rubner houses is realized with material ecologically appreciated, among which the wood, but also with plasterboard and cellulose panels and the insulating hemp and cork.

4 OPEN PROBLEMS ABOUT MATERIAL EFFICIENCY

The prefabricated residence begins to represent, as shown by examples in all the world, a model of architecture with characters, design methods and realization well precise, in degree to furnish realizations from the elevated qualitative standard, custom solutions for the client, that hopes to have an unique, modern, sustainable, durable in the time residence and, aspect not less important, from the most contained costs, both as it regards the purchase that the maintenance.

Despite the elevated resonance of the sustainable prefabrication's sector, few of them actually, reach elevated levels of energetic certification and make an efficient use of materials during the productive processes.

The technological managers of the temporariness privilege, as the preceding examples show, the constructive systems in recycled metal, aluminum, certified wood and plastic material .

Besides the material choice, the off-site design is based on advanced modular systems, on new design, models and innovative products, with the objective to minimize C&D wastes and discards to really maximize an energetic efficiency and a possible ecodesign.

The environmental comfort is mainly guaranteed from the housing system through the envelope. This has to furnish the necessary performance levels to answer to the requisites about thermal aspects, hygrometric, acoustic, visual, bright, of a normal residential activity, through a design that conjugates the design and technological aspects to those environmental.

The material choice of a prefabricated residence engraves, naturally, on the performance levels in different way:

- for wood constructive systems: the choice of the woody essences to be employed for the construction is remarkable, appraising the material's availability in site, with least energetic consumptions for lumber's transport and privileging the conifers in comparison to the broadleaf, for the most greater natural protection given by the resins. The constructive trial foresees a reduced requirement of energy in comparison to that of the traditional buildings, thanks to the easy material's workability. Problems are hardly set related to the thermal bridges, thanks to an energetic behaviour of the structure almost always homogeneous.
- for aluminum constructive systems: the league's choice is fundamental, because it must be water and corrosion resistant, for a long service life, and must guarantee a good mechanical resistance of the elements and a good workability to get profiles fit to use. The aluminum has a volume density equal to 2,7, that is around 1/3 of that of the steel. It's mechanical resistance can be modified in relationship to the application's type which is destined through the employment of appropriate binding. The design flexibility allowed by the aluminum structural profiles and the elevated resistance-hung ratio, are somehow the reasons for which in the last years this system has become object of architectural experimentations in the extraeuropean panorama. The good thermal conductibility in some cases can constitute a disadvantage which, however, it easily makes up for through particular profile's design and using thermal cuts with insulating material.

5 THE PROPOSAL

With the purpose to make operational the research, it is currently in progress a convention among Department DASTEC (Art, Science and Technique of Construction) of the Mediterranea University of Reggio Calabria and a firm in the field of the efficient fittings, named Termocasa, headquartered in Reggio Calabria.

The Convention has the purpose to effect an action of research having the following object: "*experimentation of housing (named Tecnemi) to improve the energetic efficiency and to increase energy's quota consumed coming from renewable sources, promoting the opportunities'* *of local development*", in locality Lazzaro of Motta San Giovanni commune (R.C.) The scientific responsible of the project are the Prof. A. Nesi and A. De Capua. The design part is taken care by the PhD M. Aversa.

The intervention areas of the program, regarding the production of renewable source energy and the promotion of the energetic efficiency, are:

- The planning and the construction of integrated models of intervention, both in relationship to the energy production from renewable sources both in relationship to the energetic saving, particularly in areas to strong environmental vocation;
- The consolidation, the growth and the diffusion of information and know-how that can allow aware decisions from the administrations and of the population.

The research activity lent by the university consists of producing:

- A methodology of theoretical-practice approach on whose base to program, to plan, to realize and to appraise building interventions with the purpose to guarantee the energetic efficiency of the buildings.
- Criterions and description of technical solutions and relative specific capitularies.
- This is finalized to the realization of a building prototype on which to experiment the proposed solutions.

The constructive model (structure, building wrap, fittings) currently in phase of design elaboration to the DASTEC, has the objective to experiment a strong integration of the principals factors (architecture, constructive techniques, fittings), through dry technologies, to the purpose to reach to an elevated environmental comfort, and to a meaningful energetic saving. Such abilities can be express according to some fundamental points:

- The reduction of the energetic requirement improving the efficiency of the envelope through the meaningful exploitation of the renewable energetic sources.
- The exploitation of the natural elements to get conditions of inside comfort, integrated from solar profit and of the other local climatic factors, through an approach defined by the literature "climate sensitive building". The assignment of the fittings is not therefore, as it happens in the most greater part of the cases, compensate to the performance lacks of the building, but of integration and support to the envelope's spontaneous tendency to maintain comforting inside conditions.

To forehead of an absolute integration of the fittings systems in the elements of envelope and partition, both in the nets of distribution and in the systems of provisioning, it's chosen to insert in integrated way the technological systems of acquisition and exploitation of the renewable energetic resources (solar thermal, photovoltaic, geothermal etc.).

For the technical and constructive definition of the housing form "Tecnema", coherently with the more actual technological trend of temporary constructions, it's chosen to adopt dry constructive systems.

This technology (Trockenbau in Germany, Structure-Enveloppe in France), it's characterized for the tall design grade of the technical solutions is characterized for the dosage of materials, and therefore of the performances (thermal, acoustics, fireproof, etc.), without reverting in the errors of the prefabrication.

The system essentially it's based on a constructive paradigm released in separate entity, with precise functions and performances, that are:

- external envelope
- structure
- nets and fittings endowments
- inside envelope

The structural component is conformed by a framework steel, the envelope inside and outside are constituted by panels composed by insulating layers and "skins" of finish external-inside, the dividing walls are composed from a double plasterboard plating.

6 CONCLUSIONS

Prefabrication and sustainability are now two complementary aspects of a new trend of building systems in off-site, made with materials and environmentally friendly technologies and energy efficiency, a possible scenario for development, primarily to respond to a social demand for residential.

The trend in the world of sustainable prefabricated is fairly clear and aimed at a reduction in the size and specialization of functional envelope layers to achieve higher energy efficiency. The new challenge for companies that make ready-made is, in fact, a balance between the economy of an innovative design and sustainable construction a reality and costs of raw materials.

The aim has shifted towards achieving energy-efficient structures, capable of reducing the consumption of raw materials, to select healthy and sustainable materials, to choose sites and methods of installation that can minimize the impact of climate (in particular exposure), in which the fundamental role it plays always the designer, not the constructive method. Prefabricated houses still depend on external agents that can block the installation as is the case for the connection of gas, electricity and water at less than a prefab sustainable energy to generate electricity independently, eliminating connections to electricity and gas.

The research, therefore, will offer support, test and evaluate, possible project proposals, currently in preparation, teaching experience of the authors of the document. Will be proposed design solutions that combine energy and environmental performance of materials with off-site construction systems analyzed in relation to issues affecting the location in the Mediterranean environment.

The dry construction stratified, represents in the technical panorama the more advanced example of rationalization of the constructive processes attainable through elevated industrialization grades.

In comparison to the experimentation in action, it has been verified that the "energetic" advantage of the dry construction stratified resides especially in the diversification of the layers.

From the point of view of the architectural language, the separation between structural parts and envelope system facilitates the amplification of the expressive and organizational possibilities of the external curtains, conditioned by the presence of structure elements to vertical development. From the technological point of view, the system allows to satisfy more and more ranges of punctual performances: demands of environmental character, fittings applications type, solutions to stimulate the passive use of the resources, employment of fit materials to answer to the legislations of containment of the energetic consumptions etc.

Everybody choices that certainly conduct to the attainment of a superior environmental comfort to that present in a traditional construction.

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Transforming a double window into a passive heating system

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ABSTRACT: This paper presents some of the findings of a wider study on a ventilated double window as a system to pre-heat the ventilation air. The study focused on the design aspects of this system as a function of airflow pattern generated by stack and wind effect. Experimental measurements of the thermal performance of the ventilated double window were carried out in an outdoor environment in the winter season. In the experiments, the outside and inside temperatures, the airflow rate and also the temperatures distribution along the window ventilated cavity were measured every minute. In this paper, some of the experimental results are presented. Field results from this study are expected to help designers to conceive ventilated double windows duly adapted to local climate where ventilation is an important design consideration and heat loss must be reduced. The tested system proved to be able to contribute significantly for this reduction.

1 INTRODUCTION

Building envelope plays a vital role in the whole thermal performance of the building and all its components must be carefully designed. Windows, including the glazing, the frame and the roller shutter case on its top, as can be found in Portuguese dwellings, are perhaps the weakest facade systems of a building in what concerns thermal resistance and comfort. Windows are able to provide access to natural light, warmth and a view to the outside but can also be a major cause of heat losses in winter and heat gains in summer. Air tightness is another important issue concerning fenestration.

In the last decades several new window products have emerged regarding the energy impact within the buildings. Associated to design concepts significant improvements on their thermal performance have been achieved. Some of the improvements can be applied to the existing windows. One of the solutions currently used in Portugal is to install an extra window in the same fenestration. Double window system prevents air leakage, heat loss and thermal discomfort in the winter time.

To transform a single or double window into a ventilated double window results in an easy and cheap passive heating system. This consists of introducing vents at the base of the outer window to allow a supply of fresh air. Heat that escapes from inside through the inner window and solar radiation heat up the air between the two windows. Due to wind pressure and stack effect, the air coming from the outside circulates upwards through the channel between windows and enters the building through a vent on the top of the window's case warmer than the outdoor air.

A large variety of technical solutions to preheat the ventilation air, as the ventilated double window, have been studied and developed. The unglazed transpired solar collectors (Summers, Mitchel, Klein & Beckman, 1996), the solar air collector mounted on the sun-facing walls (Pottler, Sippel, Beck & Fricke 1999) or on the roof, the window air collector that consists of two glazed windows with an intermediate device, usually a Venetian blind (Hastings & Morck 2000) or the supply air window that consists of a window with two sashes separated by an air gap (McEvoy, Southall & Baker 2003) or even the glazed ventilated double facade (Faggembauu, Costa, Soria & Oliva 2003; Arons & Glicksman 2003) are all similar systems in what concerns modus operandi. For the same purpose, earth-to-air heat exchangers through buried pipes can be used as in DB Netz AG (Hamm), Fraunhofer ISE (Freiburg) or Lamparter (Weilheim) (Pfafferott 2003). Fresh air is heated by heat transfer from the ground to buried pipes and then to air by convection. Another possibility is the construction of a conservatory, an enclosed glazed space attached to the main building with fresh air entering in it at a low level. The air is preheated within the space and enters the main building through top vents (Lechner 1991).

2 OUTDOOR TEST FACILITY

An outdoor test cell was used and adapted to carry out a set of experimental measurements in the ventilated double window under analysis. This test cell consists of a single space metallic insulated container with a width of 2.2 m, a length of 2.0 m and a height of 2.5 m. At the opening (1.43x1.0 m) on the south-oriented wall of the cell different types of windows could be fitted allowing the analysis of this passive solar system (figure 1). The cell was located at 40º 20' N, 7º 21'º W and at an altitude above sea level of 464 m.

Figure 1. Test cell facility

After a previous study based on numerical simulation (not reported in this paper) the aim of the experimental campaign was to characterize the behavior of the ventilated double window under real external climatic conditions. The measurements were carried out in different stages, comparing different window configurations. The tests were undertaken from November 2008 to January 2009.

The ventilated double window used for the current research was a modified available double window mounted on the test cell opening. Two air inlets with a total area of 50 cm^2 were installed at the bottom of the outer window. In this way, the cavity between the two window panes is used as an air path for incoming airflow that enters the gap through those vents. Having been pre-heated by the heat transferred from indoors through the inner window pane and by the solar radiation, the warmer air enters the building through vents at the top of the inner window pane.

In order to reduce thermal losses and cold air infiltration in the coldest regions of the country it is becoming quite common to add a second single glazed window on the outside of the preexisting window. This one can be a single or double glazed window. To promote the ventilation of the gap between the two windows transforms the current double window into a passive heating system that provides the building with pre-heated air for ventilation in winter conditions.

The initial double window configuration tested was a single glazed window with a standard aluminum frame on the outside, a similar window on the inside and a ventilated cavity between the two (figure 2). The glazed area was about 54% of the overall area of the opening. The glazing was 6 mm thick transparent glass throughout both windows with a distance of 9 cm, between the two glass panes and a distance of 5 cm, between frames. The glazing of the inner window was later replaced by a double-glazed unit with the following constitution: 4 mm glass, 12 mm gap, 4 mm glass. This corresponds to the current Portuguese double windows, with a single glazed outer window and a single or double glazed inner window.

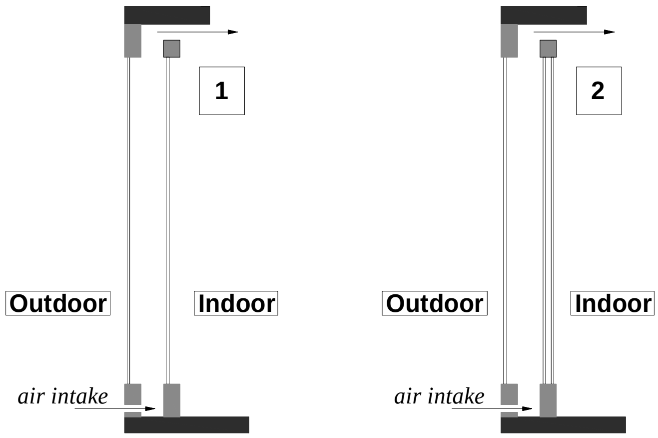

Figure 2. The two tested configurations of the ventilated double window.

3 EXPERIMENTAL MEASUREMENTS

The tests of the two different configurations of the ventilated double window were undertaken separately, so under different climatic conditions. The air flow through the gap between the window panes was exclusively due to natural ventilation. So a variable air flow caused by stack effect and wind was registered.

The average air speed was measured at the outlet of the system (the vent at the top of the inner window pane) by a transducer. Temperatures were measured by several thermocouples located along the gap between windows, at the outlet of the system (measuring the temperature of the delivered air). The temperatures of the indoor and the outdoor air were also measured. Thermocouples were shielded to eliminate the radiation effects. A pyranometer was used to measure solar irradiance and it was mounted on the South-oriented facade to be able to measure directly the incident radiation on the ventilated double window's outer surface. The used measurement equipment is described in table 1.

Table 1. Measurement equipment used in the test cell

Instrument	Measurement	Range	Accuracy
Pyranometer	Total solar irradiance	0 to 2000 W/m^2	<10%
Thermocouples	Air temperature	-270 to 400 ºC	±0.1ºC
Transducer	Air velocity (va)	0 to 10 m/s	±(0.05va+0.05) m/s

The data were collected every minute by two programmable data loggers. The indoor air temperature was kept around 20 ºC almost all the time. However, during the test of system 2, there were some problems with the electricity power provided resulting in the mean indoor air temperature being slightly below 20ºC.

Using the registered values of the air speed and temperatures, it was possible to calculate the heat loss due to air renovation and the heat recovery and heat gains obtained by the ventilated double window. The air rate entering the room based upon the air speed measurements was determined as follows:

$$V = 3600.v_{air}.A \quad (1)$$

Where, V is the volumetric air flow rate (m^3/h), v_{air} is the air speed (m/s) and A is the area of the opening (m^2). Given that the air entering the room is equal to the air exiting the room, heat loss due to air renovation (Q_{air}, in W), when no pre-heating of the ventilation air occurs, is given by:

$$Q_{air} = \frac{\rho.C}{3600} V(\theta_{in} - \theta_{out}) \quad (2)$$

Were C is the specific heat capacity of the air at constant pressure (J/kg.ºC), ρ is the density of the air (kg/m^3), V is the volumetric air flow rate (m^3/h), θ_{in} and θ_{out} are the indoor and the outdoor air temperatures (ºC), respectively. When there is a pre-heating system like the one under analysis, the useful heat (Q_{util}, in W), recovered from indoors and provided by solar radiation, for each given flow rate can be determined as:

$$Q_{util} = \frac{\rho.C}{3600} V(\theta_{top} - \theta_{out}) \quad (3)$$

Where θ_{top} is the air temperature at the window's outlet (ºC) (inlet for the room). The heat loss due to air renovation when there is a pre-heating of the ventilation air (Q_{vent}, in W) can then be determined by the following expression:

$$Q_{vent} = \frac{\rho.C}{3600} V(\theta_{in} - \theta_{top}) \quad (4)$$

4 RESULTS AND DISCUSSION

The presented experiments on the ventilated double window were conducted on consecutive days, meaning that the results were obtained with and without solar radiation (day and night periods). It was found experimentally that the obtained temperature by both systems were always above the outdoor temperature. A comparison between the measured outdoor (out, in ºC) and indoor (in, in ºC) air temperature and the temperature of the air at the top of the window gap (top, in ºC) is shown in figure 3.

Without solar radiation (night period) the lowest temperature difference between indoor and outdoor environment was about 11ºC when testing system 1 and 11.6 ºC, when testing system 2. The minimum temperature increment observed at the windows outlet was of 3.9 ºC with system 1 and 1.5 ºC with system 2. Table 2 shows air temperature mean values during the whole period of tests, with and without solar radiation (day and night periods).

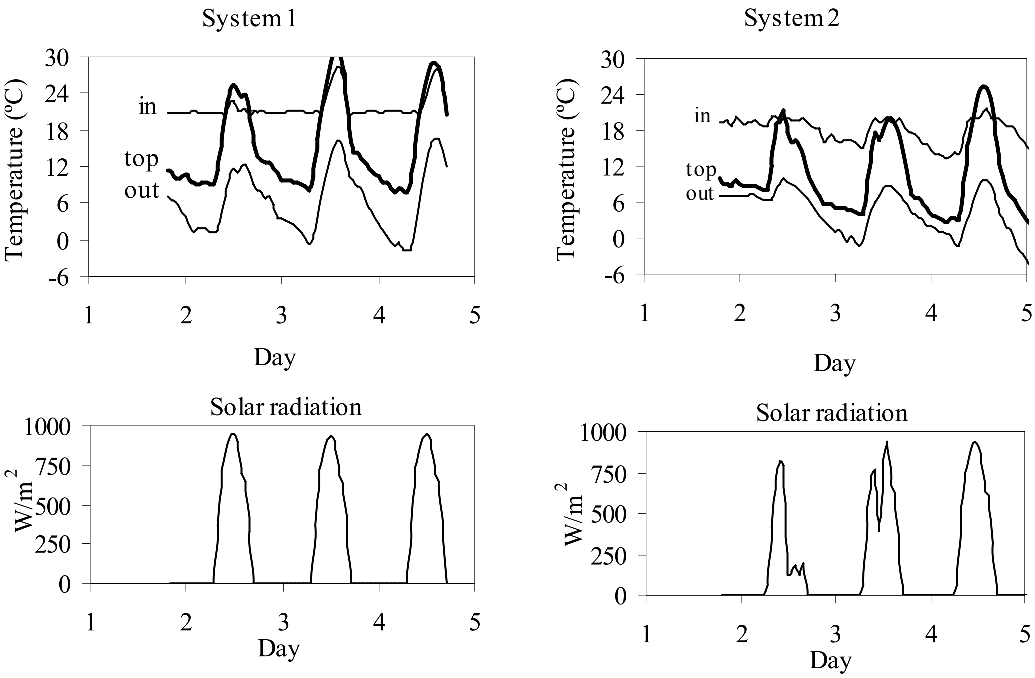

Figure 3. Air temperatures and solar irradiance on the outer surface of the double window.

Without solar radiation, as it can be observed in Table 2, the difference between the mean temperatures of the outdoor air (out) and of the delivered preheated air (top) was of 7.3ºC and 4.2ºC, for systems 1 and 2, respectively. These values were achieved for a difference between the indoor and the outdoor mean air temperatures of 17.3ºC (system 1) and 14.7ºC (system 2).

Table 2. Mean air temperatures registered (ºC)

System	out	top	in
1 night	3.5	10.8	20.8
day	8.2	18.3	21.9
2 night	2.2	6.4	16.9
day	6.1	14.7	19.2

As explained above, knowing the indoor, the outdoor and the delivered air temperatures and also the delivered air velocity, heat losses and heat gains can be calculated for the period of tests.

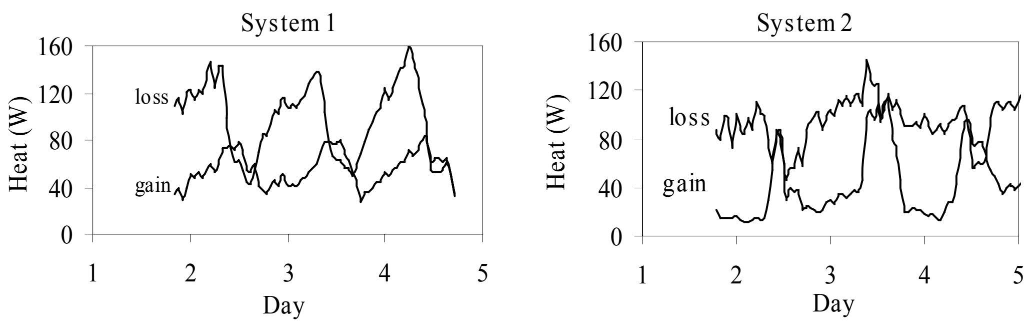

Figure 4. Ventilation heat loss supposing no pre-heating (loss) and useful heat, provided by the ventilated double window (gain).

Figure 4 shows the heat loss due to the air renovation for the environmental conditions of the experiment supposing there was no pre-heating of the ventilation air and compares it to the useful heat provided by the system under analysis. Besides the obvious increment of the air temperature due to the solar radiation, it can be observed that the useful heat at the moments with the highest solar radiation surpasses heat loss which means that there is in fact a heat gain. In those conditions θ_{top} is higher than θ_{in}.

In spite of the influence of solar radiation on the efficiency of the system, plotting solar radiation against useful heat (figure 5) reveals a great dispersion of results and a very low correlation. Of course the heat transferred from indoors to the air gap plays an important role regarding the energy provided by the system to pre-heat the ventilation air. A great dispersion was also observed in the correlation between air flow and the useful heat.

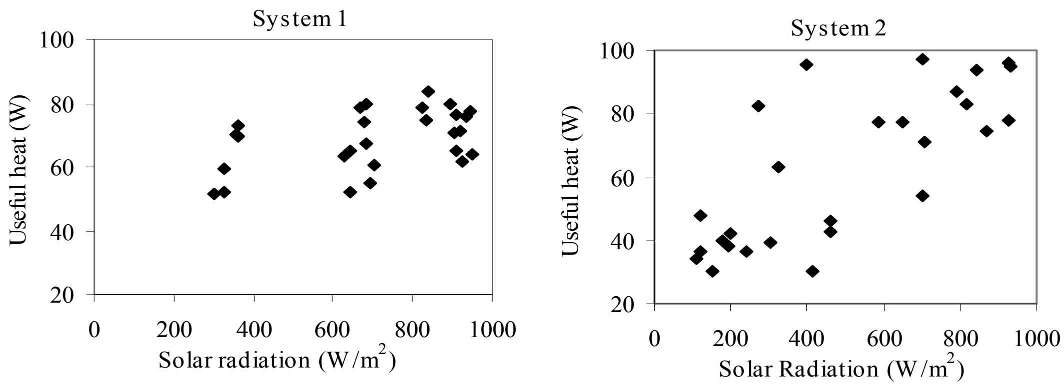

Figure 5. Correlation between solar radiation and useful heat.

Other factors must be analyzed that also contribute to the final heat gain achieved. Plotting temperature differences between indoor and outdoor air against the useful heat provided by the double window, as in Figure 6, reveals the existence of a considerable correlation between these two values. This means that the "useful heat" strongly depends on the temperature differences between indoor and outdoor air and that a great part of it is due to heat recovery.

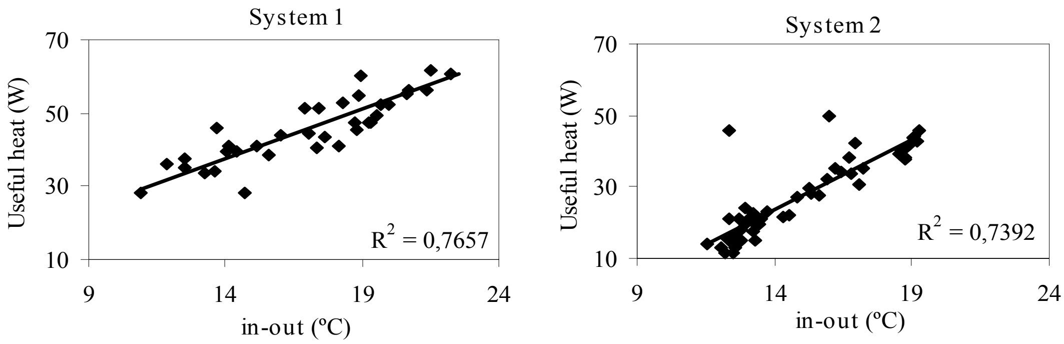

Figure 6. Correlation between temperature differences between indoor and outdoor air (in-out) and the useful heat provided by the system.

As seen above the new ventilation heat loss (Q_{vent}, in W) when a pre-heating system is considered, can be estimated, as did Baker & McEvoy (2000), using expression (4). Figure 7 shows a comparison between heat loss due to air renovation without pre-heating and the new heat loss which means the former after it has been compensated by the pre-heating of the air. This heat loss reduction depends upon the ventilated double window's performance. As it can be seen, around mid-day, at highest solar radiation, the new ventilation heat loss becomes negative, which means that the ventilated double window, at high solar radiation (figure 3) provides an air that is warmer than the indoor air and can contribute to the heating of the indoor environment.

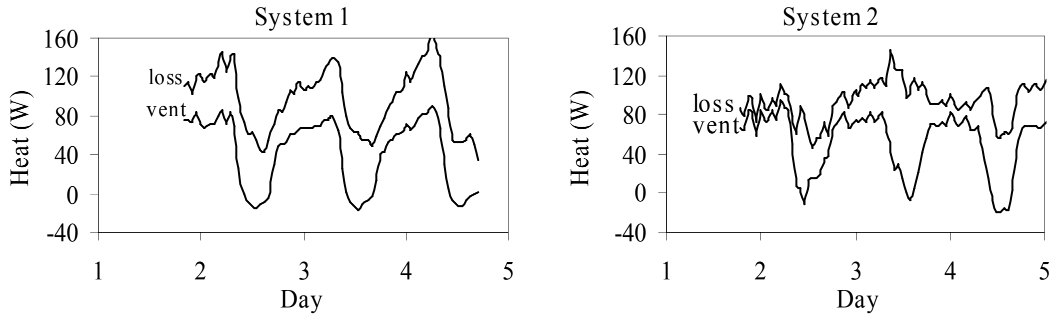

Figure 7. Heat losses due to air renovation with (vent) and without (loss) pre-heating of ventilation air.

The percentage of heat loss that is compensated with the preheating of the ventilation air can be calculated as:

$$\frac{Q_{util}}{Q_{air}}.100\% \tag{5}$$

Where Q_{util} and Q_{air} have the meanings expressed in formulas (2) and (3). Plotting the results of expression (5) into a graphic for the whole tests period on both systems, Figure 8 shows how heat loss through the ventilation air was compensated with heat gain by preheating the air delivered by the ventilated double window. Without solar radiation (night period) heat loss was compensated from 28% to 46%, by system 1 while system 2 provided from 12% to 46% of compensation. The mean value for each system was of 41%, for system 1 and 26%, for system 2. In spite of different climatic conditions, these results show how each system can recover heat loss through the window that, otherwise, could be lost to the outside. For the periods with solar radiation only, the mean values were of about 66% and 45%, for systems 1 and 2, respectively.

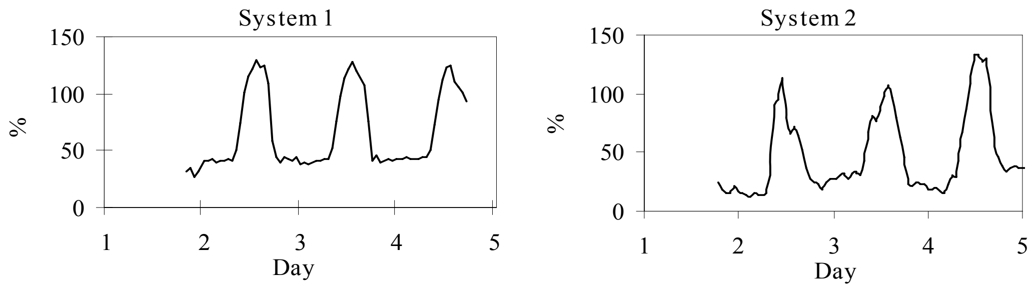

Figure 8. Proportion of the air ventilation heat loss compensated by heat gain.

5 CONCLUSIONS

This paper presents the results of an experimental study performed on a natural ventilated double window in real weather conditions. Local measured air temperatures and solar radiation were registered. Testing the double window it was found that the higher the air temperatures difference between indoors and outdoors the higher the heat gained by the delivered air through the system. It was found that there is a linear relationship between those temperature differences and the delivered heat gain.

The heat loss due to ventilation was compensated by the heat gained through the preheating of the delivered air. That compensation was at least of 28%, for system 1 and 12%, for system 2, during the night period (which means with no contribution from solar radiation). With incident solar radiation this compensation can exceed 100%. In fact, additional tests showed the effect of high solar radiation on the performance of the window, being possible to provide air warmer than the indoor air and thus contribute to the heating of the indoor environment. This window system, that is applicable to both new and old buildings, has proved to be able to provide pre-heated ventilation air in winter time, by recovering part of the heat losses from indoors and by transferring solar radiation heat gains.

This kind of system helps to reduce the global heating energy needs of a building, in winter, since it can lead to a significant reduction of the heat loss through ventilation. Furthermore, with the highly insulated envelopes of modern buildings and the correspondent low transmission losses, the heat losses through ventilation became an important part (sometimes the most important) of the total heat losses of the buildings. Therefore, the cost of the initial investment on heating devices could also be reduced as a consequence of preheating the ventilation air.
Finally, it should be noted that ventilated double windows are quite inexpensive, easy to install and require low maintenance costs.

6 NOMENCLATURE

A area of the opening, m^2;
C specific heat capacity of air at constant pressure, J/kg.ºC;
Q_{air} heat loss due to the air renovation, with no pre-heating of the air, W;
Q_{util} useful heat, W;
Q_{vent} heat loss due to the air renovation, when there is pre-heating of the air, W;
V volumetric air flow rate, m^3/h;
v_{air} air speed, m/s;
θ_{in} indoor air temperature, ºC;
θ_{out} outdoor air temperature, ºC;
θ_{top} air temperature at the window's outlet, ºC;
ρ density of the air, kg/m^3.

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A Influência do tipo de vidro na eficiência energética da envoltória

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ABSTRACT: This paper analyses the influence of the type of glass in the building's envelope energy efficiency through the prescriptive methodology of the Technical Regulation of the Quality for energy Efficiency of Commerce, Service and Public Buildings – RTQ. A building in Brasília was studied, being its envelope performance analysed, varing Solar Factor of glass. This methodology was evaluated in RTQ, and like in computer simulations, the type of glass interferes in the efficiency and mostly, the specification of certain high performance glass would guarantee a better classification of the building's energy efficiency, which is largely diffused by producers.

1 INTRODUÇÃO

A eficiência energética nas edificações pode ser entendida como a obtenção de um serviço com baixo dispêndio de energia, através do uso racional e da diminuição no consumo dos usos finais de iluminação, equipamentos e aquecimento de água, junto à incorporação de fontes renováveis de energia.

As constantes pesquisas e legislações referentes à eficiência energética confirmam a necessidade de redução do consumo de energia nas edificações, que atualmente são responsáveis por 40% dos gastos mundiais.

Publicado em 2009, o Regulamento Técnico de Qualidade para Eficiência Energética de edifícios comerciais, de serviços e públicos – RTQ, especifica requisitos técnicos, bem como os métodos para a etiquetagem do nível de eficiência desses edifícios. A Etiqueta Nacional de Conservação de Energia (ENCE) varia de A (mais eficiente) a E (menos eficiente), e serão avaliados três requisitos: envoltória, sistema de iluminação artificial e ar condicionado.

Para a classificação geral do edifício, foram atribuídos pesos relativos à contribuição no consumo energético da edificação, sendo a envoltória responsável por 30%, a sistema de iluminação 30% e de ar condicionado 40%. (RTQ,2009)

Segundo LAMBERTS (1997), "a análise do consumo de energia de uma edificação é tão importante para o processo de projeto quanto qualquer das outras ferramentas usadas comumente pelos projetistas".

A eficiência energética está diretamente relacionada às decisões do projeto arquitetônico, sendo o desempenho da envoltória o mais afetado pelas decisões do arquiteto. Entende-se por envoltória os planos externos da edificação, compostos por fachadas, empenas, cobertura, brises, marquises, aberturas, assim como quaisquer elementos que os compõem (RTQ, 2009).

Existem vários fatores que agem diretamente na eficiência energética da envoltória, já que esta compreende a área externa do edifício. Ela sofre influência das variáveis climáticas (radiação solar, temperatura, ventilação, umidade) do lugar onde o edifício esta inserido, do tipo de sítio (côncavo, convexo, plano), da implantação, da orientação das fachadas, da forma do edifício, dos fechamentos, dos materiais e ainda da área de aberturas e das proteções solares.

O uso de grandes áreas de abertura envidraçadas favorece a transferência de calor para os ambientes internos, maximizando o consumo energético. Existem discussões sobre a real eficiência de muitos vidros hoje fabricados, uma vez que prometem o isolamento térmico dos ambientes internos, mas não é comprovado em simulações computacionais. Apesar disso, é prática do mercado da construção civil, a divulgação e propaganda desses vidros inovadores, que apesar de todas suas qualidades técnicas, ainda não podem impedir completamente as trocas térmicas da edificação com o meio externo.

Assim, este artigo teve como foco principal a influência da escolha do tipo de vidro para a edificação, tendo sempre em vista a sua contribuição para um melhor desempenho da eficiência energética deste edifício.

Várias pesquisas sobre a influência da escolha do tipo de vidro na eficiência energética das edificações já foram publicadas (PEREIRA, 2002; LIMA, 2009). Porém, elas têm como base metodológica, as simulações em softwares.

Para alcançar esse objetivo, de avaliar a influência do vidro na eficiência energética da edificação, foi usado o método prescritivo do RTQ, desenvolvido pelo Instituto Nacional de Metrologia, Normatização e Qualidade Industrial (INMETRO), com metodologia especificada no Manual de uso do RTQ. A partir de um edifício modelo, etiquetado pelo LACAM (Laboratório de Controle Ambiental – FAU/UnB), foi avaliado o desempenho energético da envoltória, tendo como variável o Fator Solar de vários tipos de vidro, dado técnico presente nas fórmulas matemáticas.

Essa metodologia foi utilizada também para avaliar se nas equações prescritivas do RTQ, assim como nas simulações computacionais, os tipos de vidro interferem na eficiência energética e principalmente, se apenas a especificação de um vidro de alto desempenho garantiria uma etiqueta A para a edificação.

2 AS ABERTURAS E A EFICIÊNCIA ENERGÉTICA NA EDIFICAÇÃO

Os elementos da edificação comportam-se de forma diferenciada e as aberturas são as grandes responsáveis pela carga térmica na edificação, porque são onde ocorrem as principais trocas com o meio exterior (condução, convecção e radiação). Isso é comprovado na tabela 1, onde foi feita a estimativa de carga térmica de uma sala comercial localizada na cidade de Florianópolis e voltada para oeste. As aberturas determinam o ganho térmico do ambiente interno, além de definirem a quantidade de iluminação e ventilação naturais.

Tabela 1: Contribuição de cada elemento do projeto na carga térmica

Elemento	Contribuição de calor
Parede externa	9%
Abertura	63%
Ocupantes	7%
Iluminação Artificial	10%
Equipamentos	7%
Infiltração	4%

Fonte: Adaptado de LAMBERTS, 1997, p.100

Neste sentido, são de suma importância para a eficiência energética, as decisões de projeto relacionadas à abertura: dimensionamento, orientação, proteções solares e tipos de fechamento translúcido (ex: vidros).

O RTQ (2009) define como abertura “todas as áreas da envoltória do edifício, com fechamento translúcido ou transparente (que permite a entrada da luz). Excluem-se vãos sem fechamentos e elementos vazados como cobogós”. A ventilação natural não é considerada nessa definição, sendo este o conceito utilizado nesse artigo: as aberturas são os fechamentos em vidro.

Assim, o entendimento das características do vidro é essencial para entender seu comportamento e influência na eficiência da edificação.

3 O VIDRO

O vidro é foco de constantes melhorias tecnológias devido a sua importância na industria da contrução civil. É o material mais utilizado para fechamentos que possibilita a vizualização e interação com o meio ambiente externo, o que é muito importante para o conforto psicológico dos usuários e iluminação natural.

Suas características estéticas e transparências sempre atraíram os projetistas, que, atualmente utilizam o material de forma indiscriminada, independente das características bioclimáticas do local, contribuindo para a ineficiência energética e consequentemente para o desconforto ambiental desses espaços contruídos.

3.1 *Histórico*

A descoberta do vidro data de 5000 a.C. (mercadores fenícios), e sua utilização foi crescente ao longo da história. O aperfeiçoamento desse material e sua técnica de fabricação sempre estiveram presentes nas preocupações dos construtores.

Em 100 a.C., os romanos confeccionavam suas janelas pela técnica de sopro em moldes. Um novo método possibilitou a execução de vidros planos por volta de 500 e 600 d.C., método este que foi responsável pela maior parte da produção do vidro até o século XIX. Era feito por sopro de uma esfera e sua sucessiva ampliação por rotação em forno. O vidro moldado à rolo (técnica oriental) foi introduzido em Veneza por volta do ano 1300, com as cruzadas.

A ilha de Murano especializou-se na produção artística notável do vidro. Neste período descobre-se também um novo processo de produção: por sopro de cilindros (novamente, revolucionária para os vidros planos). Ao soprar e girar o cano simultaneamente, obtinha-se um cilindro de vidro líquido que depois era colocado em uma espécie de forno ("estendedeira") e deixado para estender.

A indústria de vidro propriamente dita nasceu na Revolução Industrial, em particular na indústria automotiva do século XX, e também da invenção de dois métodos chave de produção: o processo da folha estirada e o de flutuação (float).

3.2 *Características e tipos de vidro*

Os vidros geralmente são bons condutores de calor, pois tem alta transmitância térmica (U). É um material muito utilizado por ser transparente e permitir certo controle da radiação solar (luz e calor), dependendo de suas características físicas.

A radiação solar pode ser absorvida, refletida ou transmitida para o interior, dependendo dos valores de absortividade, refletividade, e transmissividade de cada vidro. A porcentagem absorvida se converte em calor no interior do vidro e pode ser reemitida tanto para o interior quanto para o exterior.

Os diferentes tipos de vidros possuem características ópticas distintas, e comportam-se de forma diferenciada para cada comprimento de onda da radiação, assim como para o ângulo de incidência.

A escolha do vidro está relacionada à necessidade de controle da radiação solar, sendo importante avaliar a quantidade de luz solar que será admitida e/ou bloqueada para o interior da edificação.

Os vidros transparentes ou incolores são os mais usados na construção civil devido ao seu menor custo e maior disponibilidade no mercado. Eles são transparentes às ondas curtas, permitindo boa visilibilidade e opacos às ondas longas, com alta transmissividade de radiação solar para o interior, o que causa o efeito estufa.

Os vidros verdes e os vidros fumês são absorventes, levemente pigmentados para diminuir a transmissão da onda curta, com um pequeno aumento na absorção da parte visível. A transmissividade visível (visibilidade) deve ser adequada para não gerar gastos desnecessários de iluminação artificial.

Os vidros refletivos possuem uma película, composta por uma camada metálica de substrato transparente, com efeito espelhado. Existem películas mais refletivas às ondas curtas, e outras mais refletivas em ambos os espectros. Pode-se afirmar que as películas refletivas às ondas curtas reduzem o ingresso de calor ao interior. Este tipo de película também tem reduções na sua capacidade de transmitir a luz visível. O efeito de reflexão do calor pode beneficiar o interior da edificação, mas é responsável pelo desconforto na escala urbana, uma vez que repassa a carga térmica para edificações vizinhas ou para o espaço público, interferindo no microclima local.

Os vidros duplos são também denominados insulados ou sanduíche de vidros. Trata-se de um sistema de duplo envidraçamento que permite aliar as vantagens técnicas e estéticas de pelo menos dois tipos diferentes de vidro, com o benefício da camada interna de ar ou gás. Com a utilização de uma camada externa com vidro refletivo, a onda longa vinda do exterior é absorvida e o calor dissipado para cada lado por convecção e para o interior por reirradiação. Ao contrário, colocando-se a camada refletiva no lado interno do ambiente, a onda longa é refletida, evitando-se perda de calor em climas frios. Esse sistema, apesar de possuir vantagens no controle térmico-energético, tem alto custo e pouca disponibilidade no mercado.

Cada um destes tipos de vidro tem um determinado Fator Solar (FS), que pode ser entendido como "a razão entre o ganho de calor que entra no ambiente através de uma abertura e a radiação solar incidente nessa mesma abertura." (RTQ, 2009).

Nas equações do método prescritivo para avaliação da envoltória, o FS é a variável específica relacionada ao tipo de vidro das aberturas.

Para o RTQ, o Fator Solar considerado será relativo a uma incidência de radiação solar ortogonal à abertura. O cálculo do FS é feito através de equação 1 da NBR 15220-2 (ABNT, 2005):

$$FSt = U \,.\alpha\, .Rse + \tau \quad \text{(equação 1)}$$

Onde, FSt = fator solar de elementos transparentes ou translúcidos (J/m2K); U = a transmitância térmica do componente (W/m2.K); α = a absortância à radiação solar; Rse = resistência superficial externa (m2.K/W); τ = transmitância à radiação solar.

Os catálogos devem possuir as propriedades específicas de cada tipo de vidro, o que permite o cálculo do FS e a correta especificação nos projetos arquitetônicos.

Os fabricantes, em geral, por meio de seus catálogos e amostras, transmitem a idéia de que apenas a escolha do vidro pode garantir a eficiência energética de uma edificação, pois permite o isolamento do meio externo. No entanto, em muitos catálogos não constam dados técnicos como transmitância, refletância e fator solar de cada tipo de vidro, que permita a avaliação e eficiência desses produtos.

4 METODOLOGIA DO ESTUDO

Para testar a influência do tipo de vidro na eficiência energética da envoltória, utilizamos como metodologia a aplicação das equações do RTQ, em três etapas:

1) Etiquetagem da envoltória de edifício modelo: cálculo de acordo com método prescritivo (RTQ), com todas as características e especificações originais do projeto;

2). A variável Fator Solar: substituição do tipo de vidro do edifício modelo, alterando o Fator Solar na equação para avaliação da influência do vidro na etiquetagem (eficiência) da envoltória;

3). Resultados: análise das etiquetas obtidas com os 24 diferentes vidros (variável FS) e a avaliação da contribuição para a melhoria da eficiência energética do edifício modelo.

4.1 *Etiquetagem da envoltória do edifício modelo*

O objeto de estudo foi um edifício institucional cuja envoltória foi etiquetada pelo LACAM, através do metodo prescritivo do RTQ.

O edificio, com área de 10125,0 m², está em fase de construção, e situa-se em Brasília – DF, na Zona Bioclimática 4.

As maiores fachadas possuem orientação leste e oeste, sendo muito semelhantes, com pele de vidro verde. Na fachada norte localiza-se a torre de circulação vertical, conectada à edificação principal por passarelas com fechamento em vidro. A fachada sul não possui aberturas, configurando um pano cego, e é constituída pelos mesmos materiais da fachada norte: paredes externas em painel de concreto pré-moldado e painel de gesso internamente, separadas por camada de ar com isolante.

O LACAM fez uma avaliação da envoltória, seguindo metodologia prevista no RTQ, onde são utilizadas equações específicas de acordo com cada Zona Bioclimática (equação 2). Foi definido o Indicador de Consumo (IC), que prevê de que maneira a envoltória de um edifício vai impactar em seu consumo de energia.

Ape>500m²

Limite: Fator de forma mínimo (Aenv/Vtot)=livre

$$IC_{env} = 511{,}12.FA + 0{,}92.FF - 95{,}71.PAF_T - 99{,}79.FS - 0{,}52.AVS - 0{,}29.AHS - 380{,}83.FA.FF + 4{,}27/FF + 729{,}20.PAF_T.FS + 77{,}15 \quad \text{(equação 2)}$$

Equação 02: Cálculo do IC para ZB4 (Eq. 3. 6, RTQ, p.22)

Foram calculados três tipos de IC (ICenv, ICmax e ICmin), para estabelecer os limites de intervalo de classificação do consumo da envoltória (de E a A). Todas as variáveis relativas à edificação, necessárias para alimentar a equação do IC, são apresentadas em tabela a seguir.

Tabela 02: Variáveis para cálculo do ICenv

Variável	Valor
Área de Projeção do Edifício (Ape)	956,4 m²
Área Total de Piso (At)	10125,0 m²
Área da Envoltória (Aenv)	3883,12m²
Volume Total do Edifício (Vtot)	18694,6m²
Fator de Altura (FA = Ape/Atot)	0,094
Fator de Forma (FF = Aenv/Vtot	0,20
Percentual de Abertura nas Fachadas (PAF)	0,43
Fator Solar (FS): do vidro verde especificado	0,61
Ângulo Vertical de Sombreamento (AVS)	0
Ângulo Horizontal de Sombreamento (AHS)	0

Os Resultados dos Indicadores de Consumo foram:

Cálculo do ICenv = 228

Cálculo do ICmax = 287

Cálculo do ICmin = 79

A partir dos valores do ICmax e ICmin, foi gerado o intervalo (i = 52,11) para classificação da envoltória, seguindo equação do RTQ (Eq. 3.11, RTQ, p.42).

O valor desse intervalo (i) foi utilizado nas fórmulas da Tabela dos Limites dos intervalos dos níveis de eficiência da envoltória, de acordo com o RTQ:

Tabela 3: Limites dos intervalos dos níveis de eficiência (RTQ.p.24)

Eficiência	A	B	C	D	E
Lim. Mín.	-	$IC_{maxD} - 3i + 0{,}01$	$IC_{maxD} - 2i + 0{,}01$	$IC_{maxD} - i + 0{,}01$	$IC_{maxD} + 0{,}01$
Lim. Máx.	$IC_{max} - 3i$	$IC_{max} - 2i$	$IC_{max} - i$	IC_{max}	-

Assim, originou-se a tabela específica do estudo de caso, com a classificação dos limites para etiquetagem da edificação:

Tabela 4: Intervalos de IC mínimo e máximo

Níveis de Eficiência	A	B	C	D	E
limite mínimo	-	130.95	183.07	235.19	287.31
limite máximo	130.94	183.06	235.18	287.30	-

Como o ICenv do edifício objeto de estudo foi de 228, valor que se encontra no intervalo 183.07 – 235.18, a etiqueta da envoltória para o edifício de referência foi C.

4.2 *A Variável Fator Solar(FS)*

Para a análise da influência do tipo de vidro na etiqueta da envoltória da edificação, foram selecionados 24 tipos de vidro, com as respectivas características técnicas.

Foram utilizados os mesmos dados e cálculos da edificação modelo, tendo como única variável o Fator Solar (FS), dado relativo a cada vidro. Foi simulada a substituição do vidro original da edificação por outras 24 especificações, obtendo consequentemente as etiquetas correspondentes. Ou seja, foi adotada a mesma fórmula usada no método prescritivo do RTQ, com os mesmos valores, alterando apenas o FS conforme cada vidro testado.

Para assegurar que os dados técnicos dos vidros tivessem o mesmo padrão, evitando distorções e erros de definições ou cálculos, optou-se pelo uso de apenas um fabricante, o *AFG Corporate Office*.(www.usp.br/fau/deptecnologia/docs/bancovidros/index.html)

Foram escolhidas quatro tipologias de vidro, cada uma com seis cores diferentes. As tipologias são: vidro simples, vidro duplo, vidro simples com película refletiva série P30, e vidro duplo com película refletiva série P30. Os vidros simples tem 6mm de espessura. Os duplos tem 6mm de vidro, 13mm de camada de ar, e novamente 6mm de vidro. Cada tipologia de vidro foi testada para seis cores: incolor, verde, cinza, bronze, azul e verde escuro.

Além do Fator Solar, que é o único solicitado pela fórmula, foram levantados a transmitância, radiação solar visível e radiação solar total. Estes dados são apresentados para efeito de comparação posterior, uma vez que um vidro que tenha baixo fator solar pode apresentar também pouca visibilidade para o exterior (percentual de transmissão da radiação visível ao exterior), podendo ser prejudicial ao projeto.

4.3 *Resultados*

A tabela 05 mostra os dados técnicos de cada vidro, e a etiqueta parcial da envoltória resultante para cada um deles.

Tabela 5: Dados Técnicos dos Tipos de vidro e respectivas etiquetas parciais da envoltória.

Tipo de vidro	Cor	Rad. Solar Visível		Radiação Solar Total				U/m^{2}oC (verão)	IC - ENCE envoltória
		Transm. %	Reflet. %	Transm %	Reflet. %	Absor. %	Fator Solar		
Simples não refletivo - 6mm	incolor	88	8	78	7	15	82	5.8	273-D
	Verde	75	7	49	6	45	61	5.8	228-C
	Cinza	43	5	46	5	49	59	5.8	224-C
	Bronze	53	6	48	5	47	61	5.8	228-C
	Azul	55	6	46	5	49	59	5.8	224-C
	Verde escuro	66	7	33	5	62	50	5.8	204-C
Duplo não refletivo 6:13:6	incolor	78	14	60	11	29	70	3.2	247-D
	Verde	66	12	38	7	55	49	3.2	202-C
	Cinza	38	7	35	7	58	47	3.2	198-C
	Bronze	47	8	38	7	55	49	3.2	202-C
	Azul	49	8	36	7	57	47	3.2	198-C
	Verde escuro	58	10	26	6	68	38	3.2	179-B
Simples refletivo película série P30 6mm	incolor	29	16	25	13	62	41	5.8	185-C
	Verde	25	12	15	7	78	35	5.8	172-B
	Cinza	15	7	14	7	79	35	5.8	172-B
	Bronze	18	8	15	7	78	35	5.8	172-B
	Azul	18	9	14	7	79	35	5.8	172-B
	Verde escuro	21	10	11	6	83	33	5.8	168-B
Duplo reflet. película série P30 6:13:6	incolor	25	16	16	15	69	25	1.9	151-B
	Verde	21	12	9	8	83	18	1.9	136-B
	Cinza	13	7	9	7	84	18	1.9	136-B
	Bronze	15	8	10	8	82	18	1.9	136-B
	Azul	15	9	9	8	83	18	1.9	136-B
	Verde escuro	18	10	7	7	86	16	1.9	132-B

5 CONCLUSÃO

A partir da análise dos resultados, onde foram parametrizados os dados de todos os tipos de vidro e a etiqueta que a edificação receberia, caso o vidro do projeto fosse substituído, percebeu-se que a eficiência da envoltória da edificação estudada não aumentaria de forma significativa.

A ENCE do projeto original, com vidros verdes, foi C e testando a edificação com 24 tipos de vidro, nenhum conseguiu a etiqueta A.

A melhor etiqueta alcançada foi B, sendo que estas foram para os vidros com película reflétiva e os duplos. A melhoria da eficiência energética nesse caso está diretamente ligada ao custo do vidro, sendo os mais eficientes com custo elevado, o que impossibilita seu uso em todas as edificações.

Constatou-se que os vidros refletivos apresentam os melhores resultados para a etiqueta parcial da envoltória. Porém, não se pode deixar de lado a sua influência no entorno urbano imediato, relacionado ao ofuscamento e transmissão de calor aos edifícios vizinhos, alterando o microclima e redução de iluminação natural.

No método prescritivo, o único dado tecnico do vidro avaliado é o Fator Solar, que é baixo nos vidros que alcançaram melhor etiqueta (B). Mas esses mesmos vidros possuem transmissividade visível baixa, o que nem sempre é desejável, pois a visisbiliade para o exterior é imporntante para o bem estar do usuário.

O vidro incolor piorou a eficiência energética, (etiqueta D) comprovando que o vidro mais usado na contrução civil é também o mais inadequado, sendo essencial o uso de proteções solares para evitar a radiação solar direta na maioria das efificações.

O método prescritivo conseguiu, através de suas formulas e do uso do Fator Solar responder de forma adequada à influencia dos tipos de vidro nas variações de eficiência energetica da envoltória das edificações. Essa comprovação possibilita o uso do método para testes de especificações desses materiais ainda na fase de projeto.

Dessa forma, é possível concluir que apenas o tipo de vidro, por melhores características tecnicas, não garante sozinho a eficiência energética da envoltória, como é tão difundido pelos fabricantes. Os projetistas devem se preocupar com as demais variáveis do projeto: o clima do lugar onde o edifício esta inserido, o tipo de sítio, a implantação, a orientação das fachadas, a forma do edifício, os fechamentos, os materiais, a área de aberturas e as proteções solares, tão importantes para a eficiência da edificação.

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The advantage of adaptable buildings with respect to the energy consumption over the life of the building

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ABSTRACT: This paper examines the concept of adaptable buildings with respect to heat loss and life cycle assessment (LCA) of a building. Two different building standards are used: Technical Guidance Document Part L of the Irish Building Regulations and the Passive House Standard from the PassiveHaus Institut in Germany. The calculations for both heat loss and LCA of the dwelling concentrate on the external insulation only. This is to allow for a detailed comparison of one building element and to illustrate the effect that one building element can have on the entire dwelling. It is shown how an adaptable dwelling will consume less energy over the entire life cycle of its existence and also how different building standards affect heat loss and LCA. Finally, the effects of different types of insulations are discussed.

1 INTRODUCTION

The need for energy efficient homes which minimize all related carbon emissions has been well established. According to the Environmental Protection Agency, the residential sector in Ireland consumes approximately one quarter of the total energy use in Ireland. This requirement for sustainable homes has driven design and construction innovation in terms of energy use, heat loss and renewable energy provision. However, for something to be truly sustainable it must continue to be sustainable over its entire life cycle. Therefore it must have the inherent ability to adapt to changing circumstances and thus remain relevant.

If sustainability is defined as an evolving process, then all the various components which contribute to this process must be in themselves capable of continuous change. Therefore, a sustainable building can be defined as an adaptable building. In light of this, the design and construction of dwellings must embody this adaptability in order to remain current within the overall sustainability framework. According to Friedman (2002), the era of unchangeable homes that accommodate just one lifestyle is drawing to a close, and there exists a clear need for new strategies and products. Thus far, this aspect of sustainability has largely gone unexplored, resulting in the construction of low carbon buildings, which may function in the short term, but subsequently fail in the long term. This failure can be caused by an inability to adapt to future societal needs, technologies and regulations.

This paper examines the concept of adaptability with respect to heat loss and the LCA of the building. The quantification of adaptable buildings with respect to heat loss and LCA in comparison to traditional buildings is an area that has not yet been explored. As this can result in a considerable amount of computation, this paper focuses on the external wall insulation only. This is to allow for a detailed comparison of both the heat loss and the LCA of the dwelling and to highlight the significance of adaptable buildings with respect to energy consumption.

2 THEORY AND METHODOLOGY

2.1 *Adaptable buildings*

There are a number of differences between an adaptable dwelling and a traditionally constructed dwelling, with respect to overall energy consumption. One of the main differences is the reduction of the overall embodied energy associated with the construction of the dwelling; this is a result of reduced waste due to off-site manufacturing and controlled quality procedures and the reduced number of delivery loads.

Another significant advantage is the ability to improve the performance as improved technology and more cost effective technology becomes available. However, this aspect is difficult to quantify and therefore for the purpose of this paper, it is assumed that the building envelope remains the same over the life time of the dwelling.

2.2 *Heat loss through the building envelope*

The heat loss through the building envelope is calculated using the simple (steady state) model outlined by CIBSE Guide A (1986). The total heat loss is the sum of the fabric and ventilation losses. For this paper, the fabric losses include the thermal transmittance across each surface of the dwelling and the point transmittance losses across the entire building envelope. Therefore the total heat loss can be expressed by Equation 1

$$Q_t = [F_{1cu} \sum (AU) + Ay + F_{2cu} C_V](t_c - t_{a0}) \quad (1)$$

where Q_t is the total heat loss (W); F_{1cu} and F_{2cu} are factors related to the characteristics of the heat source with respect to dry resultant temperature and are given in Equations 2 and 3; $\Sigma(AU)$ is the sum of the thermal transmittance (W/mK) and the area (m^2) over the surface of which the heat flows; t_c is the dry resultant temperature (^{o}C) as calculated in Equation 4; t_{ao} is the outside air temperature (^{o}C); y is the fraction for thermal bridging over the entire building envelope; C_v is the ventilation conductance as given in Equation 5.

$$F_{1cu} = \frac{3(C_V + 6\sum A)}{\sum (AU) + 18\sum A + 1{,}5R[3C_V - \sum (AU)]} \quad (2)$$

$$F_{1cu} = \frac{\sum (AU) + 18\sum A}{\sum (AU) + 18\sum A + 1{,}5R[3C_V - \sum (AU)]} \quad (3)$$

$$t_c = 0.5t_{ai} + 0.5t_m \quad (4)$$

$$C_V = NV/3 \quad (5)$$

where R is the radiant fraction of the heat source; t_{ai} is the indoor air temperature; t_m is the mean surface temperature; N is the number of room air changes per hour (ac/h^{-1}); V is the room volume (m^3).

2.3 *LCA*

The energy associated with the production of material and the transport of the material is calculated using Equations 6 and 7 (Adalberth, 1997), respectively.

$$Q_{man} = \sum_{i=1}^{n} m_i (1 + w_i/100) M_i \quad (6)$$

$$Q_{trans} = \sum_{i=1}^{n} m_i (1 + w_i/100) d_i T_C \quad (7)$$

where n is the number of materials; i is the material of concern; w_i is the factor for waste of the material (%);m_i is the amount of building material (ton); M_i is the energy required for manufacturing the material (kWh/ton); d_i is the distance from the manufacturer to site (km); T_C is the energy required for conveyance (kWh/tonkm).

2.4 *TGD part L vs passive house standard*

Two different standards are used for comparison of the energy lost through the building envelope. The first is the Building Regulations 2008 (S.I. No. 259 of 2008) Technical Guidance Document (TGD) L – Conservation of Fuel and Energy – Dwellings (2008); the second is the Passive House Standard (2007) as outlined by the PassivHaus Institut in Germany. The U-Values, point transmittance and ventilation rate as outlined by these documents is provided in Table 1

Table 1. Building envelope values for TGD part L and Passive House Standard.

	TGD Part L	Passive House Standard
External wall U-value (w/mK)	0.27	0.15
Ground floor U-value (w/mK)	0.25	0.15
Roof U-value (w/mK)	0.16	0.15
Window U-value (w/mK)	2.00	0.80
Door U-value (w/mK)	2.00	0.80
Point transmittance (y) (w/mK)	0.15	0.01
Infiltration allowance (h^{-1})	0.50	0.60

2.5 *Examination of external wall insulation*

For the purpose of this paper, each of the calculations focuses on the external wall insulation. This is to allow for a detailed comparison of one building element to be made with respect to how it affects heat loss through the building envelope and to examine one building element for its LCA over the life of the product.

It should be noted that if other building envelope elements were examined, e.g. ground floor insulation, roof insulation, windows, doors etc, the results would be similar as these elements on their own contribute in the same manner to the dwelling as the external wall insulation. For other elements of the dwelling such as the structural frame, dry lining and cladding, these are not included in the assessment and are the subject of further work.

3 CASE STUDY – SEMI DETACHED DWELLING

3.1 *Dwelling characteristics*

A standard semi-detached dwelling has been chosen for the case study. The sum of the fabric through which heat can be lost is $184m^2$; of this, 42% makes up the external walls, 23% for both the ground floor and the roof, 9% for the windows and 2% for the doors. The total volume of the dwelling is $223m^3$.

3.2 *Heat Loss*

The heat loss is calculated using Equations 1 to 5 for both TGD Part L and the Passive House Standard. Table 2 shows the values for the heat loss components excluding the temperature associated with the month of the year. Table 3 provides the temperature values for Dublin, Ireland for each month of the year.

Incorporating the temperature values in Table 2 with Equation 1, the heat loss for the semi-detached dwelling for one year can be calculated as 431kWh/year using TGD Part L and 260kWh/year using the Passive House Standard. When there is no external wall insulation, the heat loss can be calculated as 690kWh/year and 550kWh/year for TGD Part L and the Passive House Standard, respectively. This is illustrated in Figure 1 over a 60 year period, i.e. the design life for a dwelling in Ireland, assuming that there is no climate change. It is shown that the difference over 60 years between the two building standards is approximately equal to 10MWh.

Table 2. Heat loss components for dwelling built to TGD part L standards.

	TGD Part L	PH Standard	No Insulation (Part L)	No Insulation (PH)
y (W/m^2K)	0.15	0.01	0.15	0.01
Ay (W/K)	27.60	1.84	27.6	1.84
ΣAU+Ay (W/K)	106.29	42.44	192.87	138.38
ΣA	184	184	184	184
V (m^3)	223	223	223	223
N (ac/h)	0.5	0.6	0.5	0.6
C_V (W/K)	37.25	44.7	37.25	44.7
R	0.5	0.5	0.5	0.5
F_{1cu}	1.00	1.01	0.99	1.00
F_{2cu}	1.00	0.98	1.02	1.00
Q (W/K)	144	87	230	183

Table 3. Temperatures for Dublin, Ireland.

	t_{ao}	t_{ai}	t_m	t_c	$t_c - t_{ao}$
January	5.4	21	19.2	20.1	14.7
February	5.4	21	19.2	20.1	14.7
March	6.7	21	19.3	20.2	13.5
April	8.1	21	19.4	20.2	12.1
May	10.7	21	19.5	20.3	9.6
June	13.6	21	19.7	20.4	6.8
July	15.4	21	19.8	20.4	5.0
August	15.1	21	19.7	20.4	5.3
September	13.1	21	19.6	20.3	7.2
October	10.3	21	19.5	20.3	10.0
November	7.4	21	19.3	20.2	12.8
December	6.3	21	19.3	20.2	13.9

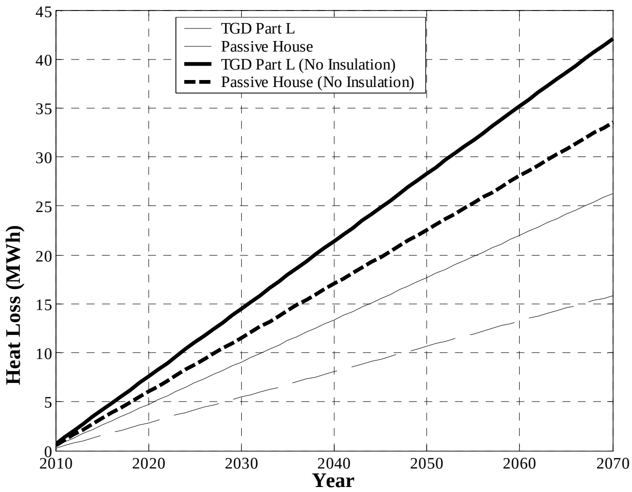

Figure 1. Heat Loss over 60 years for dwelling constructed using TCG part L and Passive House Standards.

The difference for a dwelling with no external insulation and external insulation according to TGD Part L and the Passive House Standards is 259kWh/year and 290kWh/year, respectively. Assuming the dwelling uses electricity for space heating and appliances and taking a standard rate of €0.14/kWh for electricity, this correlates to a difference of approximately €36/year and €40/year, respectively. As insulation is required for a multitude of reasons, including indoor air quality and thermal comfort, a base level of insulation must be allowed for. However, the results would suggest that it does not make economic sense to invest in a superior building envelope.

3.3 *LCA*

The external wall insulation used in the dwelling is now examined for the embodied energy over the life of the dwelling and the following assumptions are made: the building is manufactured using light gauge steel construction; the insulation used is high density mineral (100kg/m^3) wool placed outside of the steel frame; the mineral wool is manufactured by Rockwool in Bridgend South Wales; the thermal conductivity, λ, of the insulation is 0.045W/mK; insulation is transported in 40ft standard cube containers; containers are packed fully with insulation material; all materials are delivered to a supplier in Dublin 15.

3.3.1 *Thickness of Insulation*

As the dwelling is constructed using light gauge steel, structurally insulated panels (SIP), the U-Value for the external walls is calculated using BS EN ISO 10211. For an insulating material with a λ value of 0.045W/mK, the thickness required for a U-Value of 0.27 i.e. TGD part L is 140mm and for a U-Value of 0.15 i.e. Passive House Standards is 260mm. This is a significant increase in the thickness of the insulation in order to comply with the Passive House Standards and therefore the economic sense of improving the building fabric to this level is once again highlighted.

3.3.2 *LCA for manufacture and delivery of external wall insulation*

The LCA for just the external insulation to be used in the dwelling is calculated from Equations 6 and 7. According to Harvey (2007), the energy required for manufacturing mineral wool insulation, M_i = 18MJ/kg = 5121kWh/ton. One 40ft standard cube container has a volume of 77.02m^3. For the mineral wool insulation, this is a total weight of 7702kg = 7.28ton = m_i. Assuming that the container is fully packed with insulation i.e. best case scenario and ignoring waste for now, the embodied energy as a result of manufacturing one container of mineral wool insulation is 38818kWh.

Table 4 outlines the distances, method of transport and energy associated with transport using the values given by Adalberth quoting Tillman (1997). The weight of a truck and container is assumed to be 18ton. Therefore, based on these assumptions, the total embodied energy for one container of mineral wool insulation, being brought from Bridgened in South Wales to Dublin 15, including manufacture, is approximately equal to 41601kWh.

Table 4. Energy associated with transport

Journey Leg	From	To	Distance (km)	Transport	Energy (kWh/tonkm)	Total Energy (kWh)
1	Bridgend	Hollyhead	482	Road	0.28	2430
2	Hollyhead	Dublin Port	120	Ferry	0.06	130
3	Dublin Port	Dublin 15	_16.5__	Road	0.75	223
Total						2783

3.3.3 *Comparison of LCA for external wall insulation with heat loss*

From the results in Section 3.3.2, for a 140mm and 260mm thick section of mineral wool insulation, one container load carries 550m^2 and 296m^2, respectively. Therefore, for delivery to the supplier, the total embodied energy per m^2 of the insulation is 75kWh/m^2 and 140kWh/m^2, for TGD Part L and the Passive House Standards respectively.

The total area of external walls in the dwelling is equal to 78m^2, therefore the embodied energy associated with just the external wall insulation for a semi-detached dwelling constructed using TGD Part L standards and Passive House Standards is 5850kWh and 10920kWh, respectively. This is illustrated in comparison to the heat loss in the house over 60 years in Figure 2.

It can be seen from Figure 2 that the embodied energy associated with the dwelling constructed to passive house standard is much higher than that associated with the dwelling constructed to TGD part L, this is a consequence of the greater thickness of insulation required for the Passive House standard. Furthermore, the LCA payback for the dwelling constructed using TGD part L and Passive House standard is approximately 15 years and 40 years, respectively, i.e. more than double.

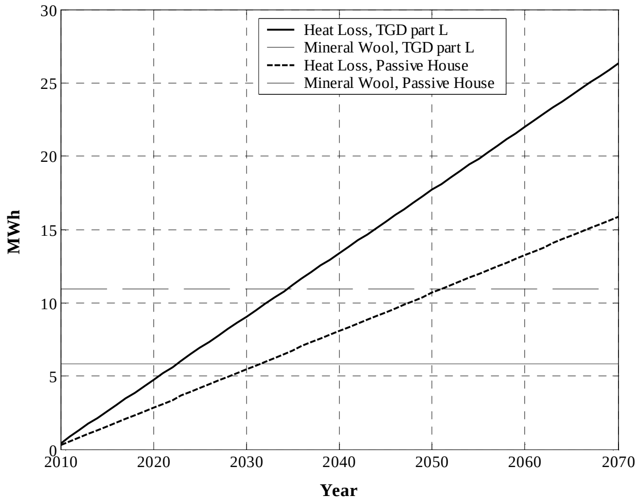

Figure 2. Heat loss vs LCA for mineral wool insulation

It is also interesting to note that the energy associated with the manufacture and transport of the insulation per year is equal to 75kWh/year and 140kWh/year for the dwelling constructed to TGD Part L and the Passive House Standards, respectively. When this is compared to the heat loss saved per year as calculated in Section 3.2, the amount of energy saved by insulating your house to TGD Part L standards is approximately equal to 184kWh/year and to the Passive House Standards is only 150kWh/year. These values are relatively low, which further suggests that it does not make either economic or environmental sense to provide a superior building envelope such as the Passive House Standard for dwellings in Ireland.

3.4 *LCA for an adaptable dwelling versus a traditional dwelling*

The LCA of an adaptable dwelling is now compared with that of a traditional dwelling. Two types of adaptable dwelling are considered: 1) the original dwelling is constructed using new parts and then these parts are reused after 60 years for another dwelling; 2) the dwelling is constructed using re-used components from another adaptable dwelling and then disposed after 60 years. The first scenario for the adaptable dwelling takes the burden for the production, delivery and use of the materials, however it does not take the burden for the disposal or transport of the re-usable components; the second scenario takes the burden for the transport of the reusable components and the use and disposal of the materials. The traditional dwelling takes the burden for the entire process, i.e. the production of the materials and the delivery of the materials to disposal.

The semi detached dwelling outlined in Section 3.1 is now examined with respect to adaptable and traditional dwellings for the external wall insulation. The assumptions regarding the delivery, location, number of deliveries and percentage associated with delivery are outlined in Table 5. The distances are taken as the maximum desired distances for adaptable homes. Please note that all values associated with transport account for a single trip, i.e. the truck returns with a full load of an alternative material. For the adaptable dwelling, a value of 5% waste is assumed with the external insulation and a value of 20% is assumed for the traditional dwelling, these are typical known values for construction.

The energy associated with each process of the LCA scenarios is shown in Table 5. As expected, the adaptable dwelling in scenario 2 has the lowest energy consumption. This scenario is 18% and 26% less than scenario 1 and 3, respectively for the dwelling built according to TGD Part L and 39% and 47% less than scenario 1 and 3, respectively for the dwelling built according to Passive House standards. These results highlight the importance of re-using materials wherever possible but also the advantage of constructing a dwelling off-site.

Table 5. Adaptable vs traditional construction

Adaptable (Scenario 1)	Distance (km)	No. of Del	% Ass with Del (%)	kWh/del (kWh)	Part L (kWh)	PH (kWh)
Production & Delivery to Supplier					6232	11480
Delivery to Factory	Nom				Nom	Nom
Manufacture of Modules					-	-
Delivery to Site	200	2	40	1008	806	806
Use of the Building					24601	15866
Total _					31639	28152
Adaptable (Scenario 2)	**Distance (km)**	**No. of Del**	**% Ass with Del (%)**	**kWh/del (kWh)**	**Part L (kWh)**	**PH (kWh)**
Delivery of Modules	200	2	40	1008	806	806
Use of the Building					24601	15866
Delivery to Disposal	300	1	40	1512	605	605
Total _					26012	17277
Traditional (Scenario 3)	**Distance (km)**	**No. of Del**	**% Ass with Del (%)**	**kWh/del (kWh)**	**Part L (kWh)**	**PH (kWh)**
Production & Delivery to Supplier					7144	13160
Delivery to Site	200	3	100	1008	3024	3024
Use of the Building					24601	15866
Delivery to Disposal	300	1	40	1512	605	605
Total _					35374	32655

4 COMPARISONS OF DIFFERENT INSULATING MATERIALS

A number of different insulation materials are now examined in order to determine the effect of both manufacture and transport on the embodied energy of the dwelling. Table 6 shows the type of insulation, the insulations λ value, the density, where the insulation is manufactured, the embodied energy from manufacture (Harvey, 2007) and the embodied energy from transport to Dublin 15.

Table 6. Energy associated with different insulations

Insulation	λ (W/mK)	ρ (kg/m^3)	Location	Q_{man} (kWh)	Q_{trans} (kWh)	Q_{total} (kWh)
Cellulose	0.045	55	Gwent (WAL)	1067	1607	2674
Fibreboard	0.049	215	Gutenberg (GER)	53321	6241	59562
Polystyrene	0.030	30	Castleblaney (IRL)	82165	575	82739
PUR (Closed Cell)	0.020	35	Castleblaney (IRL)	103407	575	103982
PUR (Beaded)	0.035	35	Belfast (UK)	103407	877	104284
Fibreglass	0.040	35	Laudner (GER)	16756	6543	23300

As scenario 2 does not take into account the energy associated with the manufacture and delivery of the insulation to the supplier, this is excluded from the comparison of different insulations in this Section. Therefore, Table 7 outlines the total amount of energy required for manufacture and transport of the insulation to the adaptable dwelling described in scenario 1 and the traditional dwelling described in scenario 3.

It can be seen in Table 7 that that the lowest values are associated with the cellulose insulation and the highest with the PUR (Beaded) insulation. This is mostly due to the energy associated with the manufacture of both insulations and a small part attributed to the transport.

Furthermore, when the results in Table 7 are compared with the savings made by insulating the house, it is clear that it is reasonable to use a cellulose material manufactured in Wales but it is not reasonable to use a PUR (Beaded) insulation manufactured in Belfast. It is also interesting to note that PUR closed cell insulation has a lower energy associated with it than PUR beaded insulation even though they have a similar energy content associated with manufacture and delivery. This is a result of the greater thickness of insulation required with the beaded insulation as it has a lower λ value than the closed cell insulation. Therefore, when choosing insulation it is important to consider the energy associated with manufacture, the location of the insulation and the thermal conductivity of the insulation.

Finally, it is clearly shown in Table 7 that for all insulation materials, the adaptable dwelling has a lower energy associated with it than the traditional dwelling. On average, the energy associated with the external wall insulation of the adaptable dwelling is 30%-40% less than that associated with the traditional dwelling.

Table 7. Adaptable vs traditional construction for different insulation materials – energy associated with manufacture and transport only

Adaptable (Scenario 1)	Part L (kWh/y)	PH (kWh/y)	Traditional (Scenario 3)	Part L (kWh/y)	PH (kWh/y)
Cellulose	20	26		68	75
Fibreboard	172	320		242	412
Polystyrene	146	278		212	363
PUR (CC)	124	235		187	314
PUR (Beaded)	217	402		294	506
Fibreglass	63	109		117	169

5 CONCLUSION

Insulation is important in dwellings in order to limit heat loss and create a healthy indoor environment. Furthermore, the introduction of carbon taxes, rising fuel costs, and increasing energy insecurity, must be considered in order to protect the homeowner's sizeable investment and provide greater certainty and energy security over a longer period. However, with respect to the heat loss of the house when different U-Value levels of external wall insulation are provided, it is shown that it does not necessarily make economic sense to invest in a superior building envelope for dwellings in Ireland.

Adaptable dwellings use less material and have fewer deliveries to site; it is shown that this method of construction provides a lower total embodied energy content when compared with a traditionally constructed dwelling. Even though the case study examined external wall insulation only, these results can be translated to other insulations used in the dwelling. Furthermore, when the amount of energy required to manufacture and import the insulation is investigated, it is shown that the type of insulation and the location of manufacture with respect to the construction site is of paramount importance.

Finally, it is recognized that the methods used to calculate the heat loss of the dwelling and the LCA of the external wall insulation are simple methods. To corroborate the findings from this paper, more sophisticated methods will be used in future research. Future research will also examine other components of the dwelling and their effect on the LCA of the dwelling.

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Sugar components as a natural reinforcement of earth based construction materials

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ABSTRACT: An important part of the world's population, approximately 3 billion people, on six continents, lives or works in buildings constructed of earth based materials. A research work developed in the Trás-os-Montes e Alto Douro University (UTAD) and focused on the biomimetic study of the *Andorinha-dos-beirais* bird nest concluded that there is a strong possibility that this bird adds a significant amount of glucose type sugar into the clay material during the building process of its nest. Results from the numerical model of the nest indicated that this natural structural system works mainly in compression, which is in line with inherent properties of earth based materials, with reduced tensile and shear capacity. Experimental tests have shown that an agglutination phenomenon may occur resulting from the building process adopted by the *Andorinha-dos-beirais* bird. Based on these conclusions, this research work intends to analyse the influence of the glucose sugar type addition into the nest structural performance. In this context, compression tests were done varying the liquid phase, sugar percentage and curing period. Experimental results can be used to sustain the use of this technique in the context of earth buildings construction and contribute for the future developed and proposal of new raw building composite materials.

1 INTRODUCTION

The search for sustainable building construction solutions which have a reduce amount of CO2 emissions and energy consumption and, consequently, are environmental friendly is extremely important it the building industry intends to make a contribution on the climate change issue (Murta et al, 2009[1]; Murta et al, 2009[2]).

Half of the world's population approximately, 3 billion people on six continents, lives or works in buildings made from earth (www.eartharchitecture.org/). In the third world countries almost half of the existing buildings are made of earth (Minke, 2005).The earth construction is a worldwide heritage that reflects the existing cultural diversity of people (Carvalho et al, 2008). Examples of ancient earth constructions are: the China Wall (2000 B.C.) (www.greatwallchina.info) and the Arge Bam city in Iran (500 B.C.) (www.flickr.com/photos/negaheno/). This impressive earth heritage also reveal that earth construction can have a very sustained durability. At the same time, cutting edge modern earth constructions, such as: the Adobe Repository for Buda Statue in Japan (2001 A.D.) (www.eartharchitecture.org/) and the Desert Cultural Centre in Canada (2006 A.D.) (www.canadianarchitect.com/), prove that earth based building materials are nowadays in demand. Earth has been used in recent years in the construction of dams in many countries (Zhang et al, 2008).

Redefining educational curricula to address sustainability issues is something that must occur at all levels of formal education (Tamoutseli, 2008), particularly in what regards the construction mega-sector. Earth based building materials are sustainable, in one hand because earth is natural, recyclable and abundant anywhere in the world, and in the other hand because the techniques used to manufacture these materials are usually simple, requiring an unexpressive amount of energy consumption and also having an unexpressive amount of CO_2 emissions associated. The building materials and the building techniques related to earth construction have been developed constantly, the emerging *quincha metálica* technique (Cortés, 2009) which intends to replace a traditional timber structure system by a metallic one keeping the traditional earth covering of the system is just one example.

The most popular traditional Portuguese building techniques that use earth as a building material are *taipa*, *adobe* and *tabique* (Carvalho et al, 2008).

The main objective of this research work is to study if a sugar component may be used as a natural reinforcement of earth based construction materials and contribute for the development of better sustainable building techniques. The sugar component can be obtained from an abundant plant or fruit which do not interfere with world food supply.

2 BACKGROUND

A biomimetic study of the *andorinha-dos-beirais* bird nest (Silva et al, 2009[1]; Silva et al, 2009[2]) has concluded that there is a strong possibility that this bird adds a certain amount of glucose into the clay material during the building process of the nest. This component may change the properties of the earth-based material, increasing the performance of this raw material. This study included: the identification of the elementary chemical and mineralogical compositions of the material samples by the scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) and by the X-ray diffraction analysis, respectively; the identification/characterization of the organic composition by using the colorimetric method, for which the protein components were detected by the biuret method and the polysaccharides/sugars components by the total sugar method. The type of polysaccharides/sugars identification and their amount quantification was done by the anion-exchange chromatography method.

3 LABORATORY RESEARCH DESIGN

The aim of the laboratory program related to this research work was to understand the potential effect of sugar on the compression strength capacity of a clayey soil. The reason for choosing a clay for this experiment was based on previous research (Silva et al, 2009[2]) which reports that clay is the main material used by the bird for its nest building.

This probably is related not only with the fact that its smaller particle size, when compared to sand particles, makes it easier to be carried during nest construction, but also due to the more stable chemical composition of sand particles, making it immune to combinations with sugar components. A very common type of clay used in soil related laboratory research was used – *china* clay.

The sugar added in the mixtures was current commercial sugar type. The use of a common type of sugar is economically justified, since its low cost will allow the use at a large scale for earth construction. Sugar crystals are orderly arrangements of sucrose molecules, which in turn are composed of carbon, hydrogen and oxygen (French et al, 2004). When the sugar is added to water, it goes into solution, but only up to a certain amount of sugar can be added to the solution for a given temperature. Sucrose can also be seen as a combination of two simpler sugars: fructose and glucose. Hydrolyze of sucrose in neutral environment (pH = 7) will result in the separation of these two components [1]:

$$\begin{array}{c} C_{12}H_{22}O_{11} + H_2O \Rightarrow C_6H_{12}O_6 + C_6H_{12}O_6 \\ \text{(sucrose) + (water) => (glucose) + (fructose)} \end{array} \quad [1]$$

While hydrolyze in acid environment (pH < 7) will result in two molecules of glucose, [2]:

$$\begin{array}{c} C_{12}H_{22}O_{11} + H_2O \Rightarrow 2\ C_6H_{12}O_6 \\ \text{(sucrose) + (water) => 2 (glucose)} \end{array} \quad [2]$$

Since rain has a pH between 5.6 and 5.7 in non-polluted atmosphere, it is fair to consider that hydrolyze during nest construction will take place in acid environment, meaning that glucose is the component responsible for the reaction. Samples with 0%, 2%, 6% and 10% sugar in weight of the total mixture were prepared (Table 1).

After consideration regarding the percentages of each component in the mixtures – specifically soil, sugar and water – it was decided to keep the water / (soil + sugar) at a constant value of 15%. The 15% value was obtained after some trial mixtures, intended precisely to estimate the water needed for mixture homogenization.

The other possibility considered and tested was to keep the water / soil ratio at a constant value when sugar percentage was modified, but it was declined since the variation in sugar would also modify significantly the viscosity of the solution.

The small increase in water / soil ratio of 1.9% between the 2% and 10% sugar content (Table 1) was necessary to compensate for the increase in the liquid phase viscosity. Otherwise the mixing process was significantly ineffective, making practically impossible to achieve an acceptable level of homogeneity.

The clay was previously dried for 48 hours before the mixing, to guarantee that the only water present in the mixture was the intended. The liquid and plastic limits of the used clay are 33.2% and 20.3% respectively, resulting in a plasticity index of 13%.

Sample size and shape was a 3 x 4.5 cm cylinder, to be tested for unconfined compression after 7, 14 and 28 days curing inside the molds. These curing periods were later altered, and a single curing period was used. This was due to the fact that the samples did not gain enough cohesion to be removed from the molds at the intended periods.

After the 28 days curing period passed without significant improvement in sample hardness, it was decided to leave the samples in the oven at 50º C for 48 hours. The increase in temperature accelerated the hardening process, allowing the testing of the samples after 30 days curing.

Table 1. Weight percentages in the mixture for every sugar content

	Sugar content			
	0%	2%	6%	10%
Soil	85 %	83%	79%	75%
Water	15%	15%	15%	15%
Water / soil ratio	0.176	0.181	0.190	0.200
Sugar / water ratio	0	0.133	0.400	0.667
Sugar / soil ratio	0	0.024	0.076	0.133

Three samples, from one batch, were tested to produce a single result. The molds were filled and weighted to guarantee minimal variations in density between the three samples (Figure 1). Overall there was only a slight change in density, even with the variation in sugar content (Table 2).

a) Clay b) Water c) Mixing d) Filling e) Weighting

Figure 1 – Procedures of the fabrication of the samples

Table 2. Average sample weight according to each sugar content

Sugar content	0%	2%	6%	10%
Average weight	58.84 g	58.72 g	58.40 g	59.04 g

The unconfined compressive tests (UCS) were performed in the Materials and Soil Laboratory of University of Trás-os-Montes e Alto Douro (UTAD) using a 5 KN capacity hydraulic testing machine, at a strain rate of 0.30 mm/minute, Figure 2.

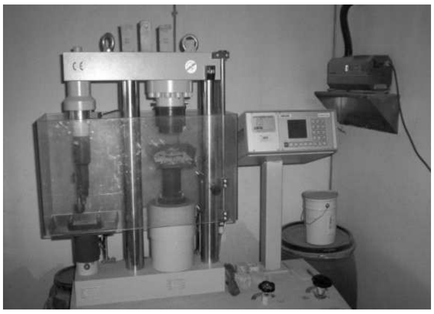
Figure 2: Compression test

4 LABORATORY RESULTS AND ANALYSIS

After being removed from the molds the samples revealed some voids in the volume (Figure 3), which increased with sugar content. This was particularly unexpected since the weight of the samples prior curing was similar (Section 3). Cracks (Figure 3, detail I), missing mass (Figure 3, detail II) and irregular top surfaces (Figure 3, detail III) were the main defects presented.

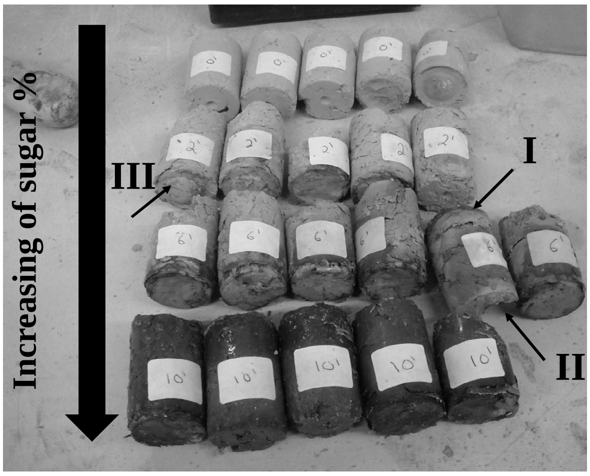

Figure 3. Some of the samples prior to UCS testing.

Some samples were so badly altered in shape that they could not be tested. This was due to deficiencies of the molding process, resulting from the high plasticity of the mixtures with sugar.

This setback casts some doubts on the final strength results obtained, since the exact cross section area of the samples could not be determined, hence the area of a circle with a 3 cm diameter was considered. The samples were weighted before testing (Figure 4).

The results with the unconfined compression tests are shown in Figure 5. The fact that the compressive strength was higher for the samples with no sugar probably reflects the better conditions in which these samples were extracted from the mold.

The fact that a higher temperature was used for the two last days of curing could also have some influence not only on the final shape of the samples but also on the compressive strength levels. To address this situation lower percentages of sugar should be tested in order to improve the curing process and avoid the need to increase temperature.

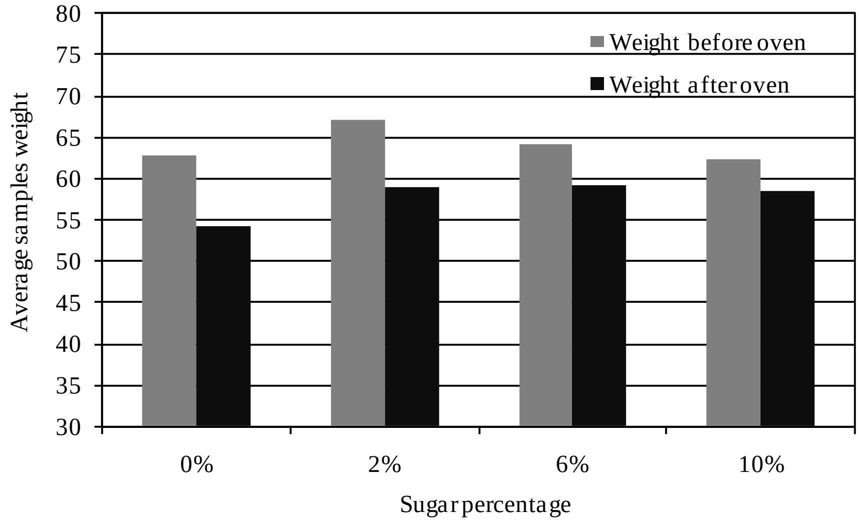

Figure 4. Average weight of the samples before and after oven.

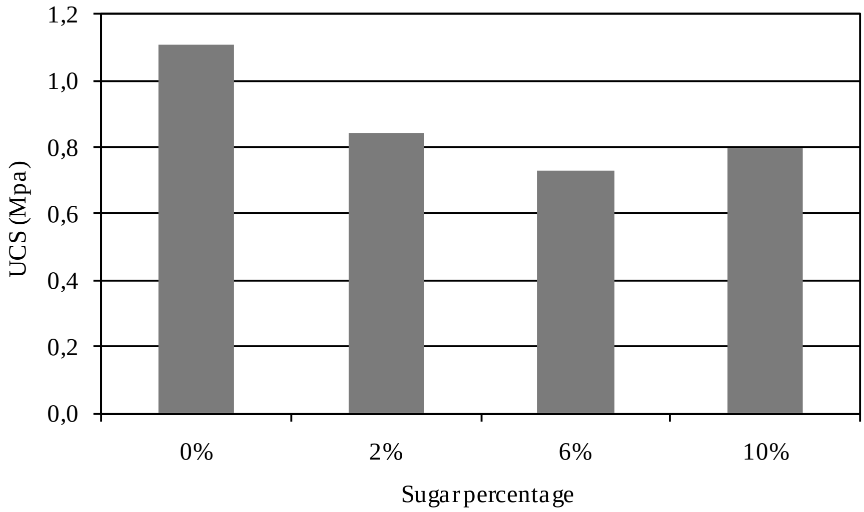

Figure 5. Unconfined compressive strength (UCS).

5 MAIN CONCLUSIONS

The work here presented was the first step in a thorough research program which is being held at UTAD university. Therefore, the options taken regarding the sample preparation and curing could not be based on any previous research ever reported. The conditions of the samples before testing revealed that some changes regarding their preparation are needed:

- Maximum sugar content should be lower. This will allow the mixtures to be prepared with the same water content (as referred in Section 3), which in turn will allow the use of just the necessary water for homogenization.
- Greater care is needed when filling the molds. A higher frequency table should prevent the samples from forming significant air voids in its volume.
- The samples need to be removed from the molds for curing, so that its condition can be controlled.
- In future tests curing in the oven should be avoided, since it might had some influence on final shape and strength of the samples.

This proposed changes in the testing process are already being put in practice and new developments should help prove the suitability of this technique for earth construction. Chemical analysis were also designed to help understand the reactions behind the expected soil improvement.

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The use of Natural Fibres on Architecture: the local economy and the Arts and Crafts

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ABSTRACT: This paper present a research work about sustainability of construction, based on the use of natural fibre materials on architecture. Several aspects will be presented and discussed, regarding social, economical and environmental issues. The objective is to propose an increased use of natural fibres on exterior facade walls of buildings, using as model the vernacular architecture. Wall typologies will be presented from an historical; a state of art and also suggesting future expected developments. The proposed façade wall types using natural fibres will be compared with the conventional hollow brick walls mostly used in Portuguese contemporary construction. The history of using natural fibres in Portugal, related with the geographic conditions and the available resources will also be described and some examples shown. Moreover, it will be pointed out the importance of the use of natural fibres on the local economy.

1 INTRODUCTION

Currently, our society faces the need to meet a response to a social requirement that has major implications in our production system and, specifically, in the field of construction materials: regarding to sustainable development (Cuchí, 2005). A sustainable society is an utopia, as since the Neolithic period that Man started to exploit resources more then nature by itself can give. This scenery got exponentially worst after the Industrial Revolution and especially on the end of the nineteenth century. A sustainable use of resources is nowadays only possible in those areas of the planet that were isolated from the consumer society, where the mutual relationship of man with nature allowed life in harmony with the ecosystems. Construction is one of the sectors that more intensively use materials.

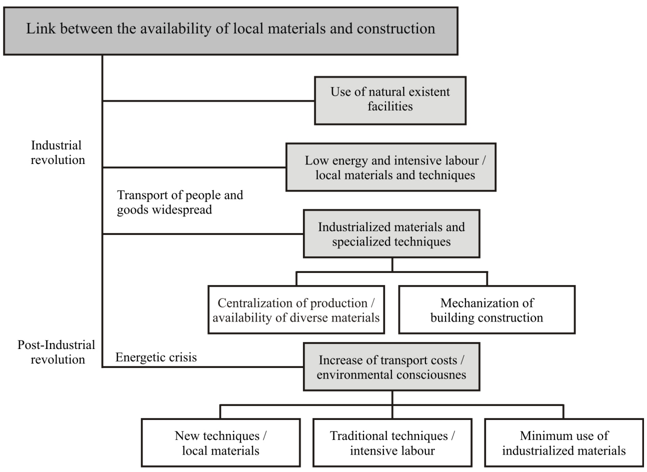

Figure 1. Link between the availability of local materials and construction

The figure 1 makes a link between the availability of local materials and the construction in the periods of the Industrial Revolution and Pos-Industrial Revolution. After the Industrial Revolution, which caused the massive production of materials and generating a strong energetic crisis, Man had as consequential choice return to the past, refocusing in the local material and artisanal techniques, in order to minimize the use of industrial materials, but additionally applying the new technologies. According to the World Watch Institute (WWI), the construction of buildings and infrastructure consumes between 45% and 60% of materials extracted from the lithosphere.

One of the Man characteristics is the ability to transform the raw materials available in nature and overcome the lack of biological tools available that other predatory species have (Dantas, 2004). The technologies that use natural fibres reveal knowledge, meanings and relationships that take together social groups, and the extinction of this knowledge undermines the identity and the own existence of those groups and those with which they interrelate. Human beings cannot exist without the integration with their environment: *Homo Faber* became conscious of their action on the nature and control the environment through actions, where the useful act, i.e., the tool using the technique, is of fundamental importance in this context (Cerqueira, 1994).

One may believe that it is still possible to live doing some things by hand, according to our own pace and with perfect knowledge of the overall process. The craft is one of several popular strategies, which enables intelligent men and women return back to scepticism and direct the work process as the design of their artefacts. The contemporary craft is necessarily peripheral relatively to the bulk of economic activity. Beginning in the seventies, it was easy to correlate the gross domestic product and energy consumption with the countries economic development. Moreover, a higher consumption means more synthetic fibres to meet the demands, larger displacement both of labour and leisure, more housing surface area and more services in general.

1.1 *Materials on the first settlements*

The first material produced by man to get a shelter was the woven and are rare the civilizations that did not develop some kind of braided natural fibres. The fragility of the material with respect to its preservation within the time, have left less traces of the emergence of the straw than the left by the pottery.

These huts or shelters were presented in various forms, depending on the conditions of the natural environment and resources or materials that were provided by nature (Veiga, 1967). The tents and nomadic dwellings are built from knowledge inherited and transmitted to new generations, with simple geometric shapes (square or circular), facilitating the manipulation by any member of the social group. This type of architecture is constantly changing as a result of its reuse over time and is closely related to the socio-economic group to which belongs, to the surrounding landscape, the aspects of lightness and transport, the natural elements and the easy assembly and disassembly (Finkielsztejn, 2006). From the end of the Palaeolithic, in regions where there was no natural shelter under rocks, the man has raised small buildings with natural fibres. Those shelters are characterized as elements of low stability and durability and, consequently, have not left very significant traces; therefore its forms can be established only tentatively.

Figure 2. Citania de Briteiros, Guimarães

Only since the Neolithic period housing archaeological remains have started to be evident, the scientific and anthropological studies allowed a faithful reconstruction of the original dwellings, where can be seen the presence of covers made of natural fibres (straw coating over wood structure); as in the case of "Citania de Briteiros", in Guimarães city (Fig. 2).

2 NATURAL FIBRES

Plant fibres are flexible, have great resistance to abrasion and can withstand the heat and light from exterior exposure. Some can also withstand the marine environment. They are all biodegraded by the action of microorganisms, an advantage in certain situations. According to its consistency, natural fibres can become rigid, malleable after drought, or maintain their consistency and hard before being cut. Some natural fibre materials are commonly used in construction, apart from wood, the most common natural fibre used in construction cork and coconut fibres are nowadays common insulation materials.

2.1 *Cork*

The cork-expanded results from the agglutination of compressed granules and connected only with its own resin under the influence of pressure and temperature, without using any chemicals. It is presented in the form of plates and aggregates and their most common applications are thermal and acoustic insulation of roofs and attics; isolation of pipes carrying liquids with high positive or negative temperatures; thermal and acoustic insulation of interior and exterior walls; slabs isolation to the transmission of percussion sounds; vibration-isolation (industrial machinery).

The cluster expanded material is a long-lasting, rot proof, resistant to compression and high dimensional stability. It has the advantage of serving both the thermal and acoustic insulation, which does not happen in conventional polystyrene foam. Its application in plates is easy, since it can be cut with a common saw. It is a 100% recyclable material. The main raw material, is of natural origin, is renewable and is a Portuguese product, so its use also promotes the Portuguese economy. Although the plates have slots which can bring acoustic or thermal bridges problems during its place, if not filling the box tubes in totality. It is relatively heavy compared to other insulation materials. Cork burns, making it less suitable for some types of uses and their protection in the fire box-of-air must be safeguarded, especially in multi-storey buildings, to prevent the spread of fire between floors (Mendonça, 2005).

Portugal, while being a country of small size, produces more cork than the rest of the world, occupying the cork a large area of Portuguese territory and has a very important contribution to the economy and ecology of several Mediterranean countries. An analysis of cork distribution by country immediately shows that Portugal has around 33% of the world; where it is find mainly in the Alentejo (72%), Lisbon and Tejo Valley (21 %). However, little is known about the use of cork as a building material in the past. In the neighbourhood of Cortiçadas, one can find traces of buildings where the cork was used as a building material (Fig. 3).

Figure 3. Wall made of Cork and Earth in Cortiçadas.

2.2 *Coconut Fibre*

Originally from India and Sri Lanka, began to be introduced in Europe after the Portuguese arrival in India. It can be used as thermal and acoustic insulation, which is highly effective, especially combined with the cork-expanded. The use in the world of natural raw and renewable materials in large quantities, has several advantages, compared to the use of a material that would end lost, and that is transformed without detriment to the environment, placing the coconut fibre in the range of friendly products. Coconut fibre has many advantages in its use, in addition to being an environmentally friendly material and easily recyclable. Belonging to the family of hard fibres, its main components are cellulose and wood that give high levels of rigidity and hardness, being perfectly suited to the markets of thermal and acoustic insulation, due to its characteristics: strength, durability and resilience, making it a versatile material. Due to its exceptional acoustic performances, it contributes to a substantial reduction in noise levels, either of impact or air, ideal for many of the problems in the acoustic area greatly exceeding the results obtained with the use of other materials. However, its application is hampered by the difficulty of webs cutting, since the fibres are very tough and offer much resistance to the blades, as well as conventional drills, locking up and not letting them to penetrate the material. Because it has not fittings, if not placed with care can lead to the emergence of sound bridges. It is also a fuel, such as cork (Mendonça, 2005).

The use of different natural fibres in Portugal architecture was, in the past, closely linked with the characteristics of climatic regions, which differ over territory. As example of nowadays constructions, using natural fibres, in Portugal regions with different climatic characteristics are: a) a construction carrying out with primitive techniques in the North of the country (Gerês), a perfect example to promote an area of natural interest by means of traditional architecture (Fig. 4) and b) The “Empena” House in Madeira Island, in the form of inverted V, that in the past served to store agricultural products and nowadays is a tourist residential houses, very typical of the Island (Fig. 5).

Figure 4. Recent constructions in the North of Portugal.

Figure 5. “Empena” House in Madeira Island.

3 BUILDING SYSTEMS FOR EXTERIOR WALLS

Housing is one of modern architecture's most important areas of investigation, from urbanism to typologies and constructive technologies, but we can conclude that flexibility was not a decisive concern, as most buildings are badly adaptable to changeable living patterns. Investigation on flexibility got more importance in the recent past, starting in the late 80’s (Gausa, 1998), and also relating to refurbishment, due to a growing environmental concern. In contrast to traditional policies of rehabilitation or demolition and replacement carried out until now, the architects Frédéric Druot, Anne Lacaton and Jean−Philippe Vassal face these issues from an ingenious angle by proposing a radical transformation. Based on an interpretation of the pre−existing, they propose a surgical intervention with the aim of granting dwellings more space, more sunlight, and more freedom of use and more services available. Such a recycling operation turns out to be more economic than the usual policies of demolition and replacement (Druot et al, 2007).

Growing necessity to save material and energetic resources, allied to a growing concern over the environmental issues and incertitude on the evolution of the economy, has impelled minimalist-approaches to Architecture and Engineering, reducing to the minimum necessary expression the constructive elements. These approaches, by some authors called "Light-tech" (Horden, 1995) and Eco-tech (Slessor, 1997), bets on the introduction of more materially and energetically efficient solutions. But not always a material optimization corresponds to a functional optimization – reduction of weight generally implies functional problems. A lightweight housing building can be problematic from the point of view of comfort, because of the insufficient thermal inertia and acoustic insulation, due to the reduced mass, but if these problems are solved, they can constitute potentially interesting solutions from the point of view of sustainability. An heavyweight envelope does not necessarily means an high thermal inertia building.

Brand (1994) proposes a strategy for constructing adaptive buildings using traditional materials, attention to local vernacular styles and budgeting in order to allow continuous adjustment and maintenance. Building is composed by different elements that should be easily dismantled by durability layers: Site; Structure; Skin; Services; Space plan and Stuff. It’s the constructive autonomy between the different layers that allow the functional life of a building to last more and thus its flexibility. Interior partition (Space plan) and also stuff are the components of a building that we should rely to increase adaptation, but we should also rely on the relation between these elements and the outer skin, especially in refurbishment.

Reduction of weight, by using the minimum material necessary, is a way to achieve eco-efficiency, allowing easy recycling, reusing and flexibility. This can be understood as an ecological approach to accomplish the function, weighting only a small part of what could weight a conventional constructive system.

Since the first documented buildings in the national territory, the construction techniques used in Portugal housing were mostly mixed, in terms of weight. They had an exterior envelope extremely heavy with an average thickness of 0.40 m in stone, brick or adobe. In the last 50 years the brick was introduced initially without insulation. Only in the eighties, double pane walls-s with thermal insulating material in the air gap were introduced. Later, in the nineties, with the introduction of a thermal regulation (1990) began to be compulsory to thermally insulate the building envelope in order to minimize the heat exchanges with the outside world; and the ETICS (External Thermal Insulation Composite System) appeared to better respond to those requirements. The ETICS system had the advantage of being applied to a new outside wall or to an existing; it was advantageous in the case of buildings with poor insulation, leaking or damaged aspect. Moreover, it could decrease the risk of condensation, treating somewhat the thermal bridges. In the construction of new exterior wall, the best solution is a combination of the ETICS and an interior single-wall with great thickness (Mendonça, 2005). But there are other comfort related aspects more difficult to characterize. In countries such as Portugal, with a daily thermal amplitude oscillating most of the year below and above the temperature of ideal interior comfort, insulation and shading of external facades are not, by itself, effective and can even be problematic.

Thermal inertia is very important in a solar passive housing on a temperate climate, as its absence can result in a night rapid descent of temperature and a resulting excessive daily thermal oscillation in the interior. Since the pavement or other elements such as external walls or interior furniture can take the role of thermal storage, the bet can be to optimize their performance by a thermal zoning of the occupancy. The magnitude and configuration of the thermal mass should be determined in order to store sun heat in agreement with the daily thermal widths and with the occupation type, for example to maintain an interesting interior temperature, during the night, in cold days (Bradshaw 1993).

3.1 *Proposed and Conventional walls*

The construction period environmental impact here presented is based on the sum of Embodied Energy (PEC) with the transport and the construction energy, converted in economical costs, that examines what goes from the extraction of raw materials until the completion of construction work. The assessments of sustainability include the study of the economic viability of the different façades developed through the quantification and comparison of PEC with the other constructive solutions existing in the market. Using this methodology, the sustainability of two proposed solutions, Natural fibre lightweight and heavyweight wall (Fig. 6a, 6b) were evaluated in comparison to conventional solutions (Fig. 6c, 6d). Lightweight wall (Fig. 6a) is composed of the materials: cement/wood shavings (12 mm), air gap, expanded extruded polystyrene, cement/wood fibre board (19 mm), black cork agglomerate, coconut fibre, air gap, 2 Gypsum boards carton (13 mm); and a heavyweight wall (Fig. 6b) is composed of: cement/wood fibre board (12 mm), air gap, black cork agglomerate, adobe, lime.

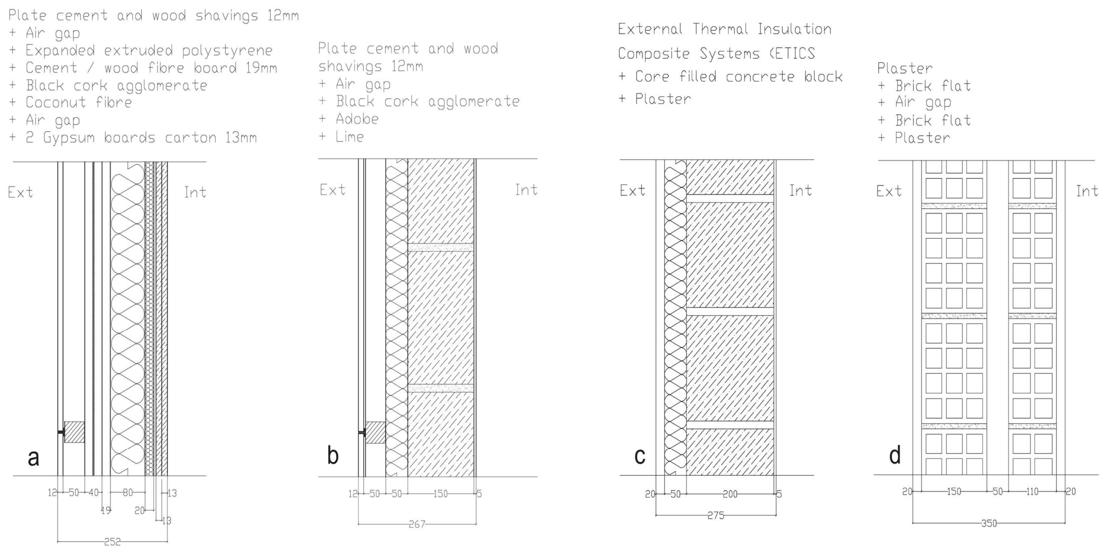

Figure 6. Proposed walls: a) Natural fibres lightweight wall, b) Natural fibres heavyweight wall. Conventional wall: c) Simple Wall o the 90's decade; d) Double Wall of the 80's decade.

The technical characteristics of a Conventional and Natural Fibres walls, obtained from a previous Social Housing study made by the authors (presented on the Conference "L'Architettura Sostenibile e le Politiche dell'alloggio sociale in Europa", held in June 2009 on Naples, Italy), are presented in Table 1.

The characteristics of the walls, above mentioned, were compared; Thickness, Acoustic insulation, U value, Embodied Energy, Specific weight, Specific useful thermal mass and Specific cost were calculated for both; additionally the average of all those values was estimated. The Best and Worst Values are marked in the table. In the case of Conventional Walls, the simple one appears as better than the double in all the characteristics analysed.

The proposed wall using natural fibres are good alternatives to the Conventional as better results were obtained in all the compared characteristics, except in the acoustic insulation in the conventional simple wall; although this parameter is not the one that most affect the residents.

Lightweight Natural Fibre wall presents best values in term of thickness, U value and Specific weight and Heavyweight wall, in the Embodied Energy, due to the higher mass, and the specific costs.

Table 1. Technical Characteristics of Conventional and Natural Fibre Walls.

Conventional Walls	Simple wall	Double wall 15+11	Average
Composition	ETICS + Hollow brick 22 + Plaster	Plaster + Hollow brick 15 + Air gap + XPS + Hollow brick 11 + Plaster + Clay Tile	
Thickness (cm)	275	350 [ii]	312.5
Acoustic insulation Dn,w (dB(A))	53 [i]	51 [ii]	52
U value (w/m2.°C)	0.42	0.49 [ii]	0.46
Embodied Energy (kWh/m2)	858	1018 [ii]	938
Specific weight (kg/m2)	268	332 [ii]	300
Specific useful thermal mass - Msi (kg/m2)	150 [i]	89	119.5
Specific cost (€/m2)	63.15	73.35	68.25

Natural Fibre Walls	Lightweight wall	Heavyweight wall	Average
Composition	Cement/wood fibreboard 12mm + Air gap + Expanded extruded polystyrene + Cement / wood fibre board 19mm + Black cork agglomerate + Coconut fibre + Air gap + 2 Carton Plaster Board 13mm	Cement/wood fibreboard 12mm + Air gap + Black cork agglomerate + Adobe + Lime	
Thickness (cm)	252 [i]	267	259.5
Acoustic insulation Dn,w (dB(A))	50 [ii]	53 [i]	51.5
U value (w/m2.°C)	0.40 [i]	0.44	0.42
Embodied Energy (kWh/m2)	442	171 [i]	306.5
Specific weight (kg/m2)	79 [i]	257	168
Specific useful thermal mass - Msi (kg/m2)	22 [ii]	89	55.5
Specific cost (€/m2)	85.9 [ii]	46.55 [i]	66.23

[i] Best values; [ii] Worst values.

The use of lightweight construction materials and systems can easily allow reach a good environmental profile. But a lightweight housing building in a temperate climate can be problematic, from the point of view of the thermal comfort because of the insufficient thermal inertia. The introduction of some thermal mass is thus essential to achieve comfort with the minimum use of mechanical heating and/or cooling systems and also from the acoustical performance point of view, as acoustic insulation relies essentially on mass, especially for the medium and low frequencies. That’s why a mixed weight system was proposed by Mendonça (2005), with an optimized mass use, in order to allow an intermediate weight between a lightweight solution and a conventional heavyweight solution. The proposed system also pretends to conciliate the thermal, acoustic and natural illumination performance. Apart from its functional efficiency, this strategy can be more consensual then the common prefabricated lightweight constructive systems (so-called prefabricated panels). It is important to refer the fact that this proposal is a system and so the proposed solution here presented and evaluated is just one possible solution for this system.

4 CONCLUSION

In this paper the possibility to achieve more sustainable housing units replacing synthetic materials by natural fibres on exterior walls was demonstrated, having in mind that functional aspects can be safeguarded. Two alternatives for external walls using Natural Fibre materials were given and a comparison study with the Conventional wall solutions revealed that they present better values in almost all the characteristics analysed. The Natural fibre elements of the proposed Walls can also be made by using artisanal methods and techniques, in order to achieve a more sustainable production cycle. As natural material, Cork and Coconut are good applicable solutions already being applied.

In the past, Portugal construction was strongly characterized by primitive techniques using the raw materials existent in the different regions over the territory. Nowadays, very little reconstructions can be found and the existent are in touristic areas such as in the Natural Park of Gerês and in Madeira Island. Cork, a 100% recyclable material, is a Portuguese product, so its use also promotes the Portuguese economy and local ecology. Indeed, Portugal produces more cork than the rest of the world, occupying the cork a large area of Portuguese territory. There are many cork applications, such as in Bottle Tops, Interior Design, Fashion Accessories (bags and jewellery, etc) and Stamp. In construction, it is used as thermal and acoustic insulation of interior and exterior walls.

Other sustainable strategy in Portugal is the Art Craft, one of several popular strategies, which enables intelligent men and women return back to scepticism and direct the work process as the design of their artefacts using natural raw materials and recovering past techniques or adapting new taking the knowledge from the old ones.

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Reabilitação Sustentável de Edifícios Industriais: Melhoria de Iluminação Natural e Conforto Térmico em Miraflores

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ABSTRACT: O uso eficiente de energia eléctrica tem vindo a adquirir uma importância crescente, tornando-se cada vez mais visível através das campanhas de conservação e poupança de energia. A iluminação é um dos sistemas onde se pode conseguir grandes reduções de consumos sem proceder a grandes investimentos, sendo imprescindível adicionar à poupança energética, os ganhos psico-fisiológicos e de produtividade, resultantes do bem-estar pessoal. Foram simuladas soluções de melhoria de iluminação natural, com recurso a um luxímetro, ao programa ECOTECT e ao Método LT. Elaborou-se uma maqueta, à esc. 1/50, com a aplicação dos materiais preconizados. Foi medido o FLD (Factor de Luz-Dia) para uma análise quantitativa da iluminação/m^2**.**ano. Os valores obtidos para a solução proposta, permitiram reduzir as necessidades energéticas em 45%, passando de 124,81 kWh/m^2.ano para 69,95 kWh e as emissões de CO2 passaram de 27,46 kg/m^2.ano para 15,39 kg/m^2.ano. A solução tem um pay-back de 3,5 anos.

1 REABILITAÇÃO SUSTENTÁVEL DE EDIFÍCIOS INDUSTRIAIS: MELHORIA DE ILUMINAÇÃO NATURAL E CONFORTO TÉRMICO EM MIRAFLORES

1.1 *Introdução*

De acordo com um estudo da Agência de Energia “Oeinerge”, o sector dos Serviços foi identificado como aquele em que a procura de energia eléctrica mais tem aumentado, apresentando a mesma procura relativa em 1994 que o sector doméstico (cerca de 37%) e tendo sofrido um acréscimo de peso relativo para 52% em 2003. Em termos genéricos pode-se afirmar que os edifícios são responsáveis pelo consumo aproximado de 62% de energia eléctrica, conforme se pode observar na figura 1.

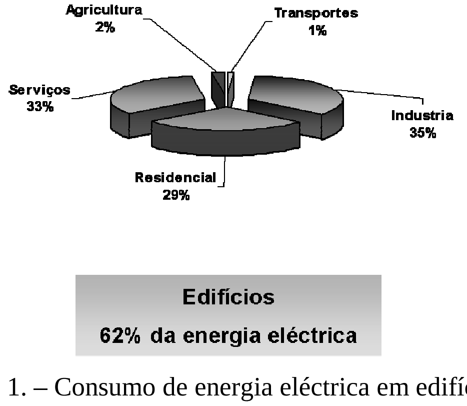


Figura 1. – Consumo de energia eléctrica em edifícios

1.2 *Sustentabilidade e Reabilitação*

O uso eficiente de energia eléctrica tem vindo a adquirir uma importância crescente no nosso país, tornando-se cada vez mais visível através das frequentes campanhas publicitárias de informação e estímulo à conservação e poupança de energia, nomeadamente as veiculadas através da Agência para a Energia – Adene.

Refere-se ainda a recente legislação (2006) que abrange quer os edifícios, no sentido de se reduzirem consumos energéticos quer os equipamentos obsoletos substituindo-os por tecnologias mais eficientes e optimizando-se, deste modo, métodos e tempos de fabrico, questões essenciais para o desenvolvimento económico e empresarial.

Considera-se premente afirmar que é cada vez mais difícil projectar ou reabilitar edifícios de uma forma eficiente e sustentável, quando não se tem uma ideia qualitativa e quantitativa do peso de determinadas medidas combinadas entre si, em fases preliminares de projecto. Este desconhecimento pode dar origem a decisões técnicas mal fundamentadas, com impactes económicos e ambientais negativos. A iluminação é um dos sistemas onde se pode conseguir grandes reduções de consumos sem proceder a grandes investimentos. Tendo ainda em consideração que o aumento da qualidade do ambiente interior gerado por um acréscimo de iluminação natural é fundamental, torna-se necessário adicionar à poupança energética os ganhos psico-fisiológicos e de produtividade, resultantes do bem-estar pessoal (Carvalho, 1999).

É objectivo deste estudo dar uma resposta quantitativa e qualitativa às necessidades de acréscimo de iluminação natural e melhoria do conforto térmico para o interior da Nave 1, tendo-se recorrido a diversas simulações para uma análise objectiva das diversas soluções (*vd* figura 4). Este estudo aprofunda uma das temáticas abordadas na Dissertação de Mestrado sob o tema *Reabilitação Sustentável de Edifícios Industriais – Estratégias de Design Bioclimático para o Complexo de Miraflores*, defendida na FA.U.T.L. em 2007.

Figura 2. – Planta de localização Nave 1

Figura 3. – Imagem exterior da fachada Sul

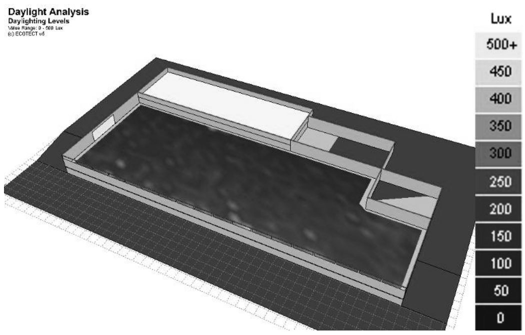


Figura 4. – Níveis de análise de iluminação natural em Lux - Nave 1

As técnicas solares passivas e bioclimáticas passaram a integrar a construção dos edifícios com o objectivo de reduzir consumos, entre os quais, a energia eléctrica. Segundo o Prof. Manuel C. Guedes, do I.S.T. "o objectivo prioritário da arquitectura bioclimática, por vezes também designada por «arquitectura solar», é a minimização do consumo energético recorrendo ao uso de estratégias de design passivo, i.e., reduzindo a necessidade de utilização de meios mecânicos de climatização ou iluminação artificial e potenciando os benefícios da iluminação natural, através de uma sábia adaptação do edifício ao contexto climático local" (Guedes, 2004).

Diversas experiências e estudos têm mostrado que, para uma iluminação de boa qualidade, a aparência de cor das fontes de luz deve estar de acordo com o nível de iluminação adequada à função do espaço a que se destina.

2 ILUMINAÇÃO EM EDIFÍCIOS DE SERVIÇOS

A filosofia de projecto na década de 70, para edifícios de serviços, ainda passava por se garantir um nível lumínico artificial constante, desprezando as variações de iluminação natural exterior e não considerava necessidades específicas decorrentes da ocupação espacial e do uso. Na figura 5, projectou-se a iluminação artificial existente constituída por lâmpadas de vapor de mercúrio na Nave 1, podendo-se constatar que esta filosofia se encontra desadaptada às exigências legislativas actuais, com consumos exagerados e reflexos negativos no âmbito da eficiência energética.

O problema da iluminação natural nestas tipologias pode ser colocado nos seguintes termos:

Em primeiro lugar deve-se considerar a interacção entre o edifício e as condições físicas do céu (iluminação directa do Sol e iluminação reflectida quer pelo solo, quer por superfícies iluminadas naturalmente). Em segundo lugar deve-se analisar a interacção entre o edifício e o espaço interior iluminado, através das aberturas existentes e a forma como recebem e transmitem a iluminação natural do exterior.

Com lâmpadas fluorescentes de elevada eficácia luminosa, conseguem-se produzir 80 lm/W ou seja, 80 unidades de fluxo luminoso por cada unidade de fluxo energético. A luz natural apresenta eficácias bastante mais elevadas: 100 lm/W para a luz do céu directa, 115 lm/W para a luz do céu encoberto e 135 lm/W para a luz do céu limpo (Carvalho, 1999).

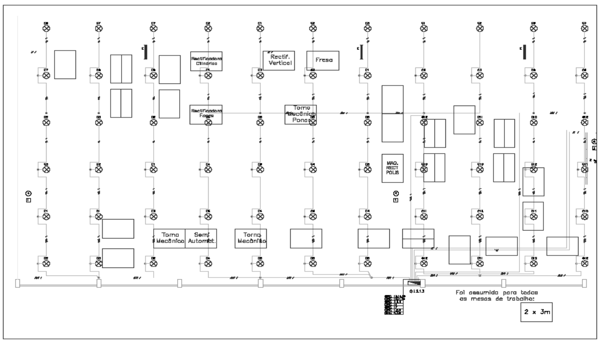


Figura 5. – Planta iluminação artificial da Nave

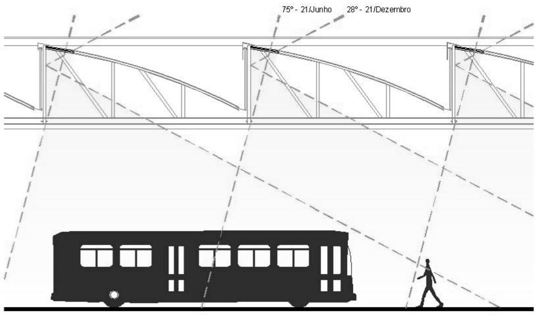
Figura 6 – Dispositivos de iluminação artificial existentes (vapor mercúrio)

3 ILUMINAÇÃO EM EDIFÍCIOS DE SERVIÇOS

Foram simuladas várias soluções de melhoria de iluminação natural (*vd* figura 7), através do recurso a medições no local (luxímetro), ao programa informático Ecotect e ao Método LT (Light & Thermal Method) referindo-se neste estudo as mais significativas:

Solução A - Substituição parcial da chapa metálica por uma chapa de policarbonato alveolar de 10mm;

Solução B - Substituição parcial por chapa policarbonato alveolar de 10mm e projecção de produto celuloso claro pelo interior da chapa existente



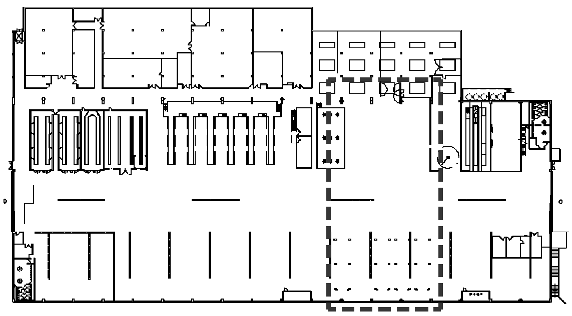


Figura 7 – Esquema de substituição parcial da cobertura por chapa de policarbonato

Figura 8 - Troço da Nave 1 em maqueta a tracejado

3.1 *Medição dos níveis de iluminação natural – Luxímetro e FLD*

Apesar dos processos informáticos utilizados para a simulação de iluminação natural, considerou-se fundamental a utilização de uma maqueta, à escala 1/50, com a aplicação dos materiais de cor idêntica à situação existente, de modo a obter um modelo que correspondesse o mais fidedignamente possível à realidade.

A maqueta reproduz um corte de um troço transversal da Nave (*vd* figura 8), troço esse representativo da principal área da Nave.

Considerou-se um tipo de céu encoberto (através da colocação da maqueta em sombra) de modo a validar os valores, através de medições da quantidade de iluminação interior face à exterior pelos vão envidraçados, sem entrada de luz directa. A constante instabilidade dos níveis de iluminação exteriores, torna impossível a comparação de valores em Lux, medidas no interior e no exterior num mesmo instante de tempo, pelo que foi necessário recorrer ao Factor de Luz-Dia (*vd* figura 11). A sonda exterior, foi apontada para a cúpula celeste e a interior foi localizada à altura equivalente de um plano de trabalho.

Para além dos valores medidos através do luxímetro e traduzidos através do FLD foi possível fazer-se um estudo qualitativo, através da captação de imagens no interior da maqueta.

Figura 9 - Imagem actual da Nave 1

Figura 10 – Simulação do produto celuloso

		Situacao Existente	Cob. Original + Vidro	Cob. Branca	Cob. Branca + Vidro
Lux	Interior	182	490	740	1730
	Exterior	2800	3200	2970	2940
FLD	Interior/Exterior	6.50%	15.31%	24.92%	58.84%

Figura 11 – Valores FLD medidos em maqueta para o existente e para as várias soluções

3.2 *Simulações Programa ECOTECT*

As análises com o recurso ao software Ecotect (*vd* figs 13 e 14) permitiram apurar, face à situação existente, que a introdução do produto celuloso claro na cobertura aumenta o FLD em todos os espaços. A introdução de envidraçado na cobertura é a solução que aumenta consideravelmente o valor de FLD em toda a área, tornando-a mais homogénea.

Conforme se pode verificar na fig 12, as várias soluções atingem um FLD entre 3% e 5%, valores recomendados pelo Prof. N. Baker em "*Daylighting in Architecture*" como complemento ideal para a iluminação artificial aliadas ao facto das fenestrações se encontrarem localizadas a cerca de 4m de altura, em relação ao plano de trabalho. Verifica-se que o valor médio da iluminação artificial obtido no plano de trabalho (70cm do pavimento) é em média de 60 Lux (*vd* fig 13), valor bastante reduzido e insuficiente, face ao excessivo consumo de cada iluminaria existente de vapor de mercúrio (250W).

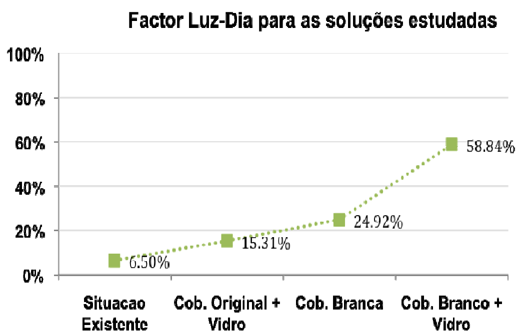


Figura 12 – Valores FLD medidos em maqueta

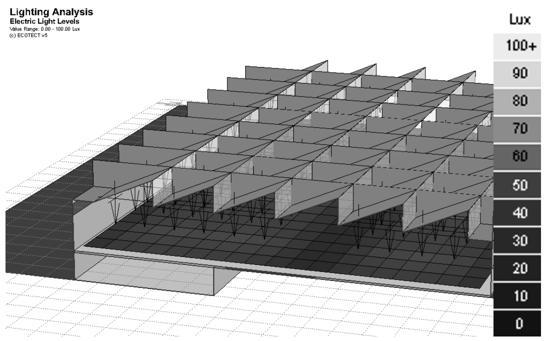


Figura 13 – Simulações obtidas no Ecotect

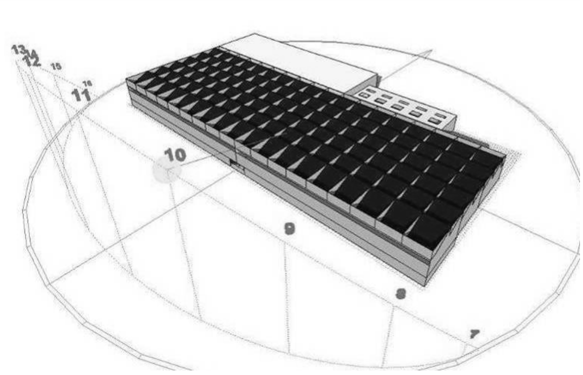


Figura 14 – Modelo Solar ECOTECT Nave 1

3.3 *Simulações com o Método LT*

O Método LT, usa um modelo matemático tendo em consideração o clima, as áreas passivas (áreas mais próximas das fachadas) e as áreas não passivas (afastadas das fachadas ou isoladas) e alguns parâmetros do design dos edifícios, como sejam: a profundidade dos espaços, orientação e área e distribuição dos envidraçados. O método LT foi aplicado ao presente caso de estudo (*vd* figura 16) para avaliar as reduções de energia eléctrica na iluminação artificial dos espaços em função de soluções que permitem aumentar a percentagem de iluminação natural, traduzindo igualmente a variação em termos das necessidades de aquecimento e arrefecimento (*vd* fig 15).

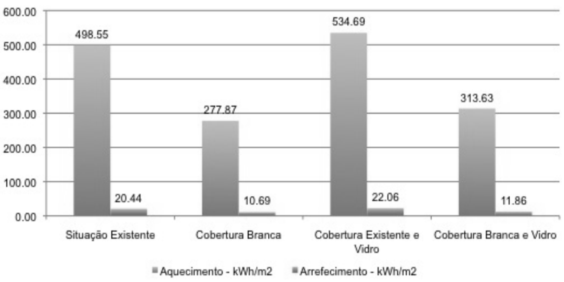


Figura 15 – Análise comparativa dos consumos das várias soluções

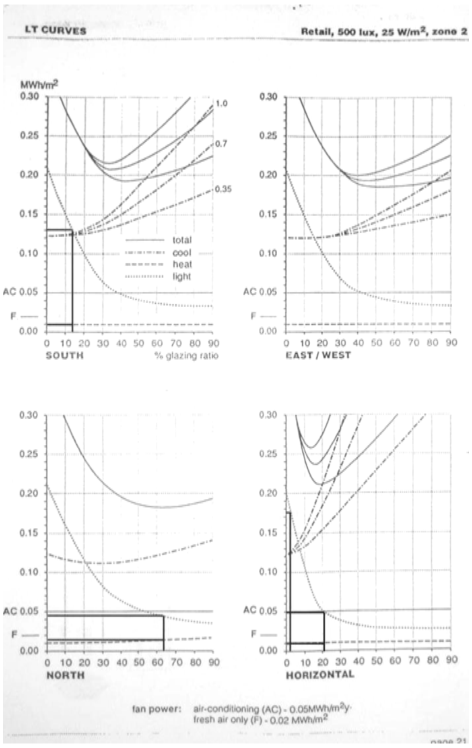


Figura 16 – Curvas LT determinação dos parâmetros a utilizar de acordo com a orientação

4 CONCLUSÕES

Na situação existente, constata-se excessiva luminosidade na zona adjacente à fachada (provocando encadeamento) e diminuição brusca da mesma em profundidade.

A primeira opção (cobertura branca) é a que se revela mais eficaz do ponto de vista térmico e reflexão luminosa junto à janela Sul, única fonte que dispõe para disseminar a luz natural, função da projecção de produto “Sonaspray” cujas características térmicas e acústicas já se referiram, mas constata-se que vai diminuindo à medida que a profundidade aumenta;

A segunda opção (cobertura cinzenta existente + vidro na cobertura) revela um ritmo de luz que é interrompido sempre que a transição entre as “clarabóias de vidro” se efectua, ou seja o ritmo claro/escuro não possibilita uma distribuição lumínica uniforme no espaço e que resulta num sobreaquecimento do mesmo.

Quanto à terceira opção (cobertura branca - aplicação de Sonaspray + iluminação natural na cobertura) foi a que se revelou mais eficiente do ponto de vista da reflexão da luz ao longo da Nave, reduzindo significativamente o período de horas de funcionamento da iluminação eléctrica e contribuindo para a melhoria do conforto térmico no Verão.

A análise qualitativa com recurso ao aumento do contraste permitiu concluir que os modelos com a cobertura em cor clara difundem bastante mais a iluminação natural por todo o espaço da nave, reduzindo o contraste entre áreas existentes muito iluminadas junto à fachada Sul (encadeamento) e áreas escuras e pouco iluminadas.

Através da pesquisa e de uma revisão bibliográfica, da realização de uma maqueta de estudo no local para medições e das várias simulações necessárias para o desenvolvimento deste estudo, considera-se que estamos em condições de contribuir para a mudança de percepção da forma como os profissionais, sejam arquitectos, gestores, órgãos decisores ou industriais podem intervir, de uma forma pro-activa e consciente para a sustentabilidade em geral e para a redução da factura energética dos seus edifícios em particular.

Este estudo teve como suporte diversas ferramentas de design, que se apresentaram ao longo do estudo e que forneceram os indicadores necessários para a elaboração de recomendações e interacções resultantes das medidas aplicadas quer o nível da melhoria da iluminação natural quer das implicações em termos das necessidades de aquecimento/arrefecimento resultantes (LiderA).

As soluções estudadas tiveram em conta as relações entre o meio ambiente, a tipologia do edifício e o utilizador e abrangeram diversos níveis de intervenção, que poderão ser faseados, desde a simples substituição de balastros electromagnéticos por balastros electrónicos, passando pela concepção de soluções de natureza mais complexa que se foram descrevendo e que se provou contribuírem significativamente para poupar energia eléctrica e emissões de CO_2 e melhorar os níveis de conforto dos utilizadores e o desempenho energético e ambiental da Nave.

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6 ANEXOS

Analise da situação actual:
Espaço amplo com muito grande dimensão coberto por chapa de aço canelada sem revestimento ou qualquer tratamento do que resulta evidente as situações seguintes:.

- Tempo de reverberação interno elevado
- Inteligibilidade muito baixa (por exemplo, com um motor de autocarro a trabalhar na nave a percepção da palavra a mais de 10 deve ser difícil)
- Isolamento térmico inexistente
- Tratamento da luminosidade inexistente

Para solucionar ou melhorar as performances globais do local escolhido propomos:

- Tratamento por projecção de Sonaspray K13 de cor light gray ou branco com 31 mm de espessura da chapa da cobertura o que nos permite obter
- Tempo de reverberação de 2 a 3 segundos na banda dos 500 hertz na zona tratada
- Inteligibilidade superior a 15 a 20 m
- Isolamento térmico de Rc= 1,06 m2 °K/W, coeficiente de condutibilidade λ= 0,029 W/m°K
- Índice reflector do tecto após projecção
  Branco árctico 81
  Branco off white 73
  Cinza light Gray 68

Área total a tratar já com a correcção de ondulação da chapa de 436,39 m2

INTERNATIONAL CELLULOSE CORPORATION asona BASWA acoustic AG 1/3

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Anexo I – Análise e aplicação da solução “Sonaspray” ao caso de estudo da Nave 1

Energy conservation
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Scientists, engineers, and contractors have realized for many years that the most commonly-used building insulation material isn't really the best insulator. Now this "conventional wisdom" of energy conservation has been confirmed and quantified through scientific studies at one of the world's leading research universities.

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Anexo II – Referências de aplicação da solução “Sonaspray” ao “Colorado Study”

Affordable Houses: a sustainable concept for a light weight steel dwelling

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ABSTRACT: An international research project was launched by ArcelorMittal in 2009 with the goal to promote a low-cost dwelling adapted to the needs of society. This challenge involved eight universities from around the world. The Portuguese team, from the University of Coimbra, was composed by a comprehensive team of architects and engineers. The design proposed by this team fulfilled the requirements in relation to structural, functional and economic aspects. Besides these requirements the team decided to further develop the solution in order to consider additional aspects leading to a more efficient solution in the context of sustainable construction. In this paper a brief description of the work carried out by the Portuguese team is provided. However, this text focuses on particular aspects leading to a more sustainable solution: the well-being of the users and the environmental impacts of the building over its life cycle.

1 INTRODUCTION

Eight countries (Brazil, Czech Republic, China, India, Poland, Portugal, Romania and Sweden) were involved in an international research project was launched by ArcelorMittal in 2009 with the goal to promote a low-cost dwelling adapted to the needs of society. In Portugal, this challenge was taken by a comprehensive team composed by several architect and engineers from the University of Coimbra.

For the development of the solution several stages were needed. In the first stage, together with the preliminary architectural project, a detailed analysis of the socio-economic characterization of the country was undertaken. The aim of the latter was to provide the team a perspective of current supply and demand in relation to the real estate sector. Based on this study, it was decided to focus the project on a dwelling for a standard family of a couple and two children (three main bed-rooms). The proposed solution is illustrated in Figure 1.

Figure 1. General perspective of the developed modular solution

Furthermore, a modular concept was defined in order to be flexible and adaptable to future demands of the family. This modular concept enables, besides it adaptability for future requirements in the same house, a definition of many other types of solutions to fulfill particular demands, such as urban and topography constraints.

In the second stage, the complete design of the dwelling was undertaken. The design was made according to the requirements of ArcelorMittal and safety requirements according to current standards.

The requirements from ArcelorMittal were twofold: the type of structure, which should be a steel structure, and the achievement of a competitive price in relation to traditional construction systems. Besides these requirements, the design fulfilled the various requirements of structural European Standards (Eurocodes) and additional requirements in relation to particular characteristics of the country. One of these special requirements was the safety verification against earthquakes, which is mandatory according to Portuguese legislation.

The proposed solution consists of a dwelling with two main floors. The lower floor entails the common part of the house while the upper floor entails the bed-rooms and other private parts of the house. This solution is suitable for a family with four members, although changing single rooms to double rooms, the number may be increased.

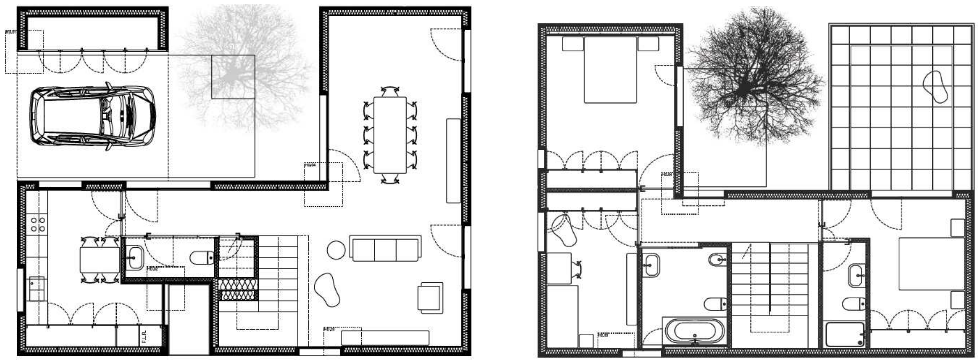

Figure 2. Layouts of the first floor (left) and second floor (right)

Given the overlap of the two floors, the upper level provides a covered parking area next to the kitchen, at the ground floor level.

The proposed solution has a total area of 164.20 m^2. The structure adopted for the dwelling consists of a light-weight steel structure. The external walls consist of an outside layer of Oriented Strand Board (OSB) panels, 12 mm thick, and an inside layer of gypsum boards with a thickness of 13 mm. The gap between the two panels is filled with rock wool 120 mm thick. The internal walls are made of gypsum boards with a thickness of 13 mm and a layer of rock wool with a thickness of 90 mm. The slabs are made of composite panels with a top layer of OSB panels (18 mm), an intermediate layer of rock wool 70 mm thick, and a bottom layer of gypsum boards 13 mm thick.

Table 1. Bill of main materials.

Material	Quantities	Unit
Concrete C25/30	31.15	m^3
Reinforcement steel	1380.00	kg
Steel cold formed	5365.17	kg
Rock wool (40kg/m3)		
with thickness of 40 mm	35.00	m^2
with thickness of 90 mm	72.00	m^2
with thickness of 120 mm	355.40	m^2
Gypsum plaster board (13 mm)	271.23	m^2
Oriented strand board		
with thickness of 12 mm	215.00	m^2
with thickness of 18 mm	253.00	m^2
Painting of internal walls	289.53	m^2
External walls in ETICS system (expanded polystyrene)	231.38	m^2

The rock wool insulation panels completely clad the steel frame ensuring that the house achieves high thermal and acoustic behaviour according to regulatory requirements. The envelope of the house is covered by an External Thermal Insulation Composite System (ETICS). The bill of the main materials is provided in Table 1.

The final cost of the house is 533.00€/m^2.

During the development of the proposed solution, other requirements apart from safety and cost were taken into consideration. One of the requirements was the well-being and comfort of the users of the house. This concern was taken into account by a careful design and detail in terms of thermal and acoustic performance of the house.

Another important concern was related to the environmental impacts of the house over its life cycle, from raw material acquisition until the end-of-life of the structure.

These additional aspects, which are mandatory in the goals of a sustainable construction, are described in the following sections.

2 THERMAL BEHAVIOUR OF THE DWELLING

The thermal performance of the dwelling was evaluated in order to assess the efficiency of the building in terms of energy consumption. The analysis was performed according to the Portuguese legislation RCCTE (2006) and complemented by advanced dynamic thermal simulations. Moreover, a viability study regarding renewable energies was also carried out in order to improve the proposed solution.

This analysis is fully described in a companion paper (Santos et al, 2010); hence, only the main conclusions of the analysis are presented in this section.

According to the Portuguese code of practice (RCCTE, 2006), several scenarios are defined for the severity of the climatic region of Portugal. For the basic scenario, it was assumed that the dwelling was built in Coimbra, a location in the centre of Portugal.

The thermal transmittances values used in this design not only verify the maximum values allowed by RCCTE for the climatic region of Coimbra, but also verify the values for the worst case scenario and corresponding reference values. The same happens in relation to the glazed openings thermal and optical properties required by RCCTE.

The adopted equipment for air conditioning were HVAC split devices for cooling or heating located in the main rooms of the house. It was further considered that the house will have solar thermal collectors (4 m^2) in order to produce domestic hot water. These solar collectors will be supported by a liquid fuel boiler when the water temperature is not enough for the demand.

The design total nominal annual needs of primary energy (*Ntc*) and the corresponding maximum value *(Nt*) are 2.39 kgep/m^2.year and 5.92 kgep/m^2.year, respectively. Therefore, the ratio between *Ntc* and *Nt* is below 50% and the energy efficiency of this building could be labelled as “Class A”.

3 ACOUSTIC PERFORMANCE OF THE DWELLING

3.1 *Acoustic legal requirements*

The acoustic behaviour of the dwelling was evaluated according to legal national requirements. The technical and functional acoustic requirements for buildings in Portugal are provided by the “*Regulamento de Requisitos Acústicos dos Edifícios*” - RRAE (2008). For a single residential building, the available legislation only imposes demands to the external facade of the building, with the following requirements:

- $D_{2m,nT,w}$ + *(C or Ctr)** ≥ 33 dB (mixed areas);
- $D_{2m,nT,w}$ + *(C or Ctr)** ≥ 28 dB (sensitive areas).

** When the glazed area exceeds 60% of the facade element, the adaptation term Ctr or C must be added to the insulation index value, depending on the type of dominant noise issue.*

The proposed dwelling may be built in several locations and it has glazing areas that represent more than 60% of the façade. Hence, the worst case must be considered with $D_{2m,\,nT,\,w} + Ctr \geq 33$ dB.

Although not required in the buildings acoustic legislation, in addition to the above requirements, requirements for airborne and impact sound insulation between enclosures were also considered. These requirements are:

- $D_{nT,w} \geq 42$ *dB and* $L'_{nT,w} \leq 70$ dB, between floors;
- $D_{nT,w} \geq 40$ *dB and* $L'_{nT,w} \leq 70$ dB, between rooms.

3.2 *Estimation of acoustic performance*

The results for the most important situations are indicated in Table 2. The sound insulation prediction was based on EN 12354 (2000), using ACOUBAT software (2001). These results meet the legal requirements described in the previous paragraphs.

Table 2. Estimation of sound insulation between rooms (reference situations)

Source	Receiving room	Sound insulation index
Outside	Room level 1 (higher glass area)	$D_{2m,nT,w} + Ctr = 33$ dB
Room level 1	Room level 0	$D_{nT,w} = 44$ dB $L'_{nT,w} = 66$ dB
Room level 1	Room level 1	$D_{nT,w} = 43$ dB $L'_{nT,w} = 65$ dB

4 LIFE CYCLE ENVIRONMENTAL ANALYSIS

4.1 *Description of the approach*

The environmental performance of the light-weight steel house was measured using the evolving, multi-disciplinary approach known as environmental life-cycle assessment (LCA), following the guidance on the International Standards Organization 14040 series of standards (2006) and the computer program SimaPro v7.0 (2008). According to the ISO methodology, LCA involves four steps. The goal and scope definition step spells out the purpose of the study and its breath and depth. The inventory analysis step identifies and quantifies the environmental inputs and outputs (inventory flows) associated with a product over its entire life cycle. The impact assessment step characterizes the inventory flows in relation to a set of environmental impacts, and finally the interpretation step combines the environmental impacts in accordance with the goals of the LCA study.

The goal of this analysis was to evaluate the environmental performance of the steel house over an assumed service life of 50 years.

The boundaries of the system under analysis included all the processes from raw material extraction and material production to the demolition of the structure and final deposition of the demolition waste –cradle to grave analysis – Figure 3.

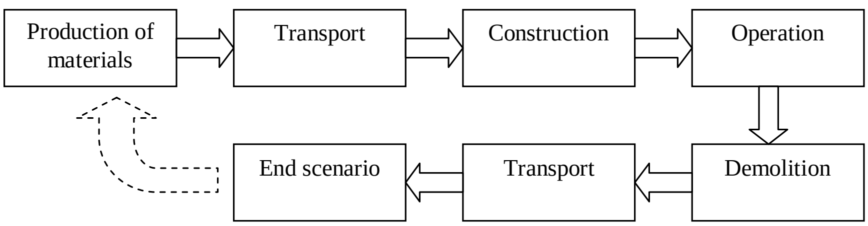

Figure 3. System boundary of the life cycle analysis

All the inventory data needed for the analysis was supplied by the software SimaPro as this tool includes the full Ecoinvent dataset (2000). In this analysis all the material data, apart from cold-formed steel, was obtained from Ecoinvent. Data contained in each dataset includes material and energy requirements and process emissions for the production of 1 kg of the product. Steel data was obtained from the Worldsteel association (2000) (former International Iron and Steel Institute).

The impact assessment method used in this work was the Eco-indicator 99 (2001). Eco-indicator 99 is a damage oriented method for life cycle assessment. In this method the inventory flows are linked to three damage categories: (i) human health, (ii) ecosystem quality and (iii) resources. The end of the environmental analysis leads to the calculation of the total score (endpoint) for the three damage categories. This last step involves the weighting and normalization procedures. The weights are set for three culture perspectives (hierarchist, individualist, egalitarian) based on a panel survey. In this study the egalitarian perspective was used as it is the one that takes a longer time perspective.

Apart from the Eco-indicator, a single indicator was also used representing the emission of green-house gases (in CO_2 equivalents) over the complete life cycle of the house. This indicator was normalized by the area of the house (164.20 m^2).

4.2 *Life cycle stages*

The life cycle analysis comprises all the stages from raw material production to the end-of-life of the structure, according to Figure 3. The analysis of the initial stage of the production of materials was based on the environmental data of each material and on the bill of materials needed for the construction of the house.

The operation stage is relative to the interval of years between the construction and the demolition of the structure and includes all the maintenance operations that are necessary over this period. The maintenance is usually estimated based in common practice and in this case study it was assumed that the external walls were recovered every 20 years (according to information from the supplier) and internal walls were repainted every 20 years.

The end-of-life stage is probably the phase more difficult to quantify and therefore subjected to a high level of uncertainties, particularly in buildings with a long life span. Due to the high level of uncertainties scenarios are usually adopted to quantify the inventory data and impacts of the different construction waste materials.

The material waste resulting from the demolition of the structure can have two major destinies: either the resulting materials can be recycled or reused or the resulting materials are no longer useful and so they are sent to landfill or to incineration.

In this analysis two end-of-life scenarios for steel are considered: (i) 80% of the steel structure is recycled and (ii) 90% of the steel structure is reuse; in each case all the remaining materials are considered to be sent to a landfill of inert materials. Table 3 summarizes the various scenarios considered.

Table 3. End-of-life scenarios

Material	Scenario 1	Scenario 2
Concrete C25/30	Sorting + Landfill	Sorting + Landfill
Steel cold formed	Recycling	Reused
Rock wool	Landfill	Landfill
Gypsum board	Landfill	Landfill
OSB	Landfill	Landfill
Reinf. steel	Landfill	Landfill
EIFS	Landfill	Landfill

4.3 *Results of the analysis*

4.3.1 Scenario 1: Recycling

In this scenario all materials except cold-formed steel are sent to a landfill. Steel was assumed to be sent for recycling. The methodology adopted in this analysis, to address the allocation problem of steel scrap in the end-of-life stage, is the closed material loop recycling approach developed by the worldsteel association (2000). This methodology was developed in order to generate LCI data of steel products, accounting for end-of-life recycling. The adoption of a close-loop approach is justified by the fact that scrap is re-melted to produce new steels with little or no change in its inherent properties. In this case, following guidance on ISO standard

14044, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials.

Figure 4 illustrates the emission of green-house gases over the complete life cycle of the house, considering the end-of-life scenario 1. The unit of this indicator is “kg CO_2 equivalents”. Considering the area of the house, this leads to 105 kg CO_2 equivalents /m^2.

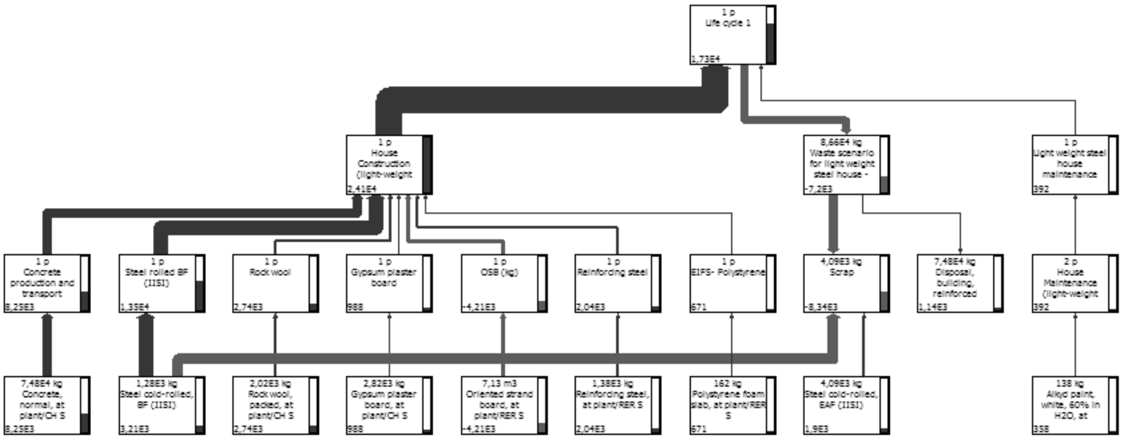

Figure 4. Flowchart of the life cycle analysis regarding end-of-life scenario 1

The results of Eco-indicator 99 are represented in Figures 5 and 6, respectively for the weighting results and for the single score results. Both figures show the contribution of the construction stage to the overall result of the life cycle analysis. This stage contributes with a major proportion for the three damages categories: Human Health, Ecosystem Quality and Resources

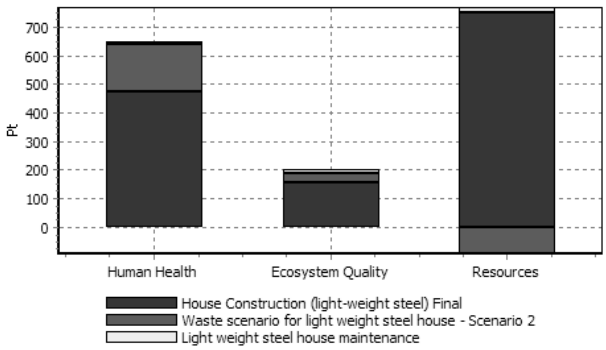

Figure 5. Weighting result of life cycle analysis regarding end-of-life scenario 1

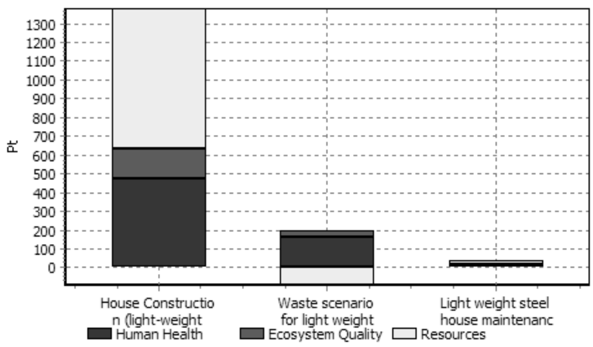

Figure 6. Single score of life cycle analysis regarding end-of-life scenario 1

4.3.2 Scenario 2: Reuse

The second scenario is similar to the previous one, apart from the assumed waste option for cold-formed steel. In this scenario the steel structure is dismountable and 90% of steel is assumed to be reused. Figure 7 illustrates the flowchart of the complete life cycle of the steel house. The close-loop approach referred in the previous case is also used in this case.

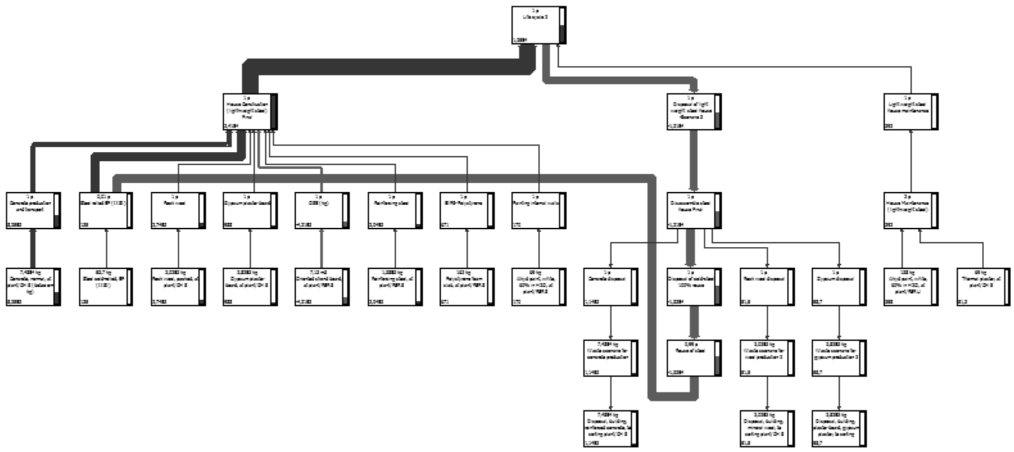

Figure 7. Flowchart of the life cycle analysis regarding end-of-life scenario 2

The flow-chart of Figure 7 represents the life-cycle emissions of CO_2 equivalents. In this case, the emission of green-house gases over the life cycle of the house is about 76 kg CO_2 eq./m^2.

In the same way, the results of the Eco-indicator 99 are represented in Figures 8 and 9, respectively for the weighting results and for the single score results.

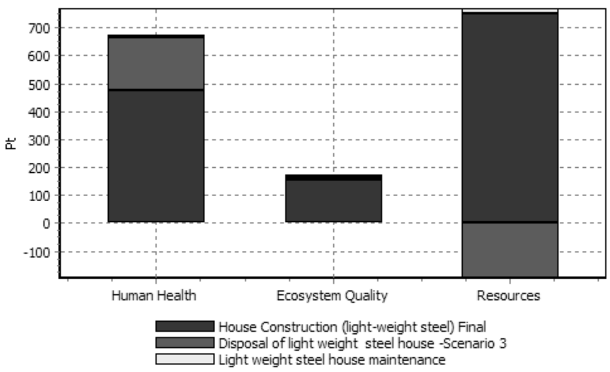

Figure 8. Weighting result of life cycle analysis regarding end-of-life scenario 2

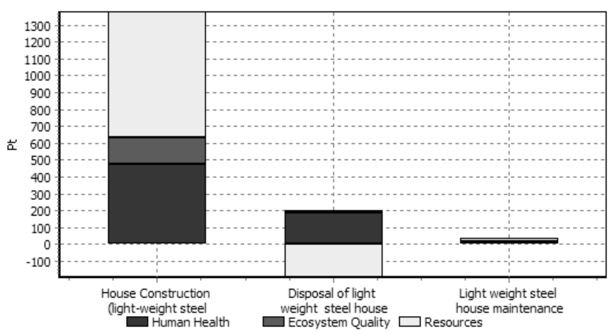

Figure 9. Single score of life cycle analysis regarding end-of-life scenario 2

4.3.3 Comparison of scenarios

Figure 10 compares the single score obtained for each analysis. Although both end-of-life scenarios are calculated based on the closed-loop approach, there is a small difference in the results, since the reuse of the steel structure avoids the reprocessing of steel from scrap. In fact, the reuse of steel corresponds to a "pure" close-loop.

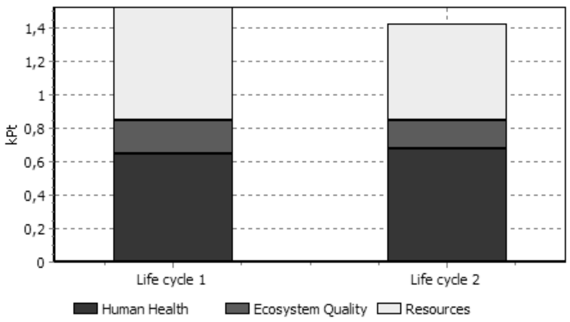

Figure 10. Single score of life cycle analysis regarding end-of-life scenario 1 and end-of-life scenario 2

5 CONCLUDING REMARKS

The estimated nominal cost for the construction of this residential light-steel building is about 550 €/m^2 (VAT not included), which shows the competitiveness of the solution in comparison with the typical traditional construction. Nevertheless, despite being a construction system with a lower price, it does not mean that the quality standards are lower as well. As it was described, the solution was properly detailed in order to achieve high quality standards with respect to thermal and acoustic behaviour, contributing to the well-being of the users. Moreover, the proposed solution provides an adaptable system to future demands of the family that enables to extend the service life of the structure beyond the period of 50 years assumed in this analysis. All these features are indicators of an efficient solution in the context of a sustainable construction system.

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Sustainable roof-top extension: a pilot project in Florence (Italy)

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ABSTRACT: This paper presents some results achieved in the research project *"SuRE-FIT: Sustainable Roof Extension Retrofit for High-Rise Social Housing in Europe"* developed, from 2006 to 2008, by 16 partners from 9 European Countries within the Programme Intelligent Energy Europe (6th Framework Programme). Through an International survey of best practices, a deep knowledge exchange and a synthesis of case studies and pilot design projects, the SuRE-Fit project analysed the opportunities given by a profitable refurbishment of roof-tops, in particular to insulate the building, to enlarge the dwellings, to include innovative installations and to suggest for new common facilities. The paper is focused on a Pilot Project, based on the research concepts, developed by the two Italian partners: Ipostudio Architects and the Municipality of Florence. The project took the chance of the refurbishment of an existing social housing block to improve both the technical and energy performances considering the expectation of inhabitants in terms of safety, health and social benefits. .

1 INTRODUCTION

Over recent years, building and urban requalification policies have progressively led to an increase in the importance of interventions for improving the energy performances of buildings. This is undoubtedly due to the development of more widespread sensitivity and awareness of the need to combine the objectives of protection, conservation and promotion of the existing building heritage with the problems of sustainable management of the environment.

On the other hand, the adaptation of legislation has contributed to consolidating this trend on an international level and, in particular, European directives on energy saving and protection of the environment. The introduction of the principle of "sustainable development" based on the interdependency of all the actions that influence the stability of the environmental system, has decisively widened the disciplinary boundaries of this research sector, radically modifying strategies and intervention models.

One of the main innovative factors consists of a global strategy that has been put in place for the protection of the environment as a constant reference point in all actions for the containment of energy consumption, providing incentives for the use of renewable energy and the reduction of sources of pollution and alteration of the ecosystem. The policy of implementing the actions gradually, according to the degree of wealth and the development requirements of the different areas of the world, has also made it possible to involve a significant number of countries in objectives (such as reducing greenhouse gas emissions) that can only be reached if pursued on a global scale.

With an estimated 40% of the overall primary energy requirement being used, on a European level, the building industry has a decisive role in consumption reduction policies. For a number of years now the European Union has been making consistent contributions to funding research in the form of various programmes focusing on sustainability; as part of these programmes numerous projects have been implemented aimed at the development of new technologies for containing consumption, the use of sources of renewable energy and the improvement of the energy efficiency of buildings. The legislation has also evolved decisively, introducing an increasingly high number of prescriptive provisions in most countries in the EU.

These and other propulsive factors – not least an incentive policy that has encouraged the increase in demand and consequent consolidation of a specific market segment – have led to models, strategies and systems being developed around the principle of sustainability using the diversity in approaches as a means of optimising the wide range of solutions that can be carried out using the innovative materials and advanced technologies now available on the market.

The common element that characterises the different systems is an approach based on the evaluation of the overall energy behaviour of the building with the aim of adopting all the solutions that improve energy efficiency. As well as the installations (gas, electric, water), the fulfilment of this requirement depends largely on the performances of the external closures of the building, that is the combination of construction elements that separate the internal spaces from the external environment and constitute the main carrier of heat exchange phenomena.

The efficiency of the climate control systems and, therefore, the reduction in consumptions, depends on the ability of the envelope to regulate the dynamics of such phenomena both passively, by alleviating or accentuating the transfer of heat energy to and from the inside, and actively, by regulating or generating flow dynamics. In fact, the contribution of the external walls to regulating heat exchange allows the action carried out by the installations, to be optimised, integrated and, in some cases, replaced.

In buildings constructed just after the entry into force of Law 363 in 1976, the first legislation issued in Italy on energy saving, the technical characteristics of external closure systems guarantee generally acceptable heat insulation performances although, in many cases, the solutions used respect the relevant legislation but do not guarantee optimal conditions of comfort (in particular regarding hygrometric conditions, ventilation and insulation from heat loads in the summer months).

In the rest of the existing heritage, particularly that built between the post-war years and the early 1970s – mainly to fulfil quantity requirements urgently – the building solutions used and the widespread degradation conditions led to very poor energy efficiency in buildings.

Therefore the contribution to lowering consumptions is extremely important and can come from the introduction of all the innovative actions and technologies that allow the energy performance of the buildings to be improved, in the requalification programmes of the existing building heritage. Intervening with appropriate technologies and coherent solutions can also become an opportunity for operations of increased importance aimed at the architectural, as well as functional, requalification, of the suburbs and intensely populated districts.

The research project *"SuRE-Fit: Sustainable Roof Extension Retrofit for High-Rise Social Housing in Europe"* developed, from 2006 to 2008, by 16 partners from 9 European countries within the Programme Intelligent Energy Europe (6th Framework Programme) concentrated on these themes.

2 THE SURE-FIT PROJECT

2.1 *Research objectives*

Large scaled efforts to refurbish the social housing building stock improving its energy efficiency requires for major financial resources not easily available. Energy neutral, industrial and flexible roof-top extension retrofit has been proven as a viable solution, both technologically and financially. Roof-top extension retrofit combines energy-saving measures with social, ecologic and economic advantages.

The main aims of researches and experiences carried out in this field, were to synthesise cutting edge technologies of roof top extension retrofit and to develop process models and guidelines for broader implementing innovative solutions.

The research project SuRE-FIT aimed to:

- consolidate the existing cutting edge technologies and best practices of roof top extension retrofit in Europe for broader implementing the production of system and component a greater dissemination of feasible design solutions;

– promoting the application and integration of small-scale RES installations, particularly PV panels, to improve the energy efficiency of high-rise buildings and large housing stocks.

The research approach has been based on the analysis of existing cases (e.g. in Denmark, Sweden, the Netherlands, Germany, etc) proposing, in parallel, new roof-top extension retrofit pilot projects in other Countries (as Italy, France, Poland, Czech Republic, etc). The experts' teamwork was organised in two groups deepening both the architecture/engineering technical issues and the financial and institutional main implications.

The project SuRE-FIT analysed the opportunities given by a profitable refurbishment of rooftops, in particular to insulate the building, to enlarge the dwellings, to include innovative installations and to suggest for new common facilities.

2.2 *Improving quality and energy performances of existing buildings*

The SuRE-FIT project took the chance of a technical and energy improvement of the existing social housing blocks to modify their overall appearance. The heterogeneous and sensitive condition of the existing housing blocks asks for a proper technical assessment to assess their improvement potential and the critical points.

The refurbishment of residential areas cannot be separated from the expectation of both inhabitants and managers in terms of safety, health and social benefits.

The roof top extension will enhance the overall appearance of buildings, the façades will be renewed, improving in parallel insulation, windows and frames. Entrance, elevators and stairwells will be upgraded in order to increase accessibility, social well-being and safety.

This shapes better living conditions of citizens in urban residential areas, with a higher involvement of and responsibility for inhabitants. Without the agreement of citizens and local authorities the building refurbishment doesn't stand a chance, according to this the SuRE-Fit approach include design and decision participation strategies, searching for a real knowledge sharing between technicians, tenants and local administrations.

The energy performance of existing social housing blocks is generally poor, mainly because of the short insulation of rooftops and facades, the low performance of existing services for heating, ventilation and warm water. The SuRE-FIT energy performance indicators include an immediate reduction of energy use by fossil resources of 50% for the existing building. The new dwelling units will be energy-neutral, using 100% renewable energy sources. Energy use of the new dwellings on top will be zero. The existing houses (below the new ones) will have a reduction on energy use of 30 to 50%.

In Europe the potential of energy reduction by this proposal can be estimated into 520 Meta-Joule, with a decrease on CO_2 emission of 10.000 Mega ton CO_2. Material savings by applying SuRE-FIT are also significant: standardised components save material use up to the 30%, both increasing the opportunities for the re-use of systems and components.

The work done over existing building blocks extends the buildings lifespan, reduces demolition wastes, supports the use of lightweight material, doesn't ask for new foundations and it could be the chance of improving the seismic resistance of all the building, through modern structural measures.

2.3 *Market opportunities for a SuRE-FIT approach*

In spite of a research for homogeneous protocols, each refurbishment project has its own specific features, requirements and social behaviour; this lack of projects with large size and scope prevented the building industry from attaining the economies of scale needed for lowering the resource requirements per unit of innovative refurbishment plans. Without standardisation and repetitions the opportunities for a greater usage of prefabricated parts/industrialisation are limited and the economical feasibility of each project stands more on properly designing and planning then on industrial production.

Refurbishment contractors have hitherto in the main, been too small and lowly capitalised; however larger-sized contractors are rapidly moving into this kind of market, in response to the shrinking new-build asset and the higher technological demands of large-scale refurbishment projects.

In many European cities there is still a housing shortage and some other Countries show a qualitative deficiency, the SuRE-FIT creates new dwelling units increasing the existing social housing stock, with a general objective of 20% m^3 more, that can be use to enlarge the dwellings in number or size. This added floor space solves a major problem for housing companies and local authorities, in particular financing the growing requirement for sustainability and energy efficiency.

The SuRE-FIT approach combines more freedom of choice between factory-made, interchangeable building components (through an industrialized and flexible design and production of roof top extensions) together with several strategic concept solutions that can be assembled according to the specific local target of buildings and clients.

Italian building market is now showing a large slowdown due to the crisis; on the other hand, the refurbishment field could have a slow growing up thanks to the government incentives until 2010, adding new financing for the energy savings.

Some critical features affect the broad affordability of roofing retrofit approach, driving towards specific target groups and building typologies; these filtering aspects can be summarised in four points.

- The local seismic conditions, that force the structural building design to compulsory national laws about standards, both for refurbishments and new constructions. This earthquakes risk ask for cautions when assessing or modifying the existing structural performances, with the need of careful analysis and commonly suggesting not to fit new weights in top of the building. This barrier to the use of a SuRE-FIT strategy could be overcome, as an example, where the existing building stock need for a structural upgrading, where the new roofing takes the place of a demolished one or where the building top is an autonomous part of a new external structure.
- The local regulation about the safeguard of the building heritage, that usually forbid the raising of buildings in the city centres, the change in the roofing pitches or the opening of new windows. On the other hand are generally allowed the rising of the 10%, if joining and not exceeding the roofing level of the buildings nearby, mainly if the new volume is an enlargement of the existing apartment without any new housing unit (this to avoid an increase in the “urban” charge of the building). The most important historical city centres (i.e. Milan and Turin) are now developing specific regulations about the use, maintenance and upgrading of roofs because it has to be deeply checked and guided the use of building tops where the sq.m cost of the central areas increase the speculations.
- The existing building market support more and more large enterprises, able to manage large estate, to propose and use innovative systems and components and to ensure definite scheduling, time and cost to the client. Building corporations with a billing between 10 and 30 billion of Euros have a growth of 2,6% and larger ones (between 60 and 200 billion of Euros) develop more of the 11%. Unfortunately the typical Italian building firm is really small (turnover < 10 billion), with an expected improvement of less of the 0,8% (with a national inflation of 4,6%).
- Energy prices are a key determinant of the attractiveness of energy efficiency investments and financial incentives are commonly linked with the need of an affordable energy saving certification and requirements. The incorporation of energy efficiency measures generate an immediate financial return for refurbishment works, increasing their financial acceptability, providing additional financial “pull” on building rates and pushing the European energy saving policies. The Italian Legislative Decree 192/05 is born in this framework and it fixes some national standard as: higher level of insulation for new and existing buildings, promotion of systems and installation with a greater efficiency, provision of a compulsory energy certification for buildings that have to be constructed or sold, rationalisation in checking heating systems, to foster a broad application of the energy assessment. These elements have to be interfaced with the existing design opportunities, changing the common building procedures and forcing designer and, most of all, the building companies to apply a newly approach to curb costs and times.

2.4 *The SuRE-FIT proposal*

The SuRE-FIT project proposal aims to evaluate the potential of solutions that foresee the height raising and extension of some types of buildings, increasing not only the number of floors but, above all, the energy efficiency and overall functionality.

The feasibility of the height raising work is conditioned by the numerous technical, regulatory and economic restrictions; this is however an opportunity that, as part of a wider requalification and urban regeneration strategy, produces results that are not just limited to the increase in the inhabitable surface area.

In fact, the height raising and adaptation of the roofs add further advantages in terms of architectural requalification and regeneration of the heritage, the creation of new housing without using new urban land, the improvement of energy efficiency and the creation of services in the district and communal areas inside the new volumes.

Based on a detailed analysis of the experiences already carried out in Europe, research has led to design criteria and guidelines for the application of retrofitting solutions for roofs to the most common types of residential building.

The different intervention strategies have been classified into three main types.

A) Contrast

Height raising strategy based on the insertion of volume characterised by a clear distinction with the existing building. This solution implies the structural support of the existing building, leaves extreme freedom in the choice of the architectural design and materials and ensures a wide margin of freedom in the choice of technologies for improving energy efficiency. Finally, this allows the work to be carried out without moving the tenants.

B) Extension

Height raising strategy based on the addition of new levels the same as the existing ones. The extension on the roof does not lead to any significant formal changes to the building. The new volume replicates the type and technologies of the building below, through the expansion of the distribution elements and installations. In this case, the work causes limited disturbance to the tenants.

C) Integration

Height raising strategy based on the integration with the existing building with the aim of recomposing the interventions in a unitary technical and architectural solution. This strategy aims to perform an overall requalification of the building intervening on the external walls and existing lodgings. The work, which inevitably requires the temporary movement of the tenants, is generally more expensive but allows substantial improvements to be made to the entire building.

The three types of intervention were subsequently tested on some pilot schemes.

The evaluation of the opportunity and advantages of height raising, in view of the costs and complexity of the operation, has also led to the careful verification of some key themes, such as:

- issues connected with the interface between the new volumes and the existing one and the evaluation of the effective technical and functional improvement of the building (accessibility, energy efficiency, safety, new services, etc.);
- structural problems due to the addition of new loads on the load-bearing structure and on the foundation systems of the existing building;
- the “weight” of the new volumes on the (architectural, environmental, social) balances of the urban context;
- the possibility to introduce living and service solutions that complement the existing ones, aiming towards a more articulated range of users (young couples, immigrants, students, etc.).

In Italy, like in other countries subject to a medium to high seismic risk, the feasibility study of the height raising solutions offers, in many cases, the possibility to integrate the advantages of a retrofitting intervention on the roofs with those of verifying and adapting the building to meet new directives and a general improvement of the performance of the structural system.

The pilot schemes developed as part of the research project simulated the feasibility of innovative solutions, designed for specific case studies, but based on an applicable technical and scientific approach, with different proportions and methods, also in other contexts.

3 THE PILOT PROJECT IN FLORENCE

The building selected for the development of the pilot project is a four storey block, built in 1983, including 33 apartments of 3 different sizes (45, 65 and 85sq.m); it is located in “Le Piagge” district, NW of Florence and is owned by the Florence Institute for Social Housing (Municipality of Florence). Poor quality of roof components, problems related to accessibility and poor energy efficiency jeopardize the quality of the building.

Fig.1 The existing building

Due to the existing seismic condition the retrofit solution has been based on the “Integration” approach. The structural concept is based on a self-bearing superstructure of steel “bridges” sustaining a platform on top. This solution avoids loading the weight of the roof top extension on the structure and foundation of the existing building.

The light pillars follow the regularity of existing slabs and make possible to add a lot of “small boxes” on façade with a fragmented design of external shapes, adding volumes to improve the layout of existing apartments. The light steel external grid (or optional structural wood components) can be completed and integrated with a collection of standardized components (frames, panels, etc), coming from different factories and easily adaptable to the project modularity (wood and rockwood sandwich boards, wood frames, glass sheets, etc).

The SuRE-FIT solution includes the refurbishment of existing dwelling and the construction of new flats. Refurbished and new units are sized according to the family needs and fitted out for special target groups such as elderly people and disabled, students and young couples.

New volumes will be made of a lightweight two-storey block (both single flats and maisonette typologies) on top of the existing dwelling. The extension includes 9 new apartments of two different sizes (65sq.m or 100sq.m, single storey or maisonette), open balconies and 410sq.m for non-residential public functions as facilities for health care, cultural activities, etc.

The technical approach to rooftop addictions will include semi-prefab component (as wood panels, metal and wood beams, glazed frames, etc) or prefab system available on the EU building market. The serviceability of designed solutions will be evaluated comparing the architectural value of each proposal with its performances, according to target groups, building procedures and expected costs.

The basic design will be assessed combining three main assets: structure (bridges, external grid and platform), new volumes (housing on upper floors, new public facilities, elevators, etc), external shell (insulation, frames, panels, photovoltaic systems, etc).

The external shell of the rooftop retrofit could be autonomous or integrated with the grid on façade. The option of applying a skin (metal, glass, photovoltaic panels, etc) could be easily adapted to the designed structure because the chosen modularity is suitable for the most part of component already available on the market.

Fig.2 The SuRE-FIT solution

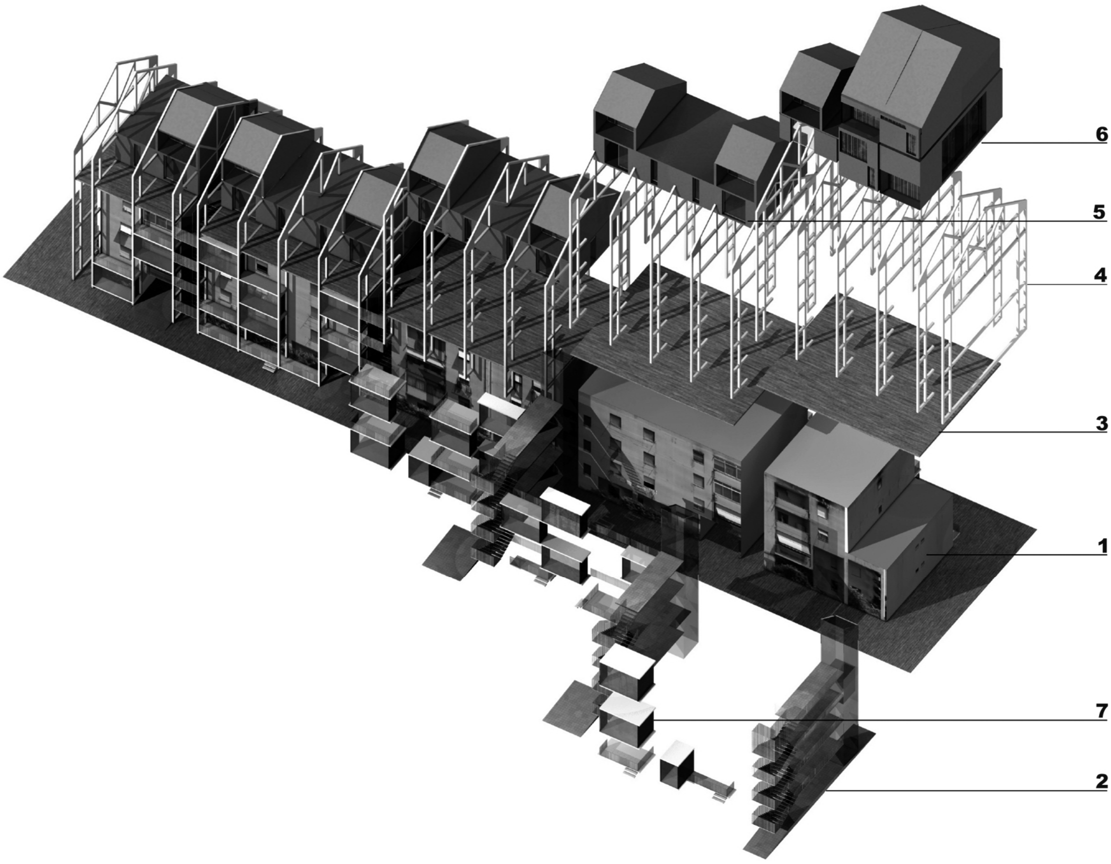

Fig.3 The Pilot Project concept:
1) Existing building 2) New staircase 3) Platform on top 4) Structural steel bridges
5) New dwellings on top 6) Public spaces and facilities 7) ”Small boxes” on facade

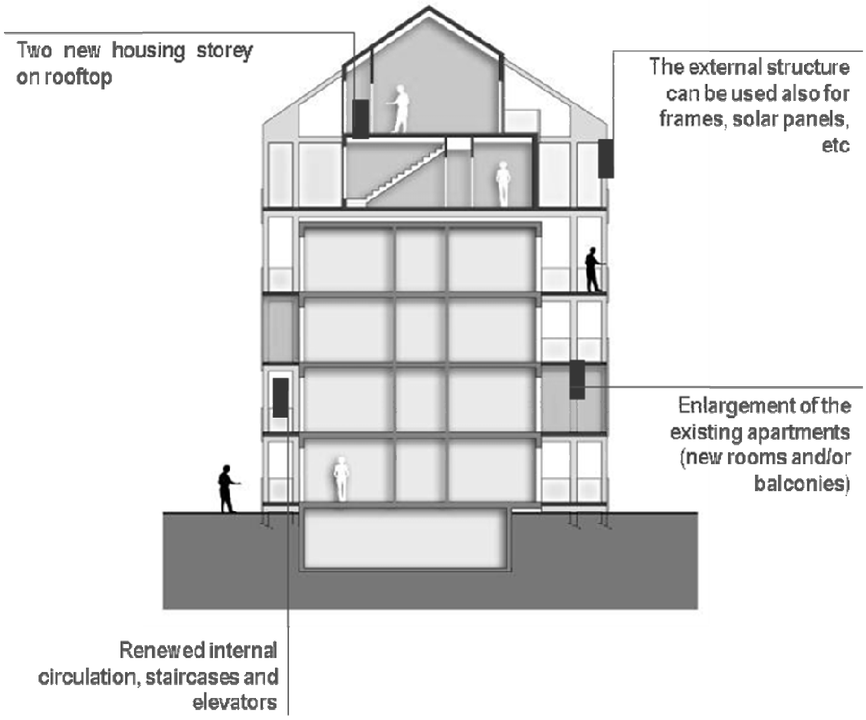

Fig.4 The structural system

4 CONCLUSIONS

In order to assess the feasibility of SuRE-FIT concepts – the objective of the pilot projects developed during the research project – an analysis of the results was made looking at benefits and barriers.

A specific barrier suggests that it does not have to count for all projects. It is the same for the benefits; some benefits will appear only when a certain strategy is followed.

Although some problems occurred during execution of the studied cases, roof-top extension is absolutely practicable as far as technical aspects are concerned. Most striking barrier for SuRE-Fit is the complicated contact with the current dwellers. In case of buildings occupied by its owners or buildings with mixed ownership the process is complex due to the many involved parties. However, an advantage of this case is that people can be convinced easier because of the possibility to share the (financial) benefits. In social housing projects this will not be the case and therefore resistance of the tenants is harder. A solution to come over this problem is to create a better living environment for all dwellers. A common space and improvement of existing facilities can do so.

Case studies analyzed and pilot projects developed in the research project have shown that major improvements can be reached with SuRE-Fit. Using an existing building as base for new dwellings is a way of answering the demand for housing in specific areas without having a large impact on the environment. An exceptional energy concept has not been a starting point in most projects. In Central Europe the main reason to choose for roof-top extension was the technical deterioration of the roof. Considering the large demand in areas that the buildings are located in roof-topping seems a viable solution.

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Environmental and economical viability associated to the sustainability criteria applied in commercial buildings

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ABSTRACT: The main challenges and contributions for the sustainability dissemination in construction are to recognize and prove the effective outcomes (economic and environmental) that could be obtained with the implementation of sustainability criteria. It means that more important than recognize the sustainability through the implementation of a sustainable voluntary tool, is to assure (and verify) the positive effects that could be reached with the application of the methodology or the classification obtained.

In this context, this paper will present the results obtained within a research project developed in Portugal with the objective of determining the economic and environmental feasibility of the criteria defined by a British Sustainable Voluntary Tool (BREEAM - Building Research Establishment Environmental Assessment Method) that has been applied in a shopping centre under the construction phase. The referred shopping has a Gross Leasable Area (GLA) of 70.488 m^2.

1 INTRODUCTION

Economic factors have always influenced and promoted the use of new practices in the market, as is the case with sustainability in construction. Before considering a sustainable project, investors, real estate promoters and customers need to clarify the question "What is the cost of sustainability?" and "What are the actual economic and environmental advantages that result from applying sustainable practices?"

The answer to these questions is often left unanswered due to the lack of information, as well as the lack of long term studies that compare the benefits of sustainable practices with more conventional ones. In the particular case of Portugal, the difficulties lie in the limited number of sustainable buildings and the lack of observational data (and economic studies) on these buildings during the different stages of the project. What is available, on an international basis, is few and far between, such as:

- "The costs and financial benefits of Green Buildings" report written by Gregory Kats (2003) which compares 33 buildings (certified or in the process of obtaining LEED certification) with other conventional buildings. The study concluded that an average investment of 2% over initial costs (compared to that of conventional buildings) will yield financial benefits which are 10 times greater than the aforementioned investment (for a 20 year period). This takes into consideration the analysis of operational costs, maintenance, the emission of pollutants and productivity;
- The "Costing Green: A comprehensive Cost Database and Budgeting Methodology" report, written by David Langdon (2004), which aimed to analyze only the expenses

that were associated to the construction phase of ecological buildings. The study concluded that many projects attained a sustainable certification with reduced initial budgets, or small supplemental investments (on average 2%);

- The article “Environmental certification for commercial real estate assets: the value impacts” (Franz Fuerst and Patrick McAllister, 2008) aimed to investigate the existing price differential between LEED and Energy Star certified constructions and non-certified buildings. The study concluded that the rent of certified building was 11% higher than that of non certified buildings.
- Similar to the previous study, the recent article “Doing Well by Doing Good? Green Office Buildings” (Eichholtz P. et al, 2009) published by the University of California, also compared Energy Star and LEED certified buildings and non-certified buildings in the same location. The results clearly demonstrated the importance of certification (especially Energy Star) when it came to increasing the value of commercial spaces and rental rates. There was roughly a 3% increase in rental rates per square meter and a 6% increase per square meter on effective rents. Selling prices were higher in about 16%.

2 COST-BENEFIT ANALYSIS OF SUSTAINABLE PRINCIPLES

The above mentioned studies were based on a relevant number of certified and non-certified buildings commonly found in certain countries such as the U.S.A and U.K. (up to February 2008, 1283 and 1358 non-residential buildings, respectively, were certified) (Saunders, T. 2008). In Portugal there is a very limited number of buildings with sustainability certification and there are no published economic studies which make difficult the practice of studies similar to those mentioned above. As such, the aim of this paper is to present an economic viability study and the environmental impacts linked to sustainability criteria applied in only one case study. In other words, the aim is to present the needed investment to improve the final classification of a building, as well as the economic and environmental implications associated with sustainability criteria that were implemented in the construction.

As such, the first task was to identify the sixty-one elements (defined for the case study) included in the BREEAM assessment tool (Building Research Establishment Environmental Assessment Method) for the scheme “Retail”, through different pre-established groups of analysis, including:

- (Group A) – Identification of criteria included in National/European legislation;
- (Group B) – Identification of criteria unsuitable for the Portuguese context;
- (Group C) – Identification of criteria that is complex to quantify and assess, or in other words, those in which direct or indirect benefits (social and environmental) are evident but their economic quantification is complex. Measures related with biodiversity, ethical values, indoor environmental quality and the choice of materials are included within these criteria;
- (Group D) – Identification of quantifiable criteria. The viability and economic performance of criteria included in this group was studied through the analysis of the Net Present Value, the Internal Rate of Return and the Payback period (Return of Investment). On the other hand, these values are also identified and analyzed according to their environmental impact (CO_{2eq} emissions and energy and water consumption). These criteria, on the main, refer to energy and water management issues.

This paper will only consider the analysis of group C and D taking into consideration that the criteria included in these groups were voluntarily introduced in the case study and are associated to a not foreseen initial investment.
In relation to the other groups, namely Group A, the costs associated to these groups will not be analyzed as they include mandatory measures relating to national legislation or common market practices. In other words, the needed investment was already considered before the introduction of new sustainability criteria.

3 DEFINITION OF THE CASE STUDY

The criteria of the BREEAM tool were applied in the Centro Commercial Dolce Vita Braga (DVB) (Dolce Vita Braga Shopping Centre) belonging to the real estate company Chamartin. The construction of the building in Braga, with a total gross leasable area of 70 488 m^2, began in April 2008 and is scheduled to open its doors to the public in October 2010. The project includes spaces for reading, shops, restaurants, a supermarket, parking, cinemas, health clubs and ample common areas.

The typology chosen for this analysis was based on its relevant impact on the "Triple Bottom Line" (baseline of sustainability). The construction of a shopping mall generates significant alterations, including environmental impacts resulting from the construction and operation phases, and social and economic impacts resulting from future alterations, such as the creation of new jobs and the alteration of local traffic.

During the initial stage, a pre-assessment, based on the BREEAM tool, was carried out to assess sustainability, in order to verify the rating of the construction without any type of improvements (initial proposal). The result was a compliance with 48.78% of the criteria which corresponds to a rating of "Good".

4 SUSTAINABILITY CRITERIA

This study proposes to analyze and present the results of two intervention scenarios applied to the initial proposal of DVB. The objective was to gradually improve the classification from "Good" to "Very Good" (rating defined by the BREEAM tool for buildings that show a compliance with more than 55% of the listed criteria) and, in a second phase, to "Excellent" (compliance with more than 70% of the listed criteria).

Based on the additional criteria, an individual and a global analysis were carried out in order to identify the real economic and environmental impacts, as shown in Figure 1.

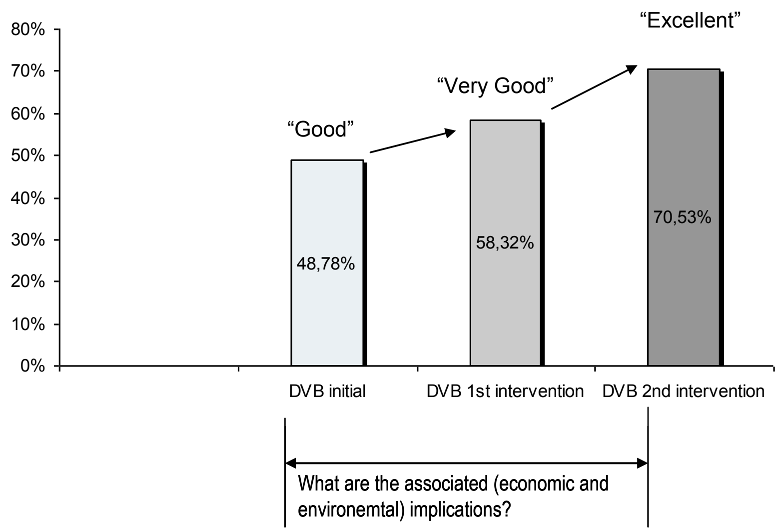

Figure 1. Comparison between the different stages

The following table lists criteria that were used during the different stages of intervention. The fourteen points that constitute part of group C and D represent those that were selected and gradually introduced, based on how well they could be adapted to the project in the construction phase, and those that had a better return on the economic investment that was required. These aspects were essential to guarantee an improvement in the classification to attain the desired rating.

Table 1. BREEAM Tool Criteria analyzed during the economic and environmental study (Source: BREEAM, 2008 - adapted)

Ref.	Breeam Criteria selected for the analysis (elements from Group C and D)
Hea14	Office space
Ene1	Reduction of CO2 Emissions
Ene5	Low or zero carbon technologies
Ene7	Cold food storage
Ene8	Lifts
Tra3	Cyclist Facilities
Tra4	Pedestrian and cycle safety
Tra7	Travel information space
Wat1	water consuption
Wat3	Major leak detection
Wat4	Sanitary supply shut off
Wat5	water recycing
Mat6	Insulation
Wst5	Composting

5 BASE CONDITIONS

One of the key elements needed to carry out the analysis of the cost benefits for each one of the principles (criterion) was the use of a holistic analysis, whenever possible, not only examining the initial investment (cost of construction) but also other expenses, like operation and maintenance costs, incurred throughout the lifecycle of the building under analysis (considering a period of analysis of 20 years).
The selected criteria, which will be presented in this paper (Sustainable Proposal), were compared against the initial proposal (with conventional solutions). The economic assessment criteria used in this study were based on the following presuppositions:

- A 5% discount rate used when calculating the NPV;
- A 20 year analysis period;
- An annual inflation rate of 2%.

The results were framed according to the following indicators:

- Initial investment – this refers to the difference between the investment on the initial proposal and the investment applied on the sustainable proposal;
- Return on Investment (expressed in years) – period (years) that the promoter will have to wait to recover the investment made on the project;
- NPV (Net Present Value) – in a simple manner, this value is used to determine the net value of an investment at time 0 (date of investment) calculated based on the annual cash flows generated by the investment during a period of 15 to 20 years;
- IRR (Internal Rate of Return) – to measure the profitability of the project through the IRR implies obtaining a IRR (%) that is higher than the stipulated interest rate (stipulated at time of financing), in this case 5%.

The environmental indicators are expressed according to the reduction in energy and water consumption and the reduction of CO_{2eq} emissions.

6 RESULTS

The following figures and tables provide the economic and environmental results of the interventions carried out.

The obtained results from the first intervention with the objective of upgrading the rating from "Good" to "Very Good" can be observed in Figure 2. This first intervention included the implementation of ten criteria from groups C and D. From among the proposed principles, there are criteria with and without economic benefits. In the case of the criteria without economic benefits, these presented a reduced initial investment and important environmental advantages. Thus, as can be observed in table 2, the joint analysis of all the criteria does not hinder the final results.

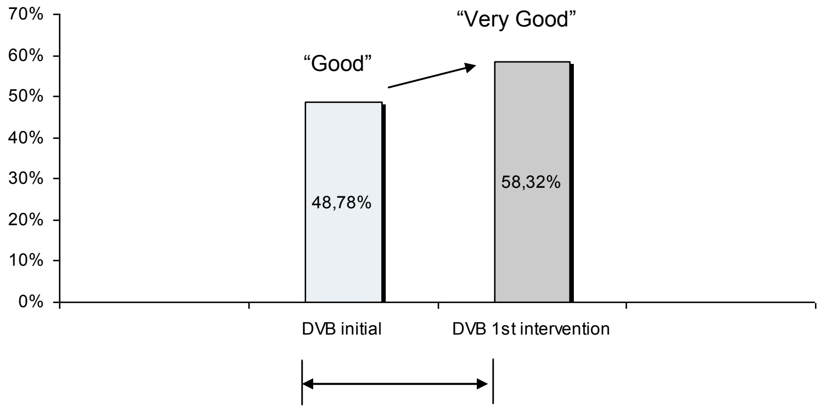

Figure 2. Alteration of rating from Good to Very Good following the first intervention criteria

The application of the additional ten principles in the first intervention, as demonstrated in table 2 was quite positive, as it was possible to demonstrate that an additional investment of 220 443.41€ (representing roughly 0.30% of the investment quota budgeted for the construction of DVB) is recoverable within an average period of 5 years.
These results, in large part, are a consequence of the measures implemented to improve the efficiency of water management, which were, on the whole, quite reasonable in what concerns the required investment, and were rapidly recoverable (in less than one year).

The resulting environmental impacts of these measures are the following:

- Reduction of 248.85 ton in CO_{2eq} emissions, which is equivalent to the emissions produced by 40 European inhabitants;
- Reduction of 260.4 MWh/year in the energy consumption, which is equivalent to the energy consumption of 45 European inhabitants;
- Reduction of 15,143 m^3 of water consumption, which is equivalent to the water consumption of 226 European inhabitants.

The results of the second intervention, with the objective of upgrading the rating from "Good" to "Excellent" are demonstrated in Figure 3. In addition to the ten principles used in the first intervention, four more were applied from Group D. Among the proposed criteria, only the one with the reference Ene1 (promote the reduction of CO_{2eq} emissions) was not between those with economic benefits. The compliance with this criterion is, however, linked to the environmental benefits (reduction of CO_{2eq} emissions) resulting from the use of the remaining additional criteria, not implying, this way, any additional investment.

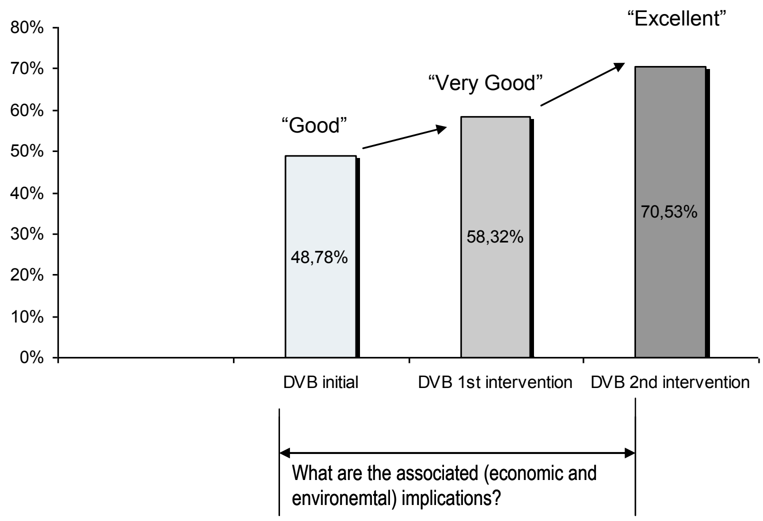

Figure 3. Alteration of rating from "Good" to "Excellent" obtained from the second intervention.

The results obtained from both interventions, shown in table 2, display the advantages of upgrading a "Good" construction into an "Excellent" construction, according to BREEAM criteria. Despite a considerable investment of approximately 4,806,982.86€ (6.62% of the investment quota budgeted for the construction of DVB), results suggest that the amount is recoverable within an average period of 5 years. The environmental advantages resulting from these measures are as follows:

- Reduction of 4,023.85 ton in the annual CO_{2eq} emissions, which is equivalent to the emissions produced by 574 European inhabitants;
- Reduction of 11,594 MWh/year in energy consumption, which is equivalent to the energy consumed by 2,031 European inhabitants;
- Reduction of 43,437.7 m^3 in water consumption, which is equivalent to the water consumed by 650 European residents.

Table 2. Summary of results obtained during the analysis.

Additional measures 1st intervention Initial proposal (Good) to (Very Good)(Criteria from Group C and D)											
	Breeam-Retail		Economical data					Environmental data			
Related category	Ref.	Criteria	Inicial investment (€)	Payback (years)	NPV (15 years) (€)	NPV (20years) (€)	IRR 15(TX Val 5%)	$TonCO_{2eq}$ reduction/year	Reduction of energy (MWh/year)	Reduction of water (M^3)	Breeam Points
Health & wellbeing	Hea14	Environmental comfort of office space	3.500,00 €	-	-	-	-	0,035	-	-	3
Energy	Ene8	Lifts – Solutions for greater energy efficiency	170.840,00 €	10,0	29.759,55 €	94.840,24 €	7%	125	250,4	-	2
Transport	Tra3	Facilities for cyclists	850,00 €	-	-	-	-	1,66	-	-	1
Transport	Tra4	Pavement for Pedestrian and cycle safety	0,00 €	-	-	-	-	n.q.	-	-	2
Transport	Tra7	Spaces for Public transportation information	0,00 €	-	-	-	-	n.q.	-	-	1
Water	Wat1	Measures to reduce water consumption 1- Dual flush toilets	3.435,00 €	<1 year	161.011,75 €	205.577,02 €	401%	43,00	-	5.291,0	1

Table 2.(cont.) Summary of results obtained during the analysis.

Related category	Ref.	Criteria	Inicial investment (€)	Payback (years)	NPV (15 years) (€)	NPV (20years) (€)	IRR 15(TX Val 5%)	$TonCO_{2eq}$ reduction/year	Reduction of energy (MWh/year)	Reduction of water (M^3)	Breeam Points
Water	Wat1	Measures to reduce water consumption 2 - Waterless No-Flush urinals	6.327,41 €	<1year	228.312,72 €	291.977,39 €	311%	62,00	-	7.558,0	1
Water	Wat3	Water leak detection system	3.500,00 €	-	-	-	-	17,00	-	2.010,0	1
Water	Wat4	Sanitary supply shut off	5.400,00 €	9,0	2.375,58 €	4.765,17 €	10%	2,33		283,68	1
Materials	Mat6	Use of insulation with less environment impact	33.491,00 €	-	-	-	-	646,6 (1ºano) 4,82	- 10,0	-	1
waste	Wst5	Composting	-6.900,00 €	-	-	-	-	29,00	-	-	1
Additional investment associated with changing a rating of **good to Very good**			220.443,41 €	5 anos	380.137,83 €	555.838,04 €	23%	931,45 (1ºano) 284,85	260,4	15.142,7	
Additional measures - VERY GOOD to EXCELLENT (Criteria from Group D)											
Breeam-Retail			Economical data					Environmental data			
Related category	Ref.	Criteria	Inicial investment (€)	Payback (years)	NPV (15 years) (€)	NPV (20years) (€)	IRR 15(TX Val 5%)	$TonCO_{2eq}$ reduction/year	Reduction of energy (MWh/year)	Reduction of water (M^3)	Breeam Points
Energy	Ene1	Emission of CO_2	-	-	-	-	-	-	-	-	10
Energy	Ene5	Low or zero emission technologies	2.693.000,00 €	4,0	6.620.766,53 €	9.387.604,30 €	29%	3.727	11.333,29	-	3
Energy	Ene7	Cold storage	1.785.304,00 €	6,0	2.217.162,76 €	3.425.764,66 €	18%	0	0,00	-	1
water	Wat5	Recycling of water from rain (including watering)	108.235,45 €	2,0	753.315,24 €	991.661,99 €	67%	12	-	28.295,0	1
water	Wat1	Measurements to reduce water consumption (1+2) conjugated with Wat 5	9.762,38 €	1,0	163.687,02 €	211.023,05 €	149%	100,00	-	12.849,0	2
Additional investment associated with changing a rating of **Very good to Excellent**			4.586.539,45 €	5,0	9.591.244,53 €	13.805.030,95 €	25,98%	3.739,00	11.333,29	28.295,0	
Additional measures 1st intervention Initial proposal (Good) to (Excellent) (Criteria from Group C and D)											
Breeam-Retail			Economical data					Environmental data			
Related category	Ref.	Criteria	Inicial investment (€)	Payback (years)	NPV (15 years) (€)	NPV (20years) (€)	IRR 15(TX Val 5%)	$TonCO_{2eq}$ reduction/year	Reduction of energy (MWh/year)	Reduction of water (M^3)	Breeam Points
Additional investment associated with changing a rating of **Good to Excellent**			4.806.982,86 €	5,0	9.745.744,91 €	14.074.337,63 €	25,42%	4.670,45 4.023,85	11.593,68	43.437,7	

7 CONCLUSION

This article provides evidence of the results obtained from introducing sustainability criteria using the BREEAM tool, applied to a shopping centre in the north of Portugal. It was concluded that it was possible to obtain a better rating (from Good to Excellent) with relatively low financial investment, and significant environmental advantages. In the concrete case of the Dolce Vita Braga Shopping Centre, an additional investment of 6.62% over the initial cost of construction would allow the building to obtain a rating of Excellent. This amount would be rapidly recoverable, with a

20 year NPV three times greater than the amount invested. In relation to the environmental results, the reductions obtained in energy and water consumptions and CO_{2eq} emissions were quite reasonable, taking into consideration that the avoided consumption could supply the consumption needs of a significant number of European inhabitants.

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7.2 *Acknowledgement*

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Alternative uses of water in buildings – An affordable sustainable solution

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ABSTRACT: Water is the most precious resource of mankind, usually regarded as a commodity and seldom given its true value. The aim of this study is to analyze the differences, starting from the project phase, between options leading to recycling, reuse or use of alternative sources of water.
A simple building solution incorporating non-conventional water supply solutions was inserted in a real architecture and engineering project and compared with the situation where this is not accounted for. Recycling or reuse gray water and use of rainwater are considered along with the technical solutions given by the current state of the art. An evaluation is performed in order to illustrate that this solution is affordable and even shows that investments in initial stage allows savings over time in terms of maintenance and operation, with simultaneous minimization of the environmental impact.

1 INTRODUCTION

1.1. *Water and sustainability*

Essential to life on Earth, water is a precious and rare item today. Although water is the most abundant material in our planet (around 1.360 million cubic kilometers), it should be noted that 95.5% consists of salt water and 2.2% is presented in the form of ice. Only 2.3% consist of freshwater, not always accessible, usable and having the required quality for the intended use. Indeed, over decades, both the growth economic model and exponential population growth, together with intensification of agriculture and industrial activities, were decisive for the pollution of available water through discharges and infiltration of contaminants. Hence, there is a strong need to rethink the water cycle strategy and its sustainability [Kibert, 2005]. In buildings, the use of rainwater and reuse or recycling of grey waters can be very important as measures for the aimed sustainability of this resource.

1.2. *Use of rainwater in buildings*

Rainwater is part of human life and the history of mankind, and many examples can be found about his capture and storage for consumption. Nowadays, in an apparently contradictory way, justified perhaps by the easy access granted by modern life [Kibert, 2005; Silva-Afonso et al., 2008], this water strategies are rarely used in urban areas, although an increasing global water stress is noted as a trend.

The concept of water stress refers to the difference between the usable water and the available natural resources. Prospects in this respect show that many countries in the world, including the ones in the Mediterranean basin (as Portugal), risk a very high water stress (more than 80% within a few decades).

It should be noted that the increasing of water consumption rate is two times faster than the population growth. According to the United Nations, by 2025, it is estimated that two thirds of the population of the planet (approximately 5500 million people) are living in countries that suffer from serious water shortages.

The progressive awareness of sustainability in the use of resources is introducing new ways to design buildings and cities, for instance, integrating the recovery of rainwater, not necessarily for all purposes but for uses that do not require high quality water (food) [Kibert, 2005; Silva-Afonso et al., 2008; König, K.W., 2001].

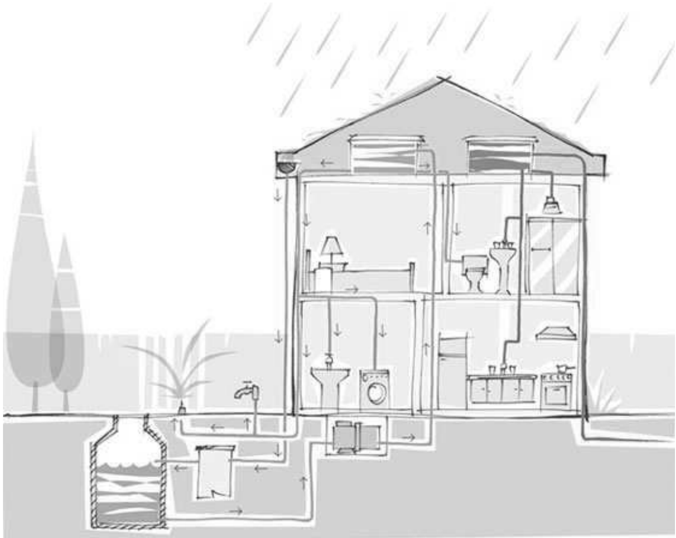


Figure 1. A simplified scheme of the system for rainwater use in a house [in http// www.aquacycle.com, 2008]

1.3. *Rules for the design and installation of rainwater harvesting systems*

The design of a system of use of rainwater should bear in mind the following rules (Figure 1) [Tomaz, 2003; König, 2001]:

- Adoption of a calculation model to assess the needs in water amounts for each project.
- Admit as collection areas those not in regular contacts with people, animals or machines.
- Adopt filtering systems that reject first waters ("first flush") after long periods without average rainfall (rejection of average 0.5 liters per m^2).
- Predict cutting valves at the beginning of the system, with diversion to the rainwater collector, in order to allow verification, maintenance or replacement.
- Predict reflux valves, with anti-rodents membrane at the exit (due to sewage overflow) of the storage deposit, which must be connected to the rainwater collector.
- Use a storage deposit with walls free of porosity and without leading to chemical reactions. High density polyethylene is nowadays the material in use for this application.
- The deposit should be buried, ensuring that rain water is protected from light and temperature variations. In this the formation of algae and the development of certain microorganisms are also prevented.
- Deposits should have a buffered opening that allows access to its interior for maintenance.
- The water entry in the deposit should be made from the bottom to the surface through a special accessory that will not cause turbulence. In this way, oxygenation of water can also be done whenever new water flux comes in.
- The water collection by pump in the interior of the deposit should happen around ten or fifteen centimeters below the top level to ensure good quality.
- The system must provide that overflow in the deposit happen three to five times per year, ensuring a good water renewal.
- In the case of rain water supplying some equipment inside the building (WC tanks, for example) there should be independent channeling without possibility of crossing with others.

The automatic valves doing the switching of the deposit to the normal grid must ensure that there is no entry of rainwater by reflux into the potable water supply grid.
- All taps feed by rain water must be marked with labels indicating "not drinking water or improper for consumption". These should only be handled by a security key.
- Maintenance and cleaning should focus on the time of the year before and after the rains.
- Main physical-chemical parameters of stored water should be checked every six months.
- Every five years total deposit emptying and washing is recommended.

1.4. *Reuse and recycling of grey water*

The wastewaters can be subdivided in black and grey waters. Although some authors refer other classifications, waters which are mixed with organic matter (toilets) are usually named as black waters. They require chemical or biological treatment and sometimes disinfection before being used again. In principle, these waters should only be reused outdoors, for instance, in gardens or green areas. Reuse or water recycling in situ offers many opportunities for rationalizing water consumption in buildings [Koeller, 2009]. Unfortunately, nowadays all water used in buildings and gardens is drinkable.

The opportunities of reusing or recycling grey waters vary according to the location where one lives. The houses are usually linked to a centralized sewer system but, in isolated homes with gardens, this opportunity becomes more evident. The grey waters, with appropriate treatment for discharges, may serve for toilet cisterns, gardens, patios and washing. It is important to stress that the reuse or recycling of wastewater decreases the volume of effluents, reducing overloads in the centralized sewer system and extending its life time.

Unfortunately, because water in the public network is not presented with its real cost (in Portugal), installation and maintenance of water reuse systems may result in a solution with an extended payback period. This period can vary with the extent of services of the existing local wastewater treatment and with the type of system that will be installed. Anyway, it is always beneficial to reuse or recycle the water, at least in terms of sustainability.

In order that reuse or recycling of grey water is possible, it is necessary to separate the discharge pipes of grey and black waters and install the system for treatment of water (Figure 2).

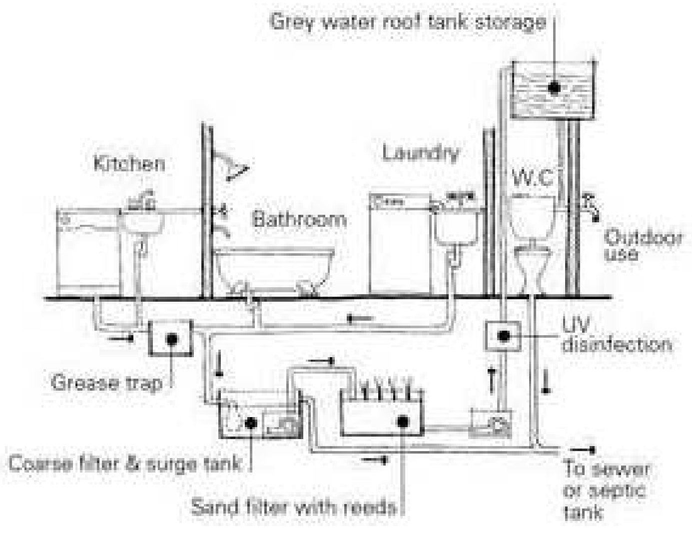


Figure 2. Scheme of a system of grey water reuse [in http// www.aquacycle.com, 2008]

In fact, the grey waters can be directly shifted from the drain of shower and washbasin to be reused only in flushing. However, it cannot be stored more than 2 hours before it is reused, which brings pre-treatment as the more convenient option. In table 1, values are shown for the daily produced typical volumes for grey and black water in a typical residential building [Pimentel Rodrigues, 2008].

Table 1. Consumption per day and per person of black and grey water

Black waters	Volume (liters/person/day)
Toilet flush	22
Grey waters	Volume (liters/person/day)
Shower	56
Washbasin	6
Kitchen basin	12
Dishwasher	5
Laundry tank	7
Laundry washer	27
Grey water total	113
Total (black and grey water)	135

1.5. *Water efficiency*

In Portugal, the need for an efficient use of water has been recognized as a national priority through the publication of the Government Resolution nº 113/2005 of 30/June, approving the National Program for the Efficient Use of Water [Pimentel Rodrigues, 2008].

This program also proposes the labeling of devices in buildings (cisterns, showers, taps and so on) to make consumers with more knowledge on their water efficiency. It is proposed in the program that this measure will be compulsory after a transitional period. Logically, it is becoming urgent to define and implement a model in Portugal for water efficiency certification and labeling for buildings. The certification and water efficiency labeling of products already exist in Portugal and have been implemented in various countries on a voluntary basis. In some cases, for example in the United States or in the Nordic countries, these adopted systems refer to one efficiency value and in other systems (Australia and Ireland), the labels provides a variable classification of product efficiency. In Portugal, these water efficiency labels are already studied and proposed by a National Association (ANQIP) [Pimentel Rodrigues, 2008].

This work aims to integrate simple water use efficiency strategies in a building project and analyze the economical and environmental impact of such proposals.

2 EXPERIMENTAL – PROJECT DESCRIPTION

The starting point of this project, designed as a common living building, refers to a single isolated villa with two floors above the ground. The architecture project is set on a flat and sandy terrain in the surroundings of a medium town, where there are no need for operations of landscaping in terms of soil movement. The foreseen construction and implantation area are around 350 m^2 and 506 m^2, respectively. Building volume is 1811 m^3 with a typical height of 6 m. The building constitution and inner design was set accordingly to regulations and in order to satisfy the requirements of the owner.

The architectural solutions were developed into two floors with a supplementary or annex building. The ground floor involves an entrance area as a distribution lobby, a living room, a bedroom with a private bathroom, a common use toilet and a kitchen with a smaller living room attached.

The access to the first floor is done trough a vertical connection, stairs that are accompanied by a small indoor garden. The space in the first floor presents two bedrooms, a common bathroom, a small reading room and an office space. The annex or supplementary building attached to the main building is constituted by a double garage, a laundry area, a toilet and a rural kitchen.

The house simple structure is built by a system of steel reinforced concrete pillars and beams supported on direct foundations with lightweight concrete slabs. The masonry walls are in standard ceramic bricks placed with common cement mortar. The flat roof is based on lightweight concrete slab. Table 2 show the different building areas and its costs. The estimated total cost of the works is around 150 000 €.

In order to achieve this work objective, simple alterations were performed in the project water distribution and drainage systems to contemplate not only a rainwater harvesting and a reuse system for grey water. Implications in the project architecture and construction costs are then discussed.

Table 2. Characterization of areas in the building space.

	Floors	Area (m^2)	Cost	Parcial cost
Main building	Ground	166.83	480€/ m^2	78 638.40€
	First floor	102.52	480€/ m^2	49 209.60€
Annex building	Ground	50.75	180€/ m^2	9 135.00€
		30.45	180€/ m^2	5 481.00€
Fence walls	Ground		50€/m	3750.00€
Storage annex	Underground	20.35	370€/m2	7 536.00€

3 APPLICATION OF WATER EFFICIENCY SOLUTIONS – RESULTS & DISCUSSION

The alterations in the sewer and water distribution systems are firstly shown in Figures 4 to 6. These were modifications necessary to make in order to establish rainwater harvesting and also for the grey water reuse. In terms of architecture no major modifications were introduced. Only the use of the small storage underground annex was partially changed. The rainwater harvesting and grey water deposits were placed there with the connections to the traditional water grid. There is still some available space for general storage.

Figure 3 shows the drainage system for residual water (normal distribution and rainwater), foreseen in the building ground floor, before and after introduction of changes related to water efficiency. The grid is set according to Portuguese rules using traditional solutions (Figure 3A).

In Figure 3(B), the new solution for water drainage is presented at the ground floor level, which includes the rainwater harvesting and also the grey water reuse from bath and washbasin only.

As it can be observed, the rainwater is lead to a storage reservoir after going trough first flush and leaves filters. Waters deviated in this filters also go to the rainwater basic grid. The storage reservoir also contains an overflow device for the rainwater grid system and a pump system towards the new grid used only for non-drinkable or food purposes (cisterns flush, garden, etc.).

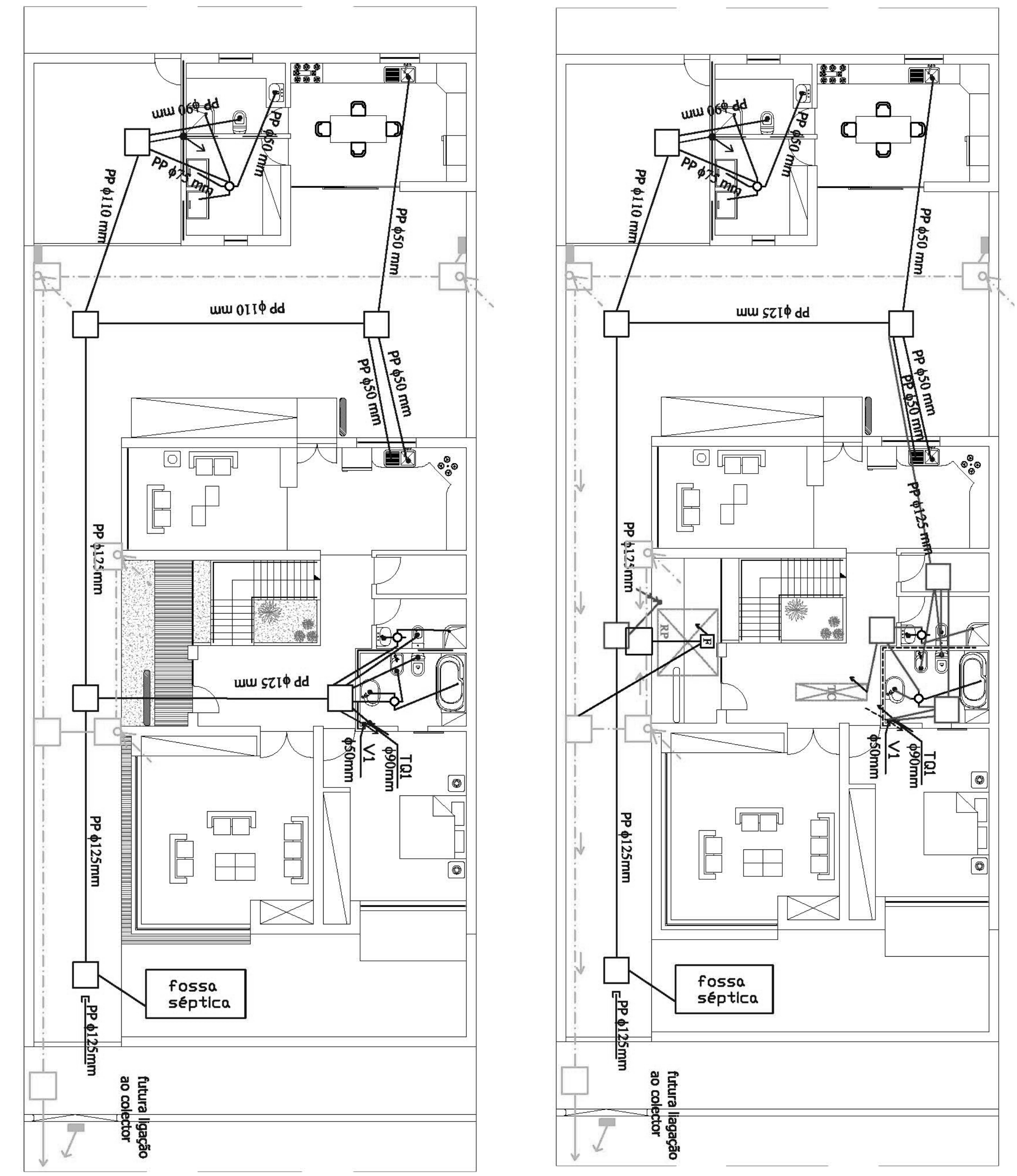
Grey water coming from baths and washbasins are lead to a small treatment unit including filtration, bio-treatment and ultraviolet disinfection. After treatment, these waters are connected to the non-drinkable water circuit, coming from the rainwater deposit (Figure 4). The water treatment and harvesting deposits were placed in this storage technical area in the underground floor, specially adapted for this use. It is a small space, with an area around 20 m^2, with an access for maintenance operations.

Figure 5(A) shows the traditional solution for water distribution in the ground floor. Figure 5(B) presents the new solution considering the distribution of rainwater and grey water from baths and wash basins to toilet cisterns, exterior gardening and laundry applications.

The modifications in the entire building project, in terms of construction costs, are not relevant since the construction areas were not increased considering the ones that were foreseen in the project (Table 2).

If one compares both solutions, a slight increase in drainage system (around 10%) and duplication of part of the water distribution system (around 40%) exist that, obviously, result in some initial investment increase. There is still the investment in terms of the rainwater and grey water deposits and equipment. There are already systems in the market that perform the functions described here and set in the modified architecture project, meaning, rainwater harvesting and reuse and also the grey waters recycling. A typical system for both functions would have an investment cost around 6500 €.

If the acquisition and construction costs of the modifications in the drainage system and in the water distribution system are added, one can estimate a total investment cost around 8000 €.



(A) (B)

Figure 3. Ground floor - Water distribution system before (A) and after (B) water efficiency measures; Deposits near the stairs (crossed boxes) are for rainwater harvesting (square) and grey water treatment (rectangle); Lines and connections to the grey water deposit near central WC in (B) represent modifications related to the grey water system. Dashed grey and full black lines represent the rainwater and sewer distribution systems.

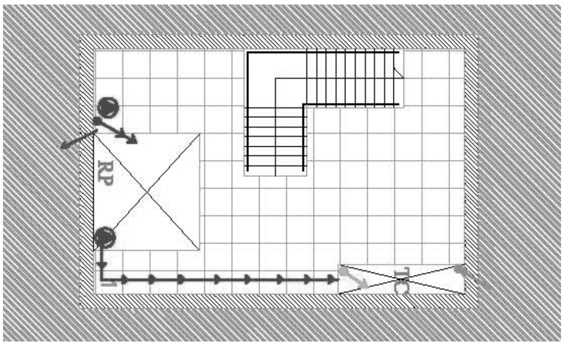


Figure 4. Underground floor technical area - Water efficiency measures; Deposits are for rainwater harvesting (square) and grey water recycling (rectangle) and its connections.

On the other hand, one can estimate average savings up to 60% of water for a region with a normal rain fall situation. Other solutions of water harvesting can be set according to the region nature. However, taking into account savings in the order of 50% and that a normal bill for this kind of building can reach monthly values of 70€, it is possible to translate direct savings of 35€ per month (or 420€ per year). Apart from the economical benefit, it is even more important the environmental aspect of these simple measures, since it is clear today that, for some Mediterranean countries including Portugal, the risk for water stress is very high in the near future. Moreover, it is also expected that the water bills for buildings will also tend to increase significantly with time due to the way costs will be assessed and due to the water stress levels. Therefore, it is expected a payback period between 12 and 15 years.

4 CONCLUSIONS

The example presented allows you to prove that it is easy to implement water efficiency measures in the construction of buildings. This case study allowed us to think about simple decisions that can significantly alter the way to build in a more sustainable but affordable way. The small investments of today may have a high economic, social and environmental impact tomorrow. Indeed, our case study showed that an initial investment cost increase of less than 8000 € in an overall value for the building of around 150000 € is quite small and it simultaneously generates lower monthly costs throughout the building life.

Apart from this economical facts, the environmental impact in an age of water stress demand a conscientious decision towards water efficiency. Considering a normal water consumption of 135 liters/person/day and that a building like this one is usually occupied by four persons, one can easily estimate a monthly consumption up to 20 m^3 and an annual saving of more than 100 m^3. Reproducing this value for millions of buildings one can quickly grasp the important water savings that simple measures can generate.

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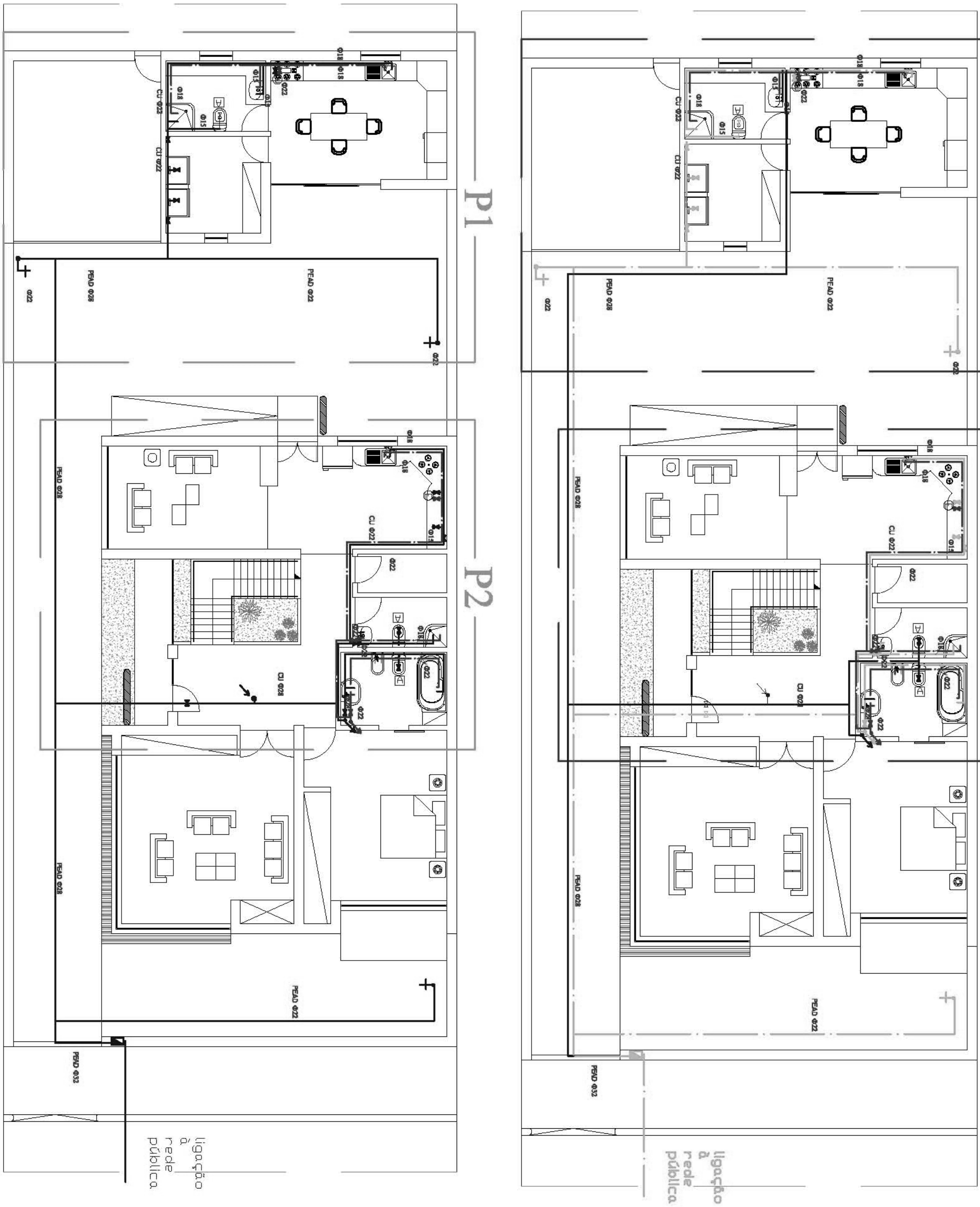

(A) (B)

Figure 5. Ground floor - Water distribution system before (A) and after (B) water efficiency measures; long dashed grey lines represent the modifications in the distribution systems due to the reuse of grey water and the use of rainwater.

Advantages of using raw materials in low cost sustainable structural solutions for single-family buildings

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ABSTRACT: In the last decades, the Portuguese housing building industry has been mainly focused on the construction based on reinforced concrete framed structures and non-structural clay brick masonry for exterior and interior partition walls. Recently, this industry started to include alternative structural materials, such as steel and timber. The earth based construction techniques and solutions still remains limited to individual cases, in which the owner and/or contractor have a particular concern and knowledge of these ecological solutions. Within this context was developed the present research work, in which a sustainable structural solution for a typical house using natural materials is proposed and studied. Two different structural solutions are defined, namely a reinforced concrete framed column-beam solution (designated by traditional solution) and a solution based on adobe masonry and timber structures for floors and roof (designated by sustainable solution). These two alternative structural solutions are then compared in terms of building costs, energy consumption and CO_2 emissions. All the main aspects related to the design of the sustainable solution, such as the design assumptions, structural models and behaviour parameters are described. Taking into account that the proposed sustainable solution is uncommon in the Portuguese building context, the difficulties faced during the design are also pointed out and commented.

1 INTRODUCTION

About half of the world population, nearly 3 billion people, over the six continents live or work in earth based buildings (Minke, 2005). In some countries with limited economic resources earth based construction might represent even more than half of the total building stock (Carvalho et al, 2008). Several existing earth constructions are classified as historical heritage (Cortés, 2009). Earth construction is a sustainable practice because earth is a natural material, recyclable and abundant anywhere, but also because the techniques used in the fabrication on those elements are usually simple, require a small amount of energy and have associated an inexpressive amount of toxic gases delivered to the atmosphere.

Moreover, the acquisition and application of the building materials currently used in the construction industry require a significant amount of energy consumption during the different stages of the process (extraction, transportation, manufacturing, application, demolition and disposal or recycling) and lead to pronounced release of noxious gases into the atmosphere.

This research work is focused on the viability analysis of the application of natural raw building materials, and traditional building techniques in the construction. Thus, earth based *adobe* masonry is proposed as structural load bearing elements, as an alternative to the traditional reinforced concrete (RC) frames. A typical Portuguese modern single family house was used as case-study, for which two different structural solutions were proposed, designed and compared: a traditional solution (ST) and a sustainable one (SS). The ST is a RC column-beam frame type main structure, with prestressed precast flooring structures and RC slabs in elements such as balconies and stairs, and partition walls made of ceramic brick masonry. The structural SS is based on load-bearing *adobe* walls and timber flooring structural systems. For each of these solutions, the overall building cost, the overall energy consumption and the overall atmospheric emission of noxious gases were quantified and compared. This led to the main conclusions here discussed, that the structural SS is obviously more advantageous both in terms of building cost as well as in what regards the environmental impact.

2 DESCRIPTION OF THE CASE-STUDY, DESIGN TOOLS AND METHODS

The building under study was idealized as being located in the city of Figueira da Foz, at an altitude of 100.00 m, in an urban area surrounded by small buildings. It is a typical of single family house suitable for a family of 3 or 4 people, with three bedrooms, which corresponds to one of the most common typologies in Portugal (around de 57% of the existing building stock, (INE, 1998). In Figures 1-2 can be observed the building architecture and spaces distribution of the studied building. The rooms are distributed in two floors: a ground floor mostly for social use and an upper floor (first floor) for private use. The overall construction areas for the ground and first floors are 285.00 m^2 and 106.5 m^2, respectively.

The ground floor consists of a living-room, a dining-room, a kitchen, a storage area, a toilet, an entrance hall and a corridor. There is also a porch which runs along two sides of the building. On the first floor there are two bedrooms (one of them with a private dressing room), an office, a bathroom, a landing and a veranda. The two floors are connected by stairs which links the entrance hall to the landing and the first floor. The roof at the first floor level is slightly sloped and covered with ceramic tiles. The roof at the second floor level is flat, inaccessible and covered with rolled pebbles. The main entrance faces towards east.

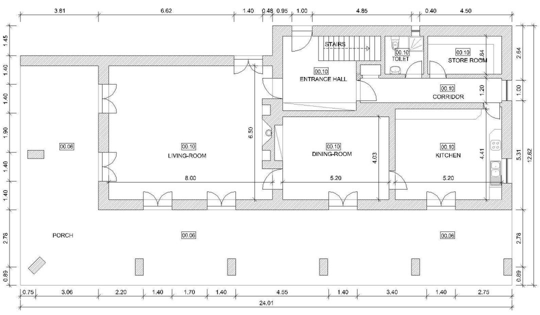

Figure 1. Architectural plan – Ground floor

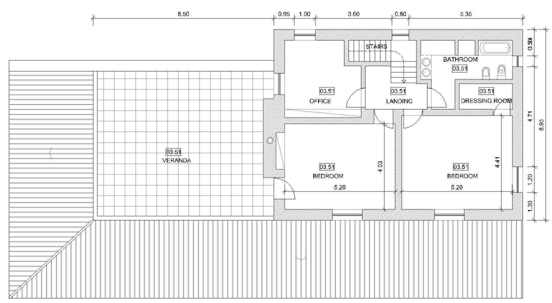

Figure 2. Architectural plan – First floor

For the design of the structural ST commercially-available software programmes were used. The computer program allowed for dynamic modal analysis, consideration various vibration modes, and allows for the determination of the structural response to seismic loadings based on response spectra analysis. The wind load is quantified automatically, considering the building location, the rugosity associated and the global dimensions of the building. Spreadsheets were developed to check and analyze the numerical results obtained from the structural computer program. Specific spreadsheets were also used for the design of isolated structural elements, such as stairwells.

For the structural SS design, and due to the lack of computer programs devoted to the automatic calculation of the *adobe* masonries, specific spreadsheets based on the provisions of standards [5, 6] were developed. For the timber structural elements design (beams and stairs), the provisions in Eurocode 5 (CEN, 1998) were adopted and also specific spreadsheets were worked up for the SS design.

3 TRADITIONAL SOLUTION

In accordance with (REBAP, 1983), it was adopted a concrete type C25/30 for all the RC structural elements (columns, beams, stairs and foundations). S400NR steel was used for reinforcing bars and S500EL steel was used for electro-welded wire mesh reinforcement in slabs. Exterior walls and interior partition walls are basically masonry made of hollow ceramic bricks. For exterior walls, the outer curtain have a thickness of 0.15 m and the inner curtain 0.22 m, both with mortar at the joints and a 0.10 m wide insulation space between them. The interior walls are single-leaf with a thickness of 0.15 m also with mortar at the joints. The structural system of floors is basically made of precast prestressed slabs. These floorings system are unidirectional and considered simply supported by RC beams.

For the building structural analysis, it was considered for the dead load the self-weight of the structural and non-structural elements. Variable loads comprised live, wind and earthquake actions.

For the weight of the structural elements, the following specific reference weights were adopted: 78.50 kN/m^3 for the steel and 25.00 kN/m^3 for RC elements. Floor and wall coverings were considered with 2.00 kN/m^2 and 3.00 kN/m^2, respectively. For live loads, in accordance with (RSA, 1985), 2.00 kN/m^2 was considered for the living areas, 1.00 kN/m^2 for the inaccessible terraces and 3.00 kN/m^2 for the access areas. For the quantification of the wind load, also in accordance with (RSA, 1985), it was considered that the building is located in Zone B and a type II rugosity. In terms of earthquake load, in accordance with (RSA, 1985), calculations were made on the basis of a class C seismic zone, type II soil, a seismic coefficient value of 0.50, a damping coefficient of 5% and a behaviour factor of 2.0 was assumed. For the foundation soil capacity, a value of 200 kPa was considered.

After quantifying the loads and their combinations, according to (RSA, 1985), the safety and design of the structure was then developed. All structural element sections were designed according to the ultimate and serviceability limit states philosophy, using for this purpose the provisions of (REBAP, 1983). The design of the ST solution adopted for the building under study results in the structural system represented in Fig. 3-6.

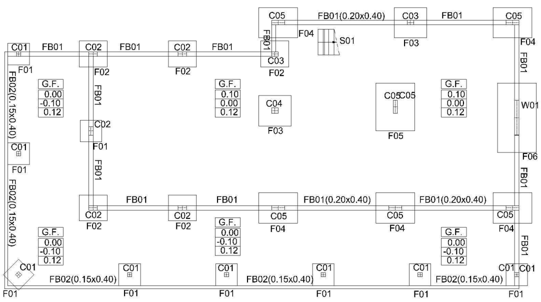

Figure 3. ST: Foundations

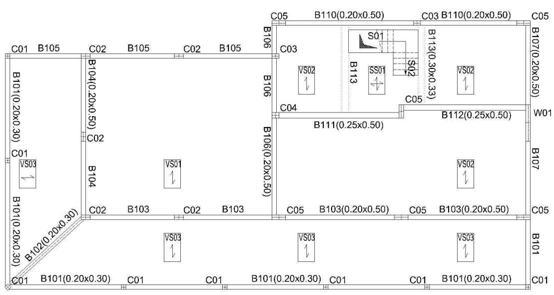

Figure 4. ST: First floor

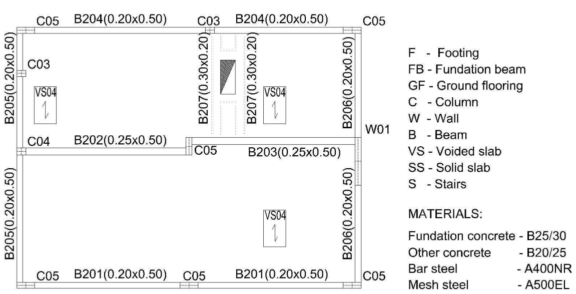

Figure 5. ST: Roof

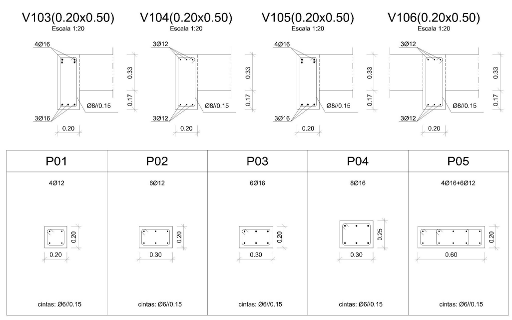

Figure 6. ST: RC elements' details

4 SUSTAINABLE SOLUTION

For the structural SS, pre-dimensioning of the structural elements was carried out based on the minimum allowable dimensions for each of these elements, as specified in EC6 (CEN, 1995) and EC5 (CEN, 1998). All elements were designed using specific spreadsheets developed.

The load-bearing walls are made of adobe, with a compressive strength of 4.0 MPa and bed joints with a class M5 (5.0 MPa) mortar, in accordance with EC6 (CEN, 1995). For structural elements at the first floor, for the roof and for the stairs, wood beams of E class, *pinus pinaster* pine, were considered, in accordance with EC5 (CEN, 1998). The load-bearing walls foundations are continuous, made of solid limestone blocks. These materials were chosen because is natural, local and abundant in the building's location area.

The structural analysis of the SS followed the same loading parameters as the considered for the ST, described in detail in the previous section. For the specific weight of the earth blocks it was considered a value of 18.00 kN/m^3, and 5.80 kN/m^3 for the wood. The other loading actions, as stated previously, were computed analogously to those defined in the previous section for the ST.

The wooden floor structural elements were designed in bending and shear, based on the provisions of EC5 (CEN, 1998). These floor systems are supported directly by the load-bearing adobe masonry walls, which were designed according to the specifications of (RSA, 1985) and EC6 (CEN, 1995).

Since the design of these structural elements (adobe and timber) is still punctual in the Portuguese construction context, and the structural design commercial software do not include tools for the design of these types of structural materials, a 3D finite element structural model was developed, using shell and frame elements, to calculate the stresses distribution in the structural elements composing the building, for each loading case and for their combination.

From the design strategy adopted for the structural SS for the building under study, were obtained the results represented in Fig. 7-10.

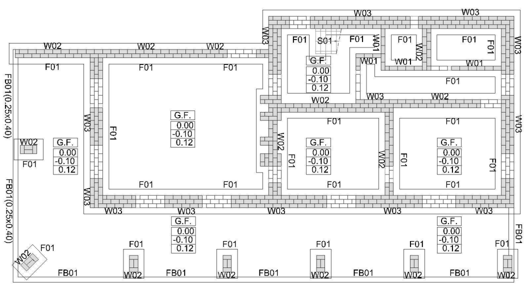

Figure 7. SS: Foundations

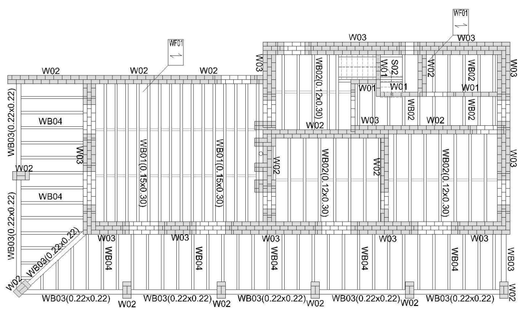

Figure 8. SS: First floor

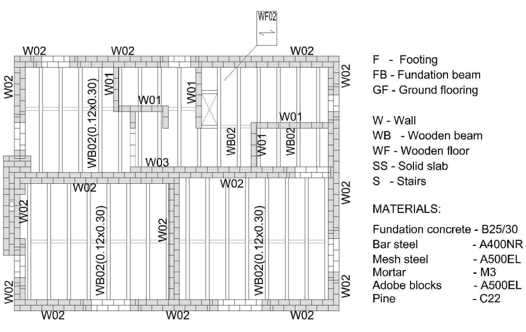

Figure 9. SS: Roof

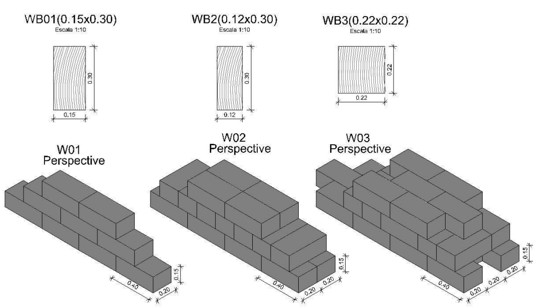

Figure 10. SS: Structural details

5 RESULTS ANALYSIS

Each building material has associated a specific cost, an energy consumption in its production and a quantity of noxious gases released into the atmosphere, resulted from all the phases, namely its extraction from the raw material, transportation, transformation, building process, maintenance, demolition and recycling.

It is possible to estimate the quantity all the environmental parameters associated associated to each phase of the complete life-cycle of the materials, as done per example in (KangHee et al, 2007), (PRE, 2009) and (Baird et al, 1997).

Table 1 presents the values of energy consumption for the building materials which are considered in this research work, following the procedures proposed by different authors ((KangHee et al, 2007), (PRE, 2009) and (Baird et al, 1997)). Comparing the values obtained by the different approaches, it is noticed an expressive difference among them. According to (Baird et al, 1997), this fact may be related to the different approaches used by each author concerning different period of time for the material life-cycle and/or different fabrication techniques. In this study, the values of energy consumption proposed by (KangHee et al.2007) were adopted and the current building Portuguese market unit costs were used (see Table 2).

Based on the results of the structural design for the ST and SS, the estimated quantities of each building material are presented in Table 3. The noxious gases estimative has been converted into CO_2 and for the functional working unit was considered the overall construction area which is 391.50 m^2 in this case. The total cost, the total energy consumption and the total CO_2 emissions associated to both the structural ST and SS solutions studied are presented in Table 4, comparing also the inherent gains estimated.

Table 1. Energy consumption (MJ/kg).

Material	KangHee (KangHee et al, 2007)	Leiden (PRE, 2009)	Baird (Baird et al, 1997)	Alcorn (Baird et al, 1997)
Concrete	2.5	0.98	2.01	0.79
Bar steel	3.0	1.18	2.01	0.79
Mortar	3.0	1.18	3.28	1.29
Brick	3.0	1.18	3.28	1.29
Earth *adobe*	3.0	1.18	3.28	1.29
Gravel	3.0	1.18	3.28	1.29
Pine wood	3.0	1.18	3.28	1.29
Sand	3.0	1.18	3.28	1.29
Cement	3.0	1.18	3.28	1.29
Earth	3.0	1.18	3.28	1.29

Table 2. Parameters of the materials.

Material	Unit	Unit Cost (€)	Energy Consumption (MJ/Unit)	Emission (CO_2/Unit)
Concrete	m^3	50.25	1292.24	99.43
Bar steel	kg	0.63	38.66	3.72
Cement based mortar	m^3	50.45	961.40	63.91
Ceramic brick	un	0.31	14.78	1.11
Stone	m^3	15.00	365.26	26.90
Earth *adobe*	un	0.15	1.45	0.09
Earth based mortar	m^3	48.88	931.48	61.92
Pine wood	kg	0.44	4.44	0.38

Table 3. Quantities of each building material.

Material	Unit	ST	SS
Concrete	m^3	120.25	28.00
Bar steel	kg	6480.00	455.00
Cement based mortar	m^3	24.80	-------
Ceramic brick	un	12969.00	-------
Stone	m^3	39.00	128.60
Earth *adobe*	un	-------	18000.00
Earth based mortar	m^3	-------	48.20
Pine wood	kg	-------	16211.05

Table 4. Comparison of the two proposed structural solutions.

Parameter	Unit	ST	SS	Better solution	Reduction (%)
Cost	€/m^2	40.82	38.73	SS	5.14
Energy consumption	MJ/m^2	1623.69	622.60	SS	61.66
CO_2 emission	kg-CO_2/m^2	135.64	47.77	SS	64.78

From Table 4, it is evident that the structural SS offers a better solution considering all the three parameters analysed. In fact, the structural SS allows for a reduction of 5.14%, in building cost, a reduction of 61.66% in energy consumption and a reduction of 64.78% in CO_2 emissions. In this case, these results show that although the structural SS may not offer a significant financial benefit, it is much more environmental friendly.

6 MAIN CONCLUSIONS

It was noticed that there is still a certain lack of experience in applying the current regulations for the design of structural solutions based on natural raw materials, as well as a lack of commercial computer programs for the design of structural elements made of natural materials, as earth based building products.

Two structural solutions were studied, defined, designed and compared, namely a ST and a SS solution, for a typical Portuguese single family house. Structural building details are proposed for both structural solutions studied. The building details defined for the structural SS have an additional relevance because there is still a lack of experience in this field.

There are several research works focused on the quantification of unitary values of energy consumption and noxious gases released into the atmosphere, for different building materials. However, these values may differ considerably among those works. This fact may be associated to different approaches and assumptions made in the measurement of the life-cycle time periods and in the considered fabrication processes.

The environmental parameters considered it the comparative analysis of the two structural solutions studied are the energy consumption and the noxious gases released into the atmosphere (converted into CO_2 emissions). The comparison of the two structural solutions has shown that the structural SS is clearly more favourable, in financial terms, but mainly in environmental terms. The results plainly demonstrate the advantages of using natural materials in the Portuguese construction context in general, and the use of adobe load-bearing walls in particular in the construction of single family houses. These results may be generalized for many other civil engineering construction works, and can contribute for a more sustainable world.

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Structural Behaviour of Dry Stack Masonry Construction

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ABSTRACT: Interlocking mortar-less or "dry-stack" masonry construction refers to a technique of building masonry walls, in which most of the masonry units are laid without mortar. Soil-cement dry-stack system is one of cost-effective construction. Savings up to 27% compared to conventional mortared masonry have been reported (Ngowi, 2005). Hydraform dry-stack construction system was introduced in 1988 in South Africa by Hydraform Africa (Pty) Lda. After nearly two decades, the system is currently being used over 40 countries worldwide. Current application of dry-stack construction extends from rural community houses, urban and suburb several applications in medium-sized social and commercial buildings such as schools, hospitals, offices, shops and stores. The intense research work has so far provided a basic understanding of the structural behaviour of dry-stack construction and the system is now more competitive. This paper highlights the structural response of Hydraform block units and walls under compressive testing.

1 INSTRODUCTION

1.1 *General*

Interlocking mortarless or "dry-stack" masonry construction refers to a technique of building masonry walls, in which most of the masonry units are laid without mortar. A limited amount of mortar is allowed for starter and top courses. The structural use of dry-stack masonry relies on mechanical interlocking mechanism between units. The interlocking mechanism provides the wall's stability, self alignment and levelling.

Dry-stack construction has existed in Africa for thousands of years. The Egyptian pyramids and the great Zimbabwean ruins, a capital of Shona kingdom, are live examples of ancient dry-stack construction (Uzoegbo & Ngowi, 2003).

Ancient dry-stack masonry consisted of robust construction and the huge structural elements were both material and time consuming construction process. On that time, interest on dry-stack masonry had been lost and attention was focussed on researching and applying industrialized materials such as fired clay brick, cement, concrete, steel and panels of various types.

The industrialized materials were expensive and not affordable for the majority of poor people. Infrastructures were provided in city centres and other points of economic and political interests. The majority of poor people living in suburbs and countryside remained homeless. In order to provide shelter for themselves, they had to opt for precarious materials which in many cases were unable to give them safety and comfort.

Renewed interest in dry-stack construction is seen in the last two decades. Among others, soil-cement dry-stack system is one of cost-effective construction since soil is the most available construction material in the earth. The intense research work has so far provided a basic understanding of the structural behaviour of dry-stack construction and the system is now more competitive than before.

Several dry-stack systems are being used over the world. More than twenty three different dry-stack systems are currently being commercialised (Ngowi, 2005). The current application of dry-stack construction extends from rural community houses, urban and suburb applications in medium-sized social and commercial buildings such as schools, hospitals, offices, shops and stores.

The worldwide research on dry-stack systems has not yet established a standard code for a rational design.

The University of the Witwatersrand in collaboration of Hydraform Africa (Pty) Ltd is currently investigating the structural behaviour of Hydraform dry-stack masonry under different applications. This paper summarises the research work so far done with Hydraform dry stack system.

2 HYDRAFORM DRY-STACK INTERLOCKING SIYSTEM

2.1 *Hydraform interlocking system*

Hydraform interlocking blocks are produced by mixing soil and cement in predetermined ratios and extruding them vertically under a pressure of about 10 N/mm^2 using a hydraulic powered machine. Full scale and corner blocks are available in the Hydraform system and the block dimensions are shown in figure 1.

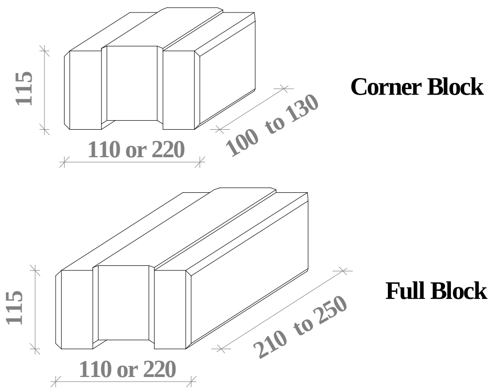

Figure 1. Block unit's layout.

A typical construction method is shown in figure 2. The base course is laid in mortar up to one course above a floor level. The middle courses are dry-stack up to lintel level. The top three courses are normally laid in mortar to form a ring beam at the top of structure. Alternatively, a reinforced concrete ring beam could be cast at the top.

2.2 *Opportunities and issues on Hydraform dry-stack system*

Hydraform soil-cement dry-stack masonry is a cost-effective construction system. The major material component is soil, the most abundant construction material in earth. In many communities, soil is a free material and no relevant technology is required to exploit it. Relevant costs are due to cement and block production machinery. However, cement appears in low quantities. For low rise residential houses, 5 to 10 % cement content by volume of dry mixture of soil and cement should be adequate. With the block making machines being mobile, one machine should be enough to produce blocks for thousand of houses. Block making machine revenue remains on proper planning and management.

Several small local entrepreneurs unable to make business on the industrialised and sophisticated construction systems are now able to run small scale business and create wealth. Job opportunities are created for jobless most of them unskilled people. Communities with low income can make plan to access decent low cost houses.

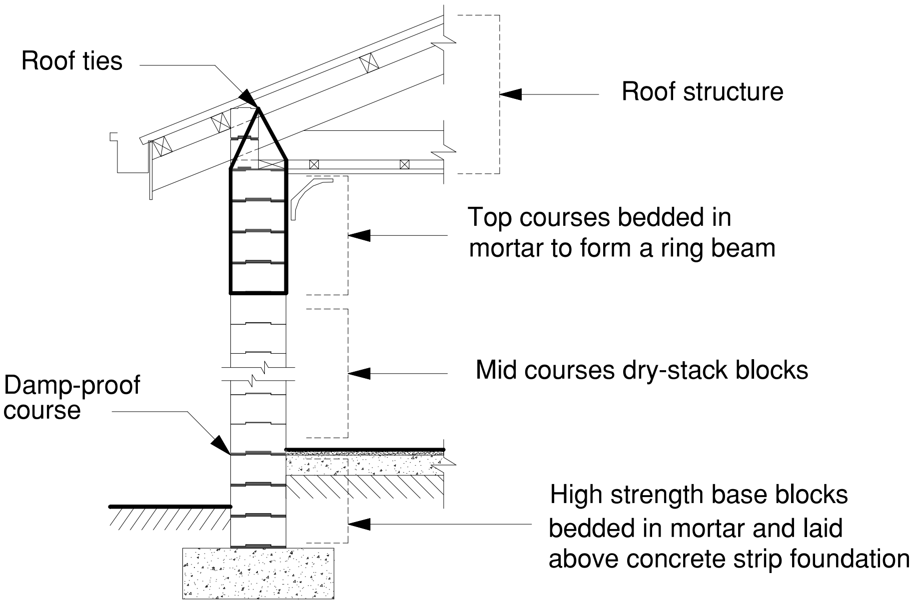

Figure 2. Typical construction detail of Hydraform dry-stack system.

Savings on mortar, faster construction process, low skilled labour employment, cheaper block production, transport savings and more are shown to be the key for the attractiveness of dry-stack system. Cost savings up to 27 % compared to conventional block masonry construction have been reported (Ngowi, 2005).

Shortage of houses, forces people to live in crowded conditions. This fact leads to social instability, crime, unhappiness and anarchy. Epidemic diseases leading to large scale deaths are common in homeless people. Hydraform building system creates for communities, decent houses which are safer and much comfortable. This empowers communities and builds happier, healthy and motivated societies.

In rural communities of low income, the hut is the most type of construction afforded. Huts can also be seen in many suburb poor areas. Hut construction material costs vegetation devastation. Adoption of soil-cement construction can significantly contribute to a health environment.

Clay block production requires large amount of energy for heating process. Heating can cost large amount of wood or consume electricity produced by burning coal and expel smoke to atmosphere. Soil-cement construction requires a very low amount of energy in a production process therefore environmental benign.

3 BLOCK UNITS COMPRESSIVE STRENGTH

3.1 *General*

In the evaluation of compressive strength of conventional masonry block units, different codes recommend different procedures. The British Standard (BS) recommends three methods. One consists of capping specimens with mortar and immersing them in water. When the mortar has reached strength of at least 28 MPa, specimens are removed from water, allowed to drain under damp sacking and tested. Other method consists of immersing specimens in water without capping them with any substance. After remaining in water for at least sixteen hours, specimens are removed and immediately tested. The third method described in BS consists of capping the specimens with fibre board and immerse them in water for at least sixteen hours. Specimens are then removed and allowed to drain under damp sacking before testing. A minimum of nine specimens are required for each compressive test (BS 6073: Part 1, 1981). South African Standards specify a testing method similar to that specified in British Standards.

The American Society for Testing and Materials (ASTM) recommends two methods. One consists in capping each masonry unit with a net paste of high-strength plaster and testing at least five specimens. Another method consists in capping the specimen with sulphur and granular material. A mixture of 40 % to 60 % of sulphur and fire clay or other suitable inert material is used to cape at least five specimens before testing (ASTM: Part 12, 1971).

For interlocking masonry block units, there is no existing standard guidelines to evaluate the compressive strength. Each dry-stack system is unique, therefore different types of interlocking mechanism will need different testing procedures. The irregular geometric form of the blocks is not compatible with the conventional method of testing.

3.2 *Compressive testing methods for Hydraform block units*

Three testing methods were considered. The first testing method refers to a shoulder loading of the block units. This testing arrangement was adopted to simulate typical Hydraform dry-stack application. The block on top sits directly on the shoulder of the unit below, creating a 3 to 4 mm interface gape in the central part of the block unit. For in plane vertical loading, the bearing area is reduced to the block shoulders.

The second testing method is the centre loading of full scale and corner blocks. When Hydraform block units are laid on mortar (foundation and ring block courses) it is likely that the vertical load or part of it will be applied on the central region of the block. The roof structure is also likely to rest on the central part of the block unit. This situation is simulated in this method of testing.

To comply with the standard testing of flat specimens in convectional masonry, cube loading test were adopted in Hydraform blocks as the third testing method. 100x100 mm cubes cut from full scale blocks were tested. Each full scale blocks were cut in four parts to form the cubes. Cubes were separated as top or bottom cubes. Top and bottom side of the block refers to how the block is positioned during production process. The bottom side of the block is more compact (dense) while the top side is less compact (low dense). The cube testing was also carried out to investigate the block internal compressive strength due to density distribution.

3.3 *Preparation of specimens*

Specimens were tested under three different humidity conditions, oven-dry, wet and normal. Dry samples were stored in an oven at a temperature of 50 ^{o}C for 24 hours before testing. Wet samples were soaked in water at a temperature of 21 ^{o}C for 24 hours and allowed to be surface-dry for one hour before testing. The normal samples were stored in pallets at normal ambient conditions (NAC) on an open space. Ten block samples were tested to obtain an average compressive strength.

Block units were classified according to the cement volume used as stabilizing agent. The corner blocks cement content was 7 and 10 % and for full blocks and cubes cement content was 5, 7, 10, 15 and 20 %. Test results are represented in Table - 1. The strengths were based on an arithmetic mean of ten samples.

3.4 *Remarks from test results*

Table - 1 summarises test results from the experiments. The corner block units cement content was 7 and 10 % and for full scale block units and cubes, cement content was 5, 7, 10 and 20 %.
The compressive test results below, led to relevant aspects, unique for Hydraform dry-stack block units. By cutting a full scale block into top and bottom cubes, different strengths can be seen for the same block unit. The bottom part of the unit is much stronger. The shoulder block

unit test results reveal same strength as the bottom stronger cube. The block unit exhibits very good resistance behaviour compared to the top (weaker) cube. The masonry wall is built using full scale and corner block units and not by the isolated top cubes. The above complex test findings made it difficult to decide which testing procedure could be adopted as standard to access Hydraform block unit compressive strength. Based on the moisture content influence on the block unit strength, associated to the real application of Hydraform system, the author suggests that both the full and corner block unit shoulder testing as well as bottom cube can be used to access the Hydraform unit compressive strength. The strength is referred to wet specimens. Wet strength is approximately 60 % of the normal strength.

Table 1. Compressive strength test results.

Description	Mean Strength [MPa]			
Blocks Designation	% of Cement Content	Wet Specimens	NAC Specimens	Dry Specimens
Corner Blocks	7	4,5	5,9	8,3
	10	8,4	12,7	15,2
Full Blocks	5	3,1	6,1	6,7
	7	4,8	8,2	8,7
	10	9,0	13,6	15,5
	20	13,8	20,2	20,0
Top Cube	5	1,8	2,5	3,2
	7	3,5	5,3	7,7
	10	7,6	10,1	12,4
	20	10,9	17,3	17,2
Bottom Cube	5	2,8	4,7	5,3
	7	4,6	7,3	9,2
	10	8,6	12,9	14,2
	20	14,4	18,5	21,1

In many codes of practice for structural use of masonry, conventional block unit grades are based on their compressive strength. This fact has effect in allowing the manufacturing industry to produce only standard grades of units allowing a rational design procedure. With design, manufacture and construction narrowed to standard grades of material, quality, safety and regulated construction can be achieved. Similarly, it is convenient to standardize Hydraform dry-stack block units in grades of their compressive strength. Table - 2 suggests the nominal compressive strength for Hydraform block units.

Table 2. Hydraform block unit compressive strength

Cement Content [%]	Nominal Compressive Strength of Block Units [MPa]
5	3,0
7	5,0
10	8,0
15	10,0
20	12,0
25	14,0

4 COMPRESSIVE STRENGTH OF DRY-STACK MASONRY PANEL

4.1 *General*

Characteristic compressive strength of masonry is an important parameter for design of walls subjected to in-plane uniformly distributed loading. Its laboratory determination for conventional masonry is highly discussed in many codes of practice. In the absence of laboratory tests, standardized values of characteristic compressive strength provided in codes of practice may be used. For dry-stack masonry there is no laboratory testing method or standard values of characteristic compressive strength yet. In this paper, the author presents recent research and laboratory testing data on Hydraform dry-stack masonry panels. Recommendations were made towards a standard determination of characteristic compressive strength.

4.2 *Hydraform dry-stack panels testing*

Dry-stack wall panels were constructed in laboratory using block units of different grades. Four dry-stack wall panels constructed with 5MPa, 9 MPa, 12 MPa and 23 MPa units were considered. The construction method followed the description in the manufacturer's manual. The first course of blocks and the top three courses were laid on mortar. The end vertical strips were also laid on mortar. The mid section of the panel (over 70 % of the all panel area) was plain dry-stack, see figure - 3. Each wall panel was 3,0 m long, 2,5 m height and 220 mm thick and was constructed on a Macklow-Smith machine platen that was mounted on a hydraulic Ram. A 3 m span steel beam was used to spread the load at the top of the wall. The spreader beam consists of a 305x305x118 mm H-section. Axial compression load was applied at a rate of 2 kN/min.

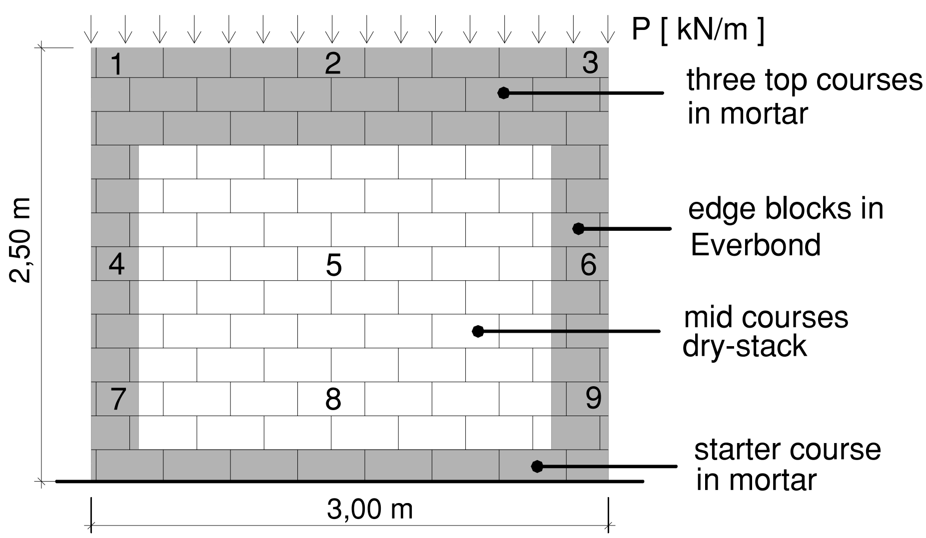

Figure 3. Wall panel construction details and strain gauge positions

4.3 *Test results*

Table - 3 shows test results conducted in the masonry dry-stack masonry panel tests. Similar to conventional masonry, the compressive strength of dry-stack masonry increases with the increase on block unit strength. Consistent proportionality was obtained between the unit strength and the wall strength. The ratio of masonry strength to unit strength decreases with increase in the unit strength and varies from 0,40 to 0,20. The lateral displacement results were not consistent and may need further tests to establish a trend.

Table 3. Hydraform block unit compressive strength

Block Unit compressive strength [MPa]	Ultimate compressive load [kN]	Bearing Area [m2]	Masonry compressive strength [MPa]	Masonry / Unit aspect ratio	Maximum lateral displacement [mm]
5	595	0,3	1,98	0,40	2,30
9	721	0,3	2,40	0,27	10,00
12	938	0,3	3,13	0,26	3,40
23	1360	0,3	4,53	0,20	40,00

Table - 4 summarizes Hydraform dry-stack masonry characteristic compressive strength as function of block unit compressive strength. A procedure similar to that used in conventional masonry was used to transform the masonry compressive strength from testing in characteristic compressive strength for design.

Table 4. Hydraform dry-stack masonry characteristic compressive strength

Unit compressive strength [MPa]	Masonry characteristic compressive strength [MPa]
3,0	1,1
5,0	1,3
8,0	1,6
10,0	1,8
12,0	2,0
14,0	2,2
16,0	2,4

Having a nominal unit compressive strength and masonry characteristic compressive strength systematized in a standard manner, design using Hydraform system becomes more rational and safe. Further research is required to evaluate and present the flexural and shear strengths of plain Hydraform dry-stack masonry.

5 CONCLUSIONS

5.1 *General*

Compressive strength of a block unit is largely used to describe several design properties of masonry wall. Unit compressive testing is important for both quality control and design. Dry-stack masonry is relatively a new technology yet to establish and document testing methods. Challenge relies on a fact that each dry-stack is unique therefore testing method will differ from system to system. This work constitutes an early attempt to standardize Hydraform dry-stack system.

Moisture content of the blocks has significant affect on the block compressive strength. Compressive strength of wet specimens is approximately 60 % of the dry specimens. For design, wet specimens are used as a standard method for evaluation of block compressive strength.

From wall panels testing, it was found that, the wall panel strength of dry-stack systems under vertical load is directly proportional to the strength of the masonry units.

Wall characteristic compressive resistance can be evaluated using a similar approach used to access the characteristic compressive strength of conventional masonry.

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How small can a house be?

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ABSTRACT: A study about the minimum necessary net internal area of dwellings that should be established by Portuguese building regulations is presented. The following tasks were carried out: selecting the furniture and equipment necessary for each dwelling; determining the size of furniture and equipment and its typical arrangement; conceiving models of functional spaces; determining the net area of functional spaces and dwellings; and comparing results with statistics on housing construction in Portugal and with mandatory area standards used in Portugal and ten other European countries. The conclusions are that the net internal area presently set by Portuguese building regulations should be increased by 5 to 15%. The net internal area figures obtained by the study are similar to mandatory regulations established by some other European countries.

1 INTRODUCTION

Nowadays, there is an overall agreement that building and operation of new houses should have a reduced environmental impact. For that purpose houses should use energy and water efficiently, save materials, have an adequate dimension, be healthy to live in, require low-impact maintenance, and last for a long time. But how do we put in practice these general recommendations? For instance, what is the adequate size of a house?

It is commonly understood that a house should be big enough to meet the needs of the occupants for living, cooking, dining, sleeping, washing and storage of household goods and have a convenient access to adequate residential amenity space. Space standards set the conditions to fulfil this objective and usually regulate minimum conditions of: overall internal floor area, size and dimension of individual rooms, ceiling height and layout of houses.

The building regulations of several European countries include space standards for housing. In Portugal the space standards for new housing were reviewed more than 30 years ago (Decree-Law No. 650/75). No space standards apply to construction work in existing buildings.

The purpose of the study is to investigate the minimum net internal areas that should be established by Portuguese building regulations for existing and new dwellings. Four research questions are addressed:

- What is the minimum net area of dwellings adequate to current Portuguese living standards?
- How does the proposal for a minimum net area of dwellings compare to the requirements set by Portuguese building regulations?
- What would the impact be if the proposal was adopted as the minimum mandatory requirement?

- How does the proposal compare to the area requirements presently enforced in other European countries?

2 THE IMPORTANCE AND DEFINITION OF SPACE STANDARDS

Space standards were introduced to set minimum habitability conditions, but have progressively lost their importance in the building regulations of several European countries. Space standards, for example, have been criticized as being an archaic relic of habitability standards and a symptom of over-regulation that restricts individual freedom. However, they have proved to be positive indicators of housing quality. They are simple to determine and verify and provide valuable information about dwelling space (Sheridan 2003).

Space standards are a measure of the acceptable intensity of dwelling occupation in the context of the prevailing cultural, social, climatic, economic and technological conditions in a particular society (Chowdhury 1985). These conditions change with time, meaning that space standards should be updated regularly.

The study of minimum space standards is important for several reasons (Sheridan 2003, HATC 2006, Wren n.d.):

- There is strong evidence that pressures arising from situations of overcrowding may lead to interpersonal aggression, withdrawal from the family, sexually deviant behaviour, psychological distress or physical illness. Furthermore, small homes which do not support the needs of occupants may lead to social cohesion issues and negative social behaviours.
- Dwellings have a long lifetime, lasting for generations. It is not easy to anticipate the evolution of users' needs and their implications for space standards. A dwelling's flexibility enables its adaptation to the changing needs of users, but depends greatly on its initial spatial characteristics. Smaller dwellings have limited scope for flexibility and do not support the needs of growing families.
- The space characteristics of a dwelling, established during design and construction, are difficult to change during the rest of its lifetime. Spatial changes, when possible, usually require costly construction work.
- Social, economic and technological changes have accelerated in recent years. These changes have implications for the use of the home and consequently for space standards.
- Houses that provide inadequate conditions to dwellers usually require more maintenance and repair works and have a shorter service live.
- Many of the houses of the existing housing stock do not fulfil the space standards of present building regulations. During rehabilitation works it is necessary to decide which dwellings are unfit and are either made fit to live in or demolished.

Relevant studies to establish minimum space standards for housing have been developed in European countries for several decades (e.g. Klein 1980, Parker Morris 1961). The approach has become progressively more sophisticated over the years. Space standards have also been set in numerous design manuals (e.g. Neufert 1970, Tutt & Adler 1979). Later editions have updated some of these manuals. Recently, new studies were conducted to provide space standards which are up to date and adequate to the local context (e.g. Pedro 1999, Boueri 2005, HATC 2006). These studies and design manuals were used as research literature for this study.

3 RESEARCH METHODOLOGY

The study was developed according to the following methodology:

- Select the necessary furniture and equipment for each functional space.
- Determine the size of furniture and equipment.
- Find out the typical arrangement of furniture and equipment.
- Draw models of functional spaces.
- Analyze models to determine area of each functional space.
- Add the area of all functional spaces to determine the area of the dwelling.

- Compare results with the mandatory area requirements presently set in Portugal and in 10 other European countries.

The parameters used to set occupants' needs were the number of people expected to occupy the dwelling, a classification of residential functions and two levels of quality.

The needs of households with 1 to 9 occupants were studied. Large households were studied because, although the average size of households in Portugal is 2.8 persons, 45% of the dwellings completed in 2007 were designed for 6 occupants and 17% for 7 or more occupants (INE 2002, 2008).

The use of the dwelling was described by functions: sleeping, cooking, eating, living, play/study/work, clothes care, personal hygiene, circulation, domestic management and being outside in private space. This classification enabled an analysis of user's activities of setting a rigid use for each room. The description of dwellings' use with functions has been used in Portugal since the 1960s for studies of housing space standards and occupants' behaviour.

The levels of quality reflect the degrees of fulfilment of occupants' needs and aspirations. As a fallback for unacceptable situations, two levels were set:

- The basic level ensures that occupants cannot suffer serious physical or mental injury. This level is usually used to evaluate whether an existing building is unfit for human habitation.
- The minimum level ensures that the common needs of users' daily life are fulfilled. This level is used to prevent the construction of new buildings detrimental to user's quality of life.

4 MINIMUM AREA STANDARDS

4.1 *Furniture and equipment*

To set the *minimum* needs of furniture and equipment it was assumed that:

- A dwelling must enclose spaces to perform all the domestic functions, in order to allow autonomous use.
- A dwelling's spaces must have sizes and shapes that allow placement of the furniture and equipment necessary to satisfy the common daily needs of its occupants.
- Disabled persons must be able to access the dwelling. To assure this, at a minimum the entrance, living room, kitchen and a toilet must be accessible.

To set the *basic* needs of furniture and equipment the programme of the minimum level was used, but only the essential items of furniture and equipment were included. At this level, the quick meals function was not included and dwellings were not required to be accessible by disabled persons.

Figure 1 present the furniture and equipment attributed to each function and number of occupants at the minimum level.

4.2 *Area by functional space*

The minimum area for each functional space is presented in Tables 1 and 2. The area for each functional space was obtained from the analysis of the models presented in Figure 7.

The area for circulation is 10% to 14% of the total area of the other spaces. These percentages were obtained by analysing the designs of seventy social housing units built in Portugal between 1990 and 1997. The increase in the circulation area is not entirely gradual, because of the need to balance additional spaces for personal hygiene in some typologies.

For the sleeping function three types of spaces were foreseen, with double, twin and single beds. In all dwellings with two or more occupants there is a double sleeping space. In dwellings with an odd number of occupants an additional single sleeping space is foreseen. The remaining sleeping spaces are twin. This distribution enables the possibility of dwellings being occupied by a couple and requires less area for the sleeping function. Different combinations can be created by dividing one twin bedroom into two single bedrooms.

4.3 *Net internal dwelling area*

The minimum area of the dwelling for each number of occupants is presented in Table 3. There is a gradual variation in the net internal area: at the basic level it increases 7.0 m² per occupant, and at the minimum level 9.0 m² per occupant.

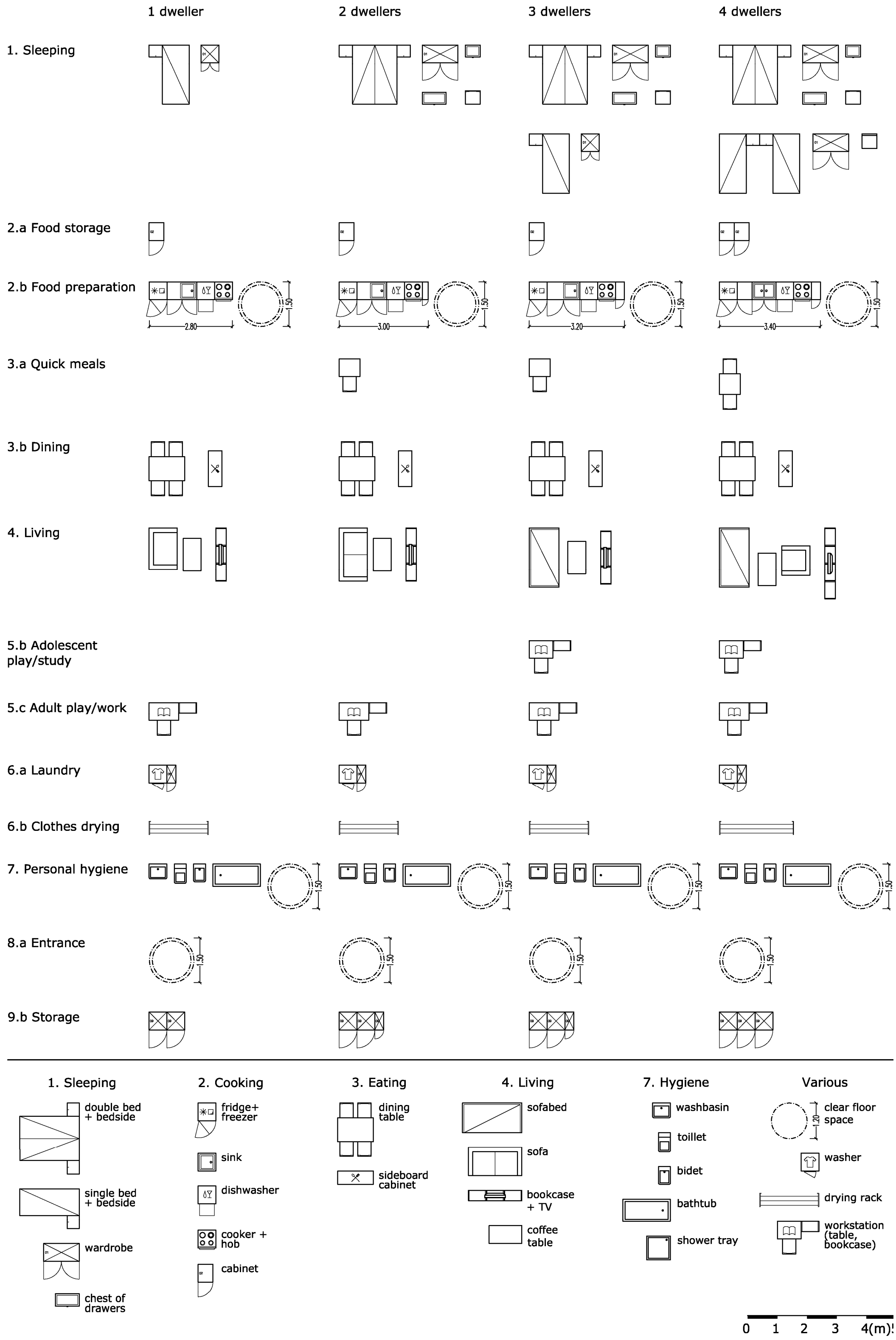

Figure 1. Minimum level – List of furniture and equipment (Part 1).

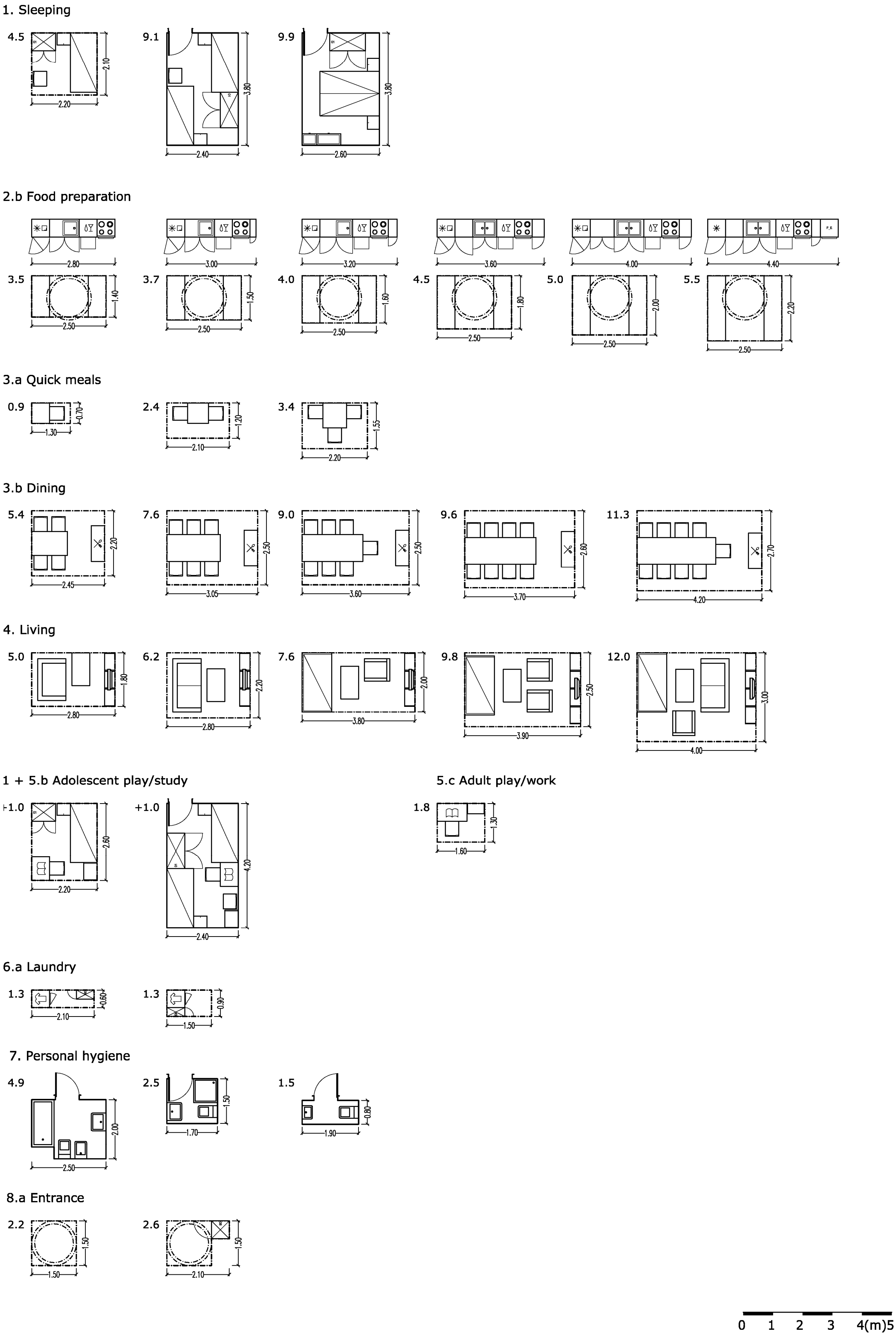

Figure 2. Minimum level – Models of functional spaces and their area (m²).

Table 1. Basic level – Area for each functional space (m²).

Functional space			Number of occupants 1	2	3	4	5	6	7	8	9
1	Sleeping	Double		8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
		Twin				7.0	7.0	7.0	7.0	7.0	7.0
		Twin						7.0	7.0	7.0	7.0
		Twin								7.0	7.0
		Single	4.0		4.0		4.0		4.0		4.0
2	Cooking	Food storage	0.5	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0
		Food preparation	2.5	2.5	3.0	3.0	3.5	3.5	4.0	4.0	4.5
3	Eating	Dining	2.5	3.0	3.5	4.5	5.5	6.5	7.5	8.5	9.5
4	Living		4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
5	Play/study/work	Adult play/work	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	Clothes care	Laundry	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		Drying clothes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
7	Personal hygiene	Main	2.5	2.5	2.5	3.0	3.0	3.0	3.0	3.0	3.0
		Second						1.5	1.5	1.5	1.5
8	Circulation	Entrance	1.0	1.0	1.0	1.5	1.5	1.5	2.0	2.0	2.0
		Communication	1.0	2.0	3.0	3.5	4.0	4.0	4.0	5.5	6.0
9	Domestic manag.	General storage	0.5	1.0	1.0	1.5	1.5	1.5	1.5	2.0	2.0

Table 2. Minimum level – Area for each functional space (m²).

Functional space			Number of occupants 1	2	3	4	5	6	7	8	9
1	Sleeping	Double		10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		Twin				9.0	9.0	9.0	9.0	9.0	9.0
		Twin						9.0	9.0	9.0	9.0
		Twin								9.0	9.0
		Single	4.5		4.5		4.5		4.5		4.5
2	Cooking	Food storage	0.5	0.5	0.5	1.0	1.0	1.0	1.5	1.5	1.5
		Food preparation	3.5	3.5	4.0	4.0	4.5	4.5	5.0	5.0	5.5
3	Eating	Quick meals		1.5	2.0	2.5	2.5	3.0	3.0	3.5	3.5
		Dining	5.0	5.0	5.5	6.0	7.0	8.0	9.0	10.0	11.0
4	Living		6.5	6.5	7.0	8.0	9.0	10.0	11.0	12.0	13.0
5	Play/study/work	Adolescents			1.0	1.5	2.0	2.5	3.0	3.5	4.0
		Adults	1.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	Clothes care	Laundry	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		Drying clothes	0.5	0.5	0.5	1.0	1.0	1.0	1.5	1.5	1.5
7	Personal hygiene	Main	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
		Second					1.5	2.5	2.5	2.5	2.5
		Third									1.5
8	Circulation	Entrance	1.5	1.5	1.5	2.0	2.0	2.0	2.5	2.5	2.5
		Communication	1.5	3.0	4.5	5.0	5.0	5.5	5.5	6.5	6.5
9	Domestic manag.	General storage	1.5	1.5	2.0	2.0	2.0	2.0	2.0	2.5	2.5

Table 3. Net internal area for basic and minimum levels (m²).

Quality level	Number of occupants 1	2	3	4	5	6	7	8	9
Basic level	21	28	35	42	49	56	63	70	77
Minimum level	32	41	50	59	68	77	86	95	104

5 COMPARISON

5.1 *Comparison with area standards established in Portuguese building regulations*

The resulting net internal dwelling areas were compared with the minimum requirements set by *General Building Regulations* (Decree-Law No. 38 382). The conclusions are that:

- The area set for the basic level is 15% to 20% lower than the area established by the *General Building Regulations* for new dwellings. This decrease is understandable since the basic level is intended to verify whether existing dwellings, many of which were built before the current space standards came into force, meet minimum habitability conditions.
- The area set for the minimum level is 5% to 15% higher than the area established by the *General Building Regulations*. This increase is due to two main changes: the toilet and bathroom include clear space for a disabled person to move, and there is additional area for the play/study/work function, which increases the area of the bedrooms.

5.2 *Comparison with Portuguese statistics on housing construction*

The evolution of the area of new dwellings in Portugal from 1996 to 2007 was analyzed. It was verified that the average habitable area of a dwelling increased gradually throughout the analyzed period, from 81.0 m^2 in 1996 to 95.2 m^2 in 2007. When comparing the total habitable area of the licensed dwellings with the total habitable area of the same dwellings according to the minimum requirements set by the *General Building Regulations*, it was verified that in 1996 the first were on average 192% of the second, and that this percentage increased to 221% in 2007 (INE 2008).

The conclusion is that, on average, dwellings are twice as big as the minimum requirements. Therefore, if the minimum level was adopted as a mandatory standard for the construction of new dwellings the impact would be small.

5.3 *Comparison with area standards in other European countries*

In Belgium, Spain, Finland, France and the Netherlands there are space standards included in the mandatory technical regulations. In Ireland, England and Wales Norway, and Sweden there are no quantitative area standards for dwellings in mandatory technical regulations. However, in some of these countries there are area standards that apply only to some types of developments (e.g. Ireland, England). Table 4 presents the internal net area of dwellings for several European countries.

Table 4. Net internal area set in several European countries (m^2).

Country	Number of occupants								
	1	2	3	4	5	6	7	8	9
Proposal: basic level (existing housing)	21	27	35	42	49	56	63	70	77
Proposal: minimum level (new housing)	32	41	50	59	68	77	86	95	104
Spain (new and existing housing)		20	30	40	48	56	64	72	80
Finland (new housing)	20								
France (new housing)	14	28	42	56	66	76	86	96	106
The Netherlands (existing housing)		24							
The Netherlands (new housing)		43.6							
England (new housing)*	37	44	57	67	81	92	105		
Ireland (new housing)*		39	54	63	74	81	91		

* Adapted values and not mandatory

The conclusions are that there is a strong similarity of the basic level with the requirement in Spain, both applying to existing dwellings; in France similarity between the minimum level and the requirement is also strong, but only in dwellings for more than 3 occupants; the floor area guidelines in England and Ireland are greater than the requirements of other countries, which is reasonable since they are not mandatory for all developments.

6 CONCLUSIONS AND DISCUSSION

6.1 *Conclusions*

There should be an increase of 5% to 15% of the net internal area presently established in the Portuguese building regulations for new dwellings. The building regulations should also set a minimum net internal area for construction on existing dwellings, which can be 15% to 20% lower than what is presently established. If these proposals were adopted, the impact in the construction industry would be small. The proposals are similar to the mandatory net area requirements set in France and Spain.

6.2 *Discussion*

The paper focuses on the overall internal floor space of the dwelling. This parameter enables to study and compare the total size of a dwelling. However, other space standard parameters are also important to ensure a functional dwelling.

Area standards were established in order to meet the needs of occupants in contemporary Portugal. These needs are determined in part by social, cultural and economic factors. Therefore, the area standards should not be applied to different contexts without adaptation.

The area standards are a 'safety net' intended to prevent the development of dwellings with inadequate space, which raise significant concerns about long-term sustainability and suitability for the designed level of occupancy. The area standards are not 'good practice' guidelines.

The increasing amount of diversity in the composition of households and acceleration in the changing ways of life justify the need for dwelling flexibility. Flexibility discourages dwelling mobility and renovation work, and contributes to extending the service life of buildings. Neither the change in needs of occupants nor an increase in area to allow greater flexibility was anticipated.

The area standards drew upon a function-based and user-oriented approach. User satisfaction with existing dwellings and stakeholder views were not investigated. Should the proposed standards be used to replace the mandatory *General Building Regulations* requirements, they should be critically assessed in terms of these two sources of information.

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Sustainable cosntruction and architecture in Guinea-Bissau: Opportunities and Challenges

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ABSTRACT: This paper presents the results of research developed under the European Project SURE - Africa , on construction and architecture in tropical warm and humid regions, such as the Guinea-Bissau, in which climatic, social, and economic conditions pose additional concerns for planners, architects and engineers. The main question analyzed was whether comfort is achievable solely by the use of passive design strategies, or if energy consuming mechanical systems are required. The aim is to reduce of both cooling and artificial lighting energy loads through passive design strategies, which can be complemented with active systems, powered by renewable energies, such as solar photovoltaic. Conclusions were drawn about the most relevant passive design strategies for comfort maintenance, those who protect from solar radiation, and promote ventilation. Exploring the use of local resources, produced from natural raw materials like earth, is one of the essential measures in the path for sustainable construction, in Guinea-Bissau.

1 INTRODUCTION

Building in Guinea-Bissau involves facing particular climatic conditions and the urban problems common to tropical countries. The lack of urban identity, particularly in the capital, Bissau, together with unregulated construction projects, the degradation of urban buildings, a housing deficit combined with a massive influx of poor rural people, urban growth without planning, and low comfort levels inside buildings are the general problems (Pereira, 2001). Powerful climatic agents such as high levels of solar radiation and air humidity, and torrential rainfall, challenge builders and architects to create sustainable ways of providing security, comfort, and economic satisfaction for the final building users (Lauber, 2005; Bay & Ong, 2006).

Within this context, more research is necessary, concerning the behaviour of traditional materials and building techniques, and new approaches such as the so-called bioclimatic or passive design. By harnessing this philosophy, sustainable strategies become available, and will result in positive economic benefits, both for the energy efficiency of buildings and the maintenance of comfort levels, in addition to benefits of the well-known concept of reasonable use of existing resources without compromising their use by future generations[i].

The aim of this research is to assess the characteristics of sustainable construction in Guinea-Bissau and, in doing so, to: Study the main strategies for sustainable design in tropical warm and humid regions; Analyse energy and comfort performance of typical building types existing; Produce best-practice recommendations for sustainable design in Guinea-Bissau.

2 THEORETICAL CONSIDERATIONS

The term "sustainable construction" appeared for the first time in a communication from Professor Charles Kibert, in an effort to relate the responsibilities of the construction industry to the aims of sustainability (Pinto & Inácio, 2001). It was defined as the creation and responsible management of healthy construction, based on ecological principles and efficient management of resources, which meant focusing on placing a minimum burden on natural resources and waste production and maximising the recycling process. It also included the life cycle of buildings, with regard to their use, maintenance and the possibility of adapting to local needs (Ramos, 2007).

Bioclimatic or passive design strategies aim at achieving building comfort and internal environmental quality. In the present case, as they are designed for warm, humid regions, the main strategies are based on heat protection, and heat dissipation (Fig. 1). The former includes mechanisms such as shading, orientation, and insulation strategies, which protect buildings from solar radiation by preventing heating gains entering the buildings (Yao et. al, 2006). In addition, heat dissipation systems act upon the heat inside the building, seeking to eliminate or reduce thermal sensation by passive means[ii], (Gonzáles, 2004). Daytime or nigh-time cross ventilation, night radiation, and thermal inertia are some of the most important dissipation techniques for humid tropical regions. Materials with high thermal mass provide efficient thermal inertia, increasing the time lag before exterior temperature levels reach the interior of the building (Lanham, Gama & Bráz, 2004), in regions with significant temperature variations, e.g. between day and night.

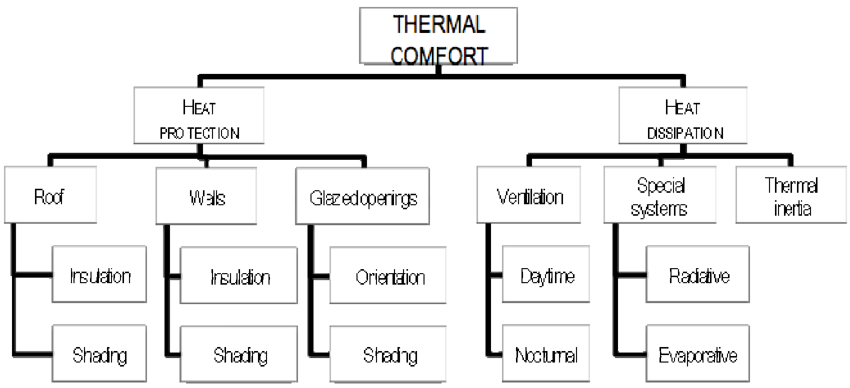

Figure 1. Passive design strategies for tropical warm, humid regions (adapted from Baker, 1987; Gonzáles, 2004; Silva, 2006).

The main strategies cited on studies developed for tropical climates are the promotion of ventilation trough openings (Salmon, 1999) and the prevention from climate agents (Lengen, 2004). In terms of town planning, regulations regarding regular road planning for the passage of breezes, and shade from trees, are crucial (Stango & Ugarte, 2006; Gonzáles, 2004), protecting buildings from overheating, and protecting roads from the consequences of rainfall.

Thermal comfort[iii] or human being's thermal sensation is mainly related to the thermal balance of the body as a whole, influenced by physical activity and clothing as well as environmental parameters (Yao et al. 2006; ISO 7730:2005(E)), and parameters related to the main body heat loss mechanisms (Baker, 1987).

In tropical regions where the temperature averages 24 to 28ºC throughout the year, higher temperature comfort zones are expected, corresponding to a dry bulb temperature as high as 31ºC, together with a relative humidity ranging from 35% to 75% (Salmon, 1999).

3 ARCHITECTURAL AND CONSTRUCTIVE TYPOLOGIES

Local architecture can be classified in terms of construction properties and by function type: on the one hand, the public sector serves families with no economic power, whilst the private sector promotes housing for economically stable and socially stratified wellbeing. In the middle, the cooperative sector meets the needs of the low middle class, organized by ministries or institutions, generally for their employees. Independent building is common in rural areas or in peri-urban environments, linked to spontaneous construction (Mota, 1948; Pereira, 2001).

The architecture of Guinea-Bissau is characterized by three main typologies:

i. Vernacular architecture - traditional housing with rammed earth or adobe walls and straw fibre roofs (Fig. 2 - left), now with the straw roof being gradually replaced by zinc foil, especially in rectangular housing (Fig. 2 - right), providing durability, light, waterproof properties and low maintenance requirements, but, on the other hand, poor thermal and acoustic insulation and requiring additional care in preventing corrosion. A better practice could be a double covering of zinc and straw, adapting the durability of the former to the better insulation properties of the latter, Figure 3 - left;

ii. Colonial architecture - colonial dwellings built with concrete blocks and a tile or Fibre-cement panels cover, in the urban centres of the main cities; Generally tall buildings, with a covered veranda at the front and overhangs above openings (Fig. 3 - right);

iii. Contemporary trends - dwellings built with prime materials such as reinforced concrete for structure, bricks or concrete blocks on the walls, and clay tiles on the roof (Fig. 4 - left); Ecotourism constructions are considered a contemporary trend as well, using natural raw materials such as earth, straw and timber; In the image below (Fig. 4 - right), the elevated floor of the house prevents humidity and promotes ventilation from below; It is also relevant to describe cooperative neighbourhood housing, characterized by dwellings built with reinforced cement, adobe and covered with zinc, in the periphery of urban zones, or high-rise housing consisting of 3 or 4 floors, built with the aid of international protocols;


Figure 2. Vernacular architecture (left). Replacing straw roof with zinc (right).


Figure 3. Double roof system, with zinc foil under a straw-covered roof. Colonial dwelling.


Figure 4. Contemporary trends - modern dwelling (left). Ecotourism housing (Picture from Schwarz).

4 CASE STUDY ANALYSIS

The case study focuses on an analysis of the typologies of existing buildings, specifically with regard to comfort, cost and reduction of the energy loads.

4.1 *Methodology*

In order to study building performance in the architecture of Guinea-Bissau, fieldwork was carried out in the country from April 11 to May 9, when measurements of comfort levels in the interior of buildings were taken, and users' comfort perceptions and opinions of their residences' performance and sustainable construction concepts recorded through questionnaires, in addition to producing an extensive collection of photographs of the architectural heritage.

Four instruments were used to develop the study, as Figure 5 illustrates:

i. Temperature and humidity measurement, using data loggers;
ii. Fieldwork questionnaires;
iii. Climate analysis, using *The Weather Tool*, an *Ecotect 5.20* software tool;
iv. Model simulation, using *Ecotect 5.20* software.

The climate analysis and building simulation were carried out using *Ecotect*, environmental building analysis software that allows the thermal response of a building, in terms of energy efficiency, or discomfort levels. The main aim was to optimise the performance of a representative house, according to local climatic conditions, materials and available technologies, thus reflecting the economic viability of the chosen solution. The four building models that were developed made it possible to unequivocally understand the best practices in building design, which are listed in the final chapter of this paper.

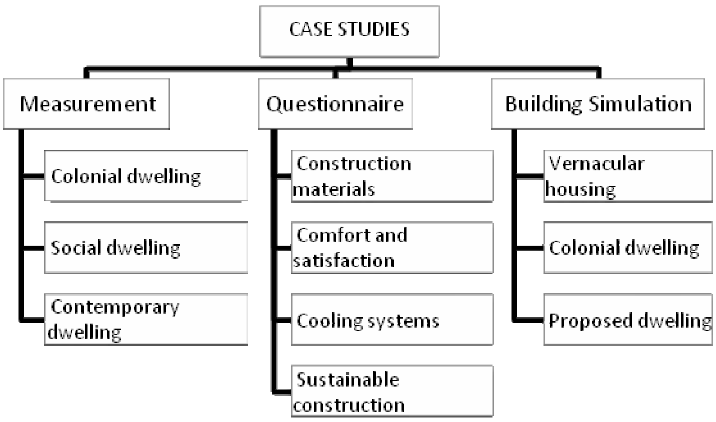

Figure 5. Illustrative draft of case studies.

4.2 *Results*

4.2.1 *Measurement of temperature and humidity*

The main characteristics of the three dwellings analysed in specific urban zones are described below:

- Colonial dwelling - concrete blocks on walls and clay tiled roof (Chão-de-Papel's neighbourhood);
- Social dwelling - cooperative housing, with adobe walls and zinc roof (Plano's neighbourhood - coastal zone);
- Contemporary dwelling - brick walls, and clay tiled roof (Quelélé's neighbourhood);

The results of the relative humidity measurements specified in Table 1 show that the closer a building is to a coastal zone, the higher the relative humidity inside the building.

The outside temperature results, Table 2, confirm that the worst outside temperature is in the Quelélé's neighbourhood, which has a temperature range of 10ºC. For this outside temperature range, strategies such as night purge ventilation and thermal inertia are important prescriptions.

Although it has a similar mean exterior temperature, the social dwelling in the Plano's neighbourhood shows higher comfort values for inside temperatures (Table 3) because of the benefits of the coastal breezes, highlighted in the humidity range.

Even with clay tiled roofs and clay brick walls, better-known for their thermal insulation properties, the contemporary dwelling in Quelélé does not reveal the best thermal behaviour, due to its location.

Table 1. Relative humidity inside buildings.

	Plano neighbourhood	Chão-de-Papel neighbourhood	Quelélé neighbourhood
	ºC	ºC	ºC
Max.	68.4	66.6	64,9
Mean	65.9	63.3	61,3
Min.	62.8	60.0	56,5

Table 2. Outside temperature.

	Plano neighbourhood	Chão-de-Papel neighbourhood	Quelélé neighbourhood
	ºC	ºC	ºC
Max.	29.8	31.8	32.1
Mean	26.4	26.9	26.6
Min.	23.6	23.5	22.3

Table 3. Inside temperature.

	Plano neighbourhood	Chão-de-Papel neighbourhood	Quelélé neighbourhood
	ºC	ºC	ºC
Max.	29,0	30,1	30,5
Mean	27,8	28,9	28,4
Min.	26,6	27,8	26,9

4.2.2 *Results of questionnaire*

The answers to the questionnaire are presented below, for a population of 100 individuals in Bissau City, 31% of which were female. It is also significant that 21% of the respondents were planners, architects or building technicians employed in the city. The questions were organized into the following topics: materials, comfort and satisfaction inside the building, cooling systems, and sustainable construction.

Concerning materials, 37% of the respondents lived in an adobe and zinc dwelling, and 21% in a block and zinc dwelling, meaning that 58% of the dwellings analysed were zinc-covered, followed by tiled roofs in 26% of cases, with block or brick walls. However, the users' preferences revealed that 64% preferred a concrete block wall and 83% a tiled roof, based on perception of high resistance, durability, availability, aesthetic qualities, and thermal insulation.

With regard to comfort conditions, most of the users experienced climate discomfort, generally caused by high temperature levels and humidity (Table 4), the latter mostly in the rainy season. The worst period cited for temperature discomfort was from midday to 6 pm in general, and more specifically from midday to 3 pm. In other hand users revealed satisfaction with shading systems in their residences, as well as natural lighting, ventilation and security.

Table 4. Users' satisfaction levels.

	Very satisfied	Satisfied	Dissatisfied	Very Dissatisfied
	%	%	%	%
Temperature	3	31	44	22
Humidity	5	52	29	14
Ventilation	16	55	18	11
Shading	13	76	8	3
Natural lighting	14	66	16	4
Security	20	55	17	8

With regard to cooling systems, the users showed a preference for no system at all, although, due to temperature levels, air-conditioning systems were considered essential or better than nothing in 60% of the cases (Table 5), and almost 50% of the users have an artificial ventilation system (Table 6). While answering, the users shared concerns about the public electrical power shortage. When questioned about the relevance of passive means of cooling, 87% of the users showed an interest, as Table 7 illustrates, and those who didn't (13%), think that the high levels of diurnal temperatures are difficult to attenuate by passive means.

Users were also freely questioned about the characteristics they think Guinea-Bissau buildings should have. 27% cited isolated dwellings with a maximum of two floors, 20% indicated security and comfort as important properties, and 15% referred to colonial type with concrete block or brick walls, followed by 13% of answers for tiled roof. On the subject of renewable energy and sustainable construction, more than 90% of the users revealed interest in knowing more and applying the systems in question, with regard to energy shortage problems.

Table 5. Opinions on air-conditioning.

	Essential	Better than nothing	Unnecessary	Rather not have
	%	%	%	%
Answers	31	29	21	19

Table 6. Opinions about the use of cooling systems.

	Ventilation	Air-conditioning	Both	None
	%	%	%	%
Answers	49	6	17	28

Table 7. Level of interest in passive cooling systems.

	Not interested	Low interest	Interested	Very interested
	%	%	%	%
Answers	0	13	46	41

4.3 *Climate analysis and building Simulation*

Bissau's climate was analysed by Auliciem's adaptive model cited by A.J.Marsh (in Ecotect), showing that the square vernacular house performed best.

Table 8. Air temperature in the rooms in each house (ºC) on a typical day.

	Circular dwelling*	Square dwelling**	Colonial dwelling***	Outside temperature
	ºC	ºC	ºC	ºC
Mean	29.32	28.80	29.65	28.5
Standard Deviation	0.14	0.38	0.49	3.9
Mean Radiant Temperature at 3 p.m.	0.14	0.38	0.49	3.9

* Rammed earth 300 mm, Straw 150 mm;
** Rammed earth 250 mm, Straw 150 mm;
*** Concrete block 250 mm, Fibre-Cement panels 8 mm.

The mean radiant temperature shows the temperature in the construction components, confirming the superior thermal inertia of rammed earth in comparison with the low thermal resistance of cement-based materials such as concrete blocks and cement board.

From the results obtained, a contemporary dwelling was designed, simulating the following parameters: orientation, glazing percentage, shading device systems, natural lighting, thermal inertia, insulation systems, and ventilation. The study was conducted in terms of reducing annual energy consumption and the best results for each of the simulated strategies are illustrated in Table 10. The solution initially tested had concrete blocks (200+50mm), tiled roof and no insulation system.

Table 9. Comfort analysis results for a proposed contemporary dwelling.

Strategy	Best result	Load consumption for cooling (kWh/m2)	Solution
Orientation	E-W axis	-	-
Glazing	30-30-15-15 (%)	6.11	1
Natural lighting	Architectural optimisation	5.75	2
Shading device	Veranda at front, overhangs around	4.39	3
Thermal inertia	Brick (200+50mm)	3.49	3.1
	Concrete block (250+50mm)	3.98	3.2
Insulation	Sandwich panels (Zinc + insulation)	4.44	3.3
	Ceiling - Fibre glass, concrete block	4.05	3.4
	Concrete Block + exterior insulation	3.37	3.5
	Double brick plus cavity - insulation	3.35	3.6
	Solution 3.3 combined with solution 3.5	3.43	4
Ventilation	Mixed-mode system	0.83	5

Bricks walls were simulated and this proved to be the best material (without insulation), nevertheless it is important to note that they are not produced or sold at present in Guinea-Bissau (Solution 3.1). Alternatively, when the thickness of the concrete blocks was increased the results were also satisfactory. In this study it was decided to proceed with default materials of the minimum legally prescribed thickness (MOPCU[iv], 2006), adding insulation systems (Solution 4). The best result is associated to ventilation promote, here simulated by the openings prescription, and a mixed-mode system, a combination of air-conditioning and natural ventilation where the HVAC system shuts down whenever outside conditions are within the defined thermostat range (20-28ºC);

5 CONCLUSIONS AND RECOMMENDATIONS

The main conclusions to be drawn from this study are:

i. Rammed earth walls on existent buildings have better performance than the usually used concrete block without insulation (on urban domains);
ii. For the Guinea-Bissau climate, the main concerns in climatic design involve prevention of overheating, meaning that the main loading requirements are for cooling systems;
iii. One of the good practices starts with orientation on E-W axis, minimum glazing distribution to East and West facades, and shadings;
iv. Natural ventilation is a relevant strategy, which acts on heat dissipation;
v. The use of mechanical cooling systems may be necessary, however it is possible to reduce its requirement to minimum;
vi. The use of insulation systems like polyurethane or expanded polystyrene, improves buildings thermal performance, without cost rise; Solutions like sandwich panels for roof can easily replace tiled roof, and concrete block walls exterior insulated, substitutes brick walls without compromising comfort levels.

Local materials production and the renewable energy resource such as the solar photovoltaic, should integrate the priorities of the local public administration. The improvement of the projects in terms of energy efficiency, reducing lighting and artificial cooling systems requirements, the change of mentality starting to consider buildings solution with 3, 4 floors for housing or office, are some of the goals for sustainable construction practice in Guinea-Bissau.

It is important to state as a final note that one of the limitations of Ecotect 5.20 is the fact that it does not provide system simulation; just cooling loads were here simulated. One way forward would undoubtedly be to use energy analysis tool such as EnergyPlus. In the present it was determined the potentiality of passive design strategies, but more investigation is required before taking any further conclusion.

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[i] Bruntland report (Our Common Future), United Nations Conference, Stockholm, 1987 (Pinto & Inácio, 2001).

[ii] Without the aid of mechanical equipment.

[iii] Defined as the mental condition in which an individual feels satisfied with the thermal environment, as in ISO 7730 (Yao et al.).

[iv]MOPCU - Guinea Bissau Ministry of Public Works, Construction and Urban Planning.

Life cycle cost as base to define low cost sustainable building solutions

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ABSTRACT: Life cycle cost (LCC) is an approach that assesses the total cost of an asset over its life cycle including initial capital costs, maintenance costs, operating costs and the asset's residual value at the end of its life.
Nowadays, most builders are only concerned with the initial capital costs (land, project and construction costs), working towards their minimization. The same logic can be applied to sustainable building.
This leads to an emphasis on the initial cost, in detriment of the other life cycle costs, and, in some cases, to the supporting of solutions that require smaller investment but have higher operational costs (such as the application of less insulation resulting in higher need for heating and cooling energy) and also lower sustainable levels (like higher carbon emissions).
In this context, the application of LCC to the sustainable building approach could bring a fresh perspective to the LCC methodology as well as a strong contribution to the economic dimension of sustainable construction.
The objective of this paper is to present a review of the main LCC approaches, different application cases to sustainable building and discuss the potential and limitations of this methodology including a case analysis.
A selected LCC methodology approach is proposed to be applied in the specific case study Hexa building (a six floor building, with commercial purposes in the ground floor and residential purposes in the other five) developed by the Sustainable team of System LiderA.
The case study shall compare the life cycle costs of diverse alternative solutions taking into account several issues such as construction materials, insulation options, glazing area and type, and also other solutions that range from an E to an A and A+ LiderA class.
Based on the Hexa building LCC preliminary results, the limitations and potential of this approach will be discussed and other research matters, to be developed in this article and future perspectives to this methodology application, will be pointed out.

1 LCC AND ITS IMPORTANCE

Life Cycle Costing is a methodology for systematic economic evaluation of the life cycle costs over a period of analysis, as defined in the agreed scoping (ISO 15686-5, 2006).
In other words, it is an economic methodology for selecting the most cost-effective design alternative over a particular time frame, taking into consideration its construction, operation, maintenance, replacement, rehabilitation costs and also residual value.

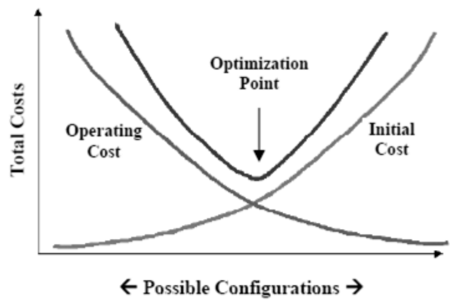

Figure 1 - LCC and efficient alternatives

According to the Royal Institute of Chartered Surveyors (1983), the objectives of LCC are:

- To enable investment options to be more effectively evaluated;
- To consider the impact of all costs rather than only initial capital costs;
- To assist in the effective management of completed buildings and projects;
- To facilitate choice between competing alternatives.

2 SUSTAINABILITY AND LCC

Ever since the Brundtland report (1987) stated that sustainable development is the "development that meets the needs of the present without compromising that ability of future generations to meet their own needs", the importance of the Sustainable approach has been consistently increasing. It brings economic, environmental and social concerns together looking to stimulate the equilibrium between the three dimensions. In this perspective, sustainable construction doesn't look for an excellent environmental performance sacrificing economic viability of a company, or an excellent financial performance at the expense of important adverse environmental and social effects.

According to Pinheiro (2006), sustainable construction takes into account the total life cycle of the asset and considers that the resources of construction are materials, soil, energy and water. From these resources, Kibert established the five basic principles of sustainable construction:

- Reduce resource consumption;
- Reuse resources whenever it is possible;
- Recycle materials at the end of the building's life and use recyclable resources;
- Protect natural systems and its function in all activities;
- Eliminate toxic materials and its byproducts in every life cycle phase.

Traditional construction is mostly concerned with cost, time and quality. Sustainable construction adds to those criteria the minimization of the use of scarce resources and environmental degradation, and also the creation of a healthy built environment (Kibert, 1994).

According to Godfaurd (2005), sustainable construction involves the consideration of the building's life cycle because the minimization and reduction of the impacts on nature depends on the performance of the building during all its phases. Following this line of thinking, life cycle cost analysis should replace the sole consideration of the initial investment cost.

As a reference, Gupta (1983) mentions that approximately 75% of the life cycle cost of an asset is related to the operation and maintenance phase, which makes unavoidable the consideration of life cycle cost when analyzing an asset.

If costs are analyzed in an equilibrated perspective of the life cycle it is understandable that the application of sustainability to the construction industry without sacrificing the economic component is a reachable reality and is of extreme importance.

In reality, few are the companies that seek to produce buildings with high quality and durability, due to the size of the initial investment needed to ensure reduced operation and maintenance costs. As the builder is usually not the final user of the asset, construction costs are supported by a different entity than operation and maintenance costs, thus the builder doesn't have any advantage in implementing such measures, raising his costs in order to reduce the costs of others.

3 LCC APPROACH

In approaches such as LCC, it becomes necessary to divide costs into groups that can be defined and estimated separately, making it easier to quantify the costs and compare different alternatives.

The process of LCC analysis depends mainly on identifying all relevant costs which occur over a specified period of study. If the analysis period is the asset's life cycle, those costs include all possible costs from the initial acquisition costs to the end of life costs.

In that case, a possible cost breakdown structure would be (Davis Langdon Management Consulting, 2007 based on ISO 15686-5, 2006) the one shown in Table 1.

3.1 *Basic steps*

Several authors propose possible steps to generate an effective LCC analysis such as King County (n.d.), Davis Langdon Management Consulting (2007) and Kelly and Hunter (2007). However, in every set of steps the same essential points can be identified.

According to Kelly and Hunter (2007), Ruegg et al (1980) and Flanagan and Jewell (2005) there are five basic steps to making decisions about options:

- Identify project objectives, options and constraints;
- Establish basic assumptions with respect to the period of study, the discount rate, the level of comprehensiveness, data requirements, cash flows and inflation;
- Compile data;
- Discount cash flows to a comparable time base;
- Compute total life cycle costs, compare options and make decisions.

3.2 *Method of cost evaluation and risk assessment techniques*

There are many different methods to evaluate the life cycle cost of an asset. As the primary objective of LCC is to facilitate the effective choice between a number of competing alternatives, the most used method is the Net Present Value (NPV).

The NPV of an alternative is the summation of all costs occurred during the period of study of the life cycle of the asset, converted to their present value (using a discount rate) so that they are comparable. The alternative with the highest NPV is the most cost effective choice (King County, n.d.).LCC deals with the future and, as the future is unknown, there is a need to be able to forecast a long way ahead in time, many factors such as life cycles, future operating and maintenance costs, and discount and inflation rates. This difficulty is worsened by the difficulty in obtaining the appropriate level of information and data. Therefore, the treatment of uncertainty in information and data becomes crucial to the implementation of LCC (Kishk et al., 2003).

To deal with these problems there are various risk assessment techniques. Nowadays, the most used ones are Sensitivity Analysis (deterministic approach), Monte Carlo Simulation (probabilistic approach) and the Fuzzy Set Theory.

Table 1 - Cost Breakdown Structure from Davis Langdon Management Consulting (2007)

Acquisition – non-construction costs	Acquisition – design and construction	Operation	Maintenance	Rehabilitation	End of life/ disposal/hand-back	Income
Site (lease/ purchase of land and/ or existing building(s) /asset(s), including related fees and local taxes)	Professional services (project management, architecture, structural/ civil/ environmental engineering, cost and value management)	Facilities management (cleaning, security, waste management)	Maintenance management (inspections, contracts management)	Adaptation (evacuation, works, re-commissioning, fit-out)	Final condition inspection including fees	Sales of land, interests in assets, salvaged materials
Finance (interest or cost of money; wider economic impacts)	Site clearance, temporary works	Rates / local taxes, land charges	Minor repairs/ replacements/ renewals	Major replacement/ renewal/ refurbishment (evacuation, works, re-commissioning, fit-out)	Restoration/ reinstatement (as required by lease/contract)	Grants, tax allowances
Client's in-house resources (property/ project management, administration/ overheads)	Construction (infrastructure, structure, envelope, services, fitting out, commissioning, handover)	Regulatory costs (fire, access inspections)	Loss of facility / business opportunity costs during downtime	Loss of facility / business opportunity costs during downtime	De-commissioning	Third party income (rents, service charges)
Professional advice (planning, legal, preparing brief, sustainability)	Fixtures, fittings, furnishings	Energy (heating, cooling, small power, lighting, internal transport (lifts))	Grounds maintenance		Demolition, disposal, site clean-up	
	Landscaping, external works	Utilities (water, sewerage, telephone)	Redecoration			
		Rent	Cleaning			
		Insurances				

4 APPLICATIONS

The presented LCC methodology approach is being tried out on a model building project called

Figure 2 - Type floor of the HEXA building

HEXA (developed by the Sustainable team of System LiderA), which is a six floor sustainable multifamily habitation building (except for the ground floor which has commercial purposes) that applies the LiderA criteria to all its components.

The objective is to compare different solutions and find out which ones are best suited to the intended life span of the building and its costs by taking LiderA's criteria into account.

For these comparisons to be possible there is need for information such as material, labour and equipment costs for the application of the possible solutions, energetic inertias of the components and the effect it has on a specific type of room, material and components' quality, durability and performance, energy usage of electric heaters and coolers.

There are different sources of information such as the manufacturers, suppliers, contractors and testing specialists, historical data and data from modeling techniques. The difficulty of life cycle cost estimation lies on the unavailability of some types of information in the design phase such as operation and maintenance costs.

4.1 *Case study*

To begin the study, a base HEXA building had to be made, to serve as reference to compare costs and savings of the other different solutions. Its characteristics are presented in Table 2.

Table 2 - Main characteristics of the base HEXA building

Characteristic	Description
Location	Lisbon
External walls	Double brick 0.11+0.15
Insulation	Non existent
Internal concrete walls to Lna	Concrete + 3cm of outside XPS
Roof	Plain gardener roof + 3 cm XPS
Thermal Inertia	Strong
Glazing windows (sliding)	Metal frame, double glazing with 6mm in between
Solar orientation	N(kitchen) – S(living room)
Ventilation	Natural ventilation (NP 1037-1)
Solar panels*	1m2/person
Conventional water heating syst.	Gas water-heater
Heating system	Electrical resistance
Cooling system	Freezer machine (absorption cycle)

The study was conducted for a dwelling on the top floor by varying the characteristics of the external walls and windows. The variations introduced were the following:

- Solution 1 – Applying 3 cm of insulation inside the double brick external walls of the base case;
- Solution 2 – Appling 3 cm of external insulation on a 0,22m brick wall instead of the double brick one of the base case;
- Solution 3 - Appling 6 cm of external insulation on a 0,22m brick wall instead of the double brick one of the base case;
- Solution 4 – Changing solar orientation of the dwelling to S(kitchen) – N(living room) (all solar orientation possibilities were studied, but this was the only one that introduced savings in comparison to the base case);
- Solution 5 – Applying double glazing with 16 mm in between instead of the 6mm of the base case;
- Solution 6 – Applying thermal cut to the glazing windows;
- Solution 7 – Applying PVC frame instead of the metal frame of the base case.

An HEXA dwelling has approximately 130 m^2 of floor area, 84 m^2 of external wall area and 17 m^2 of window area.

A study conducted by Ferreira (2010) revealed the energy consumption of, not only the base case, but also the other considered solutions. These are presented in Table 3, as well as the savings resulting from the comparison of the solutions with the base case, considering no discount rate and the energetic needs cost as the one currently applied in Portugal.

Table 3 - Energetic characteristics and costs of the solutions

	Energetic needs (kgep/m2 of floor area.year)	Energetic class	Differential savings over a 20 year period (€)	Differential savings over a 50 year period (€)
Base case	4,41	B	--	--
Solution 1	4,20	B	222,50	556,26
Solution 2	4,19	B	233,36	583,40
Solution 3	4,03	B	407,02	1017,55
Solution 4	4,38	B	27,13	67,84
Solution 5	4,38	B	27,13	67,84
Solution 6	4,36	B	48,84	122,11
Solution 7	4,33	B	81,40	203,51

On Table 4 the variation of construction and maintenance costs resulting from the comparison of the solutions with the base case. The construction costs were provided by a construction company and the maintenance costs were calculated as a percentage of the construction costs chosen according with knowledge of the different solutions.

Table 4 - Construction and Maintenance cost variations

	Construction cost variation (€)	**Maintenance cost variation over a 20 year period (€)**	**Maintenance cost Variation over a 50 year period (€)**
Base case external walls	--	--	
Solution 1	251,20	0,00	0,00
Solution 2	921,05	2076,55	5191,38
Solution 3	1758,37	2076,55	5191,38
Base case glazing windows	--	--	
Solution 5	83,80	0,00	0,00
Solution 6	429,75	42,98	85,95
Solution 7	171,90	4724,44	9448,88

The base case and solution 4 have the same construction and maintenance costs.

Total cost variation and differential savings of the different solutions over a 20 and 50 year period can be seen in Table 5 e Table 6.

Table 5 – Cost variation and differential savings over a 20 year period

	Total cost variation over a 20 year period (€)	Differential savings over a 20 year period (€)
Base case external walls	--	--
Solution 1	251,20	222,50
Solution 2	2997,61	233,36
Solution 3	3834,93	407,02
Base case windows	--	--
Solution 5	83,80	27,13
Solution 6	472,73	48,84
Solution 7	4896,34	81,40

Table 6 - Cost variation and differential savings over a 50 year period

	Total cost variation over a 50 year period (€)	Differential savings over a 50 year period (€)
Base case external walls	--	--
Solution 1	251,20	556,26
Solution 2	6112,44	583,40
Solution 3	6949,76	1017,55
Base case windows	--	--
Solution 5	83,80	67,84
Solution 6	515,70	122,11
Solution 7	9620,78	203,51

In this study demolition costs were considered as being the same for every solution.

As the base case and Solution 4 have the same construction and maintenance costs, only savings are introduced by this solution, which makes solution 4 always better than the base case.

Solution 1 is a good long term investment, having a 21 year simple payback.

Solution 5 does not present good results, having a 62 year simple payback. As most buildings' expected life rounds 50 years, it is not a useful solution.

The remaining solutions present even worse results, never reaching a simple payback.

As kgep cost is always varying, the solutions were tested for an event where that cost doubled the original one. In that case, solution 1and 5's simple payback is reduced half the original time, and the rest of the solutions 2, 3 and 3 still do not have any simple payback. This means that solutions which are not viable in the present situation, may be in the future. The same may happen as constructive methods and the components' quality improve.

4.2 Limitations and perspectives

Despite the advantages that the LCC methodology brings to sustainable construction, it has found limited application so far. The main problem identified was the lack of reliable information and the difficulty in forecasting over a long period of time factors such as life cycles, future operating, maintenance and demolition (especially if it is selective) costs and discount rates.

Another problem of the LCC approach is variability of:

- Construction costs of the same component (depending on the company that produces it and the quantity needed);
- Maintenance and disposal costs;

- Energetic savings (depending on several aspects, such as having other buildings next to the studied one or not, and the location of the dwelling in the building);
- Component life cycle and performance (depending on the company that produces it).

If the data is not reliable, the results cannot be valid. It is concept known as “garbage in, garbage out”.

On the other hand, the LCC approach makes the simple paybacks of the different solutions evident, showing which solutions are viable.

It may also take into account intangible aspects such as the fact that the higher the comfort of an office the higher tends to be the productivity of the people working there.

5 CONCLUSIONS

This paper presented a review of the main Life Cycle Cost (LCC) approaches and a possible application to a case study was briefly described.

The LCC approach presents itself as way to define low cost sustainable buildings. The presented case study showed that the decision may be different if LCC analysis is included in the process.

Another important aspect is that this kind of approach still needs further research to overcome all its limitations and also requires a valid cost data base. It is essential to gather information and create a solid database about maintenance, product performance (durability and other aspects) and costs, so that analysis can be made with less uncertainty and more precisely applied and LCC becomes a current method in Portugal and around the World.

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Energy performance and thermal behaviour of light steel buildings

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ABSTRACT: Nowadays sustainable development and the search for green and renewable energy sources is a major concern of humankind. Given the important share of energy consumption in buildings, it is extremely important to search for innovative design solutions and optimal thermal performance of buildings in order to reduce energy bills and greenhouse gas emissions, maintaining levels of thermal comfort of occupants. ArcelorMittal launched in 2009 an international research project called *"Affordable Houses"* involving eight countries. The main goal was to develop innovative and affordable concepts that are culturally adapted to each of the partner countries, using light weight steel construction. In this paper the thermal passive behaviour and the energy performance of the proposed Portuguese residential building is presented.

1 INTRODUCTION

Sustainable development is nowadays a major concern of humankind. As is widely known, this development is based on three main pillars: economic, social and environmental. Due to recent climate changes (e.g. global warming, polar ice melting and sea level rising), governments, politicians and society in general are more aware of the importance and necessity of environmental protection. Carbon dioxide is one of the most important greenhouse gases and their emissions have increased exponentially since pre-industrial times. Indeed, the burning of fossil fuels (e.g. coal, natural gas, oil) remains the main source of energy in a world where the demand is increasingly growing.

In addition to environmental problems, the burning of fossil fuels is not economically sustainable since it is a source of non-renewable energy, leading to a significant increase in prices as stocks are depleted, as happened recently in the first half of 2008.

Energy consumption in European buildings represents an important share of total energy consumption (about 36%), corresponding to 27.5% for residential buildings (UNEP, 2007). A significant part of this energy is used to achieve thermal comfort (heating and cooling), ranging from 55% to 74% depending on the climatic region. Therefore it is extremely important to search for innovative design solutions and optimal thermal performance of buildings in order to reduce energy bills and greenhouse gas emissions, maintaining levels of thermal comfort of inhabitants.

In this paper the thermal passive behaviour and the energy performance of a residential building with light-weight steel structure is studied. This building was designed as a typical single-family home in Portugal using a modular concept developed by the authors during an international research project (Affordable houses) launched in 2009 and supported by ArcelorMittal. This paper is structured as indicated next. After this brief introduction, a general description is presented, including: the building location; the Portuguese weather; and the construction components of this building. Then, is showed the certification results for this building accordingly with the Portuguese code of practice for building thermal behaviour and energy performance (RCCTE, 2006). After that, some advanced dynamic passive thermal behaviour simulations are described and analysed. Finally, are presented some conclusions about the renewable energy viability study performed for this house.

2 GENERAL DESCRIPTION

2.1 *Building location and description*

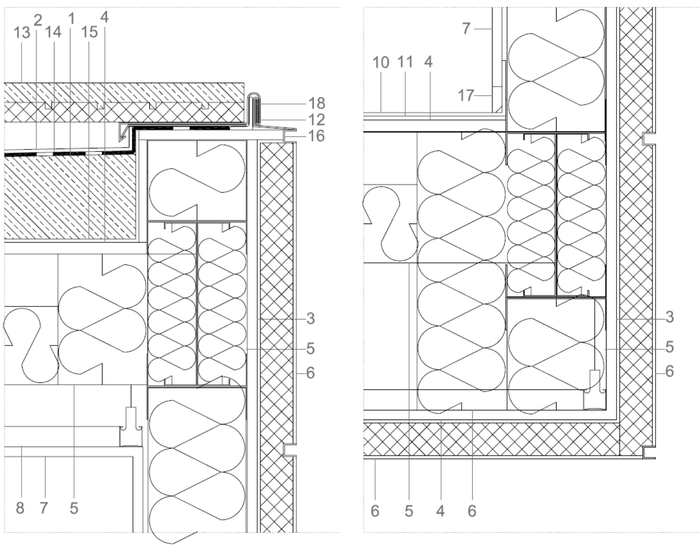
Geographically, continental Portugal is located between latitudes 37° and 42° N and longitudes of 9.5° and 6.5° W. The maximum altitude is 2000 m. This building will be located in Coimbra city in central Portugal.

The total internal net space of this residential building is 130 m^2. The ground floor is composed by a living-dining room, a kitchen, one bathroom, corridor/stairs and an opened garage. The first floor has 3 bedrooms, 2 bathrooms and corridor/stairs. More details about the architecture of this house are available in Murtinho *et al.* (2009).

2.2 *Portuguese climate*

Portugal has a diverse climate from north to south and from east to the west coast. The north part of the country has an Atlantic climate with cold and wet winters. The central regions have a mixture of Atlantic and Mediterranean climates, with mild winters and hot and dry summers, particularly in the inner regions. The southern part of the country has a very dry climate with mild winters.

According to the Portuguese Weather Institute, the daily average air temperature varies regularly over the year, reaching the highest values in August and the minimum values in January. In the summer, the values of the average maximum temperature vary between 16°C in the highest mountain (inner central-northern region) and 32 – 34°C in the inner central-southern part of the country. The values of the average minimum temperature, during winter, vary between 2°C in the inner high lands and 12°C in the south. The rainfall varies from the northern part to the southern part of the country. On average, about 42% of the annual rainfall occurs during the winter (December-February), while the lowest values happen during summer (July and August) with a share of 6% of the annual rainfall.



1 - Levelling layer
2 - Geotextile
3 - OSB board 11mm
4 - OSB board 18mm
5 - Mineral Fibre insulation
6 - ETICS (External Thermal Insulation Composite system) – Expanded polystyrene;
7 - Plasterboard 13 mm
8 - Spring Rail 25mm
9 - Suspension
10 - Linoleum 5mm
11 - Separating layer
12 - Zinc sheet
13 - Suspended composite concrete thermal tiles 600/600 mm
14 - Sealing membrane
15 - Vapour barrier
16 - Aluminium "C" profile 20x20 mm
17 - Wall Baseboard in maritime plywood painted in white
18 - Steel “L” profile (50x35x5 mm.)

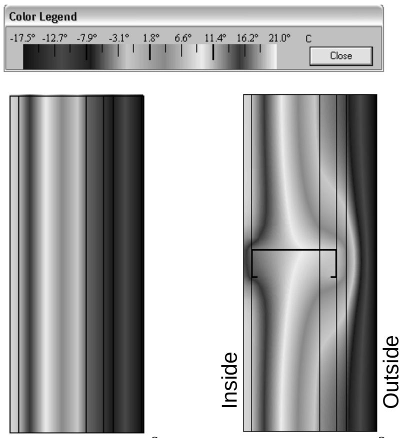
a) Roof-Wall connection. b) ExternalFloor-Wall connection.

Figure 1. Cross-section of the building envelope main construction components (walls and slabs).

2.3 *Construction components*

The building structure is a light-weight cold formed steel structure. Figure 1 exhibits the cross-section of the main construction envelope components (walls and slabs), including the connection details between the external walls and the slabs (terrace roof and external floor). Since the construction components of the building envelope are crossed by the light-weight steel frames (material with high conductivity), there is a higher thermal flux leading to an increase in the thermal transmittance values (Figure. 2). In order to take into account this thermal bridge effect and to evaluate its importance, two thermal transmittances values were computed: one neglecting the metallic frames (lower value, Figure 2a) and other assuming the thermal bridging originated by these frames (Figure 2b). Since the later values are more realistic, these were the ones used in the thermal/energy computations. The temperature distribution inside the construction components and the bridged thermal transmittances were computed using the THERM software (2003). The structural light-gauge steel frames are spaced 0.60 m apart.

The thermal and optical properties of the glazed openings predicted for this building are listed in Table 1. In order to diminish the solar gains and prevent over heating in the Summer, it will be used an exterior shade roll (medium opaque).



a) U = 0.210 W/m^2°C b) U = 0.269 W/m^2°C

Figure 2. Temperature distribution inside external walls with (b) and without (a) steel frames.

Table 1. Thermal and optical properties of glazed openings.

	U (W/m^2.°C)	Total Solar Transmission (SHGC)	Direct Solar Transmission
Double pane clear glass 8/14/6mm Air (SGG Climalit)	2.700	0.693	0.610
Aluminium frames (with thermal rupture)	3.700	----	----

3 RCCTE VERIFICATION

The adoption of the *Energy Performance of Buildings Directive* (EPBD) in Portugal led to the reformulation of previous codes and to the publication in 2006 of a new Code of Practice for the thermal behaviour of residential and small commercial buildings (RCCTE, 2006), and a new Code of Practice for buildings with HVAC power higher than 25 kW (RSECE, 2006). Both codes have been developed according to the specifications of the European Standard EN ISO 13790 (2008). In this section is briefly described the building thermal behaviour and energy certification process accordingly with the Portuguese code of practice, RCCTE (2006).

The thermal transmittances values used in this design not only verify the maximum values allowed by RCCTE for the climatic region of Coimbra (I1), but also verify the values for the worst case scenario (I3) and the reference values (Table 2).

Table 3 summarizes the Solar Heat Gain Coefficient (SHGC) of the glazed openings used in this project and also the maximum and reference values indicated by the RCCTE. The maximum SHGC allowed by the RCCTE varies with the building thermal inertia (or mass).

Table 2: Thermal transmittances requirements verification (RCCTE).

	U (W/m^2.°C)						
	Designed	Max. values			Ref. values		
		I1	**I2**	**I3**	**I1**	**I2**	**I3**
Terrace roof	0.373	**1.25**	1.00	0.90	**0.50**	0.45	0.40
External floor	0.342						
Ground floor*	0.595	**1.65**	1.30	1.20	**1.00**	0.90	0.80
External walls	0.269	**1.80**	1.60	1.45	**0.70**	0.60	0.50
Glazed openings**	2.500	**---**	---	---	**4.30**	3.30	3.30

*Separating an unconditioned space.
**Average day-night value (include the nocturne protection device).

Table 3. Glazed openings SHGC requirements verification (RCCTE).

Building thermal inertia class	**SHGC***						
	Designed	Max. values			Ref. values		
		V1	**V2**	**V3**	**V1**	**V2**	**V3**
Low	0.06	0.15	**0.15**	0.10	0.25	**0.20**	0.15
Middle or High	---	0.56	0.56	0.50			

* Values obtained when the shading protection device is 100% active.

As can be observed in Table 3, the SHGC of the glazed openings proposed for this project (Double pane clear glass 8/14/6mm Air [SGG Climalit], aluminium frames with thermal rupture and a shade roll [medium opaque] external protection device) verify the required values indicated in the RCCTE, not only for the Summer climate region of Coimbra (V2) but also for the worst case scenario (V3) and the reference values.

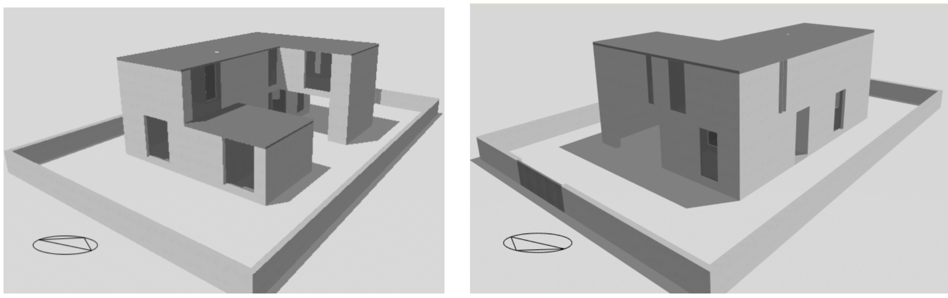
The adopted equipments for air conditioning were HVAC split devices for cooling (CoP3) or heating (CoP4) placed in the main dwellings of the house. This house will have solar thermal collectors (4 m^2) in order to produce domestic hot water (DHW). These solar collectors will be supported by a liquid fuel boiler when the water temperature rise is not enough.

The computed (*Ntc*) and the maximum *(Nt)* total nominal annual needs of primary energy for this building is 2.39 and 5.92 kgep/m^2.year, respectively. Therefore, the ratio between *Ntc* and *Nt* is below 50% and the energy efficiency of this building could be labelled as “Class A”.

4 ADVANCED DYNAMIC THERMAL BEHAVIOUR SIMULATIONS

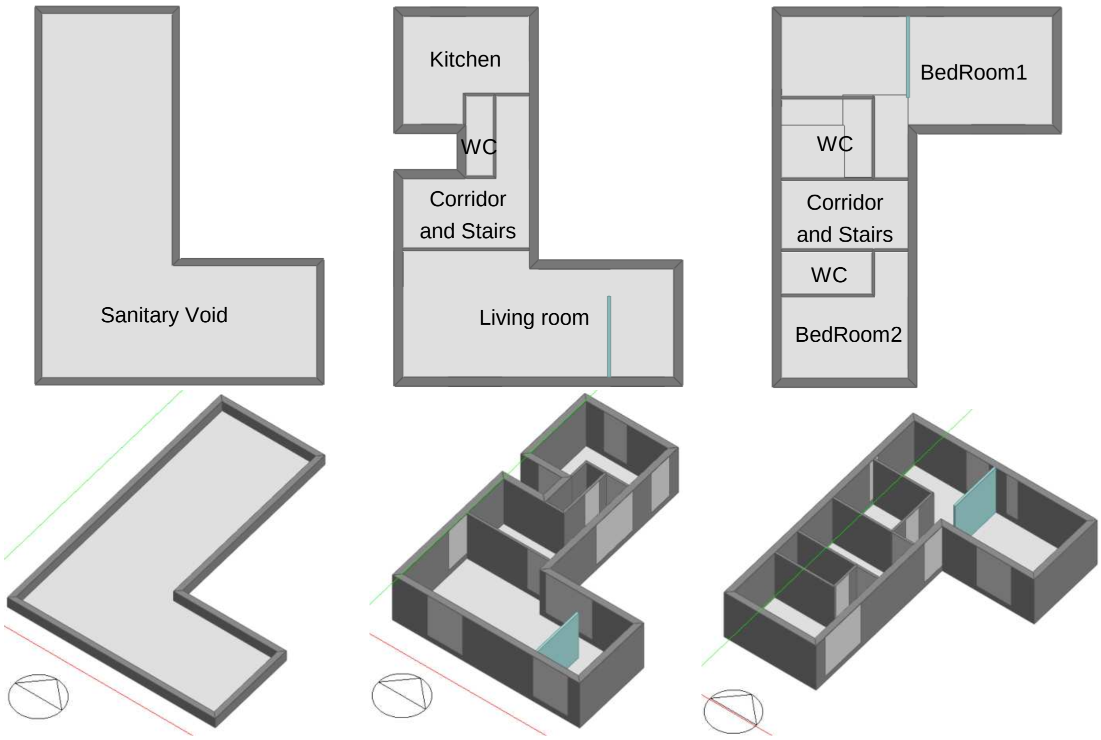
In this section is presented the advanced dynamic thermal behaviour study of the designed house. The main objective is to check the good thermal behaviour for this design, even in passive condition (without heating or cooling) and to see in more detail the temperature distribution inside the main dwellings for a design and a typical week in summer and winter. The advanced dynamic thermal behaviour simulations were performed using the EnergyPlus (2008)/DesignBuilder (2005) software. The weather data file used in these simulations was obtained from IWEC (International Weather for Energy Calculation) for the city of Coimbra (PRT_COIMBRA_IWEC.epw).

Figure 3 exhibits two outside elevation views of the DesignBuilder model used in the dynamic simulations. The building model was assembled using nine thermal zones, corresponding to the internal partitions of the building (Figure 4). The sanitary void on the basement was modelled as an unconditioned space; the ground floor has three thermal zones while the first floor has four zones. Besides these eight thermal zones, there is another one that is common to the two floor levels, and includes the corridors and the stairways.



a) Southern and eastern views b) Northern and western views

Figure 3. Elevation views of the building (*DesignBuilder* model).



a) Basement b) Ground floor c) First floor

Figure 4. Layout of the floors.

It was assumed that the house will be occupied by three or four persons with typical luminance requirements and standard internal gains with the occupancy and equipment schedule adapted from Bill Dunster Architects (2005) to match the southern European lifestyle. The minimum natural ventilation rate is 0.6 air changes per hour (minimum value imposed by the RCCTE), while the heating and cooling set point temperatures are 20 and 25ºC, respectively.

The advanced dynamic thermal simulations were performed for two distinct climate conditions: Summer (cooling season) and Winter (heating season). The thermal behaviour of this residential building was simulated for passive and active conditions, respectively when the

HVAC equipments are turned OFF and ON. In this paper only the passive thermal behaviour results are presented for the design and typical weeks during Summer and Winter seasons.

To obtain the optimized solution (presented here) several simulations were performed allowing assessing the importance of some parameters (e.g. natural ventilation, internal gains, overhangs shading, glazing) on the thermal performance of this building (not showed in this paper).

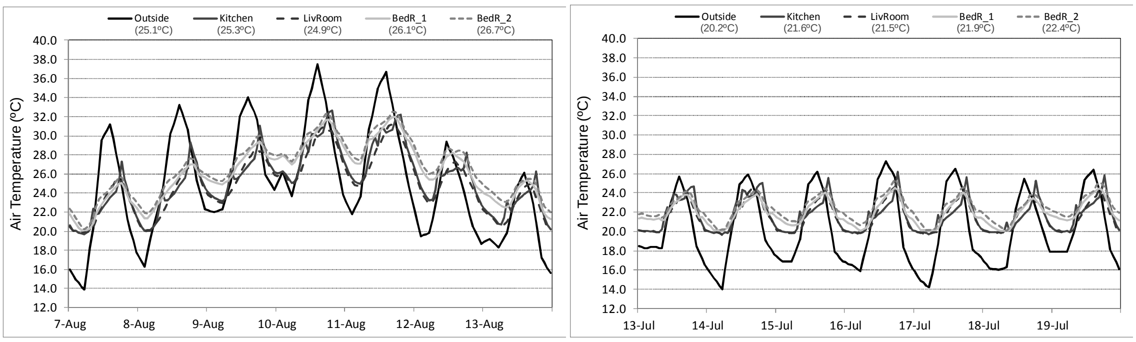
4.1 *Summer passive thermal behaviour*

Accordingly with the IWEC climate data for Coimbra (used in these computations), the Summer design week present an average temperature of 25.1ºC, while in the typical week this value is about 5ºC lower (20.2ºC).

In the cooling season the main problem related with the thermal passive performance that could emerge is the overheating, particularly in buildings with low thermal inertia (mass). Besides the good thermal properties of the building envelope (previously described), two passive measures were implemented and modelled in order to overcome this problem and increase the thermal passive performance of the building. The first one was to adequately ventilate the building when the inside air temperature exceeds 20ºC (setpoint ventilation temperature) and simultaneously the outside air temperature is lower than inside. A variable ventilation rate was modelled with values between 0.6 (minimum value defined in RCCTE) and 6.0 air changes per hour (ACH).

The second passive measure, in order to reduce the solar gains, was the use of an exterior shade roll (medium opaque) on the glazed openings of the building. This shading device is only activated when the solar radiation became greater than 120 W/m^2.

Figure 5 display the average hourly air temperature variation inside the main four dwellings of the building along the Summer design and typical weeks. This building exhibit a very good thermal performance along the summer typical week, since the inside air temperature is within the comfort gap defined by RCCTE (20ºC to 25ºC) even with the cooling equipment turned off (Figure 5b). The hottest dwelling is the Bedroom2 on the first floor and exposed to South. Observing the temperatures fluctuations along the Summer design week (Figure 5a), the outside air temperature is now much higher (4.9ºC) and consequently the inside temperature also increase. However, this increment is lower than the outside one, being more accentuated on the first floor dwellings (bedrooms). In this week the cooling system is needed to insure the thermal comfort of the residents since the temperature is above 25ºC during about five days.



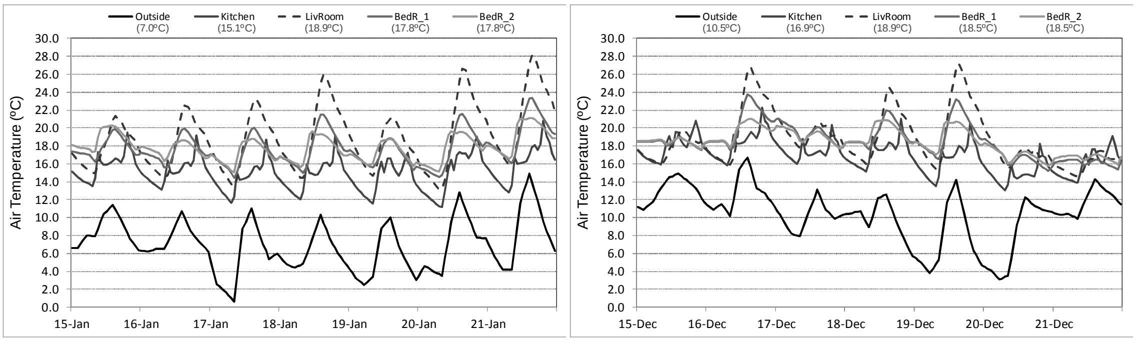
a) Summer design week b) Summer typical week

Figure 5. Temperatures variation inside the main compartments and outside the building (Summer passive thermal conditions).

4.2 *Winter passive thermal behaviour*

The heating season simulations were also performed for two different scenarios: a design week (worst case) and a typical week (more frequent scenario). For this season the average temperatures are 7.0ºC and 10.5ºC, respectively for the design and typical weeks. Now the passive measures intent to retain the heat inside the building, reducing the thermal losses. Since the outside air temperature is much lower than the inside one, now the ventilation is reduced to a minimum value (0.6 ACH). In order to maximize the solar gains and minimize the heat loss through the glazed openings at night, the exterior shade roll is only activated during the night.

The obtained average hourly results for these two winter weeks are showed in Figure 6. The kitchen (north exposed) is the coldest dwelling, even considering their internal gains, with an average air temperature of 15.1ºC and 16.9ºC during the design and typical week, respectively. The dwelling with higher thermal amplitudes is the living room on the ground floor, showing an average air temperature of 18.9ºC in both design and typical weeks. This is due to the solar gains through the south exposed windows. The passive measures taken in the Winter are not so efficient as in the Summer. Therefore the heating demand is higher in the winter than the cooling demand in the summer. This is confirmed by the average air temperatures inside the dwellings during the design and also the typical week, that are below the setpoint temperature (20ºC).



a) Winter design week b) Winter typical week

Figure 6. Temperatures variation inside the main compartments and outside the building (Winter passive thermal conditions).

5 RENEWABLE ENERGIES VIABILITY STUDY

In this section is briefly presented the viability study results for using renewable energies into this project, for installation of solar thermal collectors, photovoltaic panels and biomass boiler, in order to reduce the energy needs due to the use of fossil fuels.

The installation of solar thermal collectors (4 m^2) to produce DHW is mandatory accordingly with the RCCTE (estimated cost of 2 190€, including government incentives, accessories and the devices installation). The viability study shows that the installation of a larger number of solar panels is not economically viable. The payback time for the solar thermal collectors acquisition is about nine years.

The inclusion of a biomass boiler it was also analysed. This device allows to heat directly the inside air and to heat water that will be accumulated in a reservoir and circulated into hot water radiators placed in the main dwellings of the house (estimated cost of 5 000€, including accessories and the devices installation).

It was also studied the incorporation of some photovoltaic panels (mono-crystalline type, with a peak power of 160 W) to produce electrical energy. To achieve the total peak power of 3.68 kW (which represents the limit to benefit from the selling incentive program to the public network), 23 photovoltaic panels would be needed (estimated cost of 20 000€, including accessories and the devices installation). Given an interesting sale price, the exceeding energy will be sold to the public power network. The initial investment would be amortized after seven years. The reason why this option was not adopted is in the high initial investment.

6 FINAL REMARKS

This paper presents some features related with the energy performance and thermal behaviour of the Portuguese light-weight steel residential building proposal for the *"Affordable Houses"* international project, with particular emphasis on: RCCTE verification; advanced thermal dynamic simulations; and renewable energies viability study.

As showed in this paper, the proposed light-steel single family house is able to comply with the buildings energy performance and thermal behaviour regulations, providing high levels of comfort to the users. Moreover, light-weight steel construction has some advantages in comparison with traditional construction (concrete structure and brick walls). Although the higher thermal conductibility of the steel material, it is easy to obtain building envelop components (walls, floors and roofs) with very low thermal transmission values, even with lower thicknesses, saving net construction areas. This is usually achieved using thermal insulation materials. The use of an external thermal insulation coating system (ETICS) allow overcoming the thermal bridges originated by the steel frames.

Buildings with higher internal mass exhibits higher thermal inertia leading usually to lower thermal amplitudes inside the building. To overcame this potential drawback and obtain a good thermal behaviour on light weight buildings it is crucial at design stage to correctly define the glazed openings dimension, exposure and shading strategy, in order to control the solar gains, particularly at Summer season. On buildings with intermittent occupation, as happens in many of the residential buildings during weekdays, this apparent drawback could be an advantage! In this case when the inhabitants are in their workplaces or in school, the HVAC equipment should be turned off, being turned on when they return home at the end of the workday. Given the lower internal mass of light-weight steel buildings, the heating or cooling process is fastest in comparison with traditional heavy-weight construction, increasing the efficiency of the HVAC system.

The selection of highly efficient equipments and the use of renewable energy sources (payback time of 7-9 years) allow to significantly reduce the building energy bill and the greenhouse gas emissions, maintaining the occupants level of comfort and increasing the sustainability level of the proposed building solution.

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Light school buildings. A new way to look at public educational building.

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ABSTRACT. Is it necessary to accept as a rule that the energetic and constructive quality must be directly proportional to the building cost? Is financial availability a necessary, but not sufficient, condition, for the architectural quality?

Analyzing the scholastic buildings in Piemonte (a region in northwest Italy) we would like to understand if constructive quality, energetic performances and construction costs are inversely proportional through them or not.

Can a limited financial availability strongly condition the construction of an efficient and good quality building?

Six study cases have been analyzed by an energetic, constructive and building costs, point of view .

The intent is t to compare the buildings shell technologies and their costs, to understand which kind of constructive systems can be used to answer to the reduced amount of money the public councils can spend, without to renounce to high energetic performances.

Which are the strongest rules that condition the building choices?

Which kind of materials and constructive systems have been used? Techniques and materials are still part of the traditional way to build? Are we looking for new solutions? Could wood prefabricated buildings and low environmental impact be an alternative answer?

Could the new approach produce a social and educational consequences?

In many cases the use of new materials and constructive system started from the public sector and in only in a later period of time has been applied to the private one. The need to produce in a short period of time solutions able to answer to the new norms could have changed this situation.

1 SCHOOL BUILDINGS

1.1 *The Italian situation*

The most of the Italian scholastic building patrimony has been built before 1974, when attentions to the buildings energetic performances were quite few [Legambiente, 2008]. The panorama shows us a situation in which the most of the school buildings require surface extension or technological and energetic refurbishments.

While the primary and secondary school buildings seem to offer a good answer to the spaces requirement, the childcare facilities (nursery schools) don't have a long history in our country, and in some contexts they still are not enough to answer the families demand.

Especially in the cities extending suburbs we can check an insufficient answer to the educational buildings demands for the younger children.

In Italy the educational system provides two different kind of buildings for the children from six months age to five years age.

Children from six month to three years can join *nursery* school, while children from three years to six years would attend the *"infant school"*. These two kind of buildings offer, for the two age range, a different space organization to respond to a different educational model, even if, the total space surface has the same dimension in both the situation.

The project process and the construction cost for the educational buildings is, in general, a public administration charge, the city councils must afford for it.

In the last few years we could see many different public selection for the construction of new public infant and nursery school buildings. City Councils have been working to answer to a high social demand.

In the last years Central Government and Regional grants to City Councils for educational buildings construction have been reduced, and a selection procedure based on energetic and environmental criteria has been introduced to select the projects to finance.

The "classical" scholastic building, a concrete parallelepiped structure, is not considered a reference model anymore. The school buildings must aim to improve the thermal interior comfort and at the meantime to reduce the impacts on the ecosystem during their all life cycle.

The most general principles for a sustainable school project need to respond to criteria as:

- orientation of the interior unities in harmony with the climatic needs;
- good natural light, shadow and wind exposure to respond to the summer and the winter conditions;
- a light environmental building impact during the all life cycle.

The technological choices and the most detailed architectural solutions contribute to the definition of the livability levels of the whole scholastic complex.

The greater designer effort should be to create a contextual picture which does not just employ the traditional and usual technologies. New strategies, processes, and solution must be introduced taking strongly care of the context in which we are working.

An innovative methodology requires to start from a comparative analysis of the changes in the architecture of the school buildings and those introduced in the educational conception.

Since the first objective for an educational building is to offer salubriousness and quality of the life for the new generations, it seems clear that the adoption of sustainable strategies and technologies is necessary to maintain high levels for these two requisites.

Many Public Administrations assumed sustainability as one of the main criteria according to which developing the territory governance and a lot of them began their run thinking, planning and realizing public works with particular attention to scholastic buildings able to answer to salubriousness, echo logicality and sustainability criterions.

The scholastic buildings, through their quality, their accessibility, assume an high social value and become instruments to communicate with the citizen.

1.2 *The situation in Regione Piemonte*

An overview on Piemonte Regional buildings scholastic situation offers an homogeneous geographical and climatic analysis context.

The regional educational building situation is similar to the national one. The most of the buildings (50,82%) have been constructed before 1974, with very small attention toward energetic consumptions or to materials composition.

Actually the energy consumption estimation for the school buildings in the northern Italy is between 120-140 kWh/m^2 per year for heating, 56-83 kWh/m^2 per year for artificial lighting and electrical uses [Filippi, 2008]. These numbers underline the need of a sustainable energetic management.

In Piemonte there are 1066 "infant school" (3-5 years children). The 63,30% of them are public property and management [IRES]. The city of Turin and its surroundings own 209 of these public school buildings [Nanni, 2009].

Only the 17% of the school buildings have been realized or refurbished according with ecological and energetic sustainability principles [Oleotto,2007].

The introduction of a Federal Association of the Italian Region, *Protocollo ITACA*, offers a common instrument to measure and evaluate the environmental buildings performance from the project phase and the usage stage.

In some cases Regione Piemonte did apply *Protocollo ITACA*, based on SB Method, to evaluate and select the deserving contribution projects, on the basis of energetic and environmental performance characteristics.

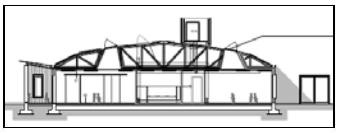
These attentions brought to the introduction of innovative constructive solutions. Such changes have also been dictated by the introduction of the new energetic national laws.

Educational buildings projects have to respond to the acoustic, hygienic, natural lighting, dimension and space organization, requirements imposed by a quite old national law, the DM 18-12-1975. From an energetic point of view the reference norms are the recent national (Dlgs192/2005, Dlgs 311/2006) and regional (DPR 59/2009) prescription which respond to the European Directive: Energy Performance of Buildings (EPBD) 2002/91/CE.

It doesn't currently exist a norm that gives a general overview of the energetic environmental scholastic buildings sustainability.

The attention to the environmental aspects is relegated to the obligation in some Public Administration to apply special protocols, or often just to the personal designer sensibility.

 	Asilo nido - Via Fenoglio, 26 - Venchi Unica	
	LOCATION	TORINO
	ARCHITECTUTAL DESIGN	Arch. Monica Semeraro
	STRUCTURAL DESIGN	
	HEATING, PLUMBING, CLIMATE CONTROL DESIGN	
	ELETTRIC and LIGHTING DESIGN	
	CONTRACTOR	
	CLIENT	
	GROSS BUILT AREA	778 m^2
	SITE AREA	1877 m^2
(Photos V.M. Rocco)	HEATING AND CLIMATIZATION SYSTEMS	Floor radiant panels
 	Nido d'infanzia - Corso Mamiani, 1	
	LOCATION	TORINO
	ARCHITECTUTAL DESIGN	Arch. Maurizio Testa M.d'Arte Piera Cervetti
	STRUCTURAL DESIGN	Ing. Giuliano Gabrieli
	HEATING, PLUMBING, CLIMATE CONTROL DESIGN	Ing. Reno Vaudano Ing. Giovanni Francesco Locigno
	ELETTRIC and LIGHTING DESIGN	Ing. Paolo Gallo
	CONTRACTOR	
	CLIENT	Torino City Council
	GROSS BUILT AREA	1020 m^2
	SITE AREA	2041 m^2
(Photos V.M. Rocco)	HEATING AND CLIMATIZATION SYSTEMS	Floor radiant panels, PV panels, gas boiler, water rain recover.
 	Asilo Nido - Via Ungaretti	
	LOCATION	MONCALIERI (Torino)
	ARCHITECTUTAL DESIGN	geom. Dario VIOLA
	STRUCTURAL DESIGN	Ing. Diego Marchesini
	HEATING, PLUMBING, CLIMATE CONTROL DESIGN	FAPA Engineering (Torino)
	ELETTRIC and LIGHTING DESIGN	FAPA Engineering (Torino)
	CONTRACTOR	
	CLIENT	Moncalieri City Council
	GROSS BUILT AREA	1330 m^2
	SITE AREA	4910 m^2
(Photos V.M. Rocco)	HEATING AND CLIMATIZATION SYSTEMS	Floor radiant panels, gas boiler, solar hot water, PV panels.

 	Scuola materna - Via Barassino	
	LOCATION	TRECATE (Torino)
	ARCHITECTUTAL DESIGN	Arch. Gianbattista Pomatto
	STRUCTURAL DESIGN	Arch. Fabrizio Carosso
	HEATING, PLUMBING, CLIMATE CONTROL DESIGN	Arch. Alessandro Bogetti Ing. Aldo Vavassori
	ELETTRIC and LIGHTING DESIGN	Per. Ind. Massimo Zenerino
	CONTRACTOR	Macrì S.n.c.
	CLIENT	Trecate Public Council
	GROSS BUILT AREA	2100 m^2
	SITE AREA	6000 m^2
(Photos G. Pomatto)	HEATING AND CLIMATIZATION SYSTEMS	Gas heating system, radiant floor panels, solar thermal energy.
	Scuola materna	
	LOCATION	MAZZÈ (Torino)
	ARCHITECTUTAL DESIGN	Arch. Gianbattista Pomatto
	STRUCTURAL DESIGN	Arch. Gianbattista Pomatto
	HEATING, PLUMBING, CLIMATE CONTROL DESIGN	Ing. Aldo Vavassori
	ELETTRIC and LIGHTING DESIGN	P.I. Massimo Zenerino
	CONTRACTOR	IDRO.ERRE s.p.a. Tecnologie e Costruzioni
(Photo G. Pomatto)	CLIENT	Mazzè Public Council
	GROSS BUILT AREA	
	SITE AREA	
	HEATING AND CLIMATIZATION SYSTEMS	Radiant floor panels, Geothermal heat pump
 	Scuola materna	
	LOCATION	VINOVO (Torino)
	ARCHITECTUTAL DESIGN	Avventura Urbana (Torino)
	STRUCTURAL DESIGN	
	HEATING, PLUMBING, CLIMATE CONTROL DESIGN	Tecnelit S.P.A.
	ELETTRIC and LIGHTING DESIGN	Tecnelit S.P.A.
	CONTRACTOR	S.e.c.a.p. S.p.a. Totino Wood Building: La Foca Construction S.r.l.
	CLIENT	Vinovo City Council
	GROSS BUILT AREA	2550 m^2
	SITE AREA	m^2
(Photo T. Pochettino) (Design Avventure Urbane)	HEATING AND CLIMATIZATION SYSTEMS	Floor radiant panels, heating pomp, thermal geologic heating production

2 STUDY CASES

We did analyze six scholastic buildings for children from six months to five years.

The infant and nursery schools have been designed and built between 2005 up to today. Each construction does respect the energetic normative levels in force in year the project has been developed.

From 2005 up to nowadays the attention towards the energetic buildings consumptions is strongly increased, bringing to an integration in the shell heating insulation values limit and to an higher requirement of the energetic performances.

The six study cases are the product of a new bioclimatic design approach.

This new point of view tries to optimize the site peculiarities, the fronts exposure, setting a great attention for the building opaque and transparent shell performances and to the installations efficiency which often consume energy from renewable sources.

LOCATION	TORINO Venchi Unica	TORINI Cso Mariani	MONCALIERI (TO)	TRECATE (NO)	MAZZE' (TO)	VINOVO (T0)
DESIGN PERIOD	2005	2005	2007	2005	2008	2008
CONSTRUCTION PERIOD	2007	2007	2008	2006	2009	2009
BUILDING TYPOLOGY	NURSERY	NURSERY	NURSERY	INFANT SCHOOL	INFANT SCHOOL	INFANT SCHOOL
GROSS AREA (mq)	778	1.020	1.330	2.100	1.073	
COST (Euro)	1.049.760,62	1.460.500,00	2.123.050,00	2.500.000,00	1.840.000,00	3.040.000,00
COST (Euro/m^2)	1.470,00	1.431,00	1.600,00	1.200,00	1.200,00	1200,00
ENVELOPE COST (Euro/mq)	1.100,00	1.120,00	1.160,00	990,00	990,00	780,00
WALL U-value (W/m^2 K)	0,66 thick =cm 41	0,25 thick =cm 28	0,30 thick =cm 50	0,29 t.=cm24,3	0,29 thick=cm 4,4	0,199
COVER U-value (W/m^2 K)	0,33 thick =cm 55	0,38 thick =cm 52 (green roof)	0,35 thick =cm 49 (green roof)	0,22 t.=cm 21,1	0,22 thick =cm 25	0,144
GROUND FLOOR ($U = W/m^2$ K)	0,79 thick =cm 22	0,40 thick =cm 41	0,31 thick =cm 40	0,25 t. =cm 21,1	0,25 t. =cm24,3	0,152
MAIN STRUCTURE AND TECHNICAL SOLUTIONS	Concrete structural frame, brick external insulated wall.	Concrete structural frame, brick external insulated wall.	Concrete structural frame, brick external insulated wall. Wood-concrete horizontal structure.	Wood X-Lam prefabricated building. External insulation and ventilated façades.	Wood X-Lam prefabricated building.	Wood platform frame building.
USE OF RECYCLED OR RECYCLABLE MATERIALS		Cork insulation panels	Wood – concrete block for the horizontal structure isolation with thermal wood fiber and cellulose panels	Chalk fiber walls panels, wood fiber insulation panels	Chalk fiber walls panels, wood fiber insulation panels	Chalk fiber walls panels
ENERGY PERFORMANCE (EPi) kWh/m^3 per year	21,3	54,22		9,68	9,68	19,10

How do the study cases take into account the site characteristics and orientation?

The buildings realized in Torino and Moncalieri are collocated on completion urbanized area, while those in Trecate, Mazzè and Vinovo, are sited out from the city centre where it is possible to select the schools fronts orientation.

The construction period brings to have different limits for acceptable energetic performances. The study cases have different heating transmission tolerable values.

The two schools in Torino and the one in Moncalieri use traditional technologies with a concrete structure and insulated bricks shell. The other three ones adopted wood prefabricated constructive systems: platform frame or tables of wood compensated panels.

In all the cases the constructive system need to be completed with the employment of insulating material to reach the energetic performances level required for the shell.

Besides the definition of the constructive system, this work does analyze the relationship between the obtained shell transmission values and its cost in relationship with the gross floor built area.

Choosing to extrapolate only the building envelope data and the costs from the total expense we did not want to deny the strong relationship that does exist in a project between the technological/architectural solution and the heating and electric installations. The aim of this analyse is to try to understand if the constructive system is changing to guarantee better insulation values where the economic reduced possibilities.

3 WOOD BUILDINGS PREFAB RICATIOAN: QUALITY AND COST

The request for high performances in terms of winter thermal insulation and for bewilderment times of the summer thermal wave brought to adopt alternative solutions for the building shell construction which are not so usual in our technological cultural context.

In this regional context the buildings shell are realized adopting a double brick wall with insulating material in the middle layer. Just in few situations masonry is insulated with an "external coat". While this solution is becoming quite common for residential buildings it seems quite innovative for the public ones.

The bricks utilized can guarantee a better thermal performance since are rich of air pores.

The management of a traditional construction system does foresee a long term for the building phase especially if there is a concrete main structure frame. In this case bricks are used as external layer, without any structural function.

Besides the adoption of the traditional construction system it is possible to find the use of wood prefabricated technologies, which are quite new for public buildings in our region.

The real novelty does not concern the wooden use, but rather the technological system.

We are talking about wood walls prefabrication using a platform frame system or compensated panels tables.(glue laminated timber, panels of solid wood in crossed layers, X-Lam).

These construction systems, unlike the "traditional ones", are considered to have a lower environmental impact. Wood is considered to be an ecological material, since it is renewable and easily workable. The production of one concrete cube meter demands an energetic contribution nine times superior to that required for an identical volume of thick wood. The production of a iron cube meter requires a 431 times energetic superior contribution [Berti, 2002].

The *platform frame* system is not new conception. It was developed from the XV century with the America discovery. Such system was introduced for self made buildings and has evolved so much that it is now possible to prefabricate all the components, even wide dimension walls.

This prefabrication system warrants a total quality control and a fast construction phase.

The *X-Lam system,* on the other hand, represents quite a new concept, it uses wood tables glued together.

The wood panels construction, in both the systems above, offers an excellent control during the production phases, thanks to the prefabrication process, which has various processing steps.

It is possible to produce structural panels as well as finished walls, including the doors and windows. The different prefabrication panels level will obviously bring to have a different management of the building site. The most of the panel will be completed in the factory, with the interior and external details, the most the construction time phase will be reduced.

The prefabrication system in Italy has a negative image, because of the bad results obtained in the past, or even because this system has usually been used to realize low cost buildings to afford emergency situation.

Thanks to wooden prefabricated systems this negative meaning is going to be over. Many examples from the German and English area show the elevated constructive and aesthetics potentialities of these wooden systems.

The advantages of this technologies are clear, especially for the assemblage step, "dried work", and for the high flexibility the system offers in the interior space organization. It is important to distinguish the prefabrication from the standardization process.

The choice of wooden prefabricated systems offers an answers to the demand for high energetic performances without problems. Wood has higher insulating characteristics in comparison to the ones offered by traditional technologies. This situation allows to reduce the walls thickness to obtain the same, or better, wall heat transfer coefficient (U-value).

The use of such prefabricated panels could bring:

- many advantages during the construction phase as the reduction of the construction time;
- possibility of easier dismantlement, thanks to the dried connections through the components, and a reduction of the environmental loads
- quality product control since from the production phase;
- the resolution of *thermal bridges* with the integration between structural system and shell;
- renewable material use (e.g. wood certification FSC, PEFC);

Looking such advantages we are wondering how much does a wooden building cost?

Is it possible to affirm that a wooden building does cost less than the traditional one?

To answer to the questions above we did analyze the data of the six study cases, comparing the buildings constructive system, the shell cost, in relation to the floor gross surface, and the energetic performances.

4 CONCLUSION

From the analysis above it is possible to estimate that the use of wooden prefabricated panels allowed the realization of an high energetic performance buildings, with a lower cost compared to a traditional technologies application.

The reduced financial availability and the high performance demand promoted an innovative and competitive technologies development

The use of wooden prefabricated technologies means:

- a very detailed executive integrated architectural and installation design project, since any change required must be studied from a structural point of view;
- the employment of specialized highly manpower for the shell and the interior partitions and of the fittings assemblage, since a common traditional Italian construction firm would find difficult to manage this kind of building technology
- a limited flexibility to the change of the interior distributive demands.

Buildings dismantlement and extension is possible but must be carefully planned.

Taking into account the wooden prefabricated buildings benefits it is necessary to understand the problems we have to afford during the management and maintenance phases.

Since the wooden products present limited lasting of functionality, which kind of prevision can we make?

Can Public Administration guarantee, because of the small amount of money they have got, a good maintenance level?

From the informations collected it seems that wooden building functionality can be guaranteed for half the time (an average of 59,1 years) in comparison to the masonry building (114,0 years), to the concrete ones (112,7 years), and to the steel ones (92,6 years) [Berti, 2002].

It seems that the new wood technology can last 80-100 years and some builders tend to warrant them even for 125 years [CEI-Bois, 2006].

The duration concept is tightly related to the maintenance activities .

It should necessary monitoring these buildings at the purpose to verify the maintenance conditions from the time and cost point of view.

A good maintenance activity should allow a long period of conservation.

Since the construction of a wood prefabricated building does requires reduced time comparing to a traditional ones, it could be possible to realize a school building extension using just the summer holidays period (three months) without any interference with the ordinary children activities.

A process to realize a new school in short time could be organized as follow:

- executive project 30 days, authorizations and constructor selection 60 days, building phase 90 days [Pepe, 2009].

Wooden prefabricated construction seems to represent a more sustainable approach. These system seems to be able to respond to the demand of an high built environment level, through the use of renewable materials and the reduction of energetic requirement.

Often new technologies are experimented in the public buildings sector and then they are adopted in the other sectors. Concerning the wood prefabricated building technologies it has been quite different, since these systems have been adopted by the Italian Public Administration much later then in the private residential sector.

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Integration of the new component into the design method for thermal insulating connections

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ABSTRACT: The new type of thermal insulating connection has been developed in order to minimize the heat costs of the building. The research is focused on the static design of the bolted steel end-plate connection with intermediate insulating layer which would break the thermal bridges in the external cladding of the building. The static design of the thermal insulating connection is using the component method as in Eurocode [EN 1993-1-8:2005] extended with a new component 'insulating layer in compression'. The materials for the insulating layer are the technical plastics with sufficient compressive and shear strength. A couple of component tests have been undertaken with the plastic layer Erthacetal H in compression and the characteristics of the new component have been implemented into the component design of the joint to predict the behaviour of the whole connection under the effect of rotational moment and normal force. The connection tests have been undertaken in order to verify the calculated values. Other tests will show the possibility of using the pre-stressed bolts to transfer the shear force via friction in the joint that is depending on the specific material used for the insulating layer. The new solution for the thermal insulating joint seems to be statically functional, easy to design, energy saving and economically efficient.

1 THERMAL INSULATING CONNECTIONS

The connections between the inner and the outer structures often cause the effect of thermal bridges in the external cladding of the building. To break the thermal flow in the steel structures it is necessary to insert an intermediate layer of thermal insulating material between the two bolted end-plates or the end-plate and the column flange. The insulating layer is under the effect of the internal forces transferred by the joint – rotational moment, normal force and shear force (Lange & Göpfert 2005), see Figure 1. The materials which have good thermal insulating characteristics as well as sufficient compression and shear strength are either elastomers/rubber (Nasdala et al. 2007) or technical plastics of the thickness from 5 to 25 mm depending on the actual requirements of the connection.

2 HEAT ENGINEERING

The heat engineering standard is predicting the obligatory values for the energetical costingness of the buildings. To minimize the heat costs it is necessary to break the thermal bridges in the external cladding which are rapidly increasing the value of the overall heat conductivity. In the steel structures the usual thermal bridges are caused by the connections between inner and outer structures, e.g. balconies, loggias, garages, roofs, cantilevers etc., see Figure 2. The thermal insulating connections offer a good solution for energy sparing as well as preventing the fungoid growth in critical points of the building. This is another step for improving structural details in ecologically and economically efficient sustainable building (Šulcová et al. 2007).

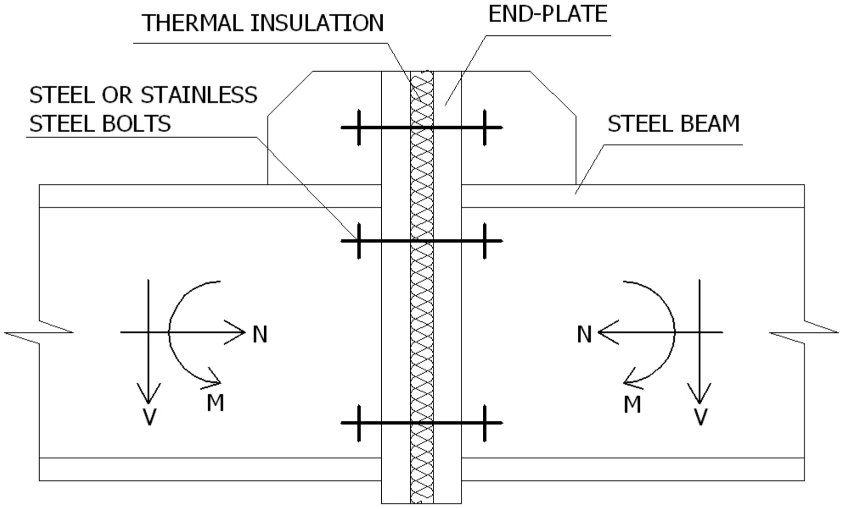

Figure 1. Thermal insulating connection under the effect of the internal forces.

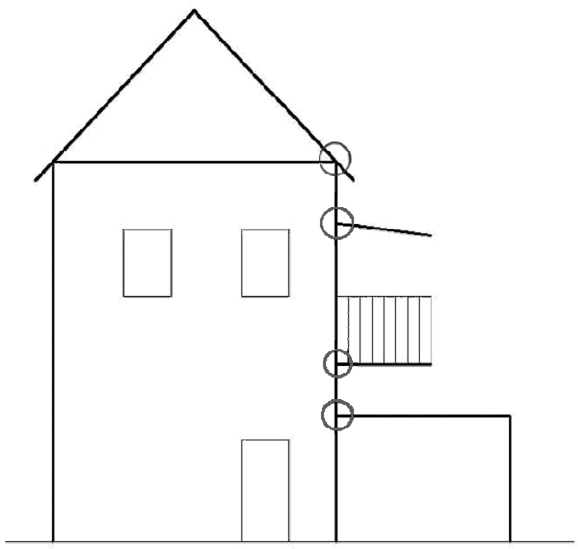

Figure 2. Critical points of the building where thermal insulating connections are necessary.

Concerning the static requirements of the connection the thickness of the thermal insulating layer can vary only between cca 5 and 25 mm which is not comparable with the thickness of the cladding insulation system. The thermal conductivity of the technical plastics and elastomers is compared to other materials in Table 1. However even with these poor characteristics of the intermediate layer the structural detail works properly when being a part of the whole structure, see the 3D thermal simulation by TRISCO (Šulcová et al. 2008). The 2D simulation by AREA has shown a big influence of the intermediate insulation on the thermal flow in the connection, for comparison see Figure 3.

Table 1. Thermal conductivity of materials concerned.

Material	Thermal conductivity [Wm-1K-1]
Steel	46
Stainless steel	16
Technical plastics, elastomers	0.2 – 0.3
Polystyrol	0.03 – 0.05

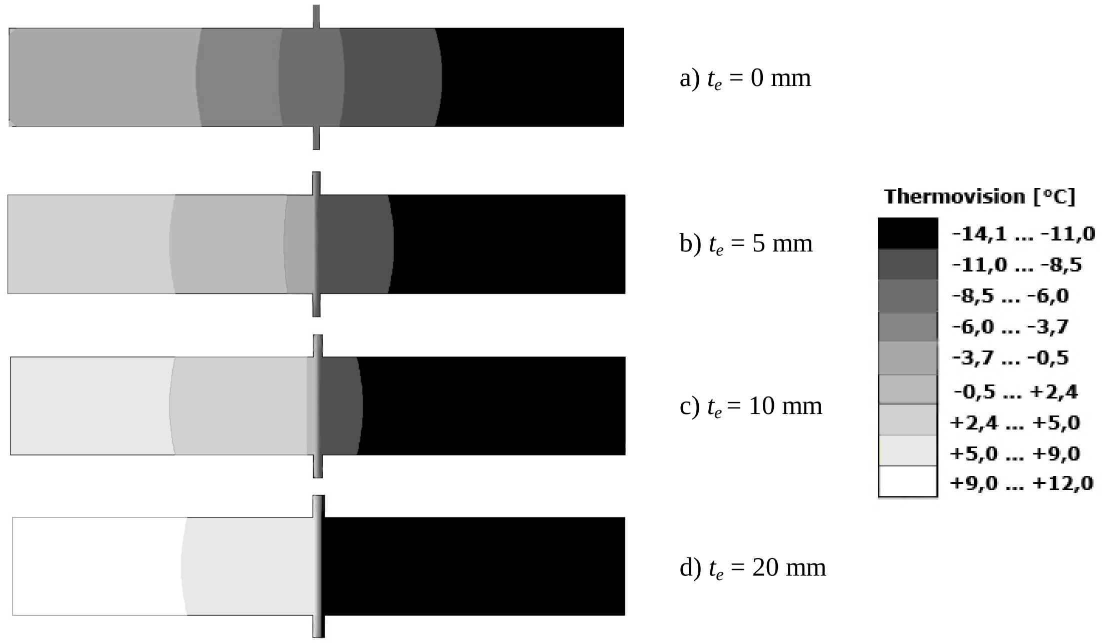

Figure 3. 2D thermovision of more or less thermal insulting steel connection (left-hand side interior structure, right-hand side exterior structure).

3 STATIC MODELING

The analytic modeling method is used for static design of the thermal insulating connection. The component method describes the joint as a moment-rotation relation. The main characteristics of the joint are the ultimate moment bearing capacity, the initial stiffness and the rotational capacity. Firstly the joint is disintegrated into so-called components which are investigated separately. Secondly the components are put together with respect to their real position in the joint and the characteristics of the joint are calculated from the partial values. The components of the thermal insulating joint are shown on Figure 4. The steel components are already well-described (Sokol et. al 2002, Sokol et al. 2006). The only new component is the 'thermal insulating layer in compression'. Once the new component is described (with a couple of experiments) the characteristics of the whole joint can be easily derived.

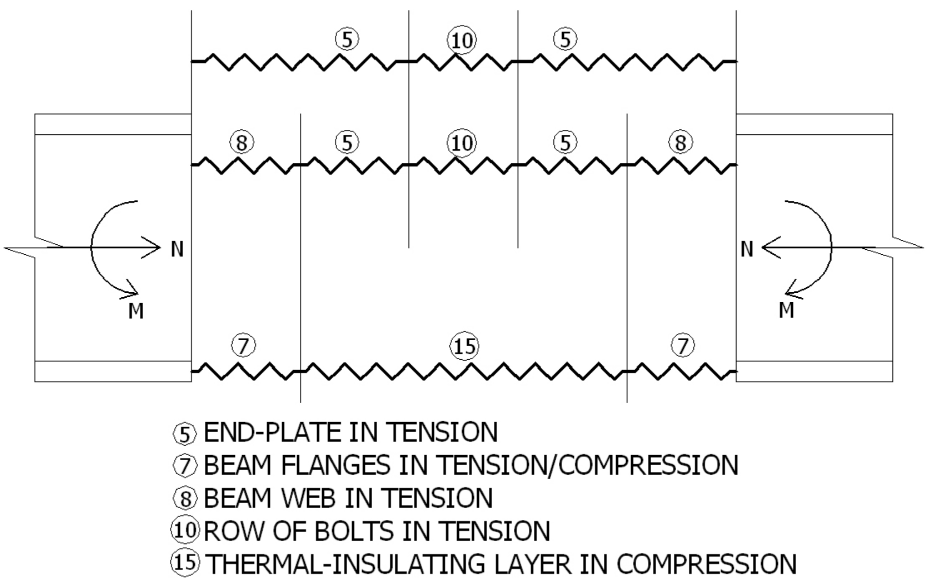

Figure 4. Components of the thermal insulating joint.

4 COMPONENT TESTS WITH ERTHACETAL H

A set of experiments had been undertaken with a technical plastic material Erthacetal H (for the characteristics see http://www.tribon.cz/). The influence of the thickness of the insulating layer was tested and the values of force-deformation relation, stiffness and the width of the compression area under the beam flange were monitored. The results are to be seen on the following graphs.

The experiments had been done for the thickness of the steel end-plate t_1 of 12 mm and 20 mm and for the thickness of the insulating layer t_2 of 8 mm, 16 mm and 25 mm, see Figure 5. The Figure 6 shows decreasing stiffness of the investigated component with the increasing thickness of the component.

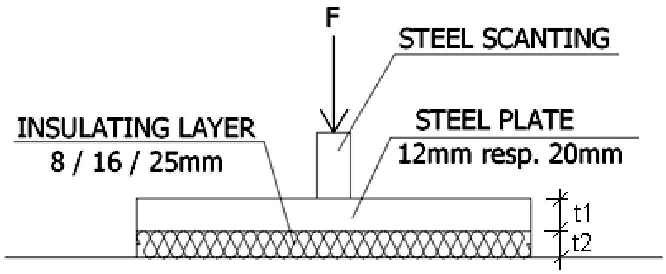

Figure 5. Scheme of component tests.

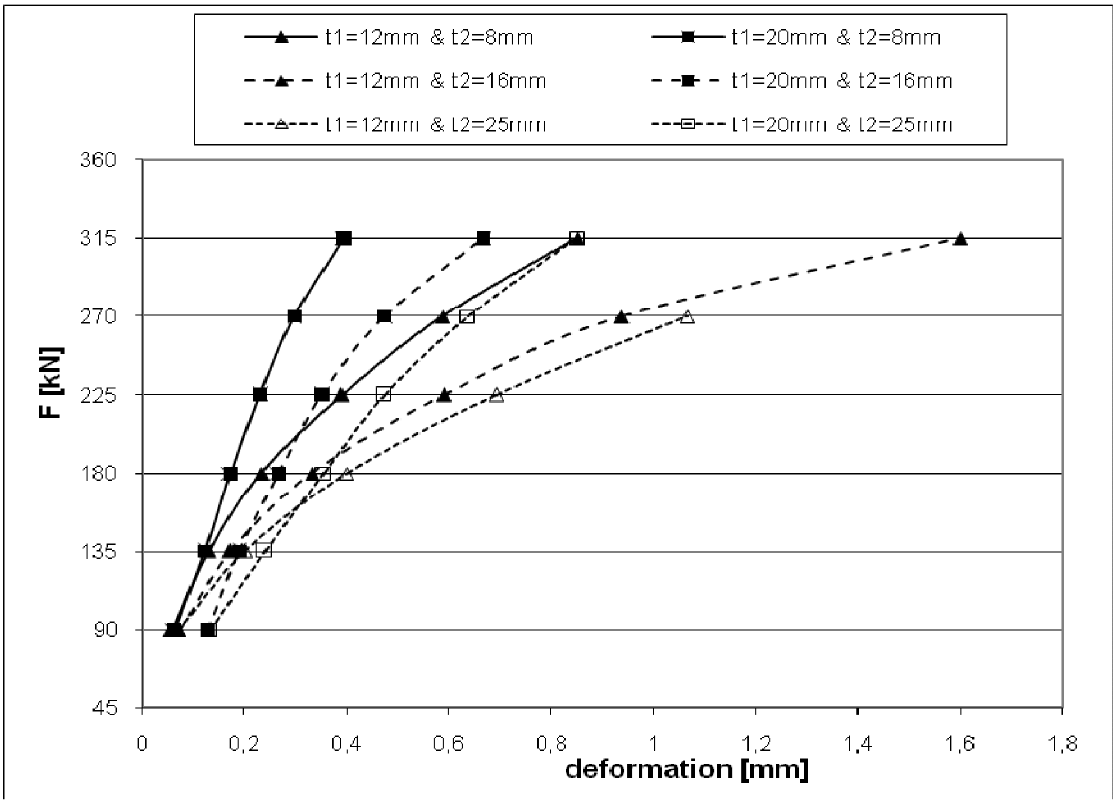

Figure 6. Force-deformation relation for different thicknesses of the component.

4.1 *Width of compression area*

The width of the compression area had been measured using the copy-paper, see results on Figures 7 and 8. It shows a good accuracy when compared with the calculated values using the analytic relation for the effective width:

$$b_{eff} = t_{fb} + 2{,}5t_1 + 2\frac{t_2}{2} \quad (1)$$

However it is also possible with a good agreement to use the modified relation for the offset width *c* of the compression area around the column flange known from design of the steel column bases:

$$c = (t_1 + \frac{t_2}{2})\sqrt{\frac{f_y}{3f_e * 1{,}45}} \quad (2)$$

where f_e is the experimentally stated elasticity limit of the insulating material Erthacetal H.

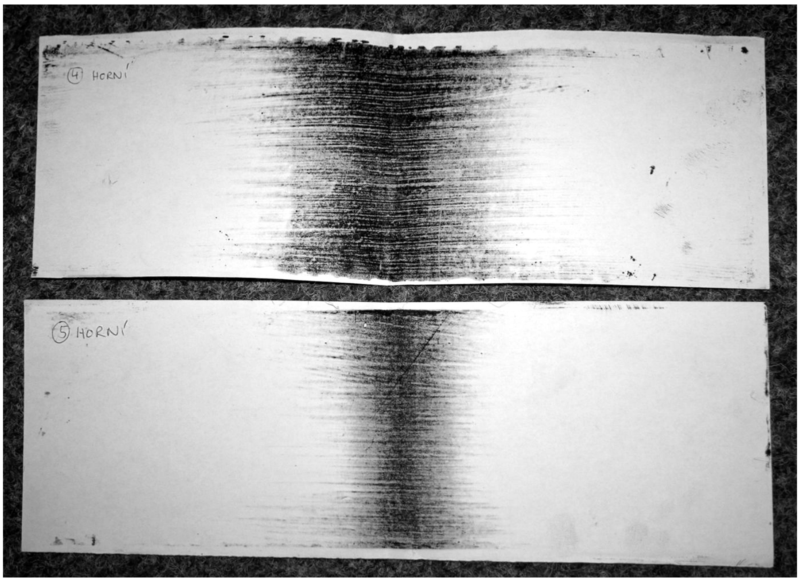

Figure 7. The compression area measured using a copy-paper during the experiments.

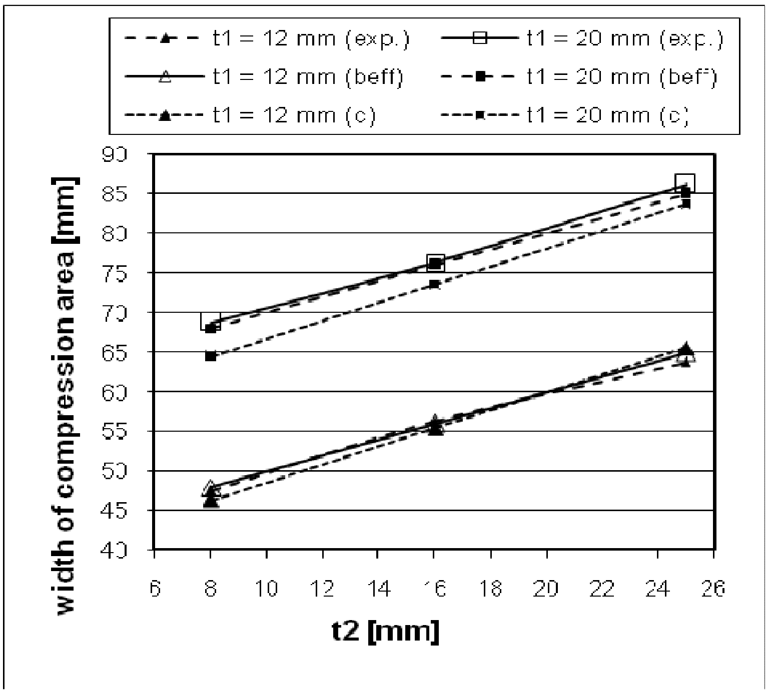

Figure 8. Width of the compression area compared with the calculated values.

4.2 *Component stiffness*

The stiffness of the insulating component is the lower the thicker the component is, which is similar to the behaviour of the steel plate component in compression and can be described with the following rule

$$k_c = k_{15} = f(t_1;t_2) * \frac{A_{eff}}{t_2}\frac{E_e}{E} \tag{3}$$

where

$$f(t_1;t_2) = 0{,}2 + \frac{1}{t_1} + \frac{t_2}{200} \tag{4}$$

and E_e is the experimentally stated Young's modulus of elasticity of the insulating material Erthacetal H. For comparison see Figure 9.

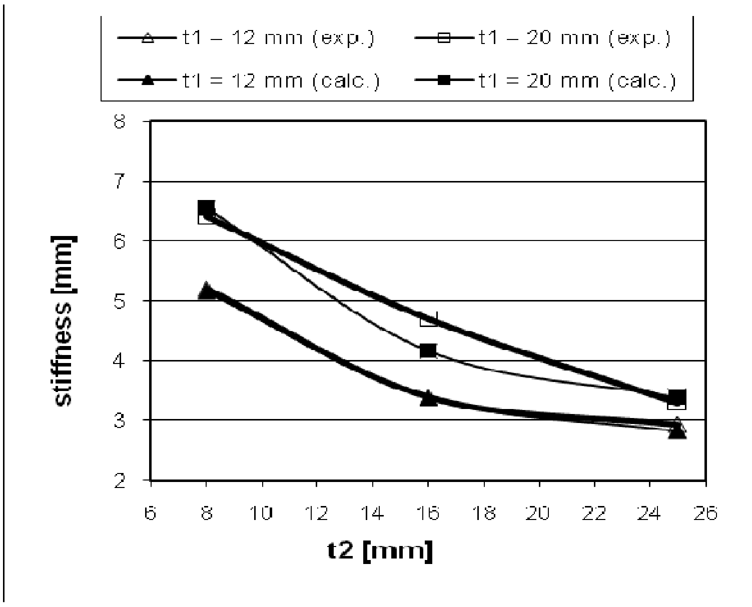

Figure 9. Component stiffness compared with the mathematical approximation.

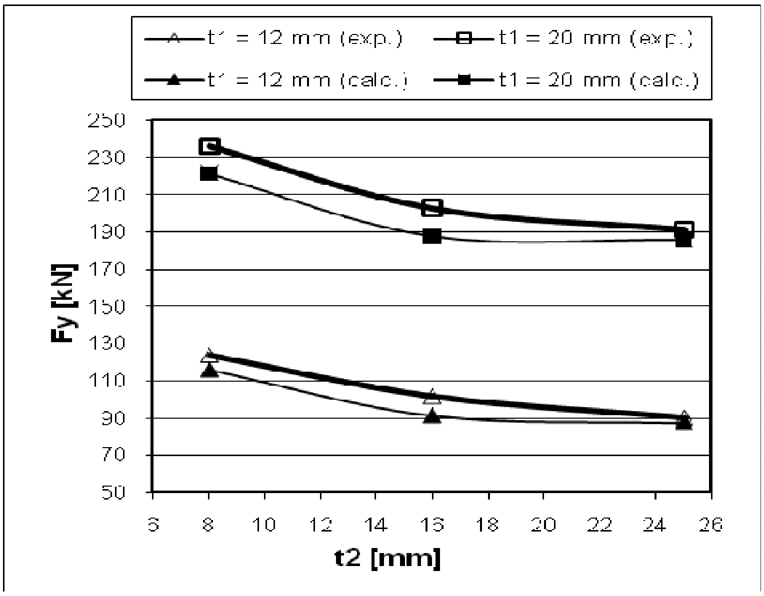

Figure 10. Limit of component elasticity compared to calculated approximation.

4.3 *Limit of elasticity*

The force at the limit of elasticity of the insulating layer is also the lower the higher the thickness of the component is, see Figure 10. It can be described as

$$F_y = f(t_1;t_2) * A_{eff}\, f_e \tag{5}$$

where

$$f(t_1;t_2) = \frac{3}{t_2} + \frac{t_1}{40} - 0{,}1 \tag{6}$$

4.4 *Creep*

The creep effect of the insulating layer is increasing with the thickness of the layer. A couple of long-term tests are being undertaken to measure the amount of creep and its influence on the loss of the stress in pre-stressed bolts during the connection lifetime. In case of large creep behaviour of the insulating material the shear force in the connection cannot be transferred via friction and the connection needs to be upgraded with a special shear bracket. Creep could also cause an enormous rotation in the structure.

4.5 *Material tests*

A couple of material tests had to be done with the insulating material to work out the Young's modulus of elasticity E_e and the elasticity limit f_e mentioned above in (3) and (5). The experimental values for Erthacetal H had been measured on the cubes sized 30 x 30 x 25 mm and the relations mentioned above are fit to these values. It is obvious that the material characteristics measured on different experimental cubes would need some change in the approximation rules (4) and (6).

5 CONNECTION TESTS WITH THE THERMAL INSULATING JOINT

The whole connection tests have been undertaken, see Figure 11, to compare the real connection behaviour with the calculated values. The moment-rotation relation of the connection has been measured as well as the width of the compression area. The results are being worked up to verify the component method as a design method for the thermal insulating connection.

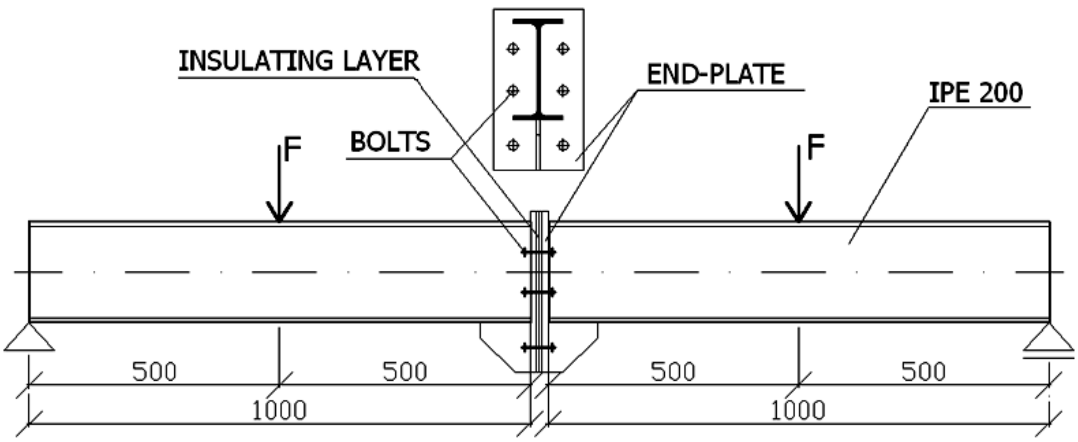

Figure 11. Scheme of the connection tests.

6 SUMMARY

The new component 'insulating layer in compression' made of the insulating plastic material Erthacetal H has been described. The results have been implemented in the design calculation of the connection using the component method to describe the whole thermal insulating connection. The connection tests as well as some long-term creep tests and material tests are being undertaken to confirm the suitability of the component method for the design of this type of connection.

The goal of this research is to introduce the new type of thermal insulating connection with a complete design solution which should be simple, functional, reasonable priced and economically efficient. It should spare a large amount of energy in ordinary family houses as well as in big business buildings.

7 ACKNOWLEDGEMENT

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Chapter 4

High performance sustainable building solutions

The keep Cool II idea and strategy: from “cooling” to “sustainable summer comfort”

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ABSTRACT: The European Energy Performance of Buildings Directive (EPBD) explicitly refers to a “passive cooling techniques, primarily those that improve indoor climatic conditions and the microclimate around buildings”. However, in Europe the demand for air conditioning is rising, especially in office buildings and is expected that the cooled floor area will be four times higher in 2020 when compared with 1990 figures. About 40% of our energy use is consumed in buildings and air conditioning represents a significant part.
To overcome this problem the conventional answer consists on to improve of the energy efficiency of cooling. However, this strategy showed limited results in terms of saving energy and reducing greenhouse gas emissions. In fact, cooling can be avoided (or the need to use energy for cooling) or significantly reduced without risking summer thermal comfort for building occupants, having thus the potential to achieve substantial reductions in energy demand and contributing to the overall objective of reduction CO2 emissions, minimizing the risk of the global warming and of the European climate protection commitments.
This paper presents the conclusions of two surveys undertaken in the frame work of the Keep Cool II Project. One centered on evaluating current practices in cooling design, construction and operation, in order to obtain a feel of how widely good practices are known and used and as a basis for the subsequent study on incentives to remedy a set of key barriers and to reach the notion of summer comfort as a service. Indeed, efficient strategies for cooling have been studied for at least two decades, and several campaigns have already been implemented in the EU member states to disseminate knowledge on summer comfort efficiency since the 1990s.
The other survey was undertaken in order to review the energy efficiency criteria, in the national building codes, concerning summer comfort or mechanical cooling system in order to elaborate recommendations towards a sustainable summer comfort. This survey intended to update, in a regional basis, the information regarding national building regulations, identifying the measures adopted and delineating good practices concerning energy consumption, summer comfort and summer requirements.
Finally, it should be stressed out the key role of the building designer towards sustainable summer comfort. Building codes requirements and design rules needs a proper use by the building designer.

1 INTRODUCTION

There is a growing energy demand for cooling in European that does not contribute to the overall objective of reducing CO2 emissions. As referred, in Europe in 2020, is expected that the cooled floor area will be four times higher when compared with 1990 figures. However, the adoption of passive cooling solutions, renewable energy sources and internal heat gains reduction can contribute to minimize or even to prevent the cooling in buildings, with a substantial potential on the energy demand reduction, without risking the summer thermal comfort.

Although these techniques are already studied and available, it is necessary to have a clear understanding about the rules and practices in building cooling design and operation in order to identify the good and the bad practices. This will also help on how to promote the adoption of those techniques and to encourage a holistic approach to energy efficiency.

The building regulations can also have a major role in controlling and limiting the energy consumption of the building sector. The changes imposed by the EPBD Directive should always be seen as an effective instrument to achieve highly energy efficient buildings. As almost every new modern office or other non-residential building, due to the existence of high internal gains from equipment loads, has an air-conditioning system, the building regulations should require a calculation of the energy needs for cooling and set a high limit for allowable cooling energy (or including it in some kind of other global energy target) for new buildings and major renovations.

This implies a new approach in building design, construction and operation phases, meaning that even if the financial cost is lower, hidden information, training or organizational costs may constitute a barrier to the fast adoption of these efficient practices. The same happens, on a more limited scale, at the level of cooling equipment choice, even when no radical changes in practices are required. Thus, summer comfort in buildings is a prime exponent of the existence of barriers to energy efficiency, which prevent or delay the adoption of the best practices in terms of economic rationality and social utility.

Under the Keep Cool II Project, the participating countries were involved in of two surveys, one centered on evaluating current practices in cooling design, construction and operation, The other survey was undertaken in order to review the energy efficiency criteria, in the national building codes, concerning summer comfort or mechanical cooling system, in order to elaborate recommendations towards a sustainable summer comfort.

2 SUSTAINABLE SUMMER COMFORT AND BARRIERS

The Keep Cool II Project aims to provide practical tools and recommendations to overcome barriers that differ phase to phase against the widespread penetration of sustainable summer comfort solutions.

In the redesign phase of the building process, decisions taken by developers, investors and financing institutions have a fundamental impact in the final result regarding the achievement (or not) of energy efficient solutions. As we will see when we formalize the different types of barriers at work, the investment decisions are affected by a mixture of information failures and misplaced incentives which effectively discourage, or at least do not encourage, the pursuit of energy efficiency.

For the developers, especially in office construction subsector, where most units are built for subsequent rent, decisions are affected by a fundamental bias to minimize the initial capital cost of investment per unit of net marketable floor space. Although net present value calculations are performed, the value of energy efficiency remains largely hidden, as operating costs tend by default to be borne by the tenants, in a typical illustration of the well-known landlord-tenant problem.

However, a more fundamental failure intervenes at an organizational level during the design phase. Building design is an example of a complex process in which many different actors, with different knowledge and objectives are set to work to respond to a common set of goals. The first need is therefore for these goals to be sufficiently well stated from the beginning, which reinforces the necessity for energy efficiency to become a top-of-agenda priority for both developers and prospective tenants.

The second step is to actually put in place the organizational conditions for a good collaboration of the diverse players towards the common goal. Left to him, each actor intervening in the process (architects, electrical engineers, mechanical engineers, air quality experts, etc.) will have a tendency to add safety margins to avoid liabilities. The multiplication of unnecessary safety margins is a typical example of a chain amplification of inefficiency, which is rendered even more intricate when, as is often the case, critical elements of the building load are not known when the building is first designed.

In addition to the complexity of the chronological organization of the design process, optimization requires to overcome another fundamental barrier to information flow, which is that each specialist speaks, in many ways, a "different language", not only in terms of his or her individual objectives and incentives, but more fundamentally in terms of units (heat, power, space, weight, money), constraints and knowledge base.

3 SURVEY FOR BARRIERS IDENTIFICTION AND MAIN RESULTS

Due to time constraints, several choices had to be made, regarding the target audience, the method (simple questionnaires or deep interviews) and the geographical scope of our survey.

As the Keep Cool II was designed to focus more on designers and practitioners of the summer comfort sector, the choice of deep interviews with key, knowledgeable professionals was made, with the intention of perhaps providing more nuanced views and insight into real practices as opposed to what "should be". The downside was that the final sample of interviews was more limited and did not permit a statistical treatment or the affirmation of quantitatively provable trends for each country. However, given the extremely subjective nature of some of the issues tackled, it is not certain that a wider sample could have been a guarantee of safety in attempting country-based generalizations.

The results, in terms of quantity and quality of information gained, vary greatly among the interviews, which partly depends on the availability and cooperation of the various interviewees to participate in rather long and detailed interviews. The professionals targeted in these interviews show a superior knowledge of what constitutes good practice, due to the fact that the professionals chosen represent some of the most experiences practitioners in their field. The consequence of this bias is that their own practices cannot be statistically or otherwise extrapolated to the whole population of their profession.

The questionnaire in the first section was divided in three parts, covering respectively practices in (1) design, (2) installation and (3) operation of cooling solutions today, *Richard et al* (2009).

3.1 *Ideal practice and actual practice*

Concerning the ideal practice and actual practice, the main interest of the deep interviews is that they enabled to discern the subtle issue of the difference between what people know is the best practice and what they or other colleagues actually apply in their everyday.

Concerning the actual versus ideal practice gap, the answers are clear: most interviewees admit that common practice is often greatly sub-optimal in the design and construction phases, and this is visible in the organization of the work, the role of the different participants, and the actual quality standards, affecting the efficiency of the final design in very basic but unfortunately powerful ways –often the same which Amory Lovins had identified 15 years ago, and which have been observed ever since.

Regarding the organization of the design process, the inclusion of a cooling system designer/planner and energy experts early in the process is recognized as desirable as but unfortunately less than systematic.

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3.2 *Rules of thumb*

One of the rare good news of these interviews is that the use of much-maligned rules of thumb to assist in the design process is not widespread within the interviewed sample. These rules of thumb for cooling systems, for instance, used to have a significant negative impact on efficiency, due to their antiquated nature (in a universe of fast-improving technology) or gross approximations amounting to excessive safety margins. It seems that commercial or academic software is now the essential tool used in calculations except for "smaller" projects, all professionals might not take the time to use these software tools).

Some effort may still be done to turn these tools more user-friendly and disseminated, but incentives are needed, be they in the form of pressure from the building owners or fee-based incentives, to push more professionals into performing up-to-date calculations.

Similarly, more incentives are needed to bring design professionals to systematically base calculations of cooling loads on the heat gains released by the actual equipment installed in the office, instead of data taken from reference tables and encouraged them to have a pro-active attitude aiming for the selection of energy-efficient solutions and equipment all through the process.

There is a large range of different perceptions for what would be the most appropriate way to reward HVAC professionals for a sustainable summer comfort design (see figure 1). However, it is possible to distinguish that among the interviewees, there is most common preference for the reward to be linked to energy savings obtained through "good design".

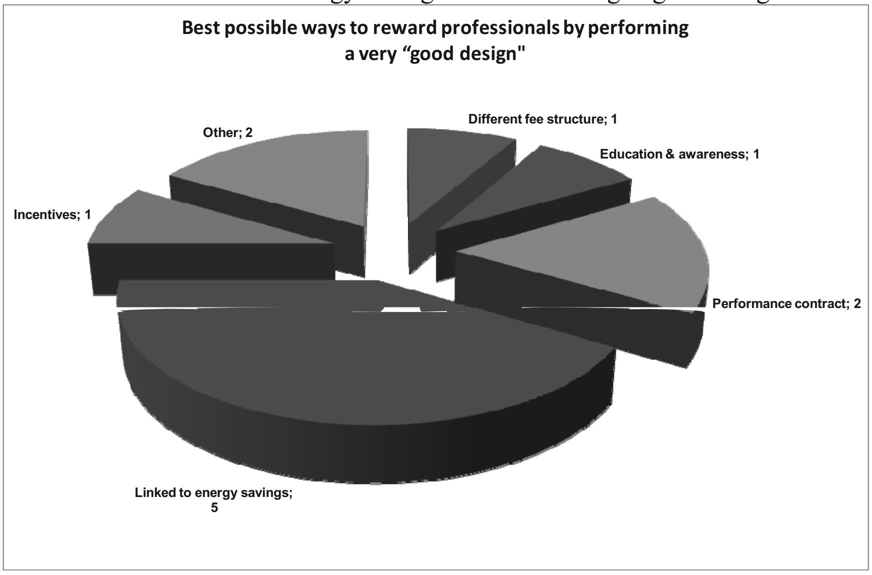

Figure 1. Perception of HVAC planners regarding best possible ways to reward "good design"

3.3 *Operation*

The operating managers of the buildings are a key group to target in future training and information actions, as their impact, for best or worse, may be of a higher order of magnitude than the simple installation of more or less efficient equipment (in buildings which do have active cooling systems).

Building codes and regulations refer to thermal comfort for the calculation of thermal cooling loads or cooling energy needs, but (perhaps understandably) do not set legally binding limits for the operation of the building, which may then well be outside the thermal comfort zone. Adaptive comfort criteria, in particular, shall be systematically promoted to this professional group in order to maximize the buildings' hybrid operation.

3.4 *Information on regulations*

Regulations, in the form of revised building codes, have recently come into force resulting from the transposition of the EPB Directive. They constitute one of the most powerful instruments to overcome deeply ingrained barriers amounting to bad practice, by effectively outlawing the worst practices and establishing guidelines for construction and renovation.

However, according to the interviewers opinion most of the new building codes are quite complex, and involve important costs in terms of time and effort in order to be fully assimilated. As a result, HVAC professionals are not totally familiar with new dispositions, which are visible in imprecise answers during the interviews, for example on cooling load limits.

The knowledge of the existing regulations is fundamental, and there is scope for improvement here. A review of the national building codes concerning envelope constructive solutions (opaque and transparent), thermal mass, ventilation rates, energy consumption methodology and correspondent values limits has been undertaken for the participating countries of the KeepCool II Project and the main results are presented.

4 SURVEY OF THE ENERGY EFFICIENCY CRITERIA AND NATIONAL BUILDING CODES

The building regulations have a major role in controlling and limiting the energy consumption of the building sector. The goal of this analysis consists on put in evidence the different strategies adopted and try to share and to supply information and experiences in so far as, the energy demand for cooling in Europe, *Gonçalves et al (2009)*.

The evaluation of the questionnaires reveals that the new building regulations were already adopted in all member states, following the Energy Performance Building Directive (EPBD), for new and existing residential and non-residential buildings, differing only on the starting date. The verification of the regulation requirements is usually before and after construction, in France only after construction, prior to sale, rental and/or use, while in Italy only at the planning stage. The role and the entities involved are quite similar: architects and engineers the energy calculations and the technical responsibility, builders the quality of construction works, insulation, installations, respecting materials and specifications of design engineers. Among the good practices, one should stress the need for verification after construction, especially in countries that only recently adopted building thermal and energy regulations, and underline that an entity responsible for the archiving for future statistical analyses.

4.1 *Energy consumption*

The prediction of the energy needs for cooling has already been calculated, in six of the eight countries of the Keep Cool II Project, based on the EN ISO 13790 standard (Ep<Epmax) and even, for Slovenia, when the energy use calculation for cooling can be done by a simplified method, the EN ISO 13790 can also be used as an option. Each country adopted one of the alternatives for the calculation of the cooling needs: monthly or seasonal method or a yearly hourly simulation procedure, with single zone or multizone options, based on simplified RC models for the building.

The survey was extended to other countries in order to a have a clearer perception of the state of the art around Europe. There are some countries in which summer and cooling needs are not a priority like Romania and Bulgaria while others like Norway, although having cold climate conditions are quite concerned with cooling needs inside offices and services and the standard for the energy demand calculation in buildings includes energy for cooling.

4.2 *Recommendations and requirements*

Mandatory U-Values – walls and roofs:

Among all countries of the Keep Cool II Project only Portugal manifests that cooling and heating seasons are both relevant the others the Winter.

The partners have already implemented requirements, differing and reflecting the building tradition and techniques. In all countries there exist requirements on the U-values and on the thermal mass of the building envelope. Six countries reported requirements concerning the U-values on both envelope elements. In Figure 2 are presented the wall and roof U-values requirements for some European countries

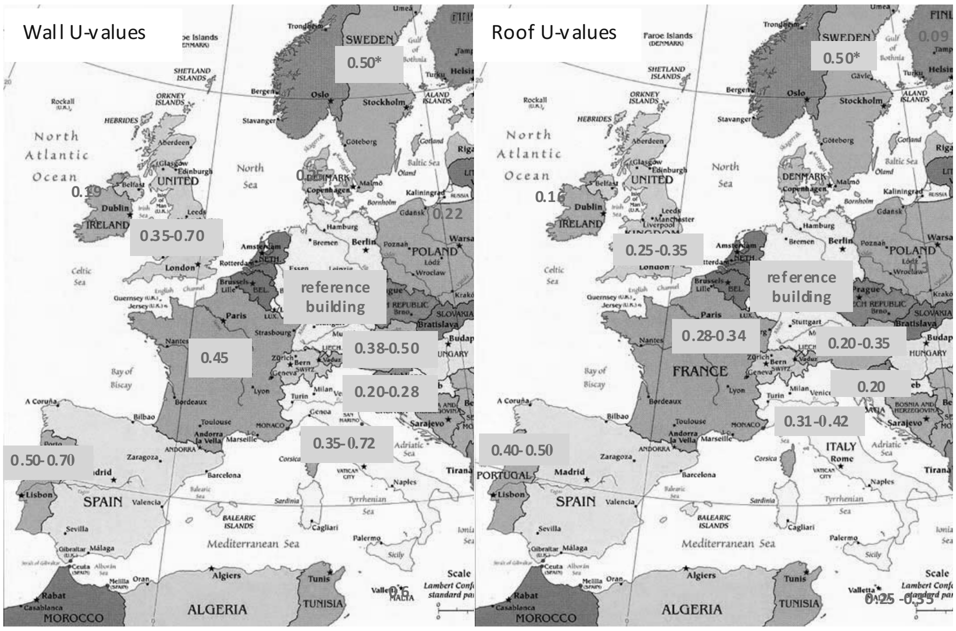

Figure 2. U-values requirements

Concerning the envelope quality each country should analyze if it is necessary to impose more restrictive requirements in terms of U-values of the opaque envelope elements. For instance, in its following revision, Portugal intends to adopt more restrictive U-values.

Requirements on windows, shading and strategies for solar heat dissipation and prevention:
Mandatory measures of shading devices in glazing façades are referred only by Portugal and Slovenia in an explicit manner (excluding only the north oriented windows).

For the solar heat prevention, the countries that don't have any requirements until now in their Building Regulations pointed out that they should implement measures such as: shading devices, glazing area and total area of the façade, glazing area per orientation.

For new buildings the glazing area per façade and orientation is recommendable in particular in combination with shading and that relationship should be included in the calculation methodology. Concerning the glazing areas the use of shading, for new buildings should be external and movable and take in account the external obstructions, and minimum requirements should also be implemented based on the $g_{\perp}$-values combined with glazing area. So, at least for new buildings it should be recommendable to implement shading factors for shading systems in connection with glazing area/orientation.

The limitation of a totally glazed transparent envelope as a solar heat prevention strategy should be established, for the different countries, based on extensive simulation studies to avoid an increase of the heating energy demands and the penalization of day lighting strategies.

Concerning heat dissipation strategies, for all types of buildings natural ventilation is always mentioned as a measure to be adopted and, whenever natural ventilation is not sufficient, then the integration of a mechanical ventilation system is recommended. Concerning dissipation strategies the only countries that do not refer to any strategy are Slovenia and Sweden. Other countries mention the natural ventilation (night ventilation) and France the earth as cooling source while Germany expressly manifested that is not taken in account.

Regarding the use of passive systems it is necessary to investigate what strategy or strategies should be included in the building regulation according the climate conditions, such as: diurnal thermal amplitudes to evaluate the night ventilation potential cooling; solar radiation intensity to adequate glazing areas and orientation as well as shading strategies without penalizing the natural light and the heating season; use of passive systems, namely the earth, as a cooling source should be investigated and the use of air conditioning systems should be avoided.

Natural ventilation for the new buildings must be always adopted and, if not possible, hybrid solutions should be recommended before opting for mechanical or AC systems but to ensure night ventilation safety demands against storms and burglary are also necessary.

From the answers it is clear that those aspects should be introduced in the building regulations.

4.3 *Summer comfort*

The survey pointed out an enormous consensus for summer comfort to be explicitly introduced in the building regulations for all type of buildings and also that summer comfort calculations should be required. Checking the indoor temperatures and standards should also be explicitly introduced. From the answers, the following comfort calculations can be followed by other countries.

Summer comfort should be introduced in the building regulation for all types of buildings adopting or standards should be explicitly introduced in the building regulation. The EN 15251 – "Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics", the adaptive thermal comfort model should be used for building design to prevent overheating, using solar shading or decreasing window size, increasing thermal capacity of the building or adopting operable windows to promote cross ventilation.

5 FINAL REMARKS

Building regulations should require the adoption of at least the most sensible passive cooling techniques, namely gain avoidance measures such as efficient shading, day lighting optimization, free-cooling whenever possible, etc. Efficient lighting systems should become a major priority.

The adaptation of passive systems must be checked and if realizable, the employment of mechanical cooling systems should always be avoided and only used if it is demonstrated that the passive solar measures (solar heat attenuation and heat dissipation) and the passive cooling systems (ground tubes, natural ventilation devices, etc...) do not guarantee pleasant thermal internal comfort conditions.

Each country should be encouraged to apply mandatory passive requirements for summer but not in a uniform way all over Europe. The requirements on the elements on the building design should be integrated in the building construction according to the climate conditions of each region. In colder areas the mechanical cooling equipments should always be replaced by good design requirements based on architectural solutions. To reduce the cooling consumption further measures can also be adopted selecting efficient electric lighting and equipment and in this way reducing the internal gains. At least for the new buildings cooling energy and summer comfort calculations should be included as well as maximum legal values for primary energy for cooling.

In particular, the energy certification of buildings, generalized in the EU by the EPB Directive, is one of the most powerful axes of action, not only by obliging all actors (developers, financiers, but also commercial appraisers, and of course users) to acknowledge energy efficiency as an objective, but also by constituting a "visible" basis for the internalization of the efficiency value of buildings in their commercial value, i.e. for example in the rents owners will be in a position to demand.

A note is necessary on the issue of renovation, which constitutes a key window of opportunity to increase the efficiency of summer comfort solutions, and which arguably represents a more important target (in terms of sheer market size) than new construction. Practices in renovation are not necessarily similar to those in new construction, if only because the scope of possible options is more reduced, especially for passive summer comfort.

As it is, this specific question deserves to be investigated in more detail in the near future: efficiently refurbishing the existing built residential and office environment is indeed the major and most urgent challenge in stationary (non-transport) energy efficiency policy. It takes particular relevance in relation to cooling, as owners and users of buildings often still choose solutions, when renovating, concentrating excessively on winter comfort, leading to excess cooling needs and insufficient attention to efficient summer comfort solutions.

Informative campaigns on passive cooling, for households and for building managers and users, should be undertaken in order to prevent overheating and to reduce mechanical cooling devices.

The adoption and use of passive systems must always be checked out and their contribution should be incorporated in the building regulation in order to achieve sustainable summer comfort. On the other end, the national building regulations should also have more exigent limit values of the cooling energy demands.

The increase of the use of air conditioning systems in Europe leads to considerable problems at peak load times, increasing the cost of electricity and disrupting the energy balance in the European countries. According to the recommendations of the European Parliament "priority should be given to strategies which enhance the thermal performance of buildings during the summer period. To that end, there should be further development of passive cooling techniques, primarily those that improve indoor climatic conditions and the micro-climate around buildings".

The general conclusion of this limited survey, beyond the obvious need for ever wider information (and particularly knowledge of existing regulations), is that the main failures are organizational and motivation-based: actors may know how to maximize efficiency, but time and complexity constraints end up in sub-optimal practices a significant part of the time

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Richard, M., Laia, C,, Geißegger, G., Jetzinger, F., Holanek, N., (2009) Keep Cool II - Work Package 2: Barriers against sustainable summer comfort. Deliverable 2.1 Rules and Practices in Building Design and Operation

Exigências de Sustentabilidade dos Materiais de Construção na Documentação Técnica de Obras

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ABSTRACT: A indústria da construção tem um impacto inegável aos níveis económico, social e ambiental, precisando de incorporar e assimilar melhor as preocupações de sustentabilidade. Existem já diversas ferramentas e métodos de avaliação da sustentabilidade do edificado, mas a objectivação técnica da informação processada constitui um grande desafio. O quadro normativo internacional (ISO/CEN) procura contribuir para a estabilização de metodologias e bases de dados, estando diversas normas em discussão e desenvolvimento. Nesta comunicação mostra-se, a partir do panorama normativo, como a informação das fichas ambientais dos materiais (EPD do tipo III) poderá ser utilizada para aferir o impacto ambiental de um empreendimento. Discute-se o modo como projectistas e empreiteiros poderão recorrer às mesmas em projecto e obra. Propõe-se que as preocupações de sustentabilidade ambiental sejam evidenciadas numa memória descritiva de sustentabilidade associada aos projectos e cadernos de encargos, com ênfase no desempenho e impacte do ciclo de vida dos materiais utilizados.

1 INTRODUÇÃO

A partir da segunda metade do século XX a construção sofreu uma rotura com o conjunto de valores nos quais se tinha alicerçado. Passamos de soluções regionais, condicionadas pela geografia, climas e materiais locais, para edifícios mais complexos, como consequência do aumento de exigências às quais o edificado teve e tem que dar resposta. Este processo evolutivo deu-se sem uma verdadeira consciência dos impactes desta actividade industrializada no planeta e na vida das populações (Duarte, 2009; Sousa, 2009).

O sector da construção é hoje em dia um dos principais consumidores de matérias-primas, produzindo resíduos e edifícios que são grandes consumidores de energia, contribuindo para o desequilíbrio entre o consumo e a capacidade regenerativa do planeta (Hegger et al, 2008). Parece assim indispensável que o sector adopte uma nova atitude (Fig. 1).

A esta nova perspectiva pode dar-se o nome de construção sustentável, conceito este que visa agregar todo um conjunto de valores e atitudes com o intuito de tornar o sector menos agressivo para o ambiente, tanto ao nível de consumo inconsequente de recursos, como das emissões de poluentes (Pinheiro, 2006). Pode-se desta forma melhorar a qualidade de vida dos utentes e do espaço onde as construções se inserem.

A incorporação destas preocupações no sector equivale a introduzir um olhar de sustentabilidade na actividade, complementando-se assim o triângulo tradicional do sector - custos, qualidade, tempo (Fig.2) (Pinheiro, 2006; Duarte, 2009).

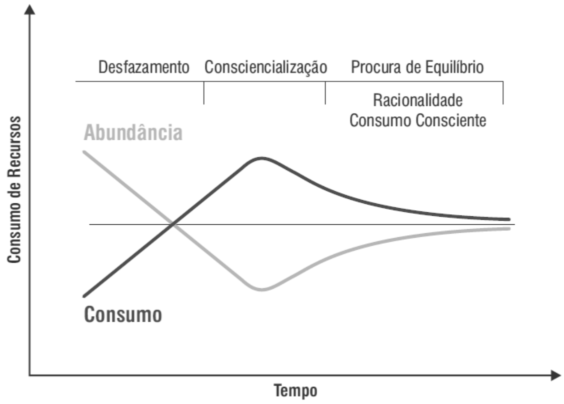

Figura 1. Mudança de atitude e procura de equilíbrio (Duarte, 2009).

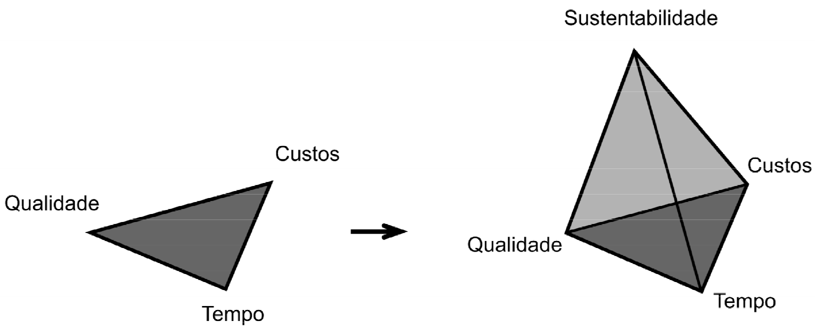

Figura 2. Representação do novo paradigma de construção sustentável (Duarte, 2009).

2 EDIFÍCIOS: ENERGIA, MATERIAIS E COMPONENTES

Apesar de serem um bem abundante, os edifícios são activos importantes e grandes consumidores de recursos, sendo da responsabilidade de quem os projecta, constrói, usa e mantém assegurar as suas funções primordiais ao longo do tempo, como a utilidade, a segurança, estrutural e no uso, o conforto, a durabilidade e também a sua eficiência energética (Hegger et al, 2008).

Em cada fase da sua vida os edifícios consomem energia e outros recursos, desde o projecto e construção, passando pela operação, até à sua demolição final. Em cada uma dessas fases consomem-se diferentes quantidades de energia e emitem-se diferentes quantidades de poluentes. No seu período de vida um edifício é também sujeito a manutenção, remodelações, ampliações e é finalmente demolido, sendo o uso/consumo de energia durante as diferentes fases significativamente influenciado pelo modo como o edifício foi concebido, construído, e usado (Ding, 2004).

Uma análise energética ao longo do ciclo de vida de um edifício envolve um estudo das necessidades energéticas do mesmo, assim como do respectivo impacte ambiental. A análise inclui tanto a energia requerida para a sua construção, como a energia utilizada durante a ocupação, manutenção, renovação e eventual demolição (Graham, 2003; Ding, 2004). Podem distinguir-se duas categorias principais do uso de energia num edifício (Fig. 3).

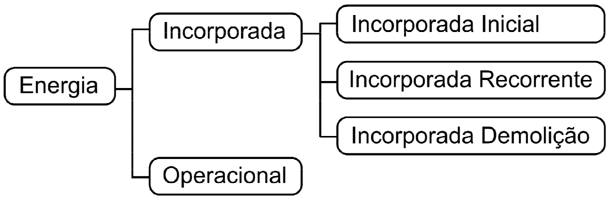

Figura 3. Categorias do uso da energia nas construções. Adaptado de (Ding, 2004).

A energia incorporada engloba a energia presente na produção de materiais, utilizada na construção, a energia que advém da substituição de materiais e das intervenções subsequentes, e finalmente a parcela respeitante ao fim de vida (Ding, 2004; Hegger et al, 2008).

O uso operacional da energia tem início aquando do princípio da utilização, continuando até que o edifício atinja o seu fim de vida.

A parcela de energia incorporada terá tendência a ganhar terreno, à medida que os edifícios se tornam energeticamente mais eficientes.

Antes de abordar as questões mais específicas da sustentabilidade dos materiais de construção, é importante entender as suas funções no edificado (Fig. 4), pois só deste modo é possível tomar de forma consciente as decisões necessárias à sua escolha, dado que os materiais têm que dar resposta a uma série de requisitos mais ou menos objectivos.

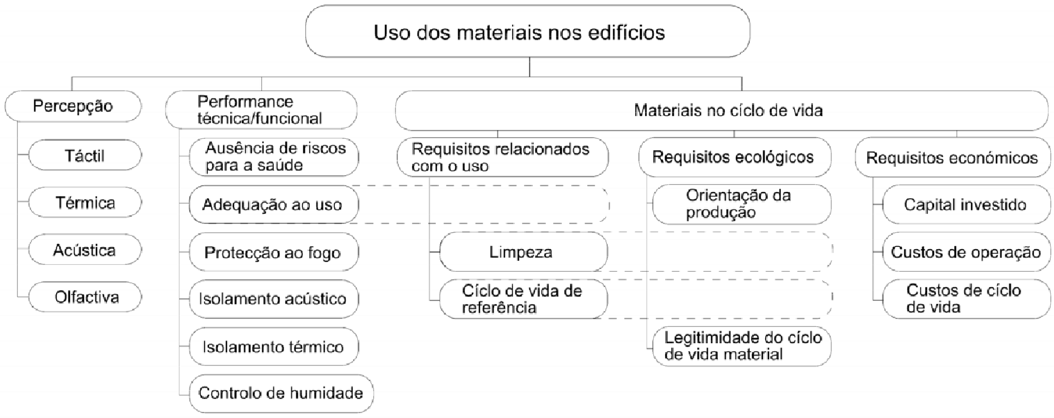

Figura 4. Aspectos relativos à selecção de materiais. Adaptado de (Hegger et al, 2008).

Para uma análise de sustentabilidade do edificado, é indispensável ter presente o seu ciclo de vida, e também as parcelas que o constituem – os materiais e componentes (Figs. 5, 6).

Os materiais são muitas vezes compostos por diferentes tipos de matérias-primas, repartindo-se por essas matérias-primas os seus impactes a nível de *input* energético, de desempenho, de consumo de recursos materiais e de emissões de poluentes (Graham, 2003).

Figura 5. Desenvolvimento da análise de ciclo de vida das construções (Graham, 2003; Duarte, 2009).

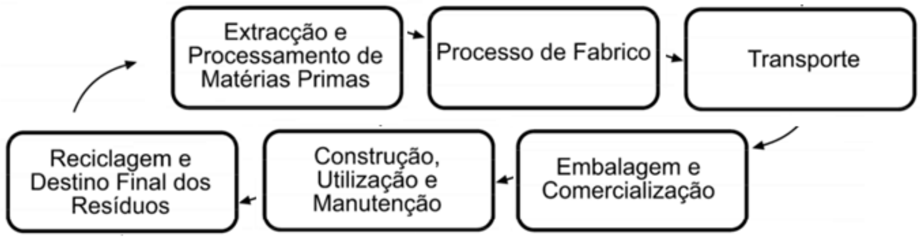

Figura 6. Fases do ciclo de vida dos materiais/componentes. Adaptado de (Bragança & Mateus, 2006).

A metodologia de análise de ciclo de vida (ACV) está preconizada na série de normas ISO 14000 e é uma ferramenta usada na avaliação do impacto ambiental ao longo da vida de um produto, processo ou actividade, com o objectivo de permitir a selecção de materiais tendo em conta o seu perfil ambiental. Esta considera todo o ciclo de vida de um produto (Graham, 2003; Ding, 2004; ISO 14041, 1998).

3 AS ETIQUETAS/RÓTULOS AMBIENTAIS DOS MATERIAIS DE CONSTRUÇÃO

As declarações ambientais de produto (EPD - Environmental Product Declaration) são etiquetas que visam comunicar ao consumidor a carga ambiental de um produto, segundo categorias pré-definidas de parâmetros baseadas num estudo ACV, podendo as fichas incluir outra informação adicional, sendo uma ferramenta estandardizada de comunicação voluntária (Lee & Park, 2001; ISO 21930, 2007).

As declarações ambientais do tipo III são as definidas como as aplicáveis aos produtos da construção (ISO 14025, 1998) (Fig. 7), sendo que os requisitos para todos os produtos de construção são especificados em concordância com as normas internacionais ISO 21930 e ISO 14025 (CEN/TC 350/WG3 N 79, 2007).

Quadro 1 - Tipos de etiquetas, normas ISO aplicáveis e segmentos de mercado alvo. Adaptado de (Lee & Park, 2001).

Etiquetas	Norma ISO	Segmento de mercado alvo
tipo I	ISO 14024	Consumidores ao nível do retalho
tipo II	ISO 14024	Consumidores ao nível do retalho
tipo III	ISO 14025	Consumidores ao nível do retalho e indústria

Genericamente, as declarações ambientais de produto, embora sejam diferentes de fabricante para fabricante, contêm informação acerca de emissões, consumo de recursos e desempenho (Duarte, 2009).

Embora estes documentos sejam ainda escassos, uma análise de alguns disponíveis permite verificar que existe uma necessidade de padronizar o formato destas mesmas comunicações, de modo a que contenham informação discriminada por categorias de impacte dos produtos, minimizando a informação de carácter subjectivo e comercial. Diferentes empresas deverão ser capazes de disponibilizar informação de modo a que os diferentes produtos pertencentes a uma mesma categoria possam ser comparados de forma objectiva, sem interferências comerciais. Além disso não estão ainda definidas categorias de produto para muitos materiais de construção como se pode observar no documento CEN/TC 350/WG3 N 79 de 2007 (Duarte, 2009; Sousa, 2009).

4 A INTEGRAÇÃO DAS EXIGÊNCIAS DE SUSTENTABILIDADE DOS MATERIAIS DE CONSTRUÇÃO NA DOCUMENTAÇÃO TÉCNICA DE OBRAS

Defende-se que informação sobre as características dos materiais escolhidos em projecto ao nível da sua sustentabilidade integre a documentação técnica de projecto a concurso, e haja a garantia que na execução dos trabalhos a entidade executante respeita essa especificação e aplica materiais que correspondam a essas exigências (Duarte, 2009).

A metodologia deverá ser aplicada aos materiais mais representativos de um edifício, de modo a concentrar esforços em melhorias com impacte e escala, sem acréscimo de trabalho de projecto significativo. Seleccionados os grupos de materiais genéricos com maior representatividade no edifício (Fig. 7), dever-se-á procurar coligir informação sobre hipotéticos materiais concretos candidatos a cada função.

A informação utilizada para a atribuição de uma classificação a um material ou produto deverá ser a proveniente das EPD. Esta informação deverá ser facilmente organizada pelos projectistas a partir das EPD fornecidas pelos fabricantes.

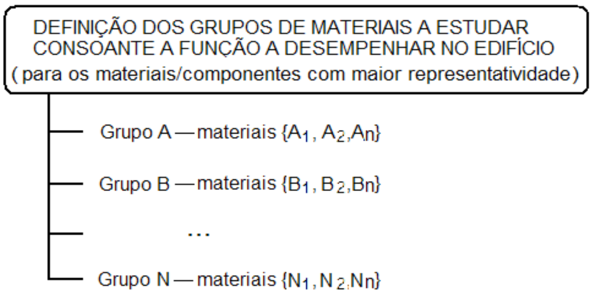

Figura 7. Grupos de materiais/componentes candidatos a uma dada função (Duarte, 2009).

A metodologia deve incluir a possibilidade de ponderar a importância do material segundo um ou vários pontos de vista. Da agregação pesada das pontuações dos materiais mais representativos será possível chegar a um ou mais indicadores da construção como um todo, permitindo aferir a avaliação global da sustentabilidade do edifício ao nível dos materiais que o constituem (Fig. 8).

Tal como uma memória descritiva de um projecto incorpora a justificação das evidências de satisfação das diversas exigências aplicáveis à obra, propõe-se que esta incorpore também justificações ligadas à sustentabilidade (ao nível da escolha dos materiais), na qual se evidencie as opções tomadas a respeito do desempenho ambiental dos produtos e soluções que prescreve. A informação sobre a sustentabilidade das soluções deverá ser elaborada a partir da especificação dos materiais, pelo que as EPD são fundamentais para essa função, embora neste momento estas sejam ainda muito escassas.

Na fase de concurso deverá ser exigido que o empreiteiro integre na informação da proposta evidências de como se propõe dar resposta às exigências de projecto segundo este ponto de vista, (Fig. 9).

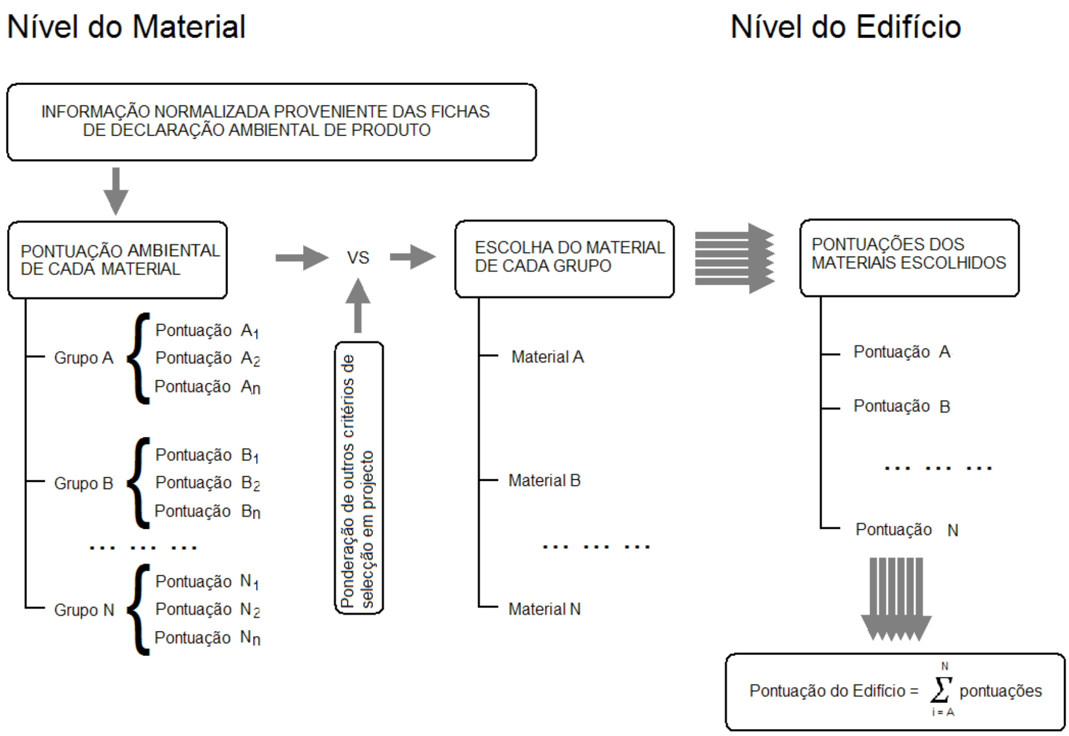

Figura 8. Funcionamento global da metodologia proposta (Duarte, 2009).

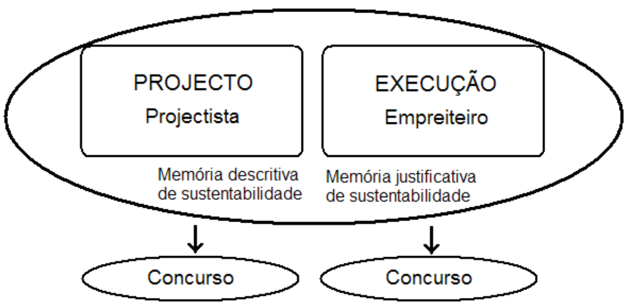

Figura 9. Entidades responsáveis pela aplicação das preocupações de sustentabilidade ao nível dos materiais/componentes na construção (Duarte, 2009).

A equipa projectista, neste processo de selecção, deverá recorrer às EPD do Tipo III de cada produto, e com base na análise e ponderação dessa mesma informação (de carácter ambiental) e dos restantes critérios que determinam as escolhas em projecto (como custos, durabilidade, estética, entre outras), proceder à escolha devidamente justificada segundo um formato padronizado, (Fig. 10).

Quer na fase de concurso, quer na de execução da empreitada, cada entidade executante deverá assegurar, através de comprovativo, que as alterações de materiais e componentes propostas, cumprem, no mínimo, os requisitos de sustentabilidade prescritos, (Fig. 11).

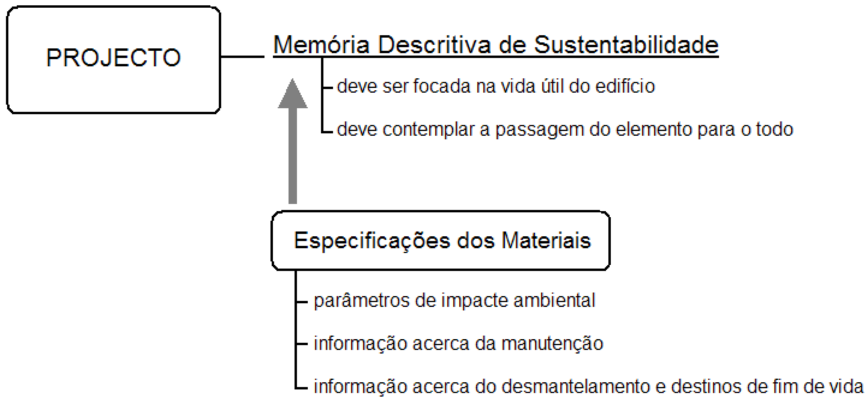

Figura 70. Papel do projectista na incorporação das preocupações de sustentabilidade dos materiais / componentes de construção (Duarte, 2009).

Seria interessante a existência de um plano normalizado de verificação de conformidade da adequação dos processos construtivos aos requisitos de minoração de restantes impactes ambientais. No entanto, a certificação de empresas segundo as normas ISO 14000 será à partida um indicador de que a empresa promove e incorpora boas práticas ambientais no processo construtivo.

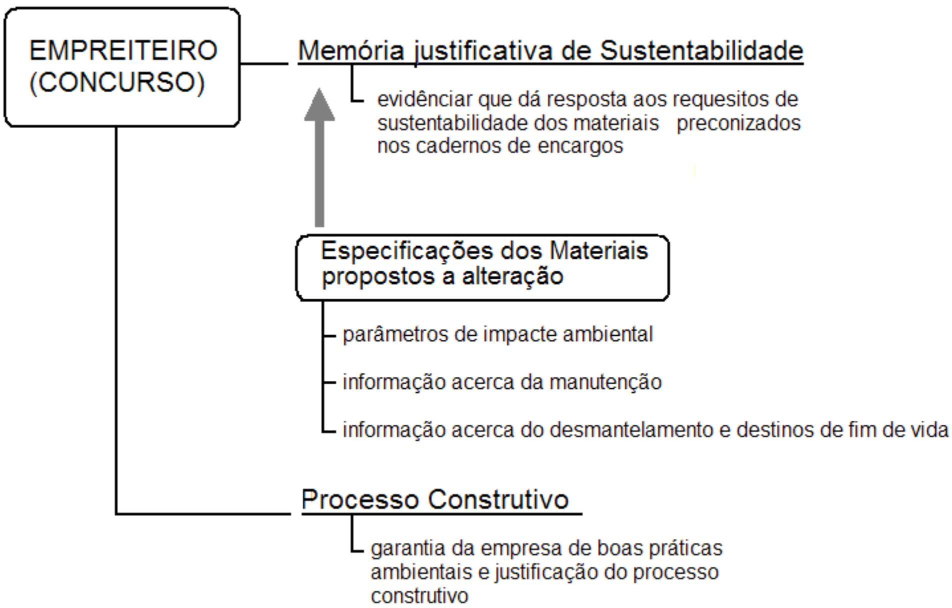

Figura 81. Papel da entidade executante na garantia da incorporação das preocupações de sustentabilidade dos materiais/componentes na construção (Duarte, 2009).

5 CONCLUSÕES

A análise do ciclo de vida das construções e dos materiais incorporados nas mesmas é fundamental na concretização das preocupações de sustentabilidade aplicadas à construção. Para tal é necessário um conhecimento da importância no desempenho dos diversos componentes do edifício, para definir medidas de sustentabilidade que tenham impacto, especialmente ao darem-se os primeiros passos nesta matéria.

As declarações ambientais de produto são um instrumento importante para o sector, no registo e comunicação da informação ambiental de materiais e componentes. A elaboração das fichas EPD do Tipo III depende da informação proveniente das ACV, processo este que deverá tornar-se mais transparente e de mais fácil aplicação e compreensão, à medida que a normalização avance nesse mesmo sentido.

Cabe aos fabricantes a missão de incorporar as preocupações de sustentabilidade ambiental e energética na concepção e fabrico dos seus produtos e explicitar essa informação. Cabe aos projectistas a selecção dos materiais e componentes com base na informação funcional, de custo ao longo da vida, e de impacte energético e ambiental, tendo em mente as implicações futuras das escolhas efectuadas. Para tal, é muito importante que se procure disponibilizar informação fidedigna e padronizada para os produtos, de modo a que estes possam ser estudados e comparados numa perspectiva do seu impacte ambiental.

Por fim refira-se que vivemos um período de clarificação de princípios e conceitos, que apenas quando aprofundados e melhor adaptados vão permitir a sua aplicação técnica de acordo com regras bem sedimentadas e estabilizadas. Até lá, vão predominar abordagens relativamente qualitativas e também tentativas de usar a sustentabilidade apenas como argumento de *marketing*.

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High-performance solutions for refurbishment of retail buildings - Retailers review

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ABSTRACT: Retail buildings are responsible for up to 20% of the energy consumption in the commercial sector which makes them an important focus for the implementation of high-performance building solutions. This is furthermore important in the refurbishment of existing buildings, as new construction has a greater environmental impact that needs to be restrained.
This paper analyses what retail companies - like Wal-Mart, Carrefour, Metro AG - are doing to increase sustainability in their buildings and presents a case study of the solutions used in refurbishing a store.
Lessons learned from retailers can be a contribution as they can usually be adapted by their peers or by other commercial buildings, provide opportunity for the optimization and affordability of new technologies and have a broaden influence not only on the upstream construction industry but also on Society, as the retail sector is becoming the greatest potential purveyor of culture.

1 INTRODUCTION

1.1 *The use of high-performance solutions in commercial buildings: Retailers review*

Retail companies are in a key position to improve and promote the use of high-performance solutions in commercial buildings' refurbishment, reducing the use of natural resources and operational costs. This paper is a literature review on what retailers are doing to improve sustainability in their buildings, focused on refurbishment and the affordability of existing solutions.

1.2 *The importance of retrofitting in existing buildings*

If commercial buildings have a life span of at least 50 years, then structural changes should occur in the role that these buildings play in renovation. It is fundamental for urban cohesion that new construction is restricted as to not contaminate soil with bearing capacity, contain the phenomena of urban sprawl and provide the urban density necessary for the viability of optimized common infrastructures, such as public transportation or improved energy grids (EBI, 2005).

Also construction materials, by weight, account for between 30 and 50% of all material flows in the economy and 44% of all waste going to landfill. Refurbishment allows reducing the use of natural resources and construction waste, having into consideration the high percentage of energy contained in construction materials and rehabilitating the existing materials in a building or recycling those that need to be replaced.

Retail is likely to be the most ecologically intensive segment of the commercial buildings sector regarding energy consumption and contributing to problems such as urban transportation and consumer waste (Centre for Design at RMIT - Planet One Sustainability Strategies, 2003).

2 SUSTAINABLE PRACTICE

2.1 *Best practice examples of high-performance solutions in retailer buildings refurbishment*

The larger multinational retail companies analyzed in this paper - Target, Wal-Mart, Metro AG, Whole Foods, Tesco and Carrefour - were selected for their market presence and accountability index, according to Fortune (Magazine CNN - Cable News Network, 2008). These companies are introducing better environmental performance solutions when refurbishing their buildings, mainly in the areas of energy consumption, water use, refrigeration and HVAC systems and sustainable design and construction, as systematized in Table 1 (Carrefour SA, 2007, Metro Group, 2007, Target Corporation, 2008, Tesco, 2007, Wal-Mart Stores, Inc., 2008, Whole Foods Market, 2008). One important question is whether this search of better environmental performance supports high-performance and affordable solutions.

Table 1. High performance solutions used by retailers

Energy consumption	Target	Wal-Mart	Metro AG	Whole Foods	Tesco	Carrefour
Passive solar energy	●	●	●	●		●
Photovoltaic technology	●		●	●	●	●
Wind energy	●					
Green energy *	●		●	●		
Fuel cells	●					
Geothermal energy			●			
Energy efficiency equipment:			●			
LEDs	●	●	●		●	●
Fan inverter drives					●	
Combined heat and power					●	
Daylight harvesting	●	●				
Munters dehumidification system		●				
Waste heat for hot water			●			
Glass covers for frozen cabinets			●			●
Walk-in freezer rooms			●			
Wake-on-LAN technology **			●			
Solar chilling			●			
Motion sensor lighting	●					
Water use						
Water efficiency equipment:						
High efficiency faucets		●	●		●	●
Waterless urinals		●				
Water recycling						
Rainwater harvesting	●				●	●
Low Impact Development	●					●
Refrigeration and HVAC systems						
Ammonia based refrigeration			●			
Gas transfer to CO_2		●	●		●	
Water source format heating, cooling and refrigeration system		●				
Secondary loop refrigeration system		●				
Sustainable Design and Construction						
Brownfield redevelopment	●		●			●
Construction and demolition waste management	●	●	●	●		●
Recycled construction materials	●	●				●
Sustainable design						
Reflective white membrane roofs	●	●				
Use of indigenous plants	●	●				
Energy management	●	●	●		●	●
Water management	●					●
Building commissioning	●					

*Energy offsetting. ** Technology used in computer systems.

2.2 *Corporate social responsibility and environmental performance in retail companies*

Business corporations are now more receptive to sustainability, as companies recognize they can not dissociate the profit obtained from the environmental and human capital that has created it. This change in business paradigm is known as the "Triple Bottom Line", and is based on the triptych people, planet and profit as a guiding principle for business operation (Elkington, 2000).

Investors are attracted to sustainability for its superior risk-return profiles and also because sustainability stands for informed and disciplined management (Centre for Design at RMIT, 2003).

The corporate social responsibility of most retail companies addresses the topics of supply chain and products, environment, employees, and social commitment. Adopting environmentally responsible policies and actions improves efficiency, lowers costs, improves productivity, attracts customers, and increases sales (Evans et al., 2006).

2.3 *Policy of action in retail companies to increase sustainability in their buildings*

Many commercial building projects are considered as investments that should earn an interesting rate of return with low financial risks. The design process is thus subjected to a rigorous financial discipline that attempts to ensure adequate performance at the lowest possible construction cost. Although some commercial building designs pursue high performance solutions and tolerate slightly higher initial construction costs, for most retailers this is not the case. However, higher performance takes the form of a better users experience and lower operating costs, both of which add value from a life-cycle cost perspective (Andrews et al., 2008).

2.4 *The decision process in refurbishing retailers' existing buildings*

Capital providers are very concerned about the risk and return equation, which often makes them consider only a short time period in the decision process (WBCSD, 2008).

Developers are the primary players in commercial construction and can be speculative, which frequently results in a short-term perspective on the buildings' financial value. Speculative developers will typically be interested in energy efficiency only if it is a significant factor in the buying decision. On the other hand, developers who rent the property to tenants have a longer term view, which may make energy-saving investments more attractive. Even though, developers may not be able to reap the benefits of such investments, as energy cost savings favor the occupier. This weakens the incentive for energy efficiency investments.

Owners that occupy their buildings are most likely to consider investments that may have paybacks over several years.

Whichever is the circumstance, too much importance is placed on the initial investment required, rather than on life-cycle cost assessments and return-on-investment calculations.

Many retailers are owner-occupiers and in fact they are in the best position to make long-term investment decisions about their buildings. They will tend to have a longer term perspective and stand to benefit directly from energy savings. This applies both to new buildings and the refurbishment of existing ones (WBCSD, 2008). However, the limited mandate time of a board of administration in a retail company (usually 3 to 4 years) contributes to a greater focus and attraction on the short-term payback of the investments especially for refurbishments, thus limiting the range of high-performance solutions to be considered for the buildings they use.

The main reasons for using high-performance solutions in building projects are perceived to be long-term economic benefits, the availability of subsidies, image benefits, the desire to reduce environmental impacts, and because of corporate social responsibility. On the other hand, the most common barriers to using high-performance solutions are perceived to be high capital costs and long payback times, ignorance and lack of understanding, a perception of risk and that high-performance solutions are unproven, an incoherent policy, and planning constraints.

The decision-making process is thus influenced by financial aspects, but also qualitative and personal factors related ton the perceived 'values' of the retailer. It is clear that the existing approaches to decision-making are not universal and there is little experience of using approaches that take into account qualitative and quantitative considerations in an organized manner that can be adapted to by most retailers (Cooke et al., 2007).

2.5 *Influence in the construction industry and in Society's behavior*

Retail is a diverse but highly concentrated industry in terms of ownership and sales and is composed by a very large number of participants. This level of concentration allows for easier communication of best practices and environmental information to the players in the industry that control the majority of space, sales and employees (Evans et al., 2006).

Due to the similarities between the companies, the lessons learned and technologies used in a company are often easily transferred to competitors or other commercial units. In addition, the retail sector is strategically positioned in the construction industry and can influence the supply stream of materials used in this sector (U.S. Department of Energy - Energy Efficiency and Renewable Energy, 2008)

Because of its broad reach, the retail sector has the potential to affect society in a way that not many other industries can. Corporately, retailers can define environmentally-oriented purchasing requirements and, at the store level, they can educate consumers. Retail controls and acts as the gatekeeper for the goods and services consumers are offered and, as such, it has the ability to influence behavior and consumption patterns (Evans et al., 2006).

3 PRATICAL APLLICATIONS

3.1 *Solutions and optimization of solutions*

Below examples of improving performance solutions that can be successfully used in the retrofitting of existing commercial buildings are presented:

- New developments in illumination, heating and cooling technologies for energy-efficient buildings (Roberts, 2008):
- Higher level of insulation and high-performance windows;
- More efficient heating and cooling equipment, lighting and appliances;
- Sustainable energy;
- Vacuum insulation panels (VIPs);
- Multi-foil insulation;
- Insulating paints;
- Triple glazing;
- Vacuum glazing;
- Aerogel as a replacement material for windows.
- Energy-efficient architectural designs (Roberts, 2008):
- Sun-facing glazing;
- Sunshades and deflectors, fixed or movable overhangs and blinds;
- Shingled glass facades;
- Motorized louvers and awnings;
- Light shelves that reflect sunlight onto the ceiling and bounce it back deep into the room;
- Ventilated rain screen systems or rendered insulation systems;
- Green roofs.
- Smart windows (Andrews & Krogman, 2008):
- Electro-chromic and thermal-chromic windows;
- Window treatments: tinted window glass, reflective window glass;
- External overhangs or awnings;

- Skylights or atriums.
- Illumination (Andrews & Krogman, 2008):
- Sensors to adjust the window shade position in accordance with the angle of the sun's rays;
- Sensors and programmed light control systems to automatically dim or turn off the light;
- Lamps or luminaries of better energy efficiency such as fluorescent light tubes and CFLs (Compact Fluorescent Lamps), T5 tubes, LEDs (Light-Emitting Diodes);
- Solar tubes;
- Day-lighting;
- Day-lighting sensors;
- Specular reflectors;
- Electronic ballasts;
- Control systems for lighting.
- Efficient heating and air-conditioning systems (Andrews & Krogman, 2008, Roberts, 2008):
- Micro CHP system;
- Heat pipes;
- Variable-air-volume (VAV) systems;
- Economizer cycles;
- Energy management and control systems (EMCS);
- Time-clock thermostats and manually-reset thermostats;
- Economizers in conjunction with energy recovery ventilators;
- Evaporative cooling systems in dry climates and design natural ventilation;
- Hot-water production through renewable or regenerative sources (solar, heat pumps or waste heat).
- Cascade solar energy systems (Han et al., 2009):
- Energy-conversion systems including photovoltaic, thermionic, and thermoelectric devices;
- Heat engines (Stirling engines or steam or gas turbines);
- Wind turbines (grid-connected, stand-alone, and hybrid systems).
- Innovative designs of building envelopes and construction modules (Han et al., 2009):
- Soap bubbles for building insulation;
- Absorption cooling;
- Combined heat engine/vapor-compression system;
- Desiccant cooling.
- Water efficiency (Roberts, 2008):
- Low- flow taps and showers;
- Water-efficient appliances;
- Variable and low flush toilets;
- Waterless urinals.
- Building operation (Roberts, 2008, Torcellini et al., 2006):
- Whole-building design process to design, construct, and operate future low-energy buildings;
- Post-occupancy energy performance evaluation;
- Measurement procedures;
- Demand-responsive controls that integrate on-site storage, day-lighting, and energy production to reduce peak demand charges and increase load factors;
- Simpler systems with greater opportunities for users to intervene.

3.2 *Lessons learned by retailers and applicability to other commercial buildings*

According to the REA - Retailer Energy Alliance (2008), the retail sector can embrace and broadcast certain energy-efficient and renewable energy strategies, as retailers build many buildings with the same basic layout in the search for optimal solutions and building cost decrease (U.S. Department of Energy - Energy Efficiency and Renewable Energy, 2008).

Even though every commercial building is unique, it is possible to replicate the lessons learned from retailers to other commercial buildings, helping to define a set of best practices that can be applied either in the new construction or in the retrofitting of existing buildings. Understanding success and opportunities in the current generation of greener buildings can improve the environmental performance of all commercial buildings (Torcellini et al., 2006).

It is a fact that retailers are making efforts to achieve better environmental performance, especially through energy savings. However, achieving the higher environmental performance typical of a low energy or net zero energy building is still far from retailers' possibilities, mostly for return on investment reasons.

4 SUSTAINABLE AFFORDABILITY

It is consensual for most of retailers that energy is the top priority when introducing environmentally friendly high-performance solutions in their buildings, largely because of the potentially high cost savings and also because they are easy to install and operate. The following other priorities mentioned by retailers were: lighting, refrigeration, heating, ventilation, and air conditioning (Evans et al., 2006).

Technologies used in commercial buildings must demonstrate some relative advantage, usually by being less costly or delivering higher performance. When applied to the refurbishment of a building, they also need to be compatible with the existing construction practices and easy to manage.

Affordability versus low cost

When considering which high-performance solutions are best for their buildings' refurbishment, the cost is usually one of the top priorities that retailers take into consideration. A cost-effective solution can be either an affordable solution or a low-cost solution, depending on its payback period. As a rule of thumb, one can say that an affordable solution typically has a payback period of 7 to 8 years (which represents at least half of the service life of the proposed high-performance solution) while a low-cost solution has a significantly shorter payback period - up to 2 to 4 years.

Case study

According to their business strategy, many of the retailers reviewed have stories of innovative environmental best practices. However, few reveal publicly the financial payback period involved (Evans et al., 2006).

To better document the high-performance solutions that retailers are willing to use in their buildings and to ascertain their affordability, the following case study was selected from one of the reviewed retailers and consists of one of its average sized stores located in Portugal.

This store has 10,000 m² gross floor area and about 8,200 m² net sales area (4,896 m² for the food department and 3,346 m² for the non-food department). The energy consumption of this commercial building was 3,938,928 kWh in 2008, at an average price of 0.07805 € per kWh. Thus the total energy cost in the year 2008 was 307,433 €. The segregation of energy consumption in the building is the following: 38.8% for interior lighting, 3.2% for exterior lighting, 9.4% for equipment, 0.7% for heating, 1.8% for cooling, and 46.1% for industrial refrigeration.

The water consumption in 2008 was 13,025 m³, at an average price of 2.07 € per m³. The total water cost was 26,961 € per year. The segregation of water consumption in the building is the following: 70% for washing, and 30% for sanitary use.

Table 2 shows which high-performance solutions this retailer has considered in the past 2 years according to its refurbishment strategy, taking into consideration the payback periods and the yearly running costs of the building.

Table 2. Case study: high-performance solutions used in a retailer's 10.000 m² store

Energy consumption	Total cost of the solution	% of energy or water savings	Estimated savings in € per year	Estimated payback time in years	Affordable solution*	Low cost solution **
Sun pipes	196,800.00 €	23.2%	26,532.00 €	7.42	•	
Free cooling in IT rooms	8,200.00 €	50.0%	9,841.00 €	0.83		•
LEDs	112,665.00 €	86.5%	35,740.00 €	3.15		•
TL5 fluorescent lamps	85,468.00 €	41.2%	24,291.00 €	3.52		•
Waste heat for hot water	18,050.00 €	1.0%	2,748.00 €	6.57	•	
Electrical systems automation	73,500.00 €	10.0%	30,743.00 €	2.39		•
Water use						
High efficiency faucets	574.00 €	10.0%	2,712.00 €	0.21		•
Waterless urinals	240.00 €	5.0%	1,356.00 €	0.18		•
Rainwater harvesting	43,232.00 €	30.0%	8,140.00 €	5.31	•	
Refrigeration						
Glass covers for frozen cabinets	69,341.00 €	14.0%	19,811.71 €	3.50		•
E-cube[1]	5,760.00 €	6.0%	18,560.00 €	0.31		•
Smartcool[2]	17,011.00 €	8.8%	12,518.00 €	1.36		•

* Payback period less than 8 years. ** Payback period less than 4 years.
[1]Frozen goods' temperature control. [2]Automation for compressors

According to the case study low-cost solutions are more attractive to business managers as they pose a smaller risk on return on investment. However, taking into consideration the buildings' life cycle as well as medium-term operating costs, affordable high-performance solutions can also be considered and applied in the building's refurbishment.

The trend is that once most low-cost solutions are used, the affordable solutions with higher payback periods will then start to be analyzed and are likely to become gradually more adopted, as they still make good business sense.

On the other hand, any investment that has a payback of over 8 years has very little chance of being considered as it represents too much uncertainty in the fast changing retail market.

5 CONCLUSION

The large stock of existing commercial buildings that need refurbishing is both a persistent problem and an opportunity to achieve better performance in the commercial building inventory and to share the lessons learned within the sector (Andrews & Krogman, 2008).

Retailers are already searching for better environmental performance. Greater attention can be paid to the constraints that they face in their buildings' management decision process, namely by developing models that can correlate which different high-performance solutions are most suitable for their business needs, thus helping them to achieve higher performance and affordability.

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Utilization of high performance concrete in the design of sustainable buildings

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ABSTRACT: Concrete is due to its mechanical properties, durability, availability of resources and ability of variable design the mostly widespread structural material for construction of buildings. The possibility to construct subtile concrete load bearing structures increases the potential for the use of concrete also in energy efficient buildings. Utilization of optimized concrete structures represents a potential for increase of complex quality of construction from the point of view of sustainable aspects. New composite high performance silicate materials could be used for construction of more strong, more durable and at the same time slender "shell" structures, enabling design with significantly reduced use of materials and leading to reduction of environmental impacts associated with the use of primary natural sources and with depositing and recycling of the structure at the end of its life cycle. Experimental investigation, case studies and experimental realizations performed by authors in the frame of long term research, focused to environmental optimization of concrete structures, support the expectation that it will be possible to reach factor 3 or even more while keeping structural reliability on the needed high level.

1 BACKGROUND

- Buildings in the industrialized world are responsible for more than 40% of the total energy consumption, 30 - 40% of CO_2 emissions and the construction sector generates approx. 40% of all man-made wastes.

- Concrete is the second most used product on the planet, after water. During the last century concrete has developed into the most important building material in the world. The production of concrete in the industrialized world annually amounts to 1.5-3 tonne per capita. World cement production has been 12 times increased in the second half of the last century (Fig. 1).

- Concrete is produced from natural materials, available in all parts of the globe. Concrete is durable and versatile material, enabling structural variability and architectural freedom.

- Cement production is associated with large energy consumption and CO_2 emissions. The cement industry produces about 5% of global man-made CO_2 emissions.

- Improving the sustainability of the concrete technology will result into significant improvements in the building sector and will represent important contribution to the solution of global sustainability issues.

There is an obvious need for the reduction of raw material consumption. The reduction of structural material consumption can be achieved by the use of concrete (silicate composites) with improved mechanical properties in combination with shape optimization.

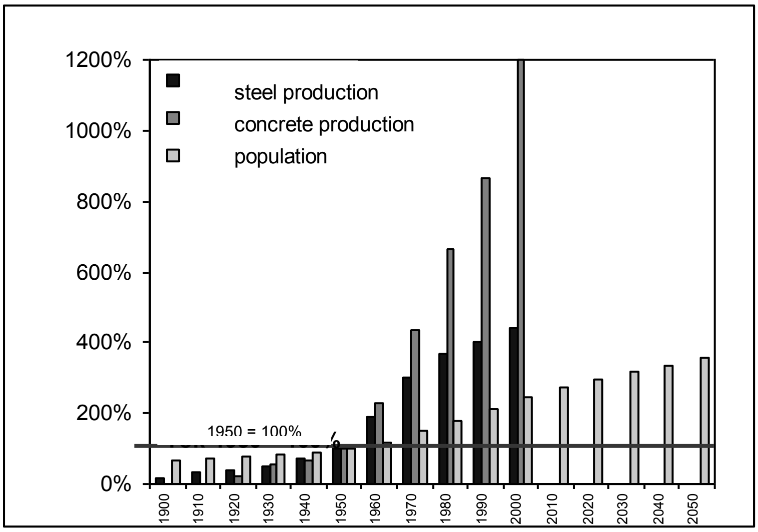

Figure 1 Tendencies of steel and concrete productions are compared with the population growth and its expected development up to the year 2050 (Hajek, 2003)

Waffle and ribbed reinforced concrete structures are widely used in building constructions. The static advantages are the consequence of the ribbed cross section, bidirectional span structure and lower self weight. Waffle floor structures can reduce material consumption to 50% in comparison to full reinforced slab while keeping similar static parameters. Another 20% can be saved by utilizing high performance concrete. The weight reduction of concrete floor structures is recently gaining the importance with regards to increasing demands on construction materials savings and on further savings related to transportation. Reduced self weight of ribbed shape represents lower load and consequently lower reinforcement consumption of floor slab itself and lower load on supporting structures. Additional savings are in transportation cost. The motivation is not based only on economical but also on environmental advantages followed from sustainable development criteria.

Partial task of the research was to verify the option of slender waffle and rib floor structures design with minimized upper deck thickness (up to 30 mm). The slab of this thickness cannot be effectively reinforced by conventional reinforcement and thus the possibility of high performance fiber concrete utilization was verified while maintaining structure reliability on high level.

2 IVESTIGATION OF HIGH PERFORMANCE CONCRETE THIN SLABS

2.1 *Mechanical testing of thin HPC slab specimens*

The first step of the research was to find out optimal concrete mixture from the perspective of workability and mechanical properties. The individual series differed in type of cement and fibres. Selected types of polypropylene and steel fibres having different shapes with and without ending were used. The content of fibres was in all tested cases 1% by volume. Test specimens were in the form of slender slabs 700/250/30 mm. In total 12 series were produced and tested (Tab. 1). The reference series S-I was reinforced in the middle by conventional reinforcement (steel mesh 100x100x4).

Verification of mechanical properties was performed in Experimental Centre of Faculty of Civil Engineering CTU in Prague. A flexural strength was tested using standard 4-point bend test method on 28 days old test specimens (Fig. 2). Resistance strain gauges LY41-50/120 were placed on test specimens. Load was applied in 0,25kN steps for period of 60 sec.

Table 1. Test specimens series specification and test results

Series No.	Reinforcement	Fibre tensile strength (MPa)	Flexural strength (MPa)	Compressive strength (MPa)
S-I	Reinforcing steel mesh 4/100/100	550	5.7	46.5
S-II	BeneSteel 50/35 polypropylene 35 mm	660	5.6	54.3
S-III	Fibrex A1 steel 25 mm	350	6.4	55.2
S-IV	Třinec 60 steel 60 mm	1000	7.8	54.1
S-V	Dramix ZP 305 steel 30 mm	1100	6.9	53.6
S-VI	Plain concrete	-	6.8	89.6
S-VII	Dramix RC 80/30 BP steel 30 mm	2300	7.2	83.8
S-VIII	Plain concrete	-	6.7	59.6
S-IX	Fibrex A1 steel 25 mm	350	8.6	80.0
S-X	Steel microfibres 9 mm	2400	14.8	176.5
S-XI	Dramix RC 80/30 BP steel 30 mm	2300	5.9	92.3
S-XII	Stratec 0,15 steel 13 mm	2400	10.4	136.8

The Table 1 presents comparison of maximum average flexural strength and compressive strength in tested series of slab specimens. Series of S-X specimens was produced in Kassel University from their UHPC (thanks to prof. M. Schmidt and his team) (Schmidt & Teichmann 2007). Series S-XII represent HPC with compressive strength around 140 MPa developed by our team at CTU in Prague.

The tests showed the potential for the use of fibre high performance concrete in construction of subtle light concrete structural elements with significantly reduced amount of concrete. Possible application is in waffle floor structure with reduced self weight.

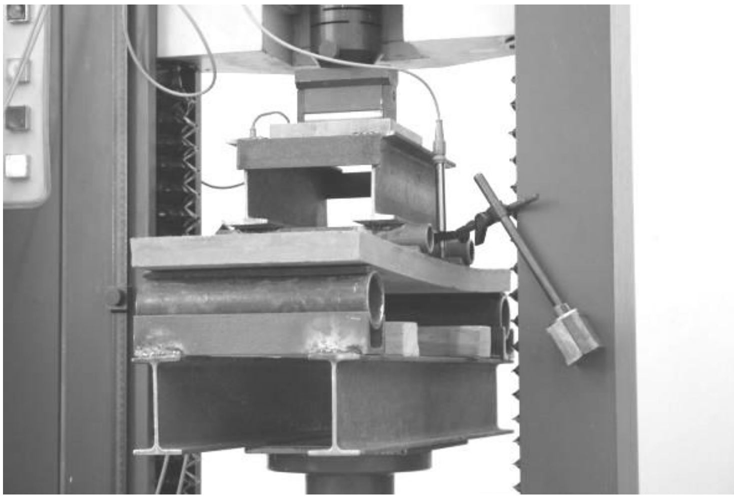

Figure 2 Thin slab specimen (thickness 30 mm) subjected to 4 – point bending test

2.2 *Environmental profiles*

The environmental efficiency of slender slabs was calculated for each mix design. In this paper there are presented results for reference series S-I reinforced by reinforcing mesh, S-IX series from HPC concrete reinforced by Fibrex A1 fibres and S-X UHPC series reinforced by steel microfibres. Embodied energy and emissions were calculated from data for plain concrete C50/60 (www.bauteilkatalog.ch 2009), data for individual fibres from (Waltjen 2008) and difference in cement quality and amount were calculated based on (Schießl & Stengel 2007).

Environmental impacts considered in this study were embodied energy, embodied CO_2 emissions and embodied SO_x emissions (Hajek & Fiala 2007). The ratio of the environmental impacts to experimentally measured flexural strength (which is proportional to load capacity, i.e. to its mechanical performance) was calculated for a case of assessed slabs. The environmental efficiency of HPC and UHPC concrete is obvious from the following graph (Fig. 3). It is due to their outstanding mechanical performance.

Table 2. Embodied environmental parameters of different types of materials

material	density	embodied energy	embodied emissions $CO_{2,equiv.}$	embodied emissions $SO_{2,equiv.}$
	[kg/m^3]	[MJ/kg]	[kg $CO_{2,equiv.}$/kg]	[g $SO_{2,equiv.}$/kg]
concrete C30/37	2 380	0,766	0,120	0,266
FC 45 1% Fibrex A1	2 454	1,849	0,179	0,545
FC 80 1% Fibrex A1	2 498	1,903	0,189	0,556
UHPC 180 Kassel	2 424	3,029	0,241	0,834
reinforcement (steel)	7 850	22,70	0,935	5,670

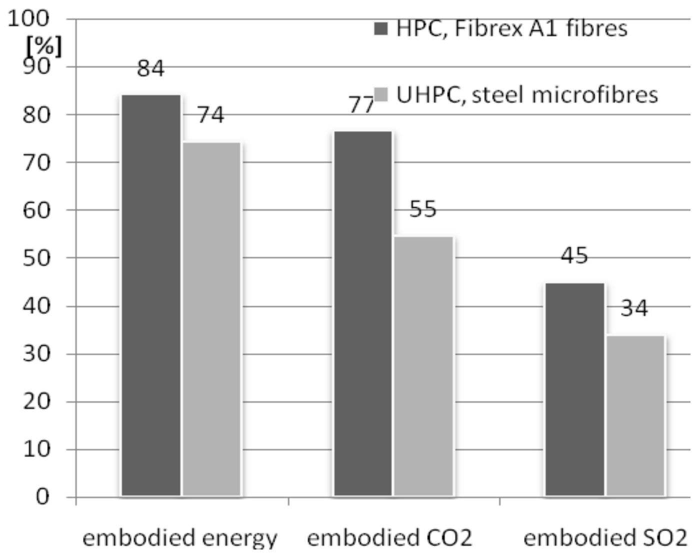

Figure 3 Environmental profiles of thin slabs. Reference level 100% is presented by a RC slab with reinforcing mesh

3 INVESTIGATION OF WAFFLE FLOOR SLAB

3.1 *Mechanical testing of representative parts of waffle slab from HPC*

To investigate the structural behaviour of lightened subtle waffle slabs exposed to flexural and torsional loads, three specimens (representative parts of waffle slabs) were tested. Based on the test results of small slab specimens, it was decided to use the mixture with Fibrex A1 fibres. All test specimens had an equal reinforcement. The steel bars R 10505 of 10 mm diameter were used. The same class of concrete with compressive strength of approx. 100 MPa was applied. There was no shear or torsional reinforcement in the tested structure. The top thin slab (30 mm thick) was from fibre concrete without conventional steel mesh.

Test specimens were subjected to different combinations of flexural and torsional loads. The position of load is apparent from the Figure 4. The first was applied the torsion. At 10 kN the forces were kept on that level and the middle force started to bend the sample until the destruction of the sample. All samples withstand roughly the same load that was approx. 65 kN induced by middle jack and torsion imposed by 10 kN forces.

Moreover, another 3 samples from HPC with more dense structure were made and tested. The mixture had the maximal grain of 0,6 mm and contained Stratec 0,15 steel fibres 1% by volume. The compressive strength tested on cubes was approx. 140 MPa. The samples were tested identically as afore mentioned. They withstood the flexure of 85 kN while being twisted by 10 kN.

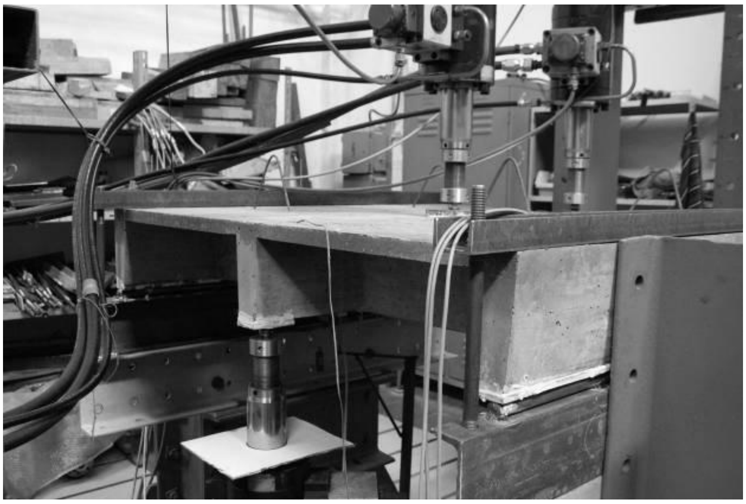

Figure 4 Testing of representative part of lightened subtle waffle slab in CTU Experimental Center

Figure 5 Failure of the specimen loaded by combination of torsion and flexural load

3.2 *Environmental assessment*

Four alternatives of floor structures have been compared: i) full RC slab from ordinary concrete C30/37, ii) waffle floor structure from ordinary concrete C30/37, iii) waffle floor structure from fibre reinforced high performance concrete and iv) waffle floor structure from UHPC. All structures were designed for the same performance – dead load 4kN/m^2, live load 1,5 kN/m^2, span 5 x 5 m, same thickness of 200 mm. The waffle floor from ordinary concrete had 60 mm thick upper deck and the thickness of the rib was 80 mm. While waffle slab from HPC and UHPC had dimensions: upper deck 30 mm, rib 50/170 mm. The data source used in the analysis was Passivehaus-Bauteilkatalog (Waltjen 2008). The graph shows evident environmental advantages of all waffle structures. The reduction of concrete consumption in optimized shape of waffle FRC floor structure can reach up to 50 to 70 % in comparison with full RC slab. Moreover this results in lower load from self weight and consequently lower load on supporting structures (columns, walls, foundations).

The environmental efficiency of waffle floor structure from UHPC is worse than from HPC concrete and even from ordinary concrete. When compared to environmental assessment of thin slabs it is obvious that structures from UHPC concrete are environmentally effective structures only if their mechanical performance is fully utilized.

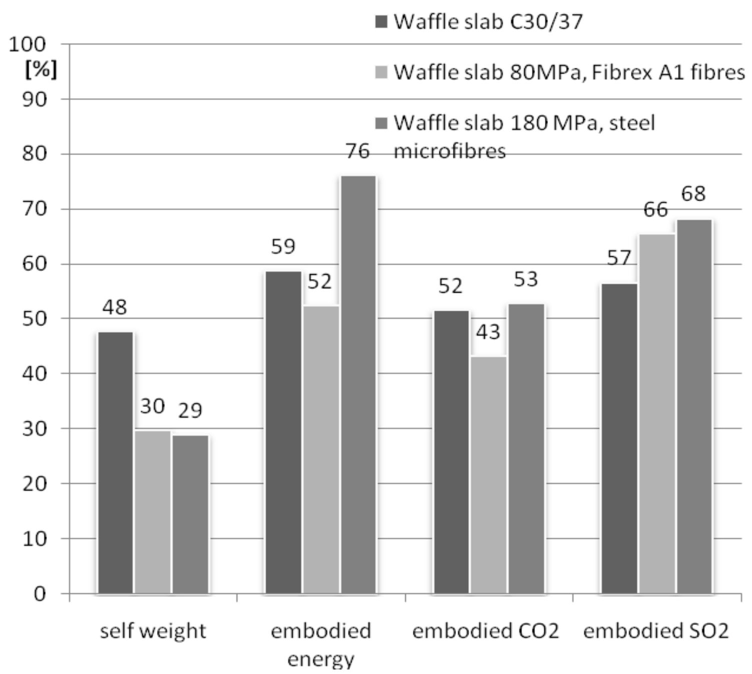

Figure 5 Environmental profiles of RC floor slabs. Reference level 100% is represented by a full RC slab

4 LIGHT PRECAST RC FRAME FOR PASSIVE HOUSE

A combination of light subtle RC frame structure with external walls and internal partitions from timber elements represents effective structural solution from economical as well as environmental point of view. Significant savings in concrete and steel consumption follow from subtle sections of precast RC members. Consequently savings in transport and manipulation costs are evident. This all makes this structural concept more environmental efficient.

This approach has been utilized in the construction of passive family house on the suburb of Prague. Load bearing structure of the 1st floor is made from precast RC light frame. The section of precast columns is 150x250 mm. It was made from common concrete C35-45XC1, reinforcement 4xR12. Edge columns are composed from two column elements creating L shape section. Columns support beams having thickness 150 mm. Floor slabs are RC composite with precast filligran lower part and cast in site upper part – total thickness 210 mm (Fig. 6).

Load bearing structure of the 2nd floor and roof structure is timber structure (Fig. 7). Entire load bearing structure is covered with timber external wall containing 400 mm of thermal insulation from mineral wool. The total expected energy consumption will be less than 20 kWh/m^2 per year.

Figure 6 Light precast RC frame structure

Figure 7 Timber frame structure on the top of RC precast part. Fixing of timber external wall.

4.1 *Environmental assessment*

Three alternatives of structure applied for construction of the same family house have been assessed in the study. Reference alternative is common structural solution from ceramic brick blocks Porotherm 44 P+D (thickness 440 mm) and RC floor structures with ceramic hollow fillers MIAKO (VAR. 1). Second alternative VAR. 2 has also load bearing structure from ceramic bricks (Porotherm 24 P+D) and the same type of ceramic floor slab. The external walls are insulated with 300 mm of PPS (polystyrene). VAR. 3 is light RC frame structure with timber external walls and timber internal partitions (constructed alternative – Fig. 6 and 7).

The analysis has been made just for one storey (1^{st} storey). In the Figure 8 are presented results - comparison of environmental profiles of described three alternatives. It is evident that alternative with light RC precast frame and timber external wall show better results in embodied energy (10% savings in relation to reference alternative) and embodied CO_2 emissions (32% less). The thickness of external wall is also the lowest – this can be economically advantages, especially in urban regulated areas with high density of houses.

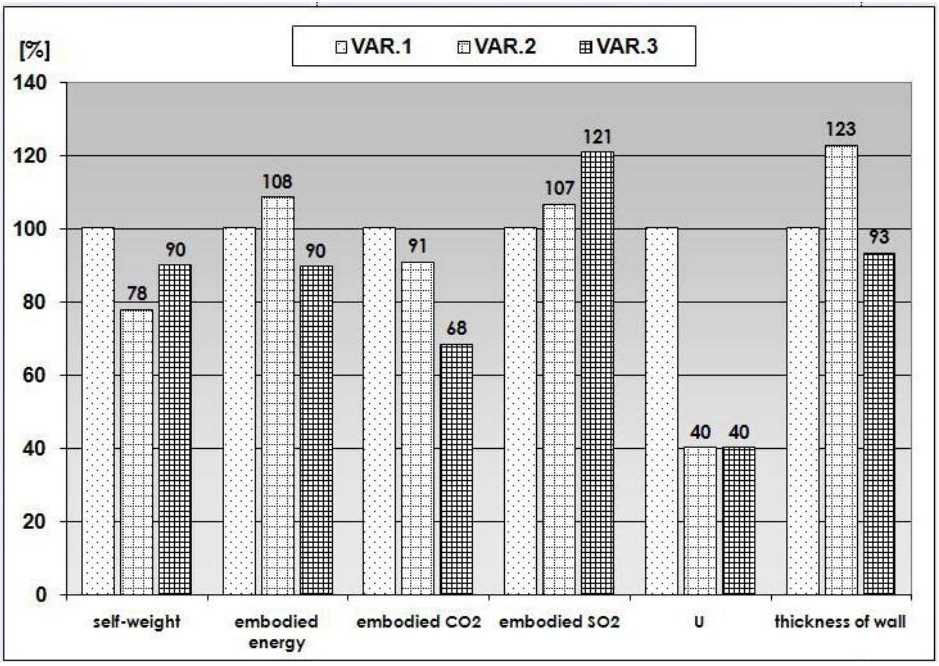

Figure 8 Comparison of environmental parameters of three alternatives of load bearing structure for passive family house

5 CONCLUSION

The complex LCA and LCC of optimized HPC structures would show not only environmental benefits, but also the cost efficiency - in spite of the fact that HPC is more expensive and has higher values of unit embodied parameters. Moreover, high performance material properties (higher ductility, fire safety, water tightness, frost resistance, etc.) make structures more durable and more resistant against climatic effects and also safer in case of exceptional loads (like climatic disasters or terrorist attacks). There is a big potential for the use of high performance silicate materials (application of HPC, UHPC) to form thin shell (ribbed, waffle, etc.) structures with reduction of the use of primary raw materials, and correspondent reduction of associated environmental impacts.

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Systemic building maintenance management for Malaysian University Campuses: An Analytical Analysis

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ABSTRACT: The value of buildings depends on the quality of maintenance invested in them. University buildings require maintenance to create suitable environment that support and stimulate learning, teaching, innovation, and research activities. This paper emerged based on the premises that if there is information on the criteria that influence maintenance of university buildings, characteristics of defects in university buildings and criteria within the users' value system, the maintenance management of university buildings will be effective and efficient compared to how it is currently executed. The paper is part of an ongoing research. This paper seeks to provide an overview on university building maintenance in Malaysia and to report part of an ongoing research. The paper reviewed related literature and present the outcome of a questionnaire survey. Questionnaires were administered on 50 university maintenance organizations. With a 66% response rate, the findings suggest that though the expenditure on maintenance is inadequate but poor management of the resource and maintenance services is also contributing greatly to the poor service delivery. The empirical survey also suggests that current maintenance management practices were not very good and most of the buildings users were not very satisfied with the services they receive.

1 INTRODUCTION

The overall vision of Malaysia is to achieve developed national status by year 2020. In order to achieve this status, higher education is to play a significant role. University buildings are part of the university's assets and resources; they are factors of production. However, once a building is completed maintenance commences. More and more stakeholders in the university management are becoming involved in one way or the other with university building maintenance. However, there is a lack of comprehensive frameworks containing established guidelines to address maintenance; effectively and efficiently. Therefore it is the aim of the research which this paper form part off to develop a model of reference points to ensure that every time maintenance is initiated and implemented, it is consistent, systematic, proactive and holistic. In this way, it will guide in defining the scope, quality, and expectations of the maintenance services as well as identifying the procedures to apply. The word "model" in the research is synonymous with decision-making framework or guideline for managing university building maintenance. Thus university building maintenance management model mean decision-making framework for the maintenance of university buildings. In this context, model consists of personnel, procedures, activities, requirements, tasks and guidelines. This paper is based on literature reviews and questionnaire survey. Based on extensive literature review, three fundamentals questions were developed to guide this paper. These questions are: what are the present university building maintenance practices in Malaysia? (1), are there any problem (s) with the current system? (2) if yes, what is / are the problem with the current systems? (3) The answers to those questions will produce a realistic and comprehensive understanding of the conditions and possible solutions to the problems of university building maintenance m in Malaysia. The objectives of this paper are (1) to provide an overview on kind, size and nature university building maintenance in Malaysia and (2) to report part of an ongoing research on the development of maintenance management model for Malaysian university buildings.

2 THEORETICAL FRAMEWORK

Education is very significant and integral part of the Malaysian Strategic Thrust. The economy of Malaysia has since the independence been planned on five years strategic plans. For each of the plans, education sector feature prominently in terms of value and policy implementations. There is an increment of more than 420% on allocation to the education sector for the last 20 years. See Table 1 for the federal development allocations to education sector from 1990 to 2010. The increase in the allocations is a proof of the Government's commitments to improve the performance of the education system in order to produce human capital with high quality capable of competing locally and internationally (Ministry of Higher Education, 2006). Allocation to higher institutions of learning constitute 2.1% of the GDP (Ministry of Higher Education, 2006)

Table 1: Development allocations for the educational and training sectors
(RM Million)

Sectors	6MP	7MP	8MP	9MP
Education	7,469.8	17,948.5	18,660	40,356.5
Training	615.4	2,237.3	4,000	4,792.6
Total	8,625.2	20,185.8	22,660	45,149.1

(Government of Malaysia, 1996, 2001 and 2006)

The increase in the allocations to the education sector is at all levels. For instance, under the Eighth Malaysian Plan, the sum of RM8, 900 million was allocated to institutions of higher learning out of the RM18, 660 million allocated to the education sector (Government of Malaysia, 2001) while under the Ninth Malaysian Plan, allocation to institutions of higher learning was increased to RM16, 069 million (Government of Malaysia, 2006). This represents an increment of more than 80%. As a percentage of total public expenditure, 4.4% was attributable to higher education. See Table 2 for the distributions of government expenditure to higher education over a period of five years.

Table 2: Public higher education institutions expenditures (2001-2005) (million)

Year	2001	2002	2003	2004	2005
Operating expenditure	2,748.0	3,811.5	4,001.9	4,398.9	4,773.2
Development expenditure	1,616.8	1,968.9	2,052.2	870,177	1,316.2

(MOHE, 2006)

Malaysia is now an educational destination to nationals from different countries particularly those from Africa, Pacific and Middle East. Malaysia's quest to transform into knowledge based economy (K-economy) where science, technology, and engineering are integrated into the production process and where creativity, imagination, and design capability are embodied in well-educated skilled workers are the main source of national prosperity and wealth is not compromise-able (Government of Malaysia, 2006). In order to achieve this objective however, the assets of the universities must be adequate. This involves improving the performance of the university systems, in terms of methods of teaching, learning, researching and the physical infrastructures (buildings and engineering services). Recent studies (Housley, 1997; Fleming and

Storr, 1999; Amaratunga and Baldry, 2000; Price, Matzdorf, Smith and Agahi, 2003; Green and Turrell, 2005; Leung and Fung, 2005; Wong, Fellows and Liu, 2007; Fianchini, 2007 and Lavy and Bilbo, 2009) have affirmed the positive correlations between performance of educational buildings and quality of education.

Buildings like other capital assets of university organization require effective and efficient maintenance. University buildings are factors of production. University buildings are procured to create suitable, conducive, and adequate environment that can support, stimulate and encourage learning, teaching, innovation and research activities. A failure in the supply of these essential services is a loss in value to the university institution, the community, the students, staffs and other stakeholders. Construction of new university buildings help to upgrading educational facilities and providing better quality of education, but it is utmost necessary to maintain the existing building to acceptable performance standard that is capable of facilitating the transfer for knowledge and carry out other academic activities. The cost of the property function in comparison with turnover of university institution ranged from 8% to 11% (Housley, 1997). Solutions to nation's economic, social, scientific and technological woes live within the walls of functional classrooms, workshop, theatres and laboratories. As a result, universities these days use the nature, design and condition of their buildings to woo students. In Malaysia, universities that in the past relied on the application sent to them through the Ministry of Education, know used their buildings as a variable to attract students (Rohaizat, 2002 and Yosuf, Ahmad, Tajudin and Ravindran, 2008). Arguably, this is also the case elsewhere. To provide quality education, university buildings have to be well maintained to ensure optimum operable performance of the buildings. Therefore, a well maintained building is critical to delivering university core business objectives.

Maintenance means different things to different people. The term has been defined and redefined by different authors. However, clearly, the various definitions suggest that maintenance revolve around building care. Nevertheless, as a working definition, maintenance is defined as the required processes and services taken to preserve, repair, protect and care for building’s fabric and engineering services after completion, repair, refurbishment or replacement to current standards to enable it to serves its intended functions throughout its entire life span without drastically upsetting its basic features and use (Olanrewaju, 2010). From this definition, maintenance does not includes activities like refurbishment, alteration, conversion, extension, and reconstruction, but it does includes repairs, rehabilitation, renovation, renewal, restoration, reformation, redecoration and the general cleaning and services. Maintenance is however, unique in the building life cycle as compared to initiatives like refurbishment, conversion and extension. For instance, as soon as building is refurbished, converted, altered, extended or reconstructed, maintenance set in, if not earlier. While maintenance is a must in a building life cycle, other initiatives are usually one off if it all they are required. Clients can decide not to refurbish or convert their buildings throughout the building’s economic or and functional life span.

But, this is not possible with maintenance since building components, materials or even design is not maintenance free (see Seeley, 1987). Whereas only about 5% of a nation’s building stocks are refurbished, converted, replaced or altered, more that 95% of any nation’s building stocks must be maintained in a year (Shah, 2007). Value based management, on the other hand, emphasis on the collaborative approach towards the creation of value to the stakeholders (Knight, 1997; Martin and Petty 2000 and Ashworth and James, 2001). Thus the emphasis here is on user value management. Therefore by extension and combination, value-based maintenance management involves the attainment of maintenance needs effectively (sustain user satisfaction) and efficiently (with optimum materials, labour and costs). Unlike with the traditional management principle that is fixated on cost and on the investor interests only, the value-based management contains both financial and non-financial measure to measure strategic performance and does not laid ultimate emphasis on the investors’ interests rather to the consumers of the services or and products.

Based on the data obtained from the Ministry of Higher Education, it suggests that maintenance expenditure had expanded by nearly 85% from 2004 to 2008. For instance, expenditure on maintenance was nearly 340 million in 2004 while it increased to more than 600 million in 2008 even though the figure for 2008 was at July 2008. Therefore the size and scope of university buildings maintenance is huge and at same time is on the increase. However, comparing these amounts with the total expenditure on education it implied the government is investing roughly 1 % on university buildings maintenance. This is however inadequate, to meet the maintenance. Studies elsewhere have shown that organizations will require between 3 and five expenditure of the monetary value of their capital for maintenance (Vanier 2001)

Intensive, literature review (Ishak, 2006; Zakaria, et al., 2006 and Ruslan, 2007) have lead to the conclusion that the maintenance practices of the university buildings are corrective, cyclical and condition based. Ruslan (2007) also affirmed that the maintenance management of university campuses is still traditional. Corrective maintenance is failure based, it is initiated after the building as failed and is intended to restore the building to it original condition. This method is in most cases very expensive, and usually leaves the users less satisfies. Conditional based maintenance is a preventive maintenance initiated as a result of some knowledge on the condition of the building on the basis of inspection prior to failure. As long as the parameter of the building where found to be within specification, it will be considered to be fine and no action will be taken. Stock condition at best provides only a snap shot of the condition of building during the inspection period. It is difficult to assess the amount of risk posed by an identified non-critical problem to future operations and productivity (Reffat, Gero and Peng, 2004). A non-critical problem during inspection might deteriorate further or becomes more serious during the actual implementation due to time lapse and error of measurement as a result of the inspections.

However, as a result of the advancement in technology and communication breakthrough concurrent with the failing in the corrective, cyclical and condition based strategies, the application of performance based maintenance has been advocated. In the performance based strategy modern equipments are used to monitor the performance of building elements and the associated services. However, this practice is more suitable for the manufacturing industry as compare to the construction industry. Although it is also suitable for some specialized building elements (Edwards, Holt and Harris, 1998) and engineering services. For instance it is possible to embedded sensors that incorporate wireless technology into a range of building components. However, this has great limitation especially in building fabrics where the applications of mathematical models prove unable to cope with the complexity of a real life situation (Umeadi and Jones, 2003). It is also very expensive to install most of the sophisticated tools on most buildings components and systems.

Therefore, in most non-manufacturing industries, like the building industry it uses is often limited to the high-tech electrical fittings, appliances and mechanical components. From the foregoing, it is concluded that none of the current maintenance management practices is without flaws and merits. Corroborating, this view, Lofsten (2000), highlighted that even the corrective maintenance cannot be entirely avoided in any organization's maintenance policy. However, it is almost unlikely that a complete solution can be identified without an increase in allocation to the maintenance sector, but it is very much possible to improve the situation by ensuring that the best solution in the maintenance programme is introduced though the development of decision making model. This is probably the only practical means of achieving best maintenance practices (Sherwin, 2002).This is because; problem of inadequate expenditure is not peculiar to Malaysia (Seeley, 1987 and Shen, Lo and Wang, 1998). It is contended that active pursuit of the development of initiatives on maintenance management practices will keep us nearer the moving target. Therefore, a good solution to this is the development Maintenance management model is essential to ensure control, gain knowledge and improve decision making. Model trigger proactive decision making processes. Framework is required in order to align maintenance resource to users' satisfactions and to also align performance with university corporate strategy.

However, university building maintenance in Malaysia lack logical, holistic and consistent framework as the key reference point for maintenance management decisions making and actions. In part, this conclusion is drawn based on the fact that across the whole building maintenance in Malaysia lack consistency and systematicness (see also Myeda, Kamaruzzaman, Abdul Samad and Zawawi, 2009 and Marinie and Zawawi, 2009). The shortcomings and even the failings of the current maintenance management processes have been well documented but the building maintenance management system can only be improved with the availability of efficient maintenance management framework that guide the decision making processes. Maintenance per se cannot be blamed if things went wrong rather it is the management that is requiring some step changes. The value-based maintenance management model comprises of five interconnected phases:

a. Criteria that influence university building maintenance management
b. Criteria that influence users' satisfactions in university buildings maintenance services
c. Maintenance reporting system
d. Defects in university buildings
e. Building maintenance performance management for university organization

3 RESULT OF PRELIMINARY SURVEY

The survey involves 50 established universities in Malaysia. The analysis of thirty two returned questionnaires were reported in this paper. The survey was directed towards the senior management staff (i.e. those concerns with university building maintenance management. The survey revealed that most of the respondents hold strategic position. Nearly, 32% of the respondents were actually maintenance managers while about 19% were facilities managers (Table 3). Substantial pats of the "other" are director of development or and maintenance "executive" (this is another title / term for maintenance manager). These backgrounds provide the respondents with wide experience capable of providing independent opinion on information that were addressed to them. From the analysis of the survey, 52% of the universities spent less than 10 million each on maintenance annually while about 10% spent about 30 million each on maintenance per annum. Similarly, about 22% of the survey universities occupied less than 280, 000 m^2 built up area while more than 40% occupied more than 1, 400, 000 m^2 built up area. Majority (42%) of the buildings were about 15 years old while only about 10% were between 30 to 50 years old. From, this it could be inferred that most of the university buildings were not that old per see yet considerable amount of money is invested for the maintenance albeit there are considerable complaints about university maintenance practices. Thus the issue then is with the maintenance practice.

In relation to the maintenance practice in the United Kingdom, Seeley (1987) also pointed out that, though available money that is usually allocated for maintenance might not be enough, but with effective maintenance practices much can be done to improve the building performance. In fact, it is obvious that with ever increase maintenance need, the money that will be allocated to maintenance will not be adequate to cater for the maintenance need. From the survey, 4.5% of the maintenance organizations believe that their customers (users) are extremely satisfied with the services provided. About 5% do not know how satisfied were their customers even though majority (77.3%) believe that their customers were only satisfied with the service been provided with (Table 4). However, this needs to be investigated through questioning the users' opinions, this will involve conducting a study whereby questions will be addressed to the users themselves (currently, a survey is ongoing to achieve this objective; the result of which will also be published elsewhere). Information receives, will be compared with the opinion of the maintenance organizations. However, available literature point to that fact, that users were not very satisfied with the performance and condition of the buildings and in fact, with the maintenance organizations.

Table3 Respondent's current position

Position	Frequency	Percentage
Facility manager	6	18.8
Maintenance manager	10	31.2
General manager	2	6.2
Administration manager	1	3.1
Other	13	40.6
Total	32	100

Source: (Primary survey, 2009)

Table 4 Level of users' satisfactions with service delivery

Level Of Satisfactions	Frequency	Percentage
Extremely satisfied	1	4.5
Very satisfied	3	13.6
Satisfied	17	77.3
Do not know	1	4.5
Total	22	100

Source: (Primary survey, 2009)

Most of the universities employed less than 30 employees each on full time basis. Only 16% of them actually employed 140-170 full time employees even though 6.2% of the organization has 60 – 90 and 110m - 140 on their full time pay rolls each. This finding can be interpreted to mean, that most were in favour of outsourcing their maintenance services. Nevertheless, another part of the survey revealed that 66% prefer to combine outsourcing with in sourcing. Majority (46.9%) of the organization rate their current maintenance practices as good while 44% rated their as fairly good. Minimum of 6.2% rated their as very good (Table 5). There is discrepancy with this finding when compare with the fact that 77% of the maintenance organization claimed that their users were satisfied with the services quality. About 53% of the organizations have conducted users' satisfactions before while 40% have not but the remainders do not know. In case, the maintenance organization ran into deficit, 61.3% apply for more money from their respective university management while 32. 3% cut from money allocated for other purpose. It is only through user satisfaction evaluation that can be made. Users need to be questioned on the services they are provided with. The findings of the evaluation or survey should the basis of any meaningful organization maintenance performance measurement benchmark.

Table 5 How organization rate their current practice

Rate	Frequency	Percent
Very good	2	6.2
Good	15	46.9
Fairly good	14	43.8
Do not know	1	3.1
Total	32	100

Source: (Primary survey, 2009)

While most (66%) of the organizations prefer to combine in-sourcing and outsourcing, considerable amount (22%) prefer to outsource their service to external specialist. Fewer than 10% prefer to in-source their maintenance services. This finding is in tandem, with the outcome on the number of their full time employees. These two findings only pointed to the fact the, university organizations in Malaysia prefer to outsource their maintenance services. Often, university organizations have failed to realize that maintenance is also part of their core services. Building maintenance is very critical to the survival of university organizations. Students and faculty members spend most if not all of their productive time in or around the classrooms, laboratories, or theatres or and tutorial rooms. Outsourcing maintenance function reduces maintenance to corrective maintenance. There are also some organizational political-proprietary data that the university would not like to expose to external parties. Tsang (2002) warned against organizations outsourcing facilitating function like maintenance. He also cautioned organizations not to consider outsourcing activities that are critical to their core activities. No doubt building maintenance is very critical to the continuous existence of a university. However, decisions on what to outsource should be based on objective and quantitative facts even though a situation where a university outsources substantial parts of it service may not be entirely healthy for any organization. According to Sherwin (2002), it is still too early to say outsourcing maintenance services is an alternative approach to maintenance service delivery.

However, times have changed. It is high time, university organizations accept and take care of their buildings (vis-à-vis the maintenance practices) efficiently. It is no longer acceptable for university to invest only on improving methods of teaching and learning without improving other assets. They should also invest on training their maintenance staffers as they would for academic staffs. Substantial commitment is require for continuous professional programmes for the maintenance operatives. After all enormous resources are committed to procure their buildings. In fact, it is failing on the part of the university management to consider the management of their buildings as non-core activities. Maintenance is also core activity of the university organizations, since without it the university would not survive. University must take care of their interrelated assets namely; buildings, technology and human resource. Outsourcing if not properly managed often led to maintenance backlogs, unnecessary increase on maintenance cost. It is argue here in that university organization should not outsource the management of their maintenance service, albeit part of the maintenance implementation could be our-sourced where extremely necessary. However, it will be more profitable if university could in-house most of their maintenance services. External maintenance organization could hold their clients to ransom. It also leaves the in-house maintenance organization staff less competent and inactive due to redundancy.

4 CONCLUSIONS

Buildings only have value if they continue to provide the intended services adequately, failure of which will render the existence of the building insignificant if not even useless. The corporate objectives of a university place building performance in a strategic position. Therefore, maintenance is inevitable, and in order to improve and sustain productivities, service delivery and satisfaction of the users, maintenance must be positively managed. The analysis of the survey support the major themes of the paper; that university buildings were not receiving the require attention. The paper only report the opinion of the maintenance organizations, but the findings revealed that the maintenance organizations feel the users are only satisfied it is very possible that the users will rate them low and only 2% of the maintenance organization feel that their current practice is very good. All this is leading to the fact that maintenance management of the university buildings are not effective and efficiency thus leading to poor service delivery, poor user satisfaction, increase in maintenance backlogs and increase in maintenance cost. University must be very critical of their procurement systems. What to out-source or in-house needs to be looked at critically before making decision on the delivery method to apply and on what and what not to outsource and to what extent to out-source. In any case, organization must not outsource facilitating functions to their core business objectives.

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Design of high tech components for controlling thermal inertia in mediterranean regions

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ABSTRACT: Control of thermal inertia during the summer season plays a fundamental role in energy efficient building design, especially in Mediterranean regions, where high insulation levels aimed at minimizing winter consumption can lead to situations of overheating in other seasons and nocturnal high temperature do not permit the usage of natural ventilation. A possible solution consists in the realization of high thermal inertia by means of phase change materials (PCM). This paper reports about fining tune and testing PCM-based slabs integrated with common radiant comfort systems, hypothesizing the use of water at aqueduct temperature sufficient for discharging PCM containing components, rather than cooled fluid. Two technological solutions were designed and analyzed by means of finite element analysis simulation. Two types of floor prototypes were then produced: a traditional screed and a dry screed one. The experimental data confirmed the building element's high potential and constituted the basis for the research development.

1 INTRODUCTION

Control of thermal inertia during the summer season plays a fundamental role in achieving both living comfort and energetic saving within the field of the design of sustainable building constructions, especially in Mediterranean regions.

To this day in fact, the high insulation levels prescribed by existing standards and aimed at minimizing winter consumption do not guarantee a similar comfort level (and, hence, similar energetic savings) in the summer seasons; in fact, they may lead to situations of overheating in the presence of significant thermal contributions within buildings. This case is anything but isolated if we consider the possibility that solar radiation hits internal building components through the glazed surfaces of envelopes or that inhabitants generate supplementary thermal loads such as, for example, those tied to common activities such as cooking or working (illumination systems and computers, for instance).

Faced with this scenario, a possible solution consists in the realization of high thermal inertia by means of phase change materials (PCM) which operate around comfort temperatures and allow energy accumulation at almost constant temperature levels, such that the overheating of built elements is avoided.

This paper reports about fining tune and testing PCM-based slabs capable of coping with the thermal comfort problems that normally characterize 'high insulation' architecture. The proposed uses are innovative and they regard both the intrinsic characteristics of PCMs (heat available when needed, heat stored and emitted at a constant temperature) and the considerable flexibility of use (various strategies can be used at the same time; the quantity of storable heat can be changed over time with little impact on the construction). This technology will exploit the latent heat storing property of PCMs in order to optimize the management of thermal flux overload in internal environments; typically occurring in mid-seasons.

The use of PCMs in buildings has been highly investigated in recent years and a quite complete overview of the state of the art can be found in (Zalba et al. 2003) and (Zhang et al. 2007). PCMs containing materials were developed as slurries (Schossig et al. 2005) and floor tiles (Lee and Hittle 2004). The research was interested initially in supporting heating devices but, in later years, many applications of PCM for cooling aims were investigated. The insertion of PCMs in buildings' external envelopes performs well in lowering temperature peaks in internal environments and shifting their occurrence in time as many studies report (Lemma et al., 2006) (Ahmad et al., 2006) (Lemma et al., 2007) (IP et al., 2008) (Miller et al., 2008) (Lazaro et al., 2009). The use of PCMs in internal building elements has increased during recent years, when the high level of insulation contained within building envelopes are making "isolated environments" of internal zones and internal thermal dynamics are becoming more relevant than outdoor exchanges. A thermally activated PCM containing ceiling panel for application in lightweight and retrofitted buildings has been developed by (Koschenz et al. 2004) and indoor wallboards have been analyzed and tested by (Kuznik et al. 2008). In regards to floor elements, a shape-stabilized PCM floor was optimized for reducing winter consumptions (Xu et al. 2005) (Zhang et al., 2006). Finally, (Takeda et al. 2004) and (Nagano et al., 2006) propose the use of PCMs to increase building mass thermal storage and optimize floor supply air conditioning systems.

In this case, we will deal with the integration of PCMs in common radiant comfort systems, hypothesizing the sole use of aqueduct temperature water for discharging PCM containing components, rather than cooled fluid. In fact, the application of PCM in internal building components requires planning in order to provide strategies for the removal of stored heat as well, in order to avoid its being re-emitted within the same spaces. Mediterranean climatic conditions make the use of night ventilation ineffective, because of the high nocturnal temperature of outdoor air.

The first phase consisted in the design of a set of technological solutions and the identification and characterization of the technological variables via thermal behavior simulation using specific software-based finite element analysis. In a second phase, two floor prototypes based on different technological solutions were produced; a traditional mortar screed and a dry screed one. The experimental data confirmed the building element's high potential and constituted the basis for the research development.

2 AN HIGH-TECH COMPONENT

2.1 *Functional model*

The strategy we aimed to pursue was an active type strategy which required the constructive integration of a number of plant installations (coils capable of containing fluids in movement) in order to optimize the loading and discharge phases of the PCM containing components.

Hypothesizing the detailed functioning of this building technology, it is characterized by two principal processes. During the loading process, the insertion in the floor slab of a layer containing change phase material that allows the floor to store heat coming from thermal flows due to solar radiation and/or internal contribution without the increase of its own temperature (latent heat storage), thus allowing the reduction of daily temperature peaks on the extrados surface of the same. During the discharge process, the thermal energy stored by the PCM during the phase transition is released thanks to the cooling of the layer itself by means of the passage of lower temperature fluids which remove the stored heat and avoid re-irradiation within the environment. The convective thermal exchange had in the cooling phase will allow the PCM to solidify to prepare for a new fusion cycle.

In a real context, these two processes are foreseen to occur concurrently and not subsequently. In fact, the cooling fluids employed are common liquids circulating in building plants, such as sanitary and aqueduct water. In this way, the system constantly removes energy from the indoor environment, reducing the thermal load surplus little by little as it accumulates.

2.2 *Technological hypothesis*

From a technological point of view, the integration of the PCM layer and the plant elements foresees the design of opportunely molded elements for housing channeling for the passage of fluids, in order to also contain the PCM and to favor the thermal exchange between it and the channeling. So far we hypothesized deriving our system from common radiant floor systems: from a constructive point of view, PCMs was integrated in two different technological typologies of screed:

- a traditional mortar screed, incorporating PCMs in the concrete matrix,
- a dry floor screed, foreseeing the insertion of PCMs in molded elements capable of containing water pipes as well.

The decision to base this research on radiant floor system technologies was due mainly to three factors:

- the possibility of integrating a sort of system which is quite diffuse for winter use, with a further use in other seasons, by simply adding PCMs applications;
- the possibility of using water from waterworks at its usual temperature, without the need for further cooling. In fact, the temperatures (16-20 degrees) are sufficient for the solidification of PCMs, thus avoiding further cooling, with all the benefits in terms of energetic costs and floor condensation problems;
- the possibility of foreseeing, in case of heavier thermal loads, its use as a complementary passive and active system, still providing a reduction of the energetic costs incurred.

The water used was drawn from the water supply network, at its own temperature, and it was subsequently re-used for sanitary use. Daily water consumption models were analyzed, in this perspective, for different building typologies, and furnished interesting findings in terms of the availability of water availability as a “cooling fluid for PCMs”.

3 NUMERICAL ANALYSIS

The models hypothesized were evaluated through numerical analysis, using common finite element method software that allowed in-scale simulations of the single built element providing detailed data regarding the state of every part of the built component in every instant.

3.1 *Numerical method used*

The enthalpy method (Comini et al, 1974) was used in order to simulate the materials’ change of phase. In fact, the comprehension of the phase changing phenomenon requires the analysis of the main related processes and, in a macroscopic perspective, heat transfer is the most important one; Even if heat transfer becomes more complex in this case because of the storage/discharging of fusion latent heat in the solid-liquid interface. The enthalpy method uses a unique equation for the solution of both solid and liquid domains. It consists in the definition of a new variable H(enthalpy) as an integral of the ρc – T curve, and the estimation of the average heat capacity values, based on well-known enthalpy properties, solving in this way a non linear problem.

In this case the equation of conservation of energy can be written:

$$\frac{\partial H}{\partial t} = k\frac{\partial^2 T}{\partial x^2} \tag{1}$$

where H is the enthalpy function, or total heat content, that in the case of an isothermal phase changing is defined as:

$$\begin{aligned} H(T) &= \int_{T_r}^{T} \rho c_s\,(T)dT && per\ (T \le T_f) \\ H(T) &= \int_{T_r}^{T_f} \rho c_s\,(T)dT + \rho L + \int_{T_f}^{T} \rho c_l\,(T)dT && per\ (T \ge T_l) \end{aligned} \tag{2}$$

For a phase changing in a temperature interval from T_s to T_l, being respectively T_s the solidification temperature and T_l the fusion temperature, it becomes:

$$H(T) = \int_{T_r}^{T_s} \rho c_s\,(T)dT + \int_{T_s}^{T} \left[\rho\left(\frac{dL}{dT}\right) + \rho c_f(T)\right] dT \qquad per\ (T_s\ < T \leq T_l)$$

$$H(T) = \int_{T_r}^{T_s} \rho c_s\,(T)dT + \rho L + \int_{T_s}^{T_l} \rho c_f\,(T)dT\ + \int_{T_l}^{T} \rho c_l\,(T)dT \quad per\ (\,T \geq T_l) \tag{3}$$

where c_f is the specific heat in the freezing interval, L is the latent heat and T_r is a reference temperature, not minor than T_s.

By definition we have $\rho c\, = \frac{\partial H}{\partial T}$. It is possible to define $C_{eff} = \frac{\partial H}{\partial T}$ the effective heat capacity

of the PCM, that varies in the temperature domain and it depends on both the sensible and latent heat contribute. It can be directly derived from equation 3 as:

$$\begin{aligned} c_{eff}\, &= \,\rho c_s && per\ (\,T < T_s) \\ c_{eff}\, &= \,\rho c_f + \frac{L}{(T_l - T_s)} && per\ (T_s\ < T < T_l) \\ c_{eff}\, &= \,\rho c_l && per\ (T > T_l) \end{aligned} \tag{4}$$

3.2 *Model simulation*

The evaluation of the model hypothesized required the analysis of the thermal performance of the two different typologies and a contrast among them, depending on a set of design parameters. A solar radiation-like load was simulated and the water was hypothesized to circulate only a set number of hours during the afternoon.

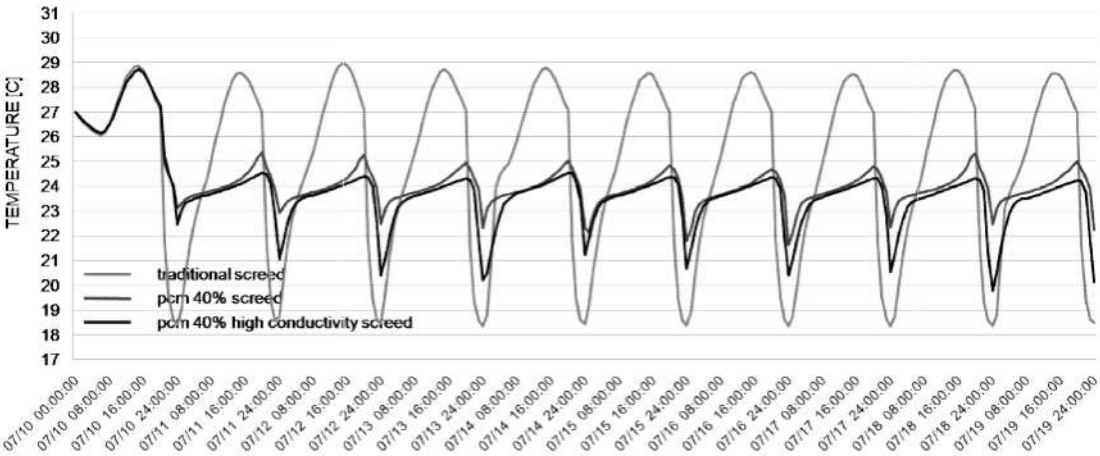

Figure 1. Numerical analysis of a traditional screed with different composition.

More specifically, the following design parameters were analyzed in order to evaluate the principal functioning methods, starting from the specific boundary conditions:

- the type of external layers and finishing;
- the solar radiation intensity;
- the water circulation schedule;
- the PCM fusion temperature needed to guarantee proper functioning;
- the quantity of PCMs, in terms of PCM percentage for the traditional screed and in terms of the thickness of the PCM layer for the dry screed one;

The performance evaluation parameter considered was the PCMs' upper surface temperature and its reduction relative to a reference case.
Numerical results highlighted a great potentiality for these kinds of technologies, with peak temperature reduction around 4°C for both the constructive technologies in the cases having PCM fusion temperature around 24-28°C (fig. 1).

4 EXPERIMENTAL ANALYSIS

4.1 *Testing environment*

Numerical results justified and guided an experimental testing, in order to verify the expected performances. For each constructive typology, 40x40 cm prototypes were built, both in the PCM containing version and in the reference version that is identical to the first except for the fact that it is without PCM applications.

The PCM used was paraffin-based in a granulate form, thus the phase change material was contained within a secondary supporting structure, in this specific case, a natural porous mineral particle ensured that the PCM, when in the liquid form, did not leak out of the granulate. The result was that the bound PCM was always a solid in its macroscopic form. The granulate dimension varied among 1-3 mm.

The radiant system was made up of with pipes measuring 13 mm as internal diameter and 100 mm as interaxis and it was connected to the laboratory's water supply.

The testing environment was air-conditioned to 25°C and the solar radiation simulated through 300 W lamps (fig. 2). Temperature and heat flux sensor were placed in the prototypes. Tests were conducted with and without water circulation.

Figure 2. The testing environment

4.2 *PCM containing traditional screed*

For the traditional screed prototype different PCM percentage prototypes were built. A mixture workability analysis led to the choice of 40% PCM content for high conductivity mortar screeds.

The test schedule consisted in two main processes:

- Radiation, through lamps, lasting 6 hours;
- PCM solidification, through water circulation, lasting 4 hours and starting 1 hour before the switching off the artificial lighting (1 hour overlap).

A comparative reading of the temperature and heat flux graphics (fig. 4) highlights the feature phases of the prototype's behavior. The heat storage occurred during the fusion – phase 2;In fact, the temperature line varies its inclination and the flux is very high and positive. By comparing the PCM prototype with the reference one it becomes evident that in this phase there is a reduction of the surface temperatures. In phase 3, the temperature inclination is similar to that in phase 1, meaning that the phase change is completed and the screed is now storing sensible heat.

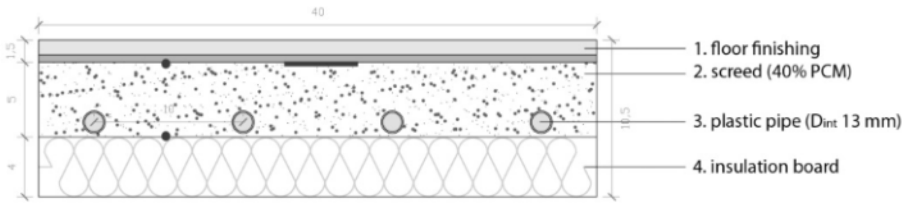

Figure 3. Traditional screed prototype cross section

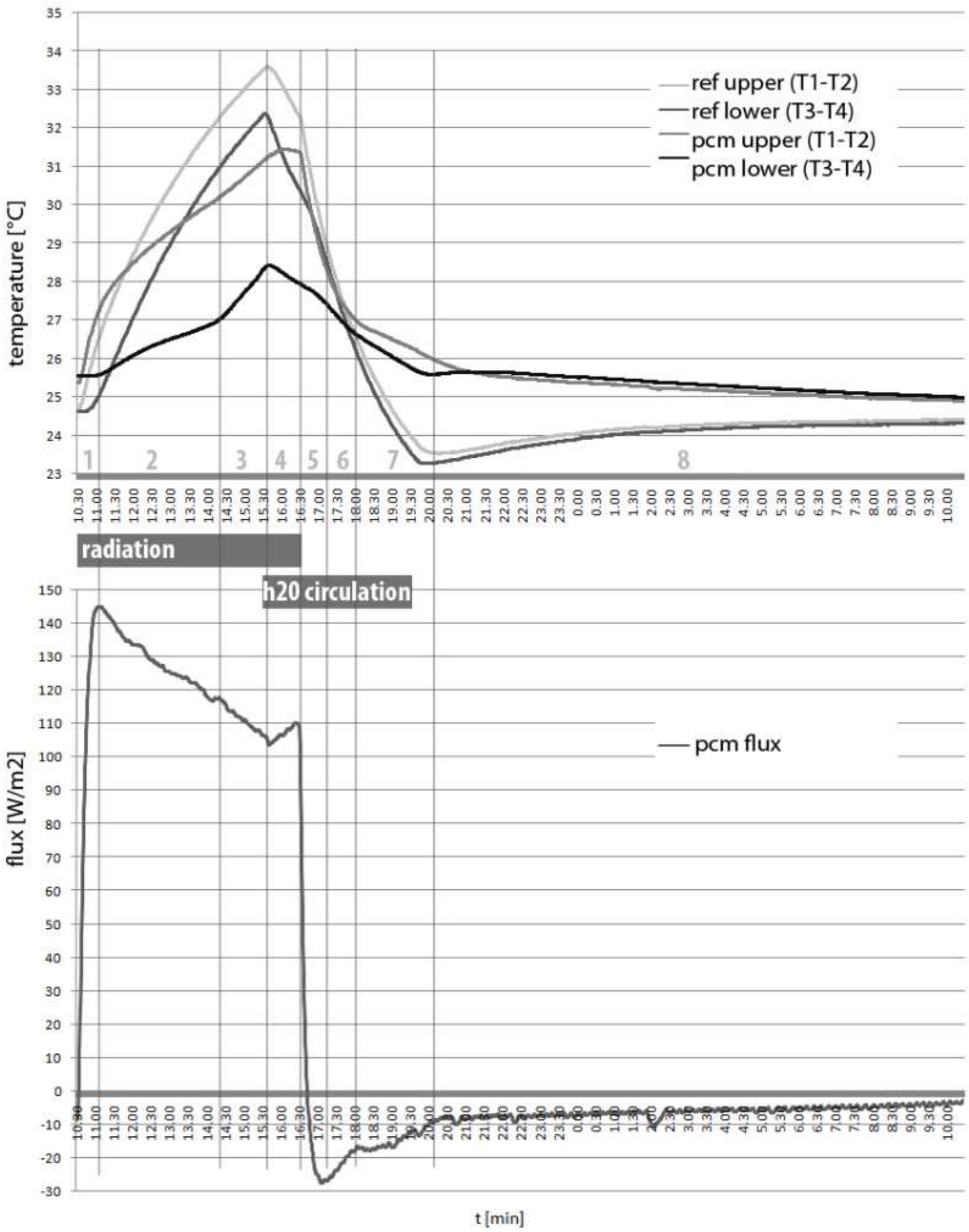

Figure 4. Experimental data of one of the tests on traditional screed: temperature and heat flux graphs

The water circulation starts in phase 4, cooling both the prototypes, but as we can see, the PCM containing prototype has minor temperature surface range - this is a good comfort feature. Note that the water circulation increases the heat flux storing, because the radiation is still ongoing and with the water circulation the temperature difference increases. The collapse of the heat flux, which indicates the end of the heat storage, corresponds to the lamps being switched off (thermal load disappears), in phase 5. Finally, the peak temperature reduction appears at around 2°C on the PCM upper surface and 4°C on the PCM lower surface.

4.3 *PCM containing dry floor layer*

The behavior model of the dry floor layer resulted similar to the traditional one, even if the thermal fluxes and effects were minor because of the type of dry screed used; high thermal capacity that lowers the thermal flux entering in the PCM layer. Note that the temperature peak reduction varies between 2-6 degrees, increasing with the thermal loads (see example in fig. 6).

An interesting result, however, was obtained from the comparison of two subsequent tests, the first one with a single lamp for the radiation, the second using two lamps. Figure 5 shows that while the energy stored (integral area of the positive heat flux line) changes with the thermal load increasing, the energy delivered by the prototype (not discharged, area of the negative part of the line) is constant in the two tests. This means that there are some portions of the prototype that cannot be "cooled" by the water circulation and it happens regardless of the variation of the load entity and probably depending on the prototype section geometry, which is the farthest from the pipes. This may depend on the low conductivity of the PCM layer (0.2 W(m*K)).

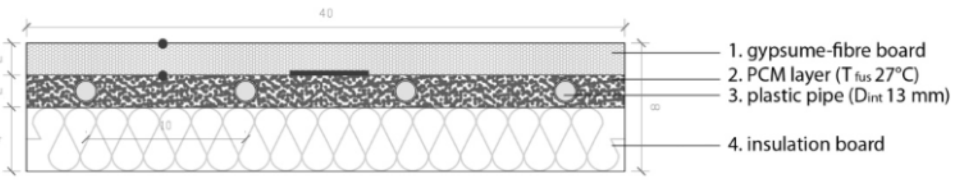

Figure 5. Dry floor prototype cross section

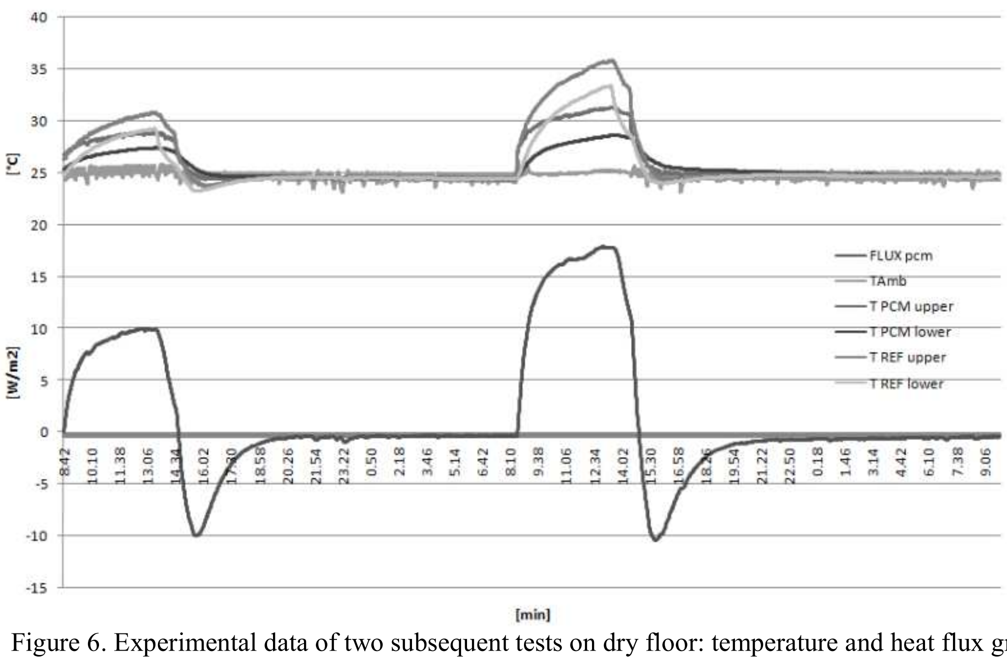

Figure 6. Experimental data of two subsequent tests on dry floor: temperature and heat flux graphs

5 CONCLUSIONS

This study addresses a research which regards the design of high-tech building components capable of managing the surplus of thermal loads in indoor environment, through the introduction of high thermal inertia.

The technology used consists in the application of PCMs in radiant comfort systems components, in order to define a latent heat storing/discharging system, to integrate in common heating system technologies. Simulations and laboratory tests showed the high potentiality for this kind of system, in terms of temperature peak reduction (around 2-4 °C) and energy discharge. Nevertheless, this preliminary study made it clear that the design and optimization of these integrated components is a complex process, and the identification of the best quantity, dimension and performance strongly depend on the thermal load entity and on the entire design context (finishing features, water circulation schedule and so on).

In this perspective, a detailed knowledge of the main design parameters' sensibility to different thermal load classes is required, considering parameters such as PCM fusion temperature, the possible melting of different PCMs, the PCM layer's thickness, the diameter of pipes. In particular, technological solutions that increase the conductivity of PCM containing layers – supporting the heat flux transfer - look very promising.

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Sustainable environment in steel structures and industrialized insulations

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ABSTRACT: The construction industry plays an important role in sustainable development, mainly by the impacts on environmental issues. The employment of steel structures and industrialized insulations in building is considered one of the sustainable alternatives for construction. The objective for this research is to evaluate how buildings with steel structures and industrialized vertical insulations can contribute to diminishing environmental impacts. The methodology includes a bibliographic research about the main parameters used in the process of sustainable construction material selection, and investigation of the production and application processes of the main vertical insulation panels found in Brazil. With the collected data, an analysis was performed on the environmental implications for the use of insulation panels and the unpreparedness of the Brazilian industry in relation to sustainability. Established herein are some suggestions to aid those involved in civil construction in incorporating environmental sustainability in design of buildings with steel structures.

1 INTRODUCTION

Buildings have been one of the largest sources of environmental degradation in the last decades, due to resource consumption, energy use and material involved, not only in construction, but also in building maintenance during its useful life.

According to Campari (2006), Brazil has a construction culture characterized by the use of reinforced concrete as the structural system and of traditional masonry for its vertical closing. Concrete preparation and masonry walls at the work site do not require skilled labor, which is important in Brazil where there is an abundance of labor. Independent of its technical and plastic qualities, reinforced concrete is the cheapest material for structural use and needs manual labour and cheap labor to be feasible, qualities that adapt to the needs of an under-developed country.

Residues are generated during the building construction process, by demolitions and restoration. In Brazil, 98% of the jobs use traditional methods. The typical rubble, heavy material left from the construction, is a great part in the form of mortar, around 60% (Campari 2006).

In a country like Brazil, with its magnitude, level of development and resources, it seems inevitable that there would be a change of values for architecture to include sustainability, because there is not sustainable development without sustainable construction.

The fact that construction continues to use primitive and polluting methods indicates that a great part of the professionals connected with civil construction are not familiar with the advantages of industrialized construction, and as such, do not contribute to the appearance of new technology related to avoid energy waste and soil pollution with residues.

The employment of steel structures and industrialized insulations in buildings is indicated as one of the sustainable alternatives for construction because it combines speed, quality and rationale, and removes an array of precarious and primitive activities from the work site.

The majority of the developed countries use industrialized panels for vertical closing of the construction. In this case, constructors plan the job as if they were assemblers, grouping the part suppliers within the work site and minimizing the environmental impacts. Promotion of more industrialized practices and techniques and more efficient management of resources and residues become the construction more environmentally sustainable.

This research had as its objective to evaluate how buildings with steel structures and industrialized vertical panels can contribute to the lessening of the environmental impacts caused by Brazilian civil construction.

2 METHODS AND MATERIAL

The first stage of the methodology involved a bibliographic research about the criteria adopted by the major certifications of sustainable performance used in Brazil for the selection of materials. This was done to identify the issues associated with the criteria of choice of materials from the perspective of sustainability in order to establish a reference for research on industrial panels and the environmental benefits when they are used. The investigated criteria were structured on the references: North American LEED (Leadership in Energy & Environmental Design) Certification, Brazilian technical reference Aqua (High Environmental Quality) and the Brazilian certification SustentaX.

The second stage of the methodology involved investigating the production and application processes of the principal types of industrialized vertical insulation panels available in the Brazilian market. The information was obtained by bibliographic research, visits to factories, and interviews with suppliers. The panels analyzed were: Plasterboard (also called gypsum board) from the Knauf company, cement board from Brasilit, OSB (Oriented Strand Board) panels from LP Brasil, and reinforced concrete panels from Premo and Precon companies.

3 RESULTS AND DISCUSSION

3.1 *Criteria for choosing materials for sustainable buildings*

The LEED system is a North American evaluation model that was established for use in the United States. While adaptations of this system weren´t approved in Brazil, LEED is being used as an auxiliary tool for design and certification for sustainable buildings in the country (US Green Building Council 2005).

AQUA, the first certification for sustainable construction adapted to the Brazilian reality, is inspired on the French HQE (Haute Qualité Environnemental) certification methodology. The adaptation of this certification for Brazilian particularities was presented in 2007, by Fundação Vanzolini, a non-profit private institution. The technical referential for certification available in the Brazilian version is the “Buildings for the service sector – Process AQUA. Offices and school buildings” (Referencial 2007).

The Brazilian certification SustentaX, furnished by the Brazilian company SustentaX that analyzes products according to sustainable socio-economic criteria, attested quality, and socio-environmental responsibility of the producer. The certification is conferred on products that meet their requirements (Grupo Sustentax 2009).

The relative criteria for choice of construction material from the three models of certification analyzed are presented below:

- Meeting of the standards in vigor for quality and product specifications
- Low emission of volatile organic compounds (VOCs)
- Minimum water consumption
- Employment of regional material
- Thermal and acoustic insulation
- Use of non-toxic sources in the composition of the products

- Producer's environmental responsibility
- Reuse of raw material
- Salubriousness of the products
- Use of recycled content and post-consumer recycled content
- Use of certified wood
- Use of material classified as rapidly renewable
- Great durability, adaptability, dismountability and potential of reuse
- Easy maintenance and conservation
- Diminishment of the socio-environmental impacts caused by construction
- Optimization of the management construction residuals – minimization of residual production and recycling or reutilization of the material
- Reduction of the annoyances, pollution and resource consumption at the work site

For the analyses of the principal industrialized vertical panels existent in the Brazilian market, the following aspects were investigated: production process, environmental impact, composition, certified quality production program, existing production standards, flexibility and potential for reuse, furnished dimensions, thermal and acoustic insulation, finishing possibilities, local extraction of raw material, plant localization and distance from the place of raw material extraction, origin of the other components, recycled content from the plant and post-consumer, production residuals, durability, maintenance, material toxicity, assembly and transport to the work site, and finally, the amount of water and energy used in production. Besides this data, the specific advantages and disadvantages in the utilization of each panel were studied.

3.2 *Analysis of industrialized vertical panels –Plasterboard*

The plasterboards are used as part of the system Drywall, suitable for fencing vertical indoors and low-humidity spaces of buildings. Drywall are lightweight closings and do not have a structural function. They are composed of a rigid structure from by galvanized steel frame to which are bolted one or more panels on both sides. The steel structure is fixed to existing construction elements. Besides the panel and the structure, screws, jointing products, tapes and metal accessories are necessary for installation.

Calcium sulfate, the principal raw material, is extracted in mines and transported by truck to the factory. The mineral is fed into an impact crusher that reduces is size. Afterwards, it goes through a grinding and calcinations stage, where it loses 75% of its water, and becomes a powder known as plaster. It is then mixed with water and additives, forming a paste that is fed between two sheets of recycled paper in a continuous rolling process. Finally, the panels are dried, cut and sanded. The whole procedure is highly automatic. During the production process, the factory liberates water vapor into the atmosphere; a result of the drying process. Also, there is a small amount of production residues that can be recycled. The greatest environmental impact occurs in the raw material extraction process and in the transport to the factory.

In the post-consumer recycling of the plasterboard, the panels should be separated from the other material and stored in a dry place. The residuals should be directed to the sorting and distribution areas that use the material again in the production chain. There are at least three ways to reuse and recycle the material: a) in the cement industry – the plaster is a necessary material that acts as a setting retardant for the cement; b) in the agricultural sector – the plaster is used as an acid corrector for soil; and c) in the plaster industry – the production process for it can reincorporate its residuals (Drywall 2009). Considering the Knauf plasterboard panels the principal characteristics are presented below:

- Usage limitation: utilized in internal areas; without a structural function.
- Composition: calcium sulfate (gypsum), recycled paper, water and additives (liquifier, starch, foaming agents, dispersants, etc.).
- Quality control programs: SPQ-Drywall (Sectorial Program for Drywall Quality), ISO 9001:2000- Quality management systems-Requirements.
- Production standards: NBR 14715:2001 – Plasterboard- requisites; NBR 14716:2001 – Plaster-board– Verification of geometric characteristics; and NBR 14717:2001 – Plasterboard – Determination of physical characteristics.
- Flexibility and reutilization: the drywall system can easily be mounted and dismounted, and can be reutilized.

- Used dimensions: width- 1.20 m and 0.6 m; length- varies from 1.8 m to 3.6 m; thickness- 9.5 mm, 12.5 mm and 15.0 mm.
- Thermal insulation: thermal conductivity of 0.16 kcal/h.m².ºC.
- Acoustic insulation: 35 to 37 dB (frame structure of 48 mm and 2 panels of 12.5 mm).
- Finishing: accepts any kind of finishing.
- Location of the principal raw material extraction: Araripina- Pernambuco.
- Plant localization/distance from raw material source: industrial district of Queimados- Rio de Janeiro/ 2.150 km.
- Components and origin: recycled paper- Germany; starch- Minas Gerais; and liquifier- São Paulo.
- Recycled contents from production and post-consumer: the paper is recyclable- it makes up around 0.5% of the total weight of the product. The plaster, in post consumer is 100% recyclable.
- Production waste: small amount of production residuals; a good part is recyclable. The water utilized in the process is recycled or evaporated in the drying process.
- Durability: minimum of 30 years with adequate maintenance and usage.
- Maintenance: cleaning – done with a sponge and detergent (avoid the use of great amounts of water). Small repairs are made with mortar, for treating joints or plaster.
- Toxicity of the product: no-odor, non-toxic panel.
- Assembly: simple, using small tools.
- Transportation to the work site: the system is composed of lightweight material- diminishes cost and pollution.
- Advantages: flexible, lightweight panel, plaster is 100% recyclable, small amount of production residuals.
- Disadvantages: raw material is not renewable, moderate useful life, utilizes only in internal areas, raw material extracted far from the processing plant.

3.3 Analysis of industrialized vertical panels – Cement board

The system that supports cement board can serve as either a structural element or a type of closing and it is composed of galvanized steel frame (Drywall or Light Steel Framing), fixation elements, mortar and tape for the joint treatment.

The cement, which is the principal material utilized in the panel production, comes processed from the Holcim factory and uses raw material from the State of São Paulo region. The extraction of the raw material for the manufacture of cement (limestone, clay, silica and pirite) is done by detonation or scrapping. During the production process, the factory produces a minimum quantity of residuals, which can be reintroduced in the manufacturing process. The materials that cannot be recycled are disposed of in an adequate manner by outsourced firms. The utilized water is treated and reused internally. The greatest environmental impact occurs in the raw material extraction process for the manufacture of cement and its transport.

The manufacture of the panels is automatic and done in series. The raw material is mixed automatically and the equipment used reduces the time, and number of employees needed for the process. It also provides a more uniform composite control and a better overall product quality, producing a smooth surface and high resistance. After densification, the panels pass through a curing process. Considering the Brasilit cement board panels the principal characteristics are presented below:

- Usage limitation: utilized in internal and external areas; the system can be structural function.
- Composition: water, cement, aggregates of natural cellulose and synthetic polypropylene fiber.
- Quality control programs: provisions being made to obtain ISO 9001:2008 certification in 2010.
- Production standards: there are no specific Brazilian standards (American standards are adopted).
- Flexibility and reutilization: the system can easily be mounted and dismounted and reutilized.

- Used dimension: width-1.20 m; length-varies, can be 2.0 m, 2.4 m or 3.0 m; thicknesses-6.0 mm, 8.0 mm, 10 mm and 12 mm.
- Thermal insulation: thermal conductibility is 0.35 W/m.K.
- Acoustic insulation: 45 dB (frame structure with 90 mm and 2 panels of 10 mm, one on each side).
- Finishing: permits the application of various types of finishing.
- Location of the principal raw material extraction: the Portland cement is processed in Sorocaba- São Paulo. The raw material for the production of the cement is extracted in the State of São Paulo.
- Plant localization/ distance from raw material source: Capivari-São Paulo/ 75 km (from the cement plant).
- Components and origin: polypropylene fiber – Jacarei- São Paulo; cellulose - State of Paraná (of controlled and certified origin).
- Recycled contents from production and post-consumer: the utilized cement has part of its raw material coming from recycled products, such as plaster and slag. Recyclable potential before consumption: the panel can contain up to 2% of the residuals from its own manufacturing process. In the recycled post-consumer material can also be used, respecting the 2% limit of the composition.
- Production waste: its manufacture produces only a small amount of residuals; a good part can be recycled. The utilized water is recycled in the plant. The residual not reused are correctly disposed of by outsourced companies.
- Durability: more than 50 years with proper maintenance and use.
- Maintenance: generally occurs in the coating of the panels.
- Toxicity of the product: non-toxic product.
- Assembly: simple, using small tools.
- Transportation to the work site: the system is composed of lightweight material- diminishes cost and pollution.
- Advantages: flexible, lightweight panel, long useful life, can be recycled, moderate built-in energy, raw material extracted close to the processing plant.
- Disadvantages: raw material is not renewable; high emission of pollutants in the manufacture of cement.

3.4 Analysis of industrialized vertical panels– OSB (Oriented Strand Board) panels

The OSB panels are indicated for wall insulations, together with a Light Steel framing system, composed of steel frames, fixation elements, mortar and tape to treat the joints. The external panel should always receive a barrier against water and wind, which afterwards, could accept whatever type of finishing.

The principal raw material used to manufacture OSB is reforested Pine wood, a renewable source and generator of carbon credits. There is no recycled material in its production and the panels are not recyclable after usage. However, it can be reused.

The factory has reservoirs that store rain water, which is treated and used in the manufacturing processes. It also used evaporated water. The principal environmental impact from the manufacture of OSB panels is the synthetic resin using formaldehyde, which is used to glue the wood fibers. These resins can be the source of formaldehyde vapor that irritate the eyes, nose and throat (Roaf 2006).

The atmospheric emissions generated by the factory comes from particulate material (raw material that accumulates in uncovered areas subject to a high incidence of storms) and from the burning of fossil fuel.

The manufacturing process of these insulation panels is completely automatic. When the tree trunks arrive at the factory, they are cleaned, debarked, and transformed into the strips that compose OSB. The strips are then dried, sieved and sprayed with resin for gluing. Afterwards, they are distributed in layers and pressed at high temperature, forming sheets ready for cutting. The productive process makes use of all the residues, such as bark and left over wood. It is used to feed the furnaces that generate the energy and necessary heat. Considering the LP Brasil OSB panels the principal characteristics are presented below:

- Usage limitation: utilized in internal and external areas; the system can be a structural function.
- Composition: Pine wood, MDI (biphenyl methane di-isocyanate), phenological resin (synthetic resin alloy) and additives having a ciflutrine base.
- Quality control programs: new factory, undergoing certification processes.
- Production standards: there are no specific Brazilian standards (North American standards are adopted).
- Flexibility and reutilization: can be easily mounted and dismounted with a Light Steel framing system. Besides this, if there is a polyethylene membrane or other type of finishing, these too, should be dismounted.
- Used dimensions: width-1.22m; length-2.44m; thickness-9.5 mm, 11 mm, 15 mm or 18 mm.
- Thermal insulation: not furnished by the manufacturer.
- Acoustic insulation: not furnished by the manufacturer.
- Finishing: in external insulations, the panels should be protected against the weather. Generally, a high-density polyethylene membrane is used. The final finishing can be: mortar coating, brick, texture, vinyl siding, wood siding or fiber cement siding.
- Location of the principal raw material extraction: Pine wood comes from reforested farms that practice sustainable management and are located in a maximum radius of 150 km from the factory.
- Localization of the factory/distance from principal raw material: Ponta Grossa- Paraná/ 150 km.
- Components and origin: the origin of the other components was not informed.
- Recycled contents from production and post-consumer: recycled material is not used in the process and the panels are not recyclable after usage, however, it can be reused.
- Production waste: 100% of the raw material is utilized. The water utilized in the factory is pluvial, collected in wells.
- Durability: 10-year guarantee against termites and 20-year guarantee for the structure.
- Maintenance: generally involves panel finishing.
- Toxicity of the product: non-toxic product. It has a low emission of formaldehyde, which does not affect the well-being and health of the people.
- Assembly: simple, using small tools. In external insulations, after the panels are mounted, the OSB should be covered with a polyethylene membrane and afterwards, finished as desired.
- Transport to the work site: The system is composed of lightweight material- diminishes cost and pollution.
- Advantages: flexibility, lightweight, uses renewable resources, low energy process, 100% raw material usage, CO_2 sequestration, raw material extraction close to the factory.
- Disadvantages: moderate useful life, cannot be recycled, needs preservative treatment, contains formaldehyde.

3.5 Analysis of industrialized vertical panels – reinforced concrete panels

Reinforced concrete panels are vertical insulations that can be industrially produced or produced at the work site. These panels have some characteristics that differentiate them from the others analyzed prefabricated panels, such as: they’re heavier; they are not used as components in structural systems of the Light Steel Framing or drywall type; they can be used as structural elements or closing; they can be manufactured in various dimensions; and the finishes can be incorporated in the manufacturing process, eliminating extra finishing costs, resource waste and pollution at the work site.

The cement utilized in the production comes processed from the Holcim plant, located in an industrial area near the factories. The other components for the manufacture of concrete, such as sand and gravel, come from regions close to the plant. The greatest environmental impact occurs in the raw material extraction process for the manufacture of concrete and its transport.

The production process begins with the determination and making of the forms or molds. Afterwards, the steel frames are positioned. In the case where the finishing is incorporated in the product, the finishing layer is positioned at the bottom of the mold, followed by an adherence barrier and then a frame and at last, the concrete is poured. The finishing can also be done with an acid attack, spraying the sand or cement setting inhibitors that disguise the irregularities and slightly exposes the aggregate. The panels can also receive a polishing or incorporate finishing with ornamental stones, texture, color, ribs or false joints (Silva & Silva 2004). After a certain time, the panel can be removed from the form and should be submitted it a humidity cure.

The lack of standards for the closing panels can result in the waste of the forms. It is important that in the phase of design, the number of types of panels to be utilized should be minimum, guarantying a greater standardization of the production, reducing costs and operational and increasing the speed of manufacture (Silva & Silva 2004). Considering the Premo and Precon reinforced concrete panels the principal characteristic are presented below:

- Usage limits: they are more utilized externally, due to their weight. Can have structural function.
- Composition: water, cement, sand, gravel, steel, non-toxic additives (chemically neutral elements), stones (in the case of panels with exposed aggregated) and in some cases, pigmentation.
- Quality control programs: ISO 9001: 2000 certified.
- Production standards: no existing in effect in Brazil.
- Flexibility and reutilization: they are heavyweight panels and because of this, they are difficult of maneuver and transport. The opening of new gaps or the placing of new window or door frames after manufactured and installed is infeasible.
- Used dimensions: dimensions, forms and geometry are determined in function of the customer's needs. The dimensions can vary: length in up to 12 m, height in up to 3.5 m and thickness from 10 cm to 18 cm.
- Thermal insulation: not furnished by manufacturer.
- Acoustic insulation: not furnished by the manufacturer.
- Finishing: the finishing can be incorporated in the manufacturing stage.
- Location of the principal raw material extraction: cement, that comes already processed from the Holcim Company located in the region of Pedro Leopoldo- Minas Gerais (MG). In some cases, white cement is used- from Egypt.
- Plant localization/distance from raw material source: Premo, Pedro Leopoldo- MG/ 10 km (from the cement factory); Precon, Vespasiano- MG/ 30 km (from the cement factory).
- Components and origin: Precon – industrialized artificial quartz sand, Cachoeira da Prata-MG; gneiss stone and gravel, Betim- MG; steel elements, Belgo Company, Juiz de Fora-MG; pigments, São Paulo region. Premo – gravel and sand, from the region (radius of approximately 10km from the factory); steel elements, Belgo Company, Juiz de Fora- MG.
- Recycled contents from production and post-consumer: the utilized cement has as part of its raw material some recycled products, such as plaster and slag. The steel used in the panels can have a recycled origin. In the post-consumer, the panels can be recycled as a base for pavements, after crushing.
- Production waste: only a small amount of residuals are generated during the manufacturing process and these are used in the process itself. In the case of panels with manufacturing defects, these panels are discarded in an appropriate deposit. Water is treated. The metal from the forms can be sold to the recycling plant or re-used.
- Durability: the panels have a 50-year guarantee, but can last longer.
- Maintenance: the principal maintenance problems are the treatments necessary to clean the surface. The joints need to be constantly checked and replaced when necessary.
- Toxicity of the product: non-toxic.
- Assembly: the panels are crane-mounted because of their weight. They can be mounted on slabs, pillars or beams using metallic inserts and screws, bolts or soldered or else, using concrete consoles.
- Transportation to the work site: the heavyweight panels increase costs and pollution.
- Advantages: long useful life, can be recycled, built-in moderate energy, less waste, factory-finished, can choose the dimensions according to the job.
- Disadvantages: heavyweight panels, lack of flexibility, non-renewable raw material, high emission of pollutants from cement manufacture, lack of standard sizes and waste from forms.

4 CONCLUSIONS

Noticeable are the following positive implications in the use of industrialized panels and steel structures: less water consumption and resource waste at the work site; clean job; less pollution and waste in general and as such, less socio-environmental impact; improved quality as they are more exact and less defective; easy mounting and dismounting and reuse of panels without causing residues (in the case of panels used in the Light Steel framing or Drywall systems); at the end of useful life, the metallic components can be dismounted and reused or recycled without diminishing their properties; faster construction; and possibility of better acoustical and thermal insulation when used with insulations such as glass wool or rock wool between the panels.

Although they are an excellent solution, the industrialized products have a high cost when compared to traditional methods for construction and require more skilled labor for mounting. This makes the system infeasible for greater part of the Brazilian constructions.

Also, it can be concluded from this research that the Brazilian industry is unprepared to deal with sustainable production and the disposal of the final products. It was found that a majority of the manufacturers do not have all the information necessary to evaluate the sustainability degree of the products they offer. None of the producers were able to inform the amount of water and energy spent in the panels production. Some did not have precise information about the origin of the components involved in production or about the thermal and acoustical properties of the material.

The suppliers should have accurate information about environmental initiatives, resource costs for production and the thermal and acoustical properties of the industrialized panels, so as to facilitate the selection and specifications for the most ideal constructive material for each construction. Besides this, the manufacturers should adopt measures to increase the environmental performance of the products, such as: retain and utilize rain water in the production process; invest in renewable sources of energy; promote initiatives that compensate environmental impacts from production; give preference to the use of CPIII cement, which is composed of 60 to 70% of sub-products from other industries and has less built-in energy, etc.

Herein are some suggestions for the incorporation of environmentally sustainable concepts in design of steel-structured building: expose the structure and as such, reduce the amount of material applied in the finishing; utilize industrialized insulation components; research forms of reuse and recycling of components before making their choice; design for deconstruction, reuse and recycling of the material; design modular construction using prefabricated units (taking into consideration the dimensions of the supplied panels, to avoid cuts in panels and residuals at the work site); procure panel solutions that are close to the work site to avoid transport pollution; think about flexibility and adaptability of the building ambience (can be facilitated with the use of closing systems of the Light Steel frame or Drywall type); consider the compatibility of architectural design and the dimensioning and detailing of the industrialized construction system.

Most difficult is to find all the sustainable aspects in one material. The priority should be to decide which is most suitable for each situation, searching for solutions with the least amount of environmental impacts that would be compatible with the context and needs of the building design.

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Environmental architecture design applied to high performance industrial buildings – Ladoeiro industrial production of alcohol

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ABSTRACT: Over the last century, industry suffered significant changes in construction methods, production processes and implementation planning. Despite it has strong impact on surrounding environment, territory and development of urban areas. However industrial buildings architecture not always contribute to environmental performance.

It´s possible, nowadays, to integrate in architecture sustainable strategies to ensure environmental comfort, reducing environmental loads, and guarantee efficient energy, water and materials consumption. Proper environmental management and implementation of innovative strategies may also contribute to greater productivity.

There are design solutions that can be applied to any industrial building based on Portuguese environmental certification system LiderA 2.0b. These support the development of an architectural project as case study for Ladoeiro industrial production of alcohol. Therefore, were developed several efficiency analysis, promoting architecture environmental integration, reduction in resource consumption and environmental comfort of buildings, to determine the level of performance achieved by LiderA system.

1 INTRODUCTION

During industrialization period, industrial plants have radically changed landscape, causing increased pollution and environmental degradation, threatening the consistency of historic cities (Figueira, 2005), contrary to the thesis of modern city, which indicated zoning and rationalization of urban land.

The evolution of industrial buildings can then be characterized by (Grube, 1972):

- Improvement of health conditions in working areas, in terms of lighting, ventilation, hygiene and work safety;
- Improved construction techniques (brick, stone and wood, gave rise to iron, zinc, steel, glass and concrete, and to innovative, economic and rational construction methods (Tietz, 2000));
- Relocation of industry, from major urban areas to peripheral accessible industrial areas;
- Increased energy consumption from natural resources, derived from the automation of production processes;
- Growth of business, resulting from the globalization of markets.

The development achieved at present didn´t appear in a sustainable way, which led to serious environmental problems such as climate change, biodiversity loss, increasing pollution and lack of standards for sustainable production and consumption. However, is growing a worldwide concern with environmental protection.

The economic growth and technological development reflects in current industry whose production logic is based on speed, simplicity, mass and low cost production.

However, the relationship of buildings with environmental performance still requires action from designers. The search for new architectural strategies can lead to the promotion of an industrial building industry more sustainable, innovative, competitive and profitable.

Sustainable architecture must be innovative as the architecture itself requires.

Today´s architects have the responsibility to assess social, economic and aesthetic relations between industrial complex and environment (Grube, 1972). They must ensure the necessary conditions of comfort, energy efficiency, environmental quality, architectural form and materials, introducing design strategies for environmental performance.

The aim of this work is to systematize and analyze different sustainable design solutions and environmental criteria that can be applied to any industrial building.

2 ENVIRONMENTAL PERFORMANCE OF INDUSTRIAL BUILDINGS

The industrial architecture has evolved considerably in recent years, however it was noticed that the universe of buildings that incorporate sustainable strategies is still very limited.

Large companies have come to realize that the application of sustainability measures allows them to produce more efficiently, enhancing its brand image and differentiate them from competition (Gauzin-Müller, 2003).

To meet new market demands, industry begins to integrate issues of environmental performance in its activities, adopting cleaner production technologies, creating products with better environmental performance, environmentally certifying their processes, products and services.

Currently there are also several voluntary assessment and classification systems that evaluate and promote environmental performance of buildings. Each country has developed its own system with different forms of analysis and criteria. These were developed to promote sustainable construction, based on checklists associated with tables of performance certification.

The implementation of recent environmental performance systems, is motivating voluntary action of industries, although its accomplishment not always induce to architectural quality.

For the environmental certification of built environment in Portugal, there is the voluntary system LiderA version 2.00b (LiderA, 2009), adapted to the country's reality. This system brought to Portugal the incentive of sustainability in buildings, although it still didn´t certificate any building or industrial complex.

Industrial buildings by their shape and size can greatly contribute to the implementation of sustainability measures, thus reducing the environmental impact of buildings while contributing to the improvement of design features in order to achieve the desired comfort.

Nevertheless the environmental impact of each industry varies, depending on its type, consumed resources, manufactured processes and products.

The application of sustainability measures in planning and analysis of the entire lifecycle of built environment (design, construction, renovation and demolition) can significantly contribute to improve its environmental performance. This is why the evaluation systems of environmental performance can have a strong contribution to achieving sustainability in industrial buildings.

The identification of sustainability criteria to assess the industry is a key factor in the evaluation and planning of sustainable construction. These criteria must be intrinsic to the creative process, being underpin in the projects decisions and serving as support for the recognition of sustainable building practices. To improve the structure of these measures were defined different strategies based on sustainability criteria of LiderA version 2.00b.

3 CASE STUDY – LADOEIRO INDUSTRIAL PRODUCTION OF ALCOHOL

This work develops a design concept for a distillery to install in the Portuguese industrial area of Ladoeiro, Idanha-a-Nova. This is an author's proposal whose development has been accompanied by research on sustainability strategies applied to industrial buildings.

The investment is based on a project in development, unique in Europe, pioneer in the study and production of new crops for ethanol (sorghum and sugar cane). This is an ambitious project to be undertaken by Mr Dilipcumar Dulobdas. This project aims to encourage the culture of new energetic species adapted to this region.

The complex intends to install in a strategic area of proximity to production areas of raw material, along the road linking the Ladoeiro the Idanha-a-Nova, a ground infrastructure outside the city.

It was established a detailed program of built and non built-up areas for this industrial complex which was systematized according to the spatial needs of buildings and equipment. The functional organization and size of the building are closely linked with the production cycle.

Given the extension program it was decided to present the points that support creative thinking in architectural design. To this end, it was first a wider range of analysis of overall strategies, evaluating the potential for integration of the architecture in the environment. Next, it was evaluated the implementation of the building proposal, seeking to understand the functional strategies of the buildings.

The analysis that follow are designed to determine how the proposed architecture solution respond to climate and environmental issues in each major area of LiderA system version 2.00b, and further determine the level of environmental performance of the proposed project.

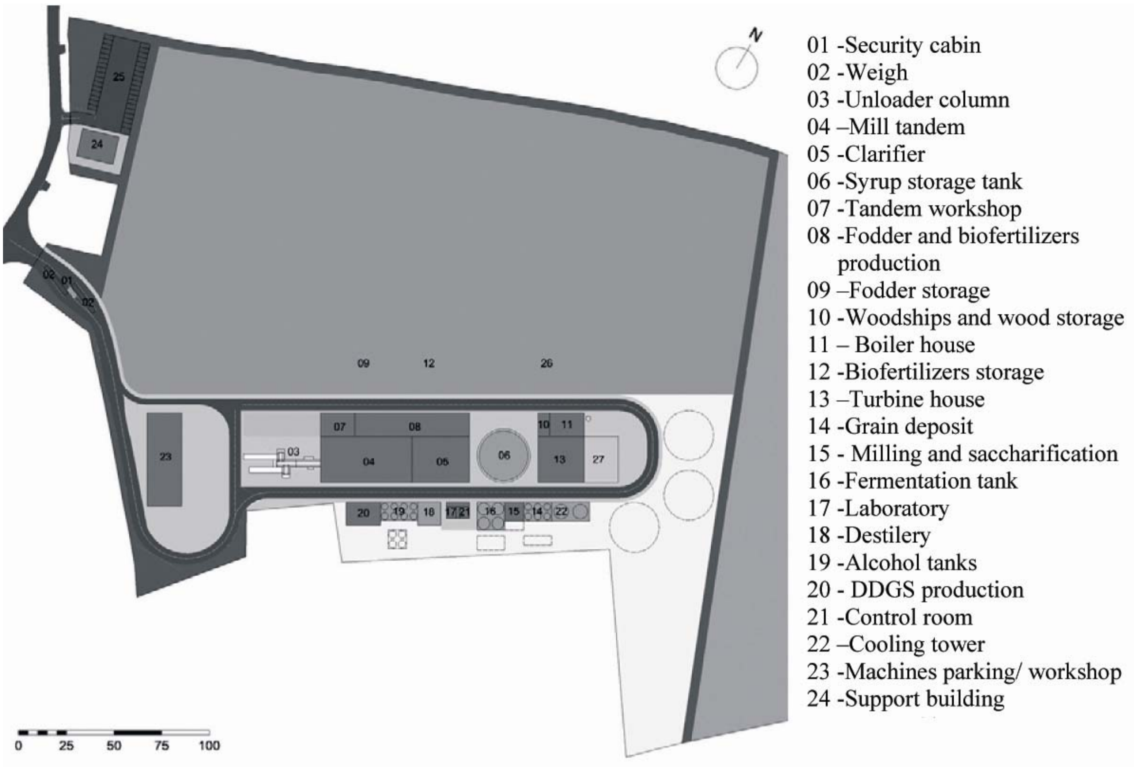

Figure 1. Proposal plan for Ladoeiro industrial production of alcohol.

Each area contains different functional requirements of comfort, and should be considered separately, so there will be develop architectural solutions covering a building or equipment for each type of building. It was chosen the industrial building of crushing and clarification, the support building, and honey tank storage, because they are elements of greater size and architectural interest.

The aim is to identify the design features applied to each of them and propose architectural solutions that improve their environmental performance.

The mill tandem and clarification warehouse is the building of larger proportions of this industrial complex, therefore has a strong impact on site. To better integrate the building were proposed several coatings and passive design strategies to make it more efficient.

The support building integrates all areas for employees. This building includes the reception for entry and exit of employees, offices, changing rooms, infirmary and cafeteria. It is build with ship containers with the association of sustainable strategies.

Given the large proportion of the syrup storage tank is proposed an external structure that minimizes visual impact, inserting a surrounding vegetation structure fed by rainwater collected from the roof.

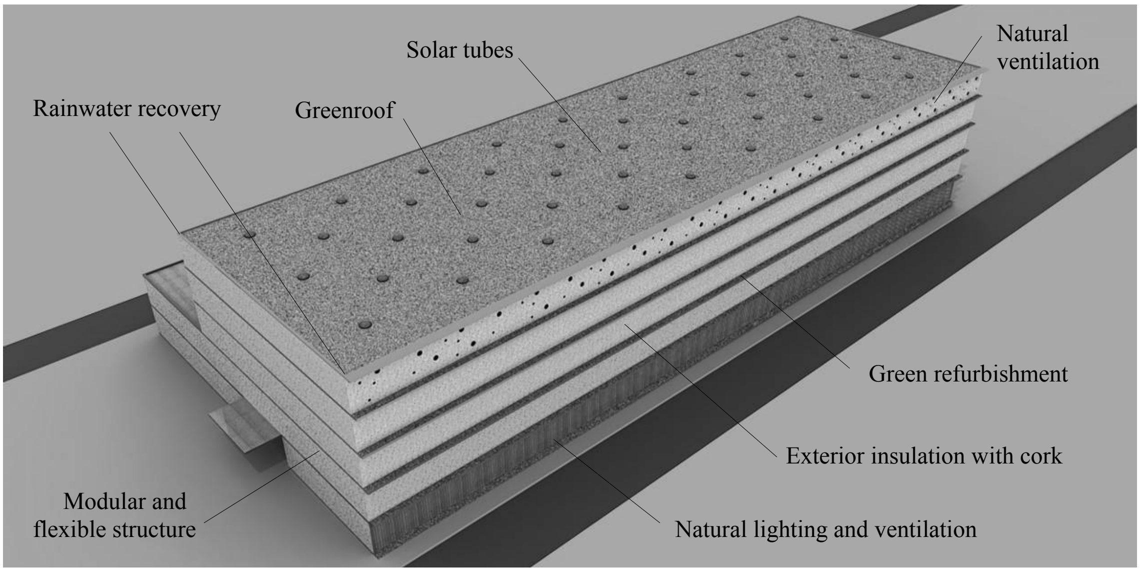

Figure 2. Architectural proposal for mill tandem and clarification warehouse.

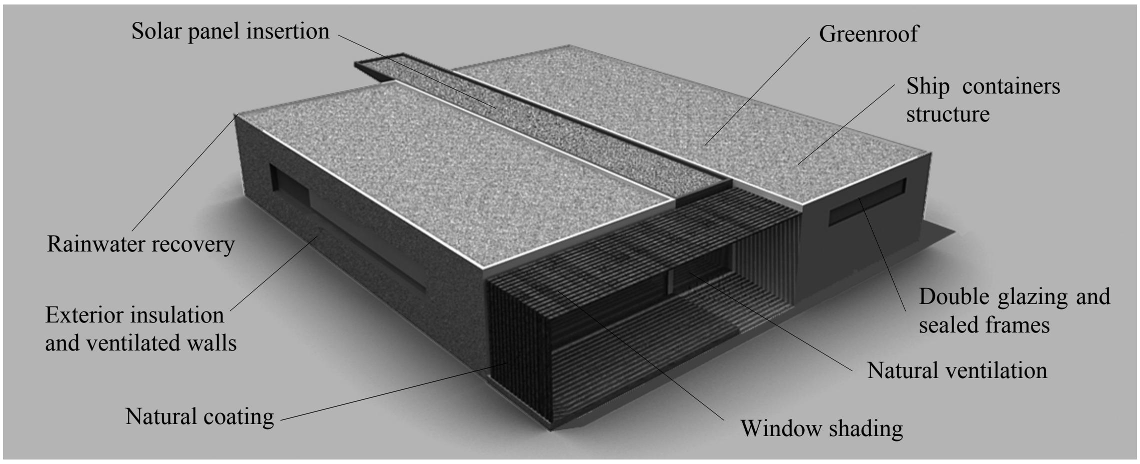

Figure 3. Architectural proposal for support building.

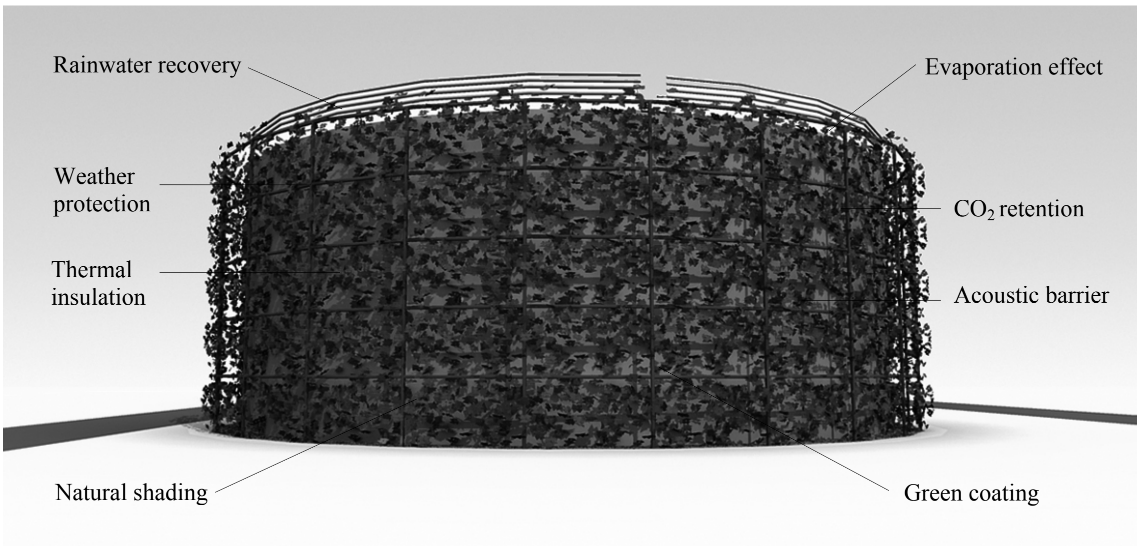

Figure 4. Architectural proposal for syrup storage tank.

3.1 *Bioclimatic considerations*

In order to identify the bioclimatic measures to integrate in buildings were proposed to the architectural solutions some of the bioclimatic strategies adapted to local climate.

Based on thermal and hygrometric data for an approximate area were built the Olgyay and Givoni diagrams of comfort.

The analysis determined that comfort can be reached during some hours in the period from May to October. However, it is recommended that during summer, to be used thermal inertia, evaporative cooling and natural ventilation indoors. In winter it becomes necessary to use solar active and passive systems to higher indoor temperatures and can be guaranteed the desired comfort conditions.

The industrial crushing and clarification building is a space of constant circulation of products and difficult to warm, therefore, there is the chance to naturally ventilate the interior, but whenever it´s too warm, above the comfort limit, it is proposed to provide evaporative cooling.

In the support building relies on the natural ventilation to cool the interior spaces. In summer it is essential to shade the openings with awnings or overhangs outside, which were designed according to the latitude of the site. But, because of the large temperature range, is necessary to complement with active solar systems that promote internal thermal comfort.

To restrict the losses and gains by conduction is intended to isolate the whole environment of the buildings with a material of national origin, cork. In support building the finish of containers is complemented with cork and ventilated facades.

3.2 *Construction materials*

The construction of industrial warehouses with steel structures is important to the normalization of the spacing between supports, minimizing cuts and waste material, which also simplifies the extension of buildings.

The integration of an extensive garden cover improves the thermal efficiency of the building. For the facades of the warehouse and tank was proposed the insertion of vegetation in order to minimize visual impact. The green walls act as ventilated façades, which shade the most exposed area to direct sunlight in summer and reduces the temperature of the facade through the evaporative effect of the plants. During winter is important to ensure greater exposure, which is possible through the adoption of deciduous plants.

It is also proposed the use of ship containers for the construction of support services. The main advantages of this system is the possibility of expanding space, simply by attaching new containers, serving many formal solutions suited to the needs of the company.

3.3 *Water*

To minimize primary water consumption it´s proposed the underground collection and storage in deposits of rainwater collected from building roofs.

By analysing the estimated annual captured rainwater of the roofs, it can be concluded that there is great potential for recovery of rainwater to support the solutions of vegetation and garden areas without using primary water.

Supported by the recent certification of water efficiency products was established a comparison of conventional water devices with devices category A, classified by this system. For this analysis were evaluated only the sanitary devices from the support building to be used by all workers. It´s estimated that the inclusion of category A systems reduces to 52% of water consumption which corresponds to a reduction in annual consumption of 82,204 liters of water.

Table 1. Volumes of annual captured rainwater

Building	Roof area (m^2)	Volume (m^3)
Mill tandem and clarification warehouse	1872	108,333
Support building	215	12,442

Table 2. Comparison of water consumption between conventional and category A systems. Estimated consumption for 136 employees.

Product	Consume (l/s)	Use /person (min)	Day consumption (l/day)	Monthly consumption (m^3/month)	Annual consumption (m^3/year)	Total consumption (m3/year)	Total consumption (%)
Shower	0,15	5	6.120	184	67.014	169.769	100
	0,08	5	3.264	98	35.741		
Sink	0,10	4	3.264	98	35.741		
	0,03	4	979	29	10.722		
Urinal*	6,00	3	2.448	73	26.806	82.204	48
	2,00	3	816	24	8.935		
Flush*	9,00	3	3.672	110	40.208		
	6,00	3	2.448	73	26.806		

* Consumption in l/use and number of daily uses.

3.4 *Natural and artificial lighting*

To determine the best natural lighting were tested two solutions of North oriented windows using models developed in Ecotect software. It brought to the conclusion that the cover 2 is more efficient, managing to achieve the desired luminance that the cover 1 does not reach. The best is to adopt solutions that reduce the need for artificial lighting and ensure the thermal comfort inside. In this case it´s proposed a prefabricated solution, efficient and economic, which facilitates the introduction of natural light into spaces of great depth, the solar tubes.

To determine the need for artificial lighting in the crushing and clarification warehouse were made several simulations of lighting in RELUX software. This study aimed to determine the potential for installation of lamps with Led bulbs, more efficient and durable, replacing the common bell equipped with metal halide lamps (HPI-BU). The lamps with Led can achieve the same brightness and greater uniformity with less power. This requires a much higher initial investment but ensures a reduction of annual consumption. Because Led lamp contains an increased level of protection and incorporates newer technology, its cost is very high, which still makes this equipment less competitive.

Table 3. Comparative analysis of luminaires

Use (h):	1440	Electricity (€/kW):	0,27		Luminaire (units):	39
	Unit consumption (W)	Unit annual consumption (kW/year)	Total consumption (kW/year)	Electricity annual cost* (€/year)	Luminaire cost** (€)	Total installation cost (€)
"RUUD" Led	207	298	11.625	3.139	2.920	117.019
"ARCLUCE" Radio	256	369	14.377	3.882	205	11.877
Difference	49	71	2.752	743	2.715	105.142

* Data provided by EDP, 2009
** Data provided by INOVODECOR, 2009

3.5 *Thermal analysis*

To test the comfort conditions inside the mill tandem and clarification warehouse were developed several models in Ecotect software based on coating solutions proposed for this building.

The determination of the contribution to thermal comfort was based on analysis of mean radiant temperature, for 15 September at midday, of four different solutions: simple coating plate, cover with garden isolation, total isolation of the environment, integration of a green facade.

Among the solutions proposed were detected improvements in the thermal comfort of the building.

3.6 *Rating the environmental performance by LiderA system*

The design concept developed was able to achieve a satisfactory classification - Class A, but with the outcome and greater definition of the requirements it will be possible to have new possibilities for improvement.

As the analysis of the criteria of LiderA held this industrial complex it appears that the measures required framing this project in terms of the classification, which means they propose measures for improvement of 50% compared to current building practices.

This is indeed a Preliminary Study project, but the progression of this project using the criteria of LiderA makes architectural approach more conscious and sustainable.

It is noteworthy that the measures taken do not intend to introduce additional costs to the project but to integrate a new approach to industrial architecture, making it more flexible and reducing its impact on environment.

4 CONCLUSIONS AND RECOMMENDATIONS

The functional organization is very effective for separating the various functions within the plant and ensures a well organized production cycle.

The proposed buildings are suitable for the local climate by incorporating the bioclimatic strategies, favoring indoor thermal.

The chosen coatings provide to buildings an aesthetic component that normally does not appear in most of the building industry, but simultaneously give it a value of functional improvement of environmental conditions.

The measures provide a considerable reduction in water and energy consumption which benefit company costs. It can be assumed that the described strategies guarantee the sustainability of Ladoeiro Alcohol Distillery, which becomes more efficient than the common industries.

It appears that some measures require a higher initial investment in the implementation phase however guarantee a return in near or medium term, besides improve the quality of buildings and minimize their impact on environment.

With the analysis of sustainable strategies for industrial built environment according to the criteria of LiderA version 2.00b becomes possible to systematize a set of strategies appropriate to the industrial Portuguese context. These measures came as a basis for design concept developed in the case study, serving as tools for the integration of sustainability in industry.

In future work would be important to define the weight and number of interventions for each criteria, and thus create a LiderA with thresholds adapted to the analysis of this building type.

The identification of sustainability criteria in the proposed architecture proved to be essential for the classification of LiderA. It has also deepened understanding of conceptual issues that must be prevalent in the architectural design of industrial buildings.

Monitoring of all phases of architectural design with sustainable solutions can lead to the promotion of a beneficial, innovative, competitive and profitable industrial activity.

It´s recommended as future work, the analysis and economic viability of this approach to other industrial buildings, so other investors be aware of the viability of strategies for environmental performance and the advantages of cost-benefit they may bring.

This lead to the conclusion that measures of environmental performance can make the industrial sector more competitive nationally and internationally. It´s essential to adopt environmental architecture design in industry, to differentiate it from international market.

5 ACKNOWLEDGEMENT

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The architectural project of Ladoeiro alcohol distillery is still under development by architect Maria Manso.

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Concepção e Automatização de Sistemas Passivos e Activos para uma Escola Net Zero Energy Building

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ABSTRACT: A utilização de técnicas passivas em edifícios escolares, das quais se destaca a incorporação de energias renováveis, complementada por técnicas activas, confere a esses edifícios um elevado potencial de auto-sustentabilidade. A sua automatização, através de gestão técnica centralizada, com a integração de actuadores com perspectivas inovadoras nos sistemas de ventilação natural e de sistemas de produção de energia renovável, potencia a classificação desses edifícios como NZEB (Net Zero Energy Building). O artigo apresenta a análise de um novo edifício escolar passível dessa classificação. Para tal, além do enquadramento bioclimático, deu-se particular atenção à componente da iluminação natural, aos sistemas de arrefecimento e aquecimento através de ventilação com permutador de calor ar-solo, colector de ar e efeito cruzado ou efeito chaminé, garantindo uma excelente qualidade do ar e conforto interior. Encontra-se ainda prevista a integração de sistemas auxiliares quando a componente passiva não consiga suprir as necessidades energéticas do edifício.

1 INTRODUÇÃO

No presente trabalho efectuou-se o estudo da implantação de um novo edifício escolar na localidade de Alcobaça, em Portugal. Fez-se um balanço energético do edifício utilizando técnicas passivas, das quais se destaca a incorporação de energias renováveis, complementadas por técnicas activas e gestão técnica centralizada, analisando-se assim, o potencial de auto-sustentabilidade do edifício (Ribeiro, 2008). A análise da acção do vento é preponderante para a caracterização da ventilação natural. Utilizou-se, nesse sentido os valores recolhidos na estação meteorológica de Alcobaça. Para definição da protecção aos ventos dominantes e diminuição da temperatura radiante foi utilizada vegetação de folha persistente, formando uma sebe viva, conforme esquema da Figura 1. A Tuia, da família das Cupressaceas, possui um alto débito de evapotranspiração, a qual regulariza e equilibra as condições climáticas extremas, criando um microclima. Foi a espécie nativa escolhida, devido à baixa porosidade conseguida na implementação de uma sebe viva, diminuindo a velocidade do vento até 90% (Brandle et al. 2005, D. L. 565/99).

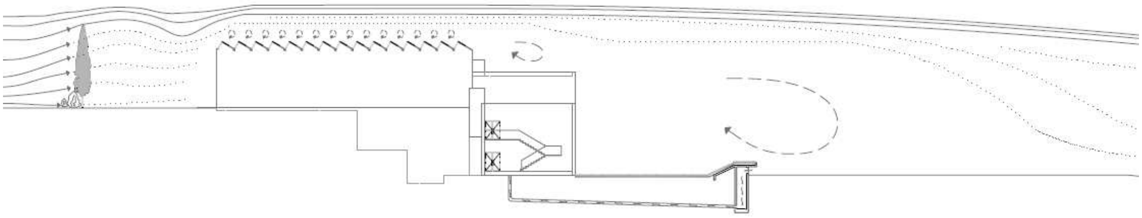

Figure 1. Esquema de vegetação em perfil para protecção dos ventos dominantes.

O edifício tem como espaço principal uma zona com salas de aula, com 56 m^2 cada. Aí existe um sistema de ventilação natural, composto por um colector de ar na fachada com quatro aberturas (registos de fachada automatizados) em cada secção de sala de aula, duas no nível inferior a 20 cm do pavimento e duas no nível superior a 50 cm do tecto falso. O colector é ainda composto por 6 módulos PV, montados sobre uma estrutura em alumínio, dispostos no sentido N-S, distanciados de 10 cm da parede. Os registos de fachada aqui implementados foram desenvolvidos por (Gonçalves 2005), no edifício Solar XXI, tendo neste edifício apenas actuação manual, deixando ao critério dos utilizadores a sua manipulação. Neste estudo automatizou-se o funcionamento dos registos, através de dois actuadores, um linear e outro rotacional, em cada registo, optimizando a sua utilização. Para se efectuar a ventilação cruzada foi colocada uma bandeira de lamelas de vidro orientáveis sobre a porta de cada sala de aula, as quais são abertas ou fechadas em função da temperatura, humidade e qualidade do ar interior, em comparação com a temperatura e humidade exterior, medidas por sensores aí instalados. O efeito da ventilação cruzada pode ser complementado com o efeito de chaminé, utilizando os corredores de circulação adjacentes, os quais têm um ducto que os interliga na vertical em todo o comprimento e formando uma saliência na cobertura, na qual são implantadas as grelhas de ventilação na sua face Sul (Figura 2).

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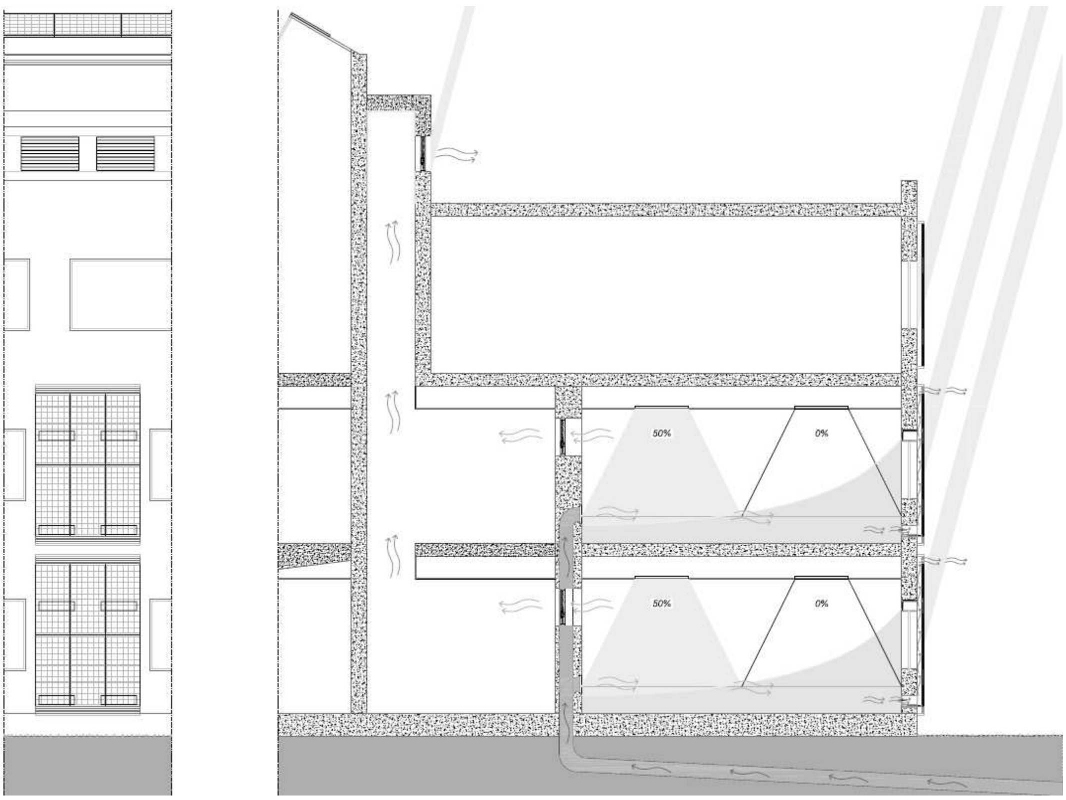


Figure 2. Sistema integrado de ventilação e iluminação natural com sistemas de fachada PV em colector de ar e permutador de calor ar-solo.

A colocação de um revestimento nos últimos 2 m do ducto, em chapa de alumínio polido, permite elevar a temperatura nessa zona, potencializando o efeito de chaminé. É ainda incorporado um permutador de calor ar-solo que utiliza manilhas de betão enterradas à profundidade de 3 m. Este possibilita a introdução de ar novo na sala de aula para aquecimento ou arrefecimento, conforme a estação do ano, uma vez que as condições de temperatura ao nível do solo são praticamente constantes. Obtêm-se daí vantagens evidentes tanto para o processo de aquecimento como de arrefecimento controlado por actuadores sobre registo de condutas circulares de ventilação. A difusão é efectuada por um ventilador, montado axialmente numa conduta metálica circular, com eixo a 65 cm acima do pavimento (Figura 3), servindo unicamente como meio complementar para assegurar a qualidade do ar interior, nas situações de inexistência de vento no exterior ou quando o nível de CO_2, estiver para atingir os valores limites regulamentares (EN13779, 2003). Toda esta manipulação é efectuada automaticamente pela gestão técnica centralizada, sendo unicamente permitido aos utilizadores modificarem alguns parâmetros durante um curto período de tempo, fim do qual a gestão assume o controlo. O sistema solar térmico projectado é composto por colectores interligados pela rede de tubagem primária, na cobertura. Este é composto por colectores parabólicos compostos (CPC), com uma área de 1,99m^2, dispostos segundo a orientação E-W em suporte metálico de montagem em cobertura plana e com uma inclinação de 60º, de modo a obter o máximo rendimento para o período de Inverno e minimizar os ganhos nos meses de Julho e Agosto. Neste período as necessidades de água quente são praticamente nulas.

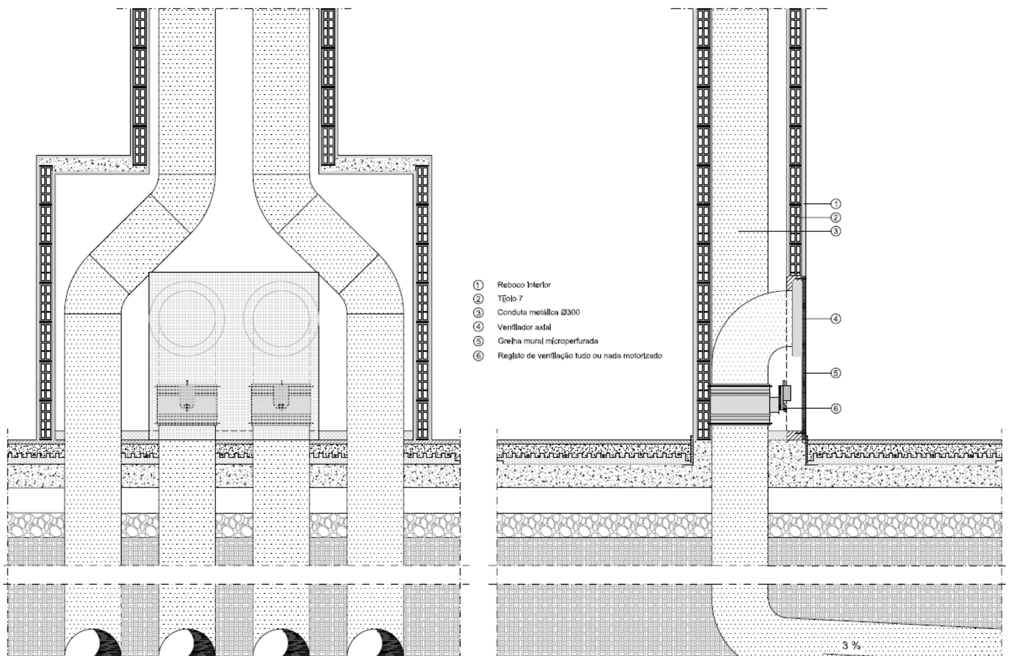


Figure 3. Pormenor com vista frontal (esq.) e corte (dir.), do ducto e difusão de ar do sistema de permutador ar-solo no piso 0.

Os 64 colectores serão alinhados com o azimute Sul, em paralelo de canais, formando baterias de 4, com uma interdistância mínima de 2,5m, para que no dia mais desfavorável, 21 de Dezembro, às 12horas, nenhuma área do colector esteja com sombreamento. Este sistema será a fonte principal de aquecimento ambiente e AQS do edifício. No aquecimento foram utilizados dois sistemas distintos, piso radiante na zona das salas de aula e termoventilação com baterias de água quente na zona de serviços e ginásio do piso 2. Esta termoventilação é executada em dois patamares. A primeira numa unidade de tratamento de ar novo (UTAN), ao nível da cobertura, onde se efectua um pré-aquecimento para uma temperatura de 18ºC. A segunda com pós-aquecimento em espaços de controlo individual, onde se permite um salto de +3ºC. Esta medida, por si só gera economia no consumo energético associado ao funcionamento da UTAN, bem como a utilização de baterias de água quente, cuja energia térmica provem primordialmente do sistema solar térmico, torna o sistema de aquecimento extremamente económico. O apoio às AQS e AQP é efectuado, num primeiro nível em funcionamento de tarifa bi-horária, por uma resistência eléctrica de 9kW em cada um dos 3 depósitos, e no último nível uma caldeira de condensação com potência de 85 kW e rendimento de combustão de 109%, ligada ao depósito de AQS, na parte superior do mesmo e directamente à saída para o aquecimento, no primário do separador hidráulico. Este evita interferências entre circuitos pelo funcionamento dos circuladores, tornando-os independentes, pois o diferencial de pressão entre colectores de ida e retorno é praticamente nulo. O sistema de arrefecimento activo prevê-se de utilização esporádica e destina-se às zonas do piso 2 e auditório no piso 1. É conseguido pela instalação de uma bateria de água fria na UTAN, a qual é alimentada por um *chiller* de compressor com bomba simples, vaso de expansão e depósito de inércia. Esta termoventilação é executada em dois patamares, o primeiro na unidade de tratamento de ar novo (UTAN), onde se efectua um arrefecimento para uma temperatura de 23ºC e o segundo, com pós-aquecimento em espaços de controlo individual, onde se permite um salto de +3ºC. A potência de arrefecimento do *chiller* é de 22,5kW, com uma potência absorvida de 8,74kW e um EER de 2,57. Nos ganhos passivos brutos, podem ser contabilizados todos os sistemas passivos capazes de contribuir para as necessidades de aquecimento. Neste caso foram considerados como possíveis de contribuição, os ganhos solares térmicos introduzidos nos sistemas de aquecimento, piso radiante e termoventilação, ganhos brutos do permutador de calor ar-solo e ganhos pelo colector de ar na fachada. A protecção solar dos envidraçados é conseguida pela utilização de estores exteriores com lamelas orientáveis, permitindo a modulação da luz natural para o interior sem criação de encandeamento, minimizando os ganhos solares no verão, através do seu factor g=0,09, quando na posição de fechado. Na simulação PV foi utilizando o programa de cálculo, "Sunny Design" (Sunny Design 2008), disponibilizado pelo fabricante do inversor, a SMA, na localização de Lisboa, local mais perto existente na base de dados. Para este sistema foram utilizados dois tipos de montagem, um em colector de ar na fachada, com uma inclinação de 90º e outro sobre a cobertura do ginásio, onde cada linha tem uma interdistância de 2,5m e uma inclinação de 30º. Nesta última tipologia aproveitou-se a disposição zenital da cobertura, para na face Sul se efectuar a montagem PV e na face Norte a introdução de iluminação natural a esse espaço. A qualidade da energia disponível no edifício NZEB é de extrema importância para que no contexto global aquele tenha uma elevada eficiência energética. Foram seleccionados equipamentos eléctricos de elevada eficiência na concepção de um edifício escolar, tendo sido dada particular atenção à UPS, utilizando uma unidade "On-Line" de dupla conversão com "Super Eco Mode", variadores de velocidade dos motores das unidades de AVAC e Elevador, com estes a terem a classe EFF1 de eficiência energética em motores. Assim o grau de tolerância às harmónicas num sistema de alimentação depende da susceptibilidade da carga. Tendo em atenção estes aspectos foi implementada no QG, uma bateria de condensadores automática anti-harmónicas de 50kVAr, que em três patamares injecta de forma progressiva, energia reactiva na rede, para que o sistema tenha um cosφ próximo de 1 e elimina as harmónicas através de filtros. Este sistema é de compensação passiva e a sua escolha deveu-se, por um lado à tipologia da instalação não necessitar de um equipamento sofisticado para a compensação do factor de potência, tal como o existente em compensadores activos, por outro, a sua escolha deveu-se às menores perdas do sistema passivo comparativamente com um activo, as quais são respectivamente de 15W e 2100W.

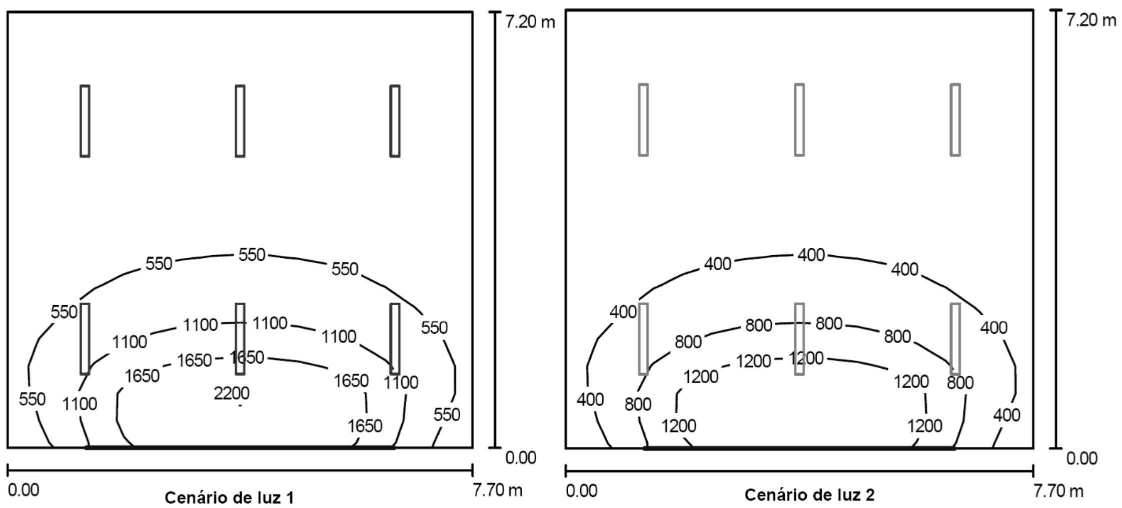
2 RESULTADOS

O funcionamento do sistema de permuta será controlado pela gestão técnica centralizada, segundo critérios que evitem um sobre-aquecimento ou sobre-arrefecimento no interior do espaço servido, mediante as necessidades actuais. Tirando partido da amplitude térmica entre o exterior e o solo à profundidade de enterramento da tubagem, que em média ronda os 10ºC, o fluxo de ar fresco introduzido no interior do edifício pelo permutador de calor ar-solo, e a sua difusão por efeito térmico com arrastamento por ventilação cruzada para o ducto no corredor ou colector de ar na fachada, cria as condições de conforto interiores, sem necessidade de utilização de sistemas mecânicos de arrefecimento.

Na simulação da iluminação natural e integração com a iluminação artificial, foi utilizado o programa de cálculo "Dialux" e efectuada a avaliação de energia segundo a EN 15193 (EN15193, 2006). Além do cálculo luminotécnico onde se determinou o posicionamento das luminárias de modo a se conseguir um nível médio de lux, correspondente a cada tipologia de espaço e sua utilização, foi avaliada a energia dos sistemas intervenientes, a qual é obtida pela ponderação das horas de utilização diurnas e nocturnas anuais, conjugadas com os factores de regulação, manutenção, presença, ausência, eficiência, abastecimento de luz do dia, controlo da luz artificial e transmissão luminosa dos envidraçados.

A regulação "Daylight" (Staff , 2004), que foi implementada nas salas de aula, irá permitir um ajuste automático na iluminação artificial, maximizando a componente natural através da interacção do controlo solar nos estores de lamelas de lâminas orientáveis, nos dois primeiros espaços.

Na Figura 4, apresentam-se os resultados obtidos pelo cálculo no programa "Dialux", numa sala de aula tipo. Os valores correspondem a uma utilização a 100% de iluminação natural e a uma utilização da iluminação artificial a 100%, complementada pela iluminação natural. Se considerarmos isoladamente os valores energéticos calculados pela avaliação energética do programa "Dialux", pelas áreas iluminadas e não iluminadas, temos respectivamente, 139,62kWh/ano e 180,99kWh/ano, com o LENI (EN15193, 2006) respectivo a ser de 3,93kWh/ano.m^2 e 9,08kWh/ano.m^2, sendo as áreas de cálculo, respectivamente de 35,51m^2 e 19,93m^2, para cada sala de aula. O LENI (EN15193, 2006) global é de 5,78 kWh/ano.m^2, muitíssimo inferior ao limite de 38,1 kWh/ano estabelecido para esta tipologia.



Cenário de luz 1

Superfície	ρ [%]	E_m [lx]	E_{min} [lx]	E_{max} [lx]	E_{min} / E_m
Plano de uso	/	616	147	2710	0.239
Solo	20	565	178	1742	0.316
Tecto	80	246	100	608	0.408
Paredes (4)	50	252	119	601	/

Cenário de luz 2

Superfície	ρ [%]	E_m [lx]	E_{min} [lx]	E_{max} [lx]	E_{min} / E_m
Plano de uso	/	446	107	1962	0.239
Solo	20	409	129	1261	0.316
Tecto	80	178	72	440	0.408
Paredes (4)	50	182	86	435	/

Figure 4. Cenário 1 – 100% iluminação artificial; Cenário 2 – 100% iluminação natural.

Com a disposição final da cobertura (Sick 1996, Laukamp et al. 2001), conseguiu-se que a iluminação natural do ginásio ficasse com uma melhor uniformidade e, além disso, fosse possível a disposição de módulos na superfície orientada a Sul, com uma inclinação ideal de 30º, sem obstruções (Figura 5). Estes módulos além da componente electroprodutora, favorecem ainda o edifício, na componente térmica, pois com um U menor, existe uma consequente redução das perdas térmicas pela cobertura. Esta solução é também mais vantajosa, pelo aumento da produtividade energética e também pela diminuição das perdas nos inversores, que se traduziu numa produção energética global de 84372 kWh/ano. O cálculo do RSECE (D.L. 79/2006) na tipologia monozona, baseou-se no método simplificado do factor global de conversão, tendo para isso sido estimadas as horas de funcionamento de cada equipamento a instalar no edifício, onde com as respectivas potências, foi determinado consumo energético anual, convertidas para energia primária.

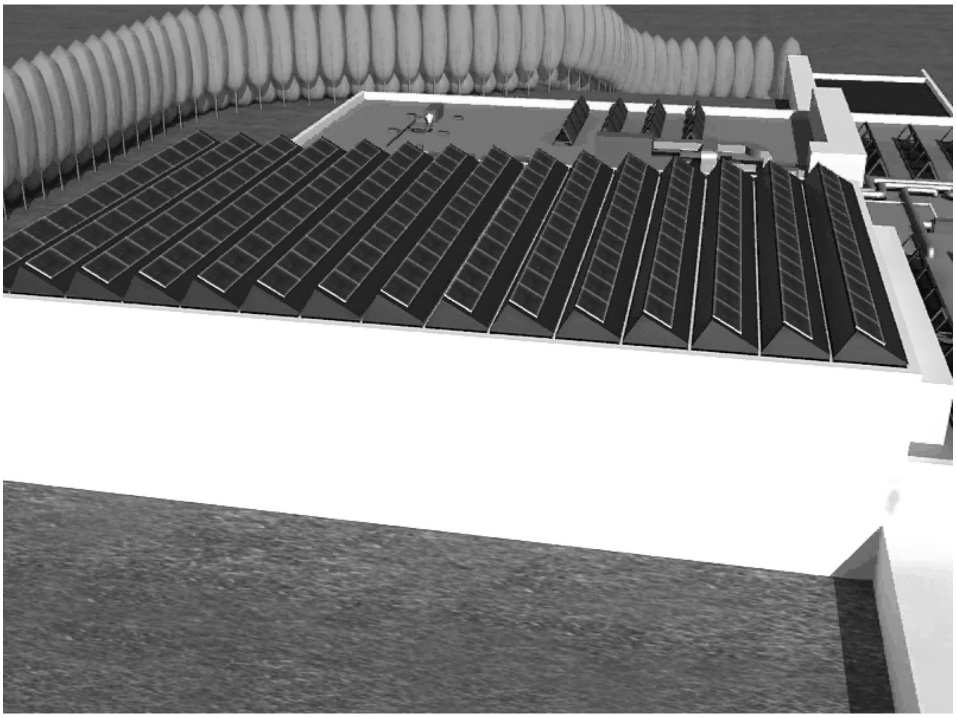


Figure 5. Configuração da cobertura PV do ginásio.

Neste cálculo obtiveram-se os valores de Cei = -0,01 (kgep/m^2.ano) e um IEE = -0,01. A previsão do consumo de energia para os restantes equipamentos foi efectuada através da elaboração de um padrão de funcionamento de equipamentos (climatização, tomadas e equipamentos diversos), numa base anual em folha de cálculo, onde se prevê por sectores o respectivo consumo energético. Essa previsão em projecto é de importância extrema e de grande dificuldade para, como é o caso, se atingir o objectivo de ter um edifício com a classificação NZEB (Voss, 2008).

3 CONCLUSÕES

No presente trabalho efectua-se o estudo da implantação de um novo edifício escolar na localidade de Alcobaça, em Portugal. Fez-se um balanço energético do edifício utilizando técnicas passivas, das quais se destaca a incorporação de energias renováveis, complementadas por técnicas activas e gestão técnica centralizada, analisando-se, assim, o potencial de auto-sustentabilidade do edifício. A utilização do permutador de calor ar-solo tanto para o processo de aquecimento como de arrefecimento, o qual é controlado por actuadores sobre registo de condutas circulares de ventilação, não permite substituir um sistema de climatização de ar convencional, mas pode fornecer a maioria da energia de aquecimento ou arrefecimento da zona principal do edifício. A chaminé solar é um sistema extremamente útil, ainda mais quando aplicada na face Norte dos espaços de maior utilização, nomeadamente as salas de aula. Esta consegue satisfazer tanto os processos de ventilação como os de iluminação natural. No sistema de ventilação, principalmente no arrefecimento, esse efeito substitui com eficácia a aplicação de sistemas activos. O sistema de piso radiante presente nos pisos 0 e 1 foi escolhido por funcionar com um sistema de baixa entalpia. Só assim é possível a integração com a produção de energia pelo sistema solar térmico, a custos rentáveis, além de que numa situação de necessidade de apoio pela caldeira o seu consumo também será menor, pois não necessita de atingir uma temperatura tão elevada. A termoventilação foi considerada unicamente para o piso 2, face à tipologia de utilização com necessidades de ventilação superiores aos pisos 0 e 1. O sistema de pré e pós tratamento do ar, tanto no aquecimento como no arrefecimento, mostrou ser uma medida eficiente de gestão dos recursos existentes face às previsíveis reduzidas necessidades térmicas nesse piso.

A qualidade da energia na rede do edifico foi também uma preocupação desde início deste estudo. Para tal, foi introduzido a montante uma bateria de condensadores automática cujo objectivo é garantir um factor de potência igual a 1. Neste campo, também se conseguiu que a UPS seleccionada, fornecesse à rede socorrida energia com um factor de potência igual a 1.

A redução de produção eléctrica, resultante do sistema fotovoltaico ter sido instalado na vertical nas fachadas foi contrabalançada, em termos energéticos, com a melhoria dos ganhos térmicos internos das salas de aula, através do colector de ar associado a essas estruturas na fachada. A utilização de equipamentos com elevada eficiência, conjugada com a utilização de técnicas passivas de aquecimento e arrefecimento, controladas pela gestão técnica centralizada, foram fulcrais para a concretização da classificação NZEB (Voss, 2008). Conseguiu-se uma produção eléctrica global superior aos consumos do edifício.

A 1ª lei da termodinâmica, designada como "Princípio da Conservação de Energia" e a lei de *Lavoisier*, têm uma relação intrínseca. O que se verifica neste estudo, conseguindo-se a classificação NZEB para o edifício escolar, é a demonstração prática da aplicação, "Na Natureza nada se cria, nada se perde, tudo se transforma", solução que cada vez mais devemos e teremos de prosseguir para um Mundo Sustentável.

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Facades Modules for Eco-Efficient Refurbishment of Buildings: An Overview

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ABSTRACT: The search for new technologies for energy efficiency in buildings is urgent once conventional technologies currently used in the refurbishment of buildings, in the most cases are not efficient. The work presents the initial studies about a new facade system: "Facade Modules for Eco-Efficient Refurbishment of Buildings". It is expected to be a new technology among the new and growing set of products that will solve the need for functional and aesthetic demands. These new elements should result in a modular system, capable of being used combined or separately with simple, flexible and versatile application procedures. Initial studies and simulations in Design Builder software were done having as object a cell (25 m²) with different arrangement of facade modules with passive and current solutions to Guimarães city. Preliminary results show a decrease of energy consumption in the analyzed cases, representing an advantage from passive solar systems and the reduction of energy consumption.

1 INTRODUCTION

In the last years, the increase of the energy consumption in the buildings sector, as well as the improved public sensitivity for environmental subjects, resulted in an attempt to find the causes for such occurrence and to search mitigation solutions to this tendency. Several studies present as conclusion that there is a great potential of energy consumption reduction at the level of housing and services. New legislation and incentives have been created, showing that there is an attempt to act and to intervene in these areas. Energy consumption reduction to prevent energy waste is one of the main objectives of the European Union (EU).

In this context, the search for new technologies to energy efficiency in buildings is urgent and pertinent, once conventional technologies currently used in the refurbishment of buildings in the most cases are not efficient. Compared with the technologies that incorporate high performance components, construction industry practically has not been integrating technologies in its operations to pursuit sustainability.

New architectural and construction products developed to be applied in building facades are the most effective way to achieve this aim. Facades are privileged components to propose solutions, since they have a major influence in the energy consumption of building and in occupants comfort; because they have elements that contribute significantly to the heat transfer. To aim project quality it is necessary to search for new facades technologies and to identify parameters and environmental variables that can support the process to obtain adapted solutions in order to reach energy efficiency and ideal~~s~~ conditions of environmental comfort for occupants.

Facade technologies were undergone in the last decades to substantial innovations by integrating specific elements to adapt the mediation of the outside conditions to user requirements, both in the quality of materials and components and in the overall conception and design of the facade system. These improvements include passive technologies, such as multi layered glazing, sun protections, ventilations, etc (Castrillón, 2009).

The “intelligent glass facades” including the glass performance, such as the late development of reflective, low-e, self-cleaning, absorbent, etc. had a relevant development in the last years. It is likely to the impact and further development of improved materials and construction systems become widespread. Facade types have been suffering an important development and they are being diffused more and more, including new technologies, besides passive and active solutions of climatic adaptation (Compagno, 2002).

1.1 *Recent developments*

Today, the integration of several functions in recent developments in the facades area had proceeded. As facade defines the potential of the building more than any another element, it should be flexible as such. This flexibility could be reached in several ways, for example, in terms of techniques, implementation of solutions with mobile, replaceable and exchanged elements.

Various facade system producers and architects have recently developed service integrated facades. These are composed of parts with fixed glazing, operable windows and decentralized HVAC service installations.

In the development integrated process, facility managers, climate designers and manufacturers of HVAC components are involved. Due to these short distances, such units provide a high efficiency in air conditioning and heat recovery. As every facade element is equipped with HVAC installations, it is easy to provide individual comfort control for every office space for example. Disadvantages of such systems lie in the lack of compatibility with operable windows and mainly in a large number of maintenance points like filters (Ebbert & Knaack, 2008). As example, two types of modern systems of facades can be mentioned, the Capricorn (Fig. 1) and the Temotion (Fig. 2).

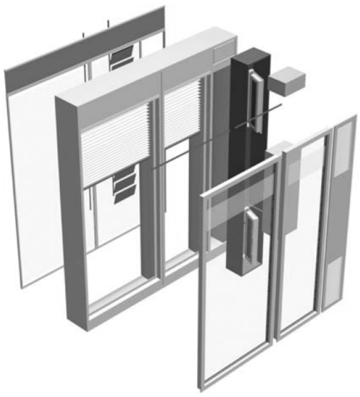

Figure 1. Temotion Facade. Reference: Wicona Productos y Referencias. Temotion, 2009.

Figure 2. Capricorn Facade. Reference: Schineider Electric. Capricorn Haus, 2009.

The Capricorn Haus Düsseldorf (Fig. 2) have an exterior facade with integrated active components, was recently developed by the firm Trox and Schueco. The design of the facade includes transparent and opaque components, combining visibility, natural light and reduction of solar gains, when compared to conventional curtain walls. The Capricorn Haus facade incorporates all the technology and equipment to regulate the indoor climate.

The company Wicona-Hydro, the Fachhochschule Biberach, and the Universität Dortmund have developed a facade that includes a number of functions, including optimized energy management, automatic adjustment of heating and cooling needs and natural and mechanical ventilation. Also integrated in the facade are sun and glare shields, and it is also possible to regulate the daylight admission and lighting, as well as the colour of the light (Castrillón, 2009).

The main feature is the integration of a vertical operable element in the facade that allows natural ventilation and at the same time includes within the volume of the vertical louvered space to receive equipment that provides mechanical heating cooling and ventilation when needed. The box-cased double facade in the window element is separated from the ventilation system, allowing direct fresh air admission. Additional features are the deflection of natural light and the integration of artificial light in the module.

In the new facades technologies, the future foresees the use of materials that can provide several functions. The objective is the development in membranes, molecules and nanotechnology area (nano coatings, adhesive materials technology, smart materials - glass coatings, phase change materials, etc.). The "future envelope" includes insulation, transparency, air quality, waterproofing and flexible permeability (Knaack & Klein, 2008).

The future facade includes various functionalities. A better integration with the building services concept, such as adaptability in response to changing climatic conditions and user requirements, as well as the integration with the structure of the building are all tasks of “tomorrow façade”. Energy considerations constitute the main driving force behind new developments in the facade industry: the necessity of energy savings, insulation against heat and cold, energy storage measures as well as alternatives for energy generation have to be explored (Knaack et al, 2007).

However it is observed that some facade modules or panels have larger dimensions to integrate facade systems with various functions. This standardizes the building respecting aesthetic, and, furthermore, decreases the architect’s freedom of creation.

The ideal would be the development of a dynamic and flexible facade system in way to adapt to the climatic changes, to the occupants requirements and, however, to adapt to the building. An idea would be the development of a system that facilitated the assembly of the facade, containing passive elements, glazing and of reception of solar energy to improve the comfort conditions in agreement with the climatic needs and be mounted in agreement with the solar orientations and wanted functions.

Before in this article presents the initial studies on the development of a new facade system: "Facade Modules for Eco-efficient Refurbishment of Buildings". Waited that this system is a technology in the new and growing need of products that solve the legal, functional and aesthetic demands, executing the function of reducing the energy expenses with HVAC systems and lighting in housing and office buildings, increase the benefits of the solar radiation use; to be a versatile, innovative and attractive product to being applied in the whole buildings type, existing buildings (refurbishment solutions) or new buildings, allowing to architects an active drawing and application of this facade solution.

2 OBJECTIVES

The main objective is presents the initial results of thermal performance simulations to prove advantages of passive elements incorporation in a proposal to modulate facade system, with the purpose of decreasing heating energy consumption.

3 METHODOLOGY

In this initial research studies were accomplished by means of computational simulation with the software Design Builder for a model that will be detailed later on. Initial simulations with different glazing types were made. Later on were proposed in those model different arrangements of facade modules with passive and traditional solutions for two envelope types: a Portuguese traditional system in double masonry and a light gauge steel framing system.

3.1 *Design Builder Software*

Design Builder software is a friendly graphic interface for the program EnergyPlus simulation engine, to the family of software tools for modeling building facades and fenestration systems. Developed for use at all stages of building design, Design Builder combines state-of-the-art thermal simulation software with an easy-to-use yet powerful 3D modeller. This software allows calculating building energy use; evaluating facade options for overheating and visual appearance; visualization of site layouts and solar shading; thermal simulation of naturally ventilated buildings; lighting control systems model savings in electric lighting from daylight; Calculating heating and cooling equipment sizes, etc.

3.2 *Standard Model Definition*

For the definition of the "standard model" was considered a one-storey isolated cell, with regular geometry 5,0 x 5,0 (25m²) (Fig. 3) and a ceiling height of 2,80m, and a total dimension of 2,5 x 2,5 (6,25m²) for the facade modules composition. These dimensions try to obey the recommendations from "*Regulamento Geral das Edificações Urbanas*" of Portugal (RGEU, 2007).

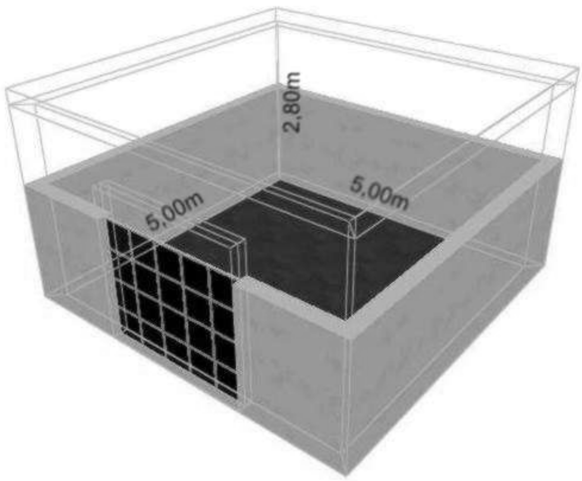

Figura 3. Standard Model

3.3 *Envelope*

Simulations were executed for the south solar orientation, considering the annual period for Guimarães city. A portuguese traditional system in double masonry and walls usually used in a light gauge steel framing system was considered in the model for the opaque envelope. The traditional system is composed by lightweight concrete slabs and insulation (stone wool); external walls in double masonry with interior insulation and cement mortar plaster. The light gauge steel framing system is also composed by lightweight concrete slabs and other insulation components (expanded polystyrene - EPS), and EIFS (External Insulation and Finish System), OSB boards, stone wool and gypsum plasterboard was used in the walls.

Table 1 presents thermal transmission coefficient values (W/m² ºC) for portuguese traditional system components. It was initial simulations; this way was considered for the traditional system slabs the composition of the lightweight concrete and insulation layers only.

Table 1. Synthesis - Thermal transmission coefficient values (W/m² ºC)

Thermal transmission coefficient - Traditional System		
Element	Thickness	U (W/m²)
External Walls	0,365	0,464
Roof	0,25	0,584
Ground Floor	0,30	0,578
Thermal transmission coefficient – LGSF System		
Element	Thickness	U (W/m² ºC)
External Walls	0,199	0,14
Roof	0,223	0,216
Ground Floor	0,27	1,248

3.4 *Internal Gains*

RCCTE Portuguese standard (RCCTE, 2006) presents 4W/m² as value for referring to total internal gains (occupation, lighting and equipments), however due to possibilities and simulation options offered by the software Design Builder, the internal gains was separated for the occupation, lighting and equipments (Table 2).

Table 2. Internal Gains (W/m²)

Internos Gains	Valores (W/m²)
Occupation *	5,6 W/m² (2 people)
Lighting *	9,4 W/m²
Equipaments	8 W/m²

* Values from Swiss standard.

As RCCTE standard does not contemplate schedules (days of the week, hour and time) of occupation, lighting and equipments use for housing buildings, those values were adopted from research "Obtenção dos perfis de utilização, iluminação e de equipamentos das habitações residenciais " (SOUZA, 2008).

3.5 *Temperatures*

The value 20°C was considered as reference of heating indoor temperature (winter) and 25°C for cooling indoor temperature (summer), in agreement with RCCTE.

3.6 *Glazing*

After the execution of 3 glazing types simulations (Table 3) for a project typical day in winter (December 21) and summer (June 21), was chose the solar control glazing to do the facades composition of the initial simulations.

Table 3. Glazing Types

Glazing	Outermost Pane	Inner Pane
Double Solar Control	Solar Control Glass 6mm	Low-e Glass 6mm
Double Self-Cleanning	Self-Cleanning Glass 6mm	Low-e Glass 6mm
Simple Glass	Simple extra-claro float glass 6mm	

3.7 *Module variety*

The facade modules considered in the simulations were:

- Standard module (SM): basically composed for double glass with thickness of 6mm (solar control glass and low-e glass) and air layer of 12mm;
- Trombe wall module (TW): an extra-clear float glass (6mm) for the composition of trombe wall (0,5 x 2,50m²) was used to this module. This glass has a high shading coefficient (SC) allowing the maximum solar radiation penetration. The trombe wall was considered with and without superior and inferior ventilation opening (0,10 x 0,20m²) in the storage wall.

In winter these openings stayed open from 9:00h to 18:00h and in summer closed during the day and opened during at night. Furthermore was considered in the trombe wall a box-of-air, to 5cm offset of glazing. Trombe wall storage element was composed in traditional concrete (0,15m of thickness). Figures 4a, b, c presents the facade compositions simulate for Guimarães city in Portugal.

Figure 4. Facade Module. a. Standard module facade (low-e double glass); b. 1 Trombe wall and standard module; c. 2 Trombe wall and standard module.

4 RESULTS

The first results presents the internal temperatures for a typical project day in the Winter (December 21) and in the Summer (June 21), with use of different glazing and sunshades (horizontal blinds and overhang) in the facade.

4.1 *Glazing*

Figure 5 and 6 present the mean air temperature variation for winter and summer with the use of three glazing compositions: solar control glass, self-cleaning glass and extra-clear float glass. Considering that: SCG = double solar control glass CG = double self-cleaning glass and ECG = Simple extra-clear float glass.

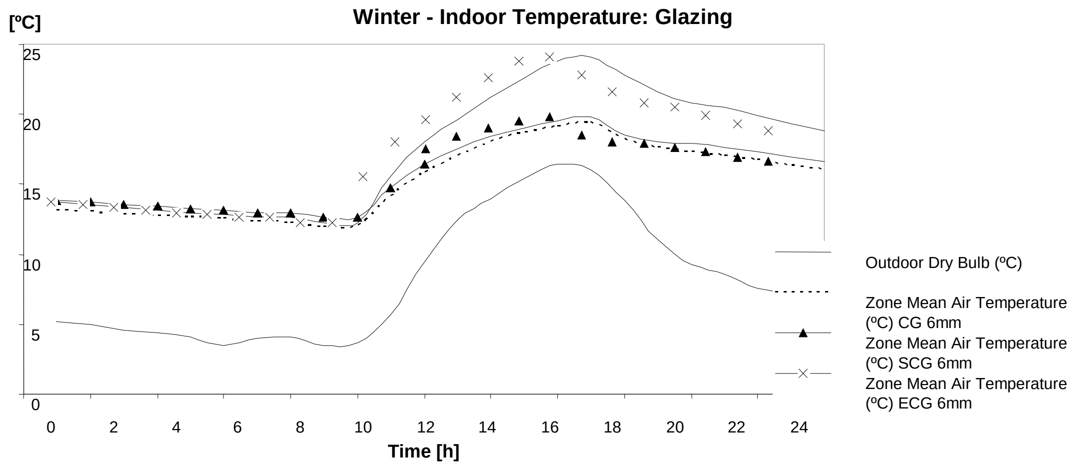

Figure 5. Indoor Temperature - Winter

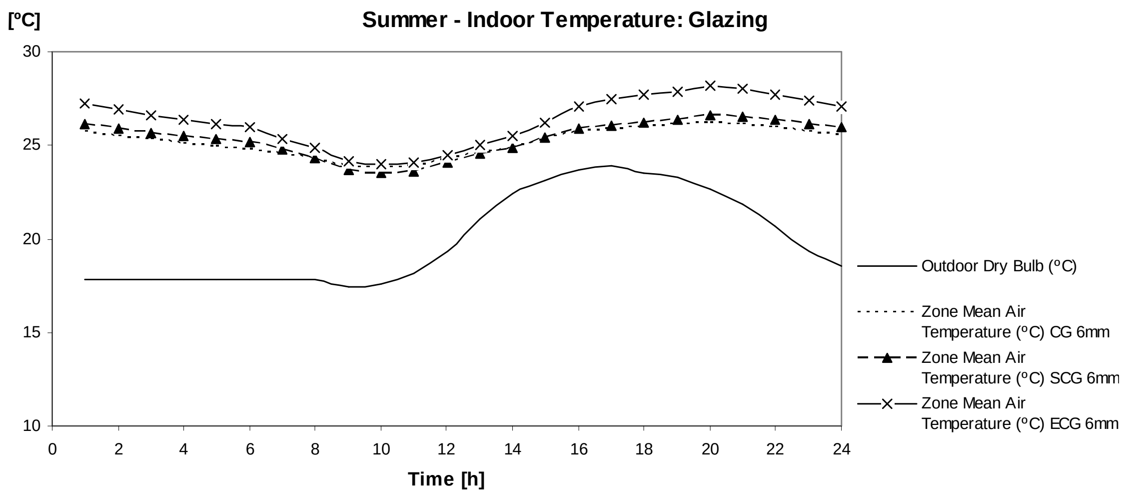

Figure 6. Indoor Temperature - Summer

Graphs indicate that for winter, that extra-clear float glass use provided an increase of the indoor temperature towards other glazing types; this indicates that glass type presents a good performance to use in passive systems as trombe wall.

Double solar control and double self-cleaning glazing had practically identical performance. Double solar control and double self-cleaning glazing had temperatures below the maximum recommended by RCCTE (25ºC) for the summer. Simple glazing had higher temperatures. Choosing randomly the double solar control glazing, for example, and considering the use of horizontal blinds and overhang was obtained results of indoor temperatures for winter and summer in agreement with the Figure 7 and 8.

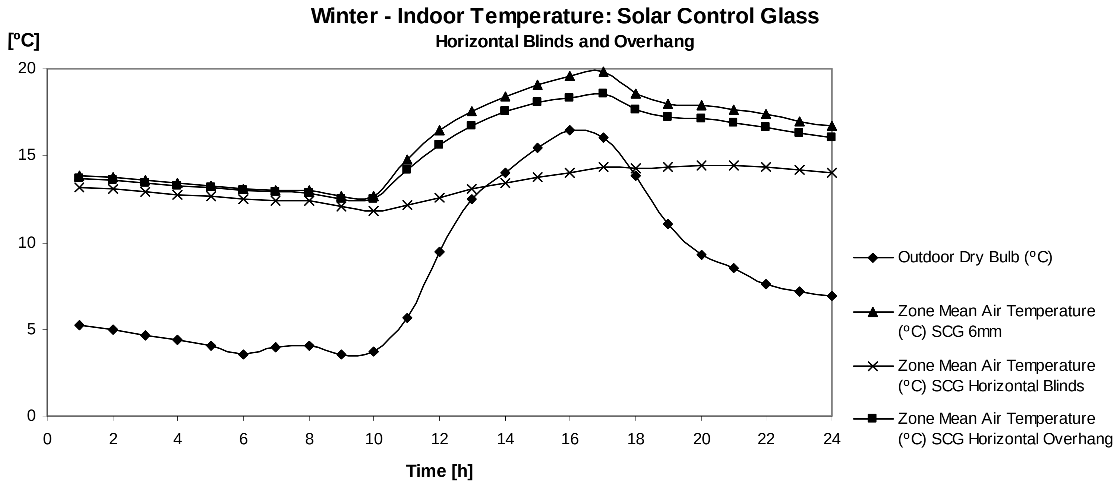

Figure 7. Indoor Temperature - Winter.

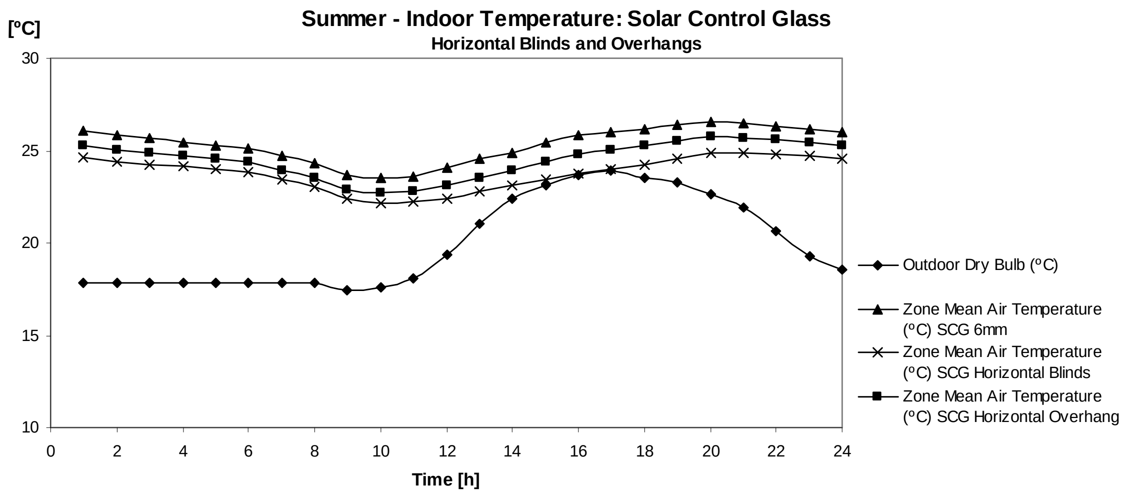

Figure 8. Indoor Temperatures - Summer.

That indicates the temperature differences between horizontal blinds use towards horizontal overhang use. Horizontal blinds caused a mean air temperature decrease in winter, this means that it for use in the facade should be mobile, in way to facilitate the solar radiation entrance in the winter and to cause an indoor temperatures increase. For summer, horizontal blinds use implied in the indoor temperatures decrease more than horizontal overhang use.

Figure 9 presents the heating energy values needs for 5 types of facades composition, simulated for Guimarães climate and positioned in the south solar orientation.

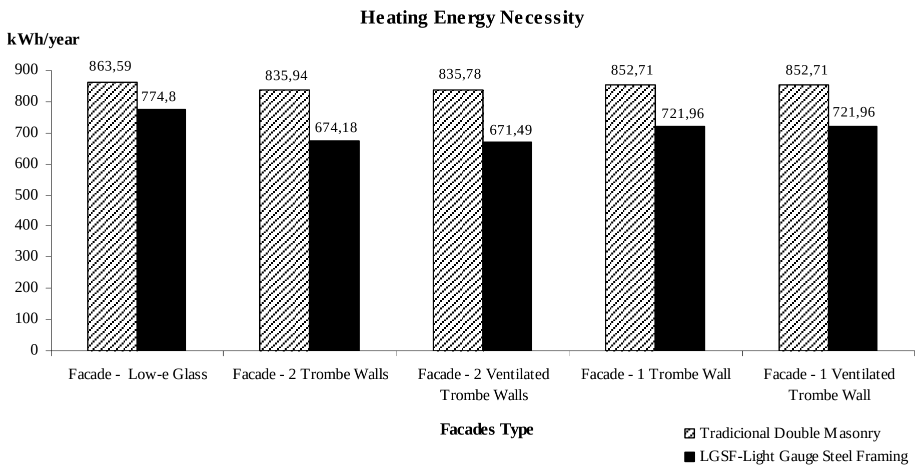

Figure 9. Heating Energy Necessity

Figure 9 show that walls and slabs of the light gauge steel framing system use in the simulation model had smaller energy consumption for heating, mainly due to facade with 2 trombe walls.

Decrease of the energy consumption happens in agreement with the addition of heating passive solutions, in this case trombe wall. Table 4 presents the energy expenses decrease based in a double solar control glass facade (Solar control glass 6mm - Air 12mm - low-e glass 6mm).

Table 4. Consumption decrease according to the façade type.

Cover	Facades Type	Annual Heating Necessity (kWh)	%
Traditional	Facade - *Low-e Glass*	863,59	-
	Facade - 2 Trombe Walls	835,94	-3,20
	Facade - 2 Ventilated Trombe Walls	835,78	-3,22
	Facade -1 Trombe Wall	852,71	-1,26
	Facade - 1 Ventilated Trombe Wall	852,71	-1,26
LGSF	Facade - *Low-e Glass*	774,8	-
	Facade - 2 Trombe Walls	674,18	-12,99
	Facade - 2 Ventilated Trombe Walls	671,49	-13,33
	Facade -1 Trombe Wall	721,96	-6,82
	Facade - 1 Ventilated Trombe Wall	721,96	-6,82

5 CONCLUSIONS

Passive technologies both for heating and cooling, have a decisive importance to carry out, and are necessary that new studies are developed to demonstrate effectiveness and importance its to the energy consumption decrease. Preliminary results showed an energy consumption decrease to heating (13%) with the incorporation of passive technologies (trombe wall). This indicates the advantages of the passive solutions incorporation in the facade.

Thereafter it is waited that these facade modules application, with other types of passive solutions, besides those studied, contribute for the energy consumption reduction with systems HVAC and lighting in the buildings, increasing the benefits of the solar radiation use. Intend to create versatile, innovative and attractive modules, possible of being applied in the whole buildings typology, refurbishment solutions and new buildings, allowing to the architects an application of this facade solution in their projects.

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Development of research related to alkali-silica reaction in concrete with recycled aggregates

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ABSTRACT: Since there is a possibility of incorporating recycled aggregates (RA) as a complement to primary aggregates (PA) in concrete production, taking advantage of construction and demolition waste, there are some questions on the durability of concrete with recycled aggregates (CRA) that need to be answered.
The durability of concrete with primary aggregates only (CPA) is conditioned, among other factors, by its degradation due to alkali-silica reactions (ASR). Since the first cases of ASR in CPA were identified, this expansive reaction has been a research theme resulting in the development of prevention and mitigation methodologies and in the comprehension of the chemical reactions involved.
The present paper proposes to describe the current development of a research program on ASR in CRA based on an experimental campaign involving the production of CRA with different replacement ratios of coarse PA with coarse concrete RA, the use of different cement classes, and variations on the concrete curing conditions and on the reactivity of the mixes.

1 INTRODUCTION

Alkali-silica reaction (ASR) is one of the chemical degradation causes of concrete with mineral aggregates (CMA). These reactions are included among the internal expansive reactions and occur in the simultaneous presence of high amounts of alkalis, reactive aggregates and humidity. During the reaction a silica-alkaline gel is developed that expands in the presence of humidity leading to various phenomena within the concrete that condition and change its properties. Research in this area has tried mostly to understand the expansive mechanism and the methodologies for its prevention and mitigation.

The incorporation of recycled aggregates (RA) in concrete, namely those from crushed concrete, as a complement to mineral aggregates (MA) leads to some questions related to its durability. In order to know the CRA in the same areas as the CMA it is necessary to study the possible causes of their degradation.

The theme of the research work presented in this paper was triggered by the possible occurrence of ASR in CRA and its manifestation perhaps being a consequence of the potential reactivity of the RA from the original crushed concrete.

An experimental campaign on ASR in CRA is presently being developed in order to understand how the total or partial incorporation of RA in concrete changes this deleterious reaction development, and to what extent the incorporation of RA in concrete is effective without risk of ASR.

Various CRA will be produced containing different replacement ratios of coarse MA with concrete coarse RA, different cement classes, variations in the weathering conditions of the original concrete (OC) and in the reactivity of the mixes.

In the various situations under analysis there is always a reference concrete, exclusively with MA. The RA for replacement purposes comes from an OC whose origin and characteristics are controlled.

2 RESEARCH RELATED TO ASR IN CRA

CRA have various properties apart from those of CMA that may lead to a different performance concerning ASR. There are studies on the topic of ASR in CRA, some of which are included in the references at the end of this paper, which mention the occurrence of ASR in the accelerated mortar or concrete expansion tests. However, some other references state that the use of RA did not always lead to high expansion rates.

These studies do not allow fully understanding and relating the development of ASR in CRA and CMA, even though they highlight differences in the progress of expansive reactions in CRA probably due to the characteristics of the RA and CRA themselves.

In terms of experimental analysis of ASR in CRA the bibliography referred presents relevant aspects and some proposals to change the methodologies of ASR testing (e.g. remarks on the accelerated test in mortar bars for RA according to ASTM C 1260 test method).

Some researchers consider that, in terms of the accelerated test in mortar bars, crushing concrete to obtain RA for the samples or the use of fine RA from primary crushing of a CMA influences the aggregate's characteristics and influences the expansion results. Therefore proposals were made to test separately the aggregates and the adhering mortar in the RA or to use only those RA resulting from a secondary crushing, i.e. crushing coarse RA. The pre-saturation of RA to be used in the expansion tests is also recommended to avoid erroneous results of samples with shorter ages.

With the intention of obtaining more data on the development of ASR in concrete with total or partial incorporation of RA and of investigating whether the expansive reaction is more damaging in CRA than it is in CMA, the following points present the results so far of the study under way of the authors of the present paper.

2.1 *Research methodology*

The experimental work is partly based on the recommendations of the Portuguese specification LNEC E 461 from the Portuguese National Laboratory of Civil Engineering that presents a methodology to evaluate the reactivity of a single aggregate or of an aggregate mixture. This specification is based on the alkali reactivity obtained by petrographic analysis which is complemented by accelerated expansion tests in mortar bars or concrete prisms.

CRA are produced and evaluated according to the mix compositions and test recommendations referred to in the specification for CMA. The evaluation of RA and CRA will take into account the specification and the observations of different authors on expansion tests in specimens with this type of aggregate. Changes in CRA properties will be studied through current tests of physic-mechanical evaluation, porous structure and microstructure.

RA from crushing controlled OC (made with MA with identical characteristics to those used to produce the CRA) will be used. Various situations that can influence ASR development were simulated in the study. Three CRA families will be produced with different MA-RA replacement ratios, reactivity levels, RA ages and cement types. Table 1 presents the different situations and the methodology employed.

Table 1. Scenarios created to study the development of ASR in CRA.

Scenarios concerning the CRA	Methodology used in the production of the CRA
- Influence of the RA	- Replacement ratios of 0, 20, 50 e 100%
- Different reactivity levels	- Use of reactive and non-reactive MA and RA
- Influence of the RA's age	- Use of weathered and non-weathered RA
- Physical changes and in the porous structure	- Use of 2 types of cement

2.2 *Experimental work done so far*

The experimental work is still in a preliminary stage, corresponding to the MA characterization and the production of two types of OC. Type A was made with non-reactive fine and coarse MA and type B with reactive fine and coarse MA. The same mix composition and cement type (CEM I 42.5R) was used for both OCs.

The OC's weathering is done in outdoor natural environment and in accelerated conditions (climatic chamber with 38º C and HR > 95%). This methodology allows the production of RA, reactive and non-reactive, coming from recent concrete (outdoor environment) and old concrete (accelerated weathering conditions).

After weathering, the OC's are crushed and the corresponding RA will be characterized and their properties confronted with those of the original MA. After these first steps, various families of CRA will be designed and produced. The next phase is the analysis of CRA's performance under the influence of ASR. Current tests will be performed in hardened concrete, as well as the evaluation of the its porous structure and reactivity, and the microstructure observation according to the evolution of the ASR in the CRA.

In points 2.2.1 and 2.2.2 some of the options are explained and some results from the first stage of the experimental campaign are presented.

2.2.1 *MA characterization*

The MA to be used in the concrete mixes was selected for their reactive potential and the possibility of keeping the aggregate's characteristics identical, both for the OC and the RCA. Table 2 groups the MA used in the experimental campaign and identifies the OC type in which they were used.

Table 2. MA used in the experimental campaign

Denomination	Potential reactivity	Type of aggregate	OC type
AGP-NR1	Non-reactive	Limestone gravel	A
AGP-NR2	Non-reactive	Limestone gravel	A
AFP-NR	Non-reactive	Siliceous sand	A
AGP-R1	Reactive	Siliceous pebble	B
AGP-R2	Reactive	Siliceous pebble	B
AFP-R	Reactive	Siliceous sand	B

The types of MA described were submitted to petrographic analysis and also to mortar bars expansion tests. The latter, based on ASTM C 1260 and similar to RILEM's test AAR-2, allows checking the MA potential reactivity to alkali through the measurement of the average expansion of 3 mortar bars during at least 14 days. The bars (25 x 25 x 285 mm) are produced with the MA under analysis, crushed to a given size distribution, and immersed in a solution of sodium hydroxide 1M at a temperature of 80 ± 1ºC - Figure 1.

Figure 1. Casting of the mortar bars (left) and expansion measurement (right)

According to LNEC E 461 specification if after 14 days the average expansion of the mortar bar is higher than 0.20% the aggregate is considered highly potentially reactive; however, if the expansion value is within the interval 0.10-0.20% at that age it is recommended that the test proceeds until 28 days. The aggregate's reactivity is considered doubtful if the expansion at 28 days is lower than 0.20%.

To study the evolution of expansion the test took 28 days for all MA. Figure 2 shows graphically the results of the reactive and non-reactive MA tested.

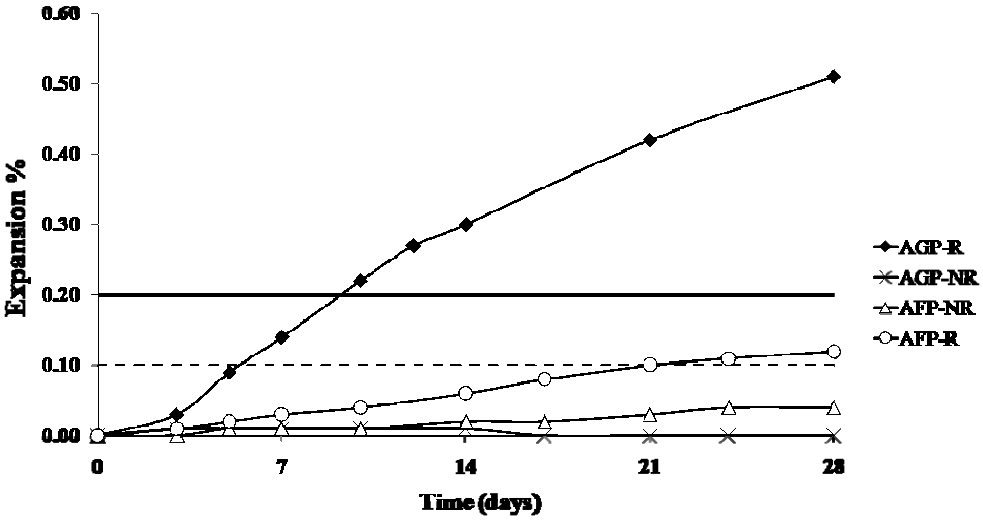

Figure 2. Expansion of the mortar bars during 28 days, according to ASTM C1260

The results demonstrate the reactive potential of the AGP-R with an average expansion at 28 days of 0.51%, with the limit achieved after only 10 days. Gels were observed in the specimens with AFP-R. Given also the results of the petrographic analysis their reactivity to alkali was proved, even though it is slow to develop and therefore it is not detected at 14 days with the ASTM C 1260 test. In these cases it is recommended to perform the concrete prisms test according to the RILEM AAR-3 or RILEM AAR-4 test methods.

According to the limits established, the aggregates AGP-NR and AFP-NR are considered non- alkali reactive. This creates two sets of aggregate for the production of OC types A and B. Aggregate with similar characteristics will be used to produce the various CRA.

The size distribution was determined to physically characterize the aggregate, based on NP EN 933-1, which classifies by average size the aggregate of a given sample. Other physical and chemical tests of the MA will be performed at this stage of the experimental campaign.

Succinctly the test starts by sampling the MA and creating two specimens using the adequate procedure. The material is dried in an oven at 110 ± 5 ºC and then weighted. The specimens are then washed to eliminate most of the fines under 0.063 mm and dried, and their dry weight is determined. The resulting material is then passed through a column of calibrated sieves. The quantity retained in each sieve provides the MA size distribution. The dimensions of the sieve meshes used in this work are those from the basic series plus those of series 2, both from NP EN 12620, which regulates the characteristics of aggregate for concrete. Figures 3 and 4 show the size distribution of the fine and coarse MA used in the production of OC types A and B.

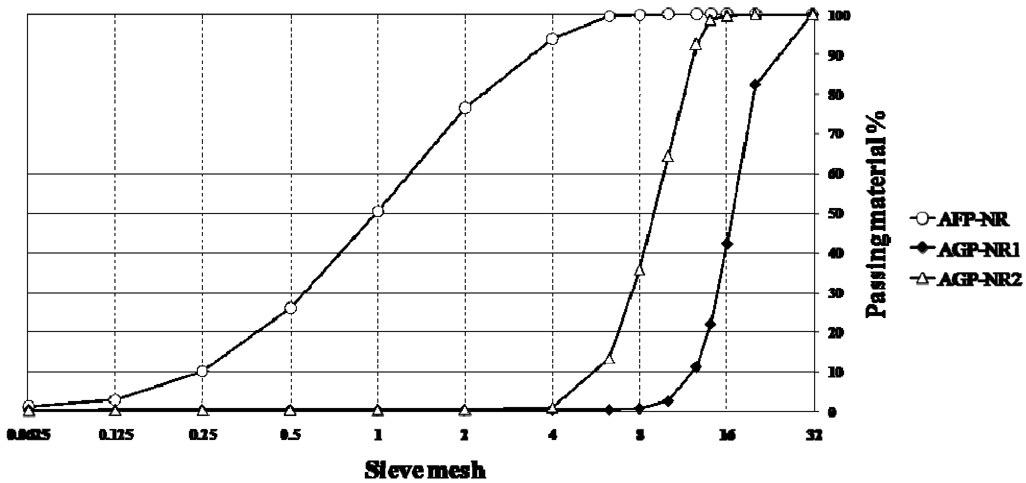

Figure 3. Size distribution of the MA used in OC type A

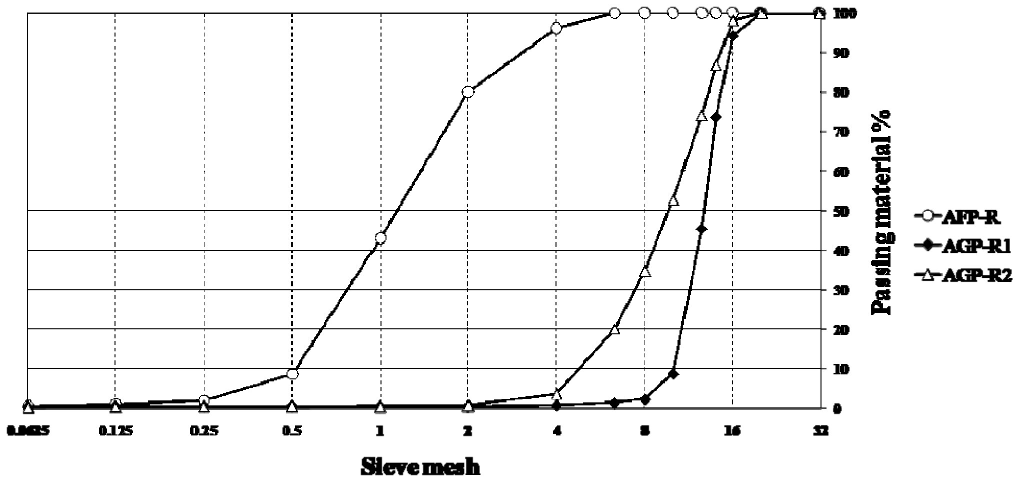

Figure 4. Size distribution of the MA used in OC type B

In both cases the final results validation feel within the limits set by standard NP EN 933-1. The sum of the material retained and of the residue differed less than 1% in mass from the dry mass of material over 0.063 mm.

2.2.2 *OC characterization*

The two types of OC, exclusively made of MA either reactive or non-reactive, were produced with the same composition. This is explained by the need to differentiate the OCs fundamentally by the type of MA used. The cement was in both cases CEM I 42.5R.

To characterize the OC the compressive strength (Figure 5) and splitting tensile strength were measured according to NP EN 12390-3 and NP EN 12390-6, respectively. Cubic and cylindrical specimens were prepared and were kept under the conditions stated in NP EN 12390-2. The test was performed in the Construction Laboratory of Instituto Superior Técnico (IST) using a 4 column hydraulic press with a controlled loading rate.

Figure 5. Hydraulic press used in the compressive strength test

Presently 6 concrete prisms are being weathered at 38 ± 2 ºC and at relative humidity over 95%, according to ASTM 1293 and similarly to the RILEM AAR-3 test method. The prisms allow following the OC expansion due to ASR for at least 12 months. No results of this text are ready to be presented.

Table 3 shows the results from the 28-day compressive and splitting tensile strength of the OC. A difference in the average compressive strength of the two mixes is visible due probably to the use of the same amount of material in the mixes notwithstanding the unequal characteristics of the MA. However the RA from these OC will not be mixed in any CRA mix, and therefore this problem is not relevant.

Table 3. Compressive and splitting tensile strength of OC

				Compressive strength			
Denomination	Force (kN)			f_c (MPa)			f_{cm} (MPa)
BO type A	1137	1326	1247	50.53	58.93	55.42	55.0
BO type B	1457	1478	1440	64.76	65.69	64.00	64.8
				Splitting tensile strength			
Denomination	Force (kN)			f_{ct} (MPa)			f_{ctm} (MPa)
BO type A	239.7	213.4	256.5	3.39	3.02	3.63	3.4
BO type B	226.6	231.4	232.8	3.21	3.27	3.29	3.3

2.2.3 *Natural and accelerated weathering of OC*

It was considered that the age of the RA may influence the development of ASR in CRA due to characteristics of the adhering mortar. Therefore an old concrete was simulated in part of the prepared OC by accelerated weathering in a climatic chamber and a recent concrete in the remaining part by outdoor natural weathering.

Accelerated weathering is proceeding at the Construction Laboratory of UBI (University of Beira Interior) in a walk-in climatic chamber. The concrete is cast in blocks that are subjected to 38 ± 2 ºC and a relative humidity higher than 95%, protect by plastics to minimize the calcium and alkalis lixiviation. These conditions are based on the recommendations of RILEM AAR-3 to study ASR using concrete prisms.

Figures 6 and 7 illustrate both weathering conditions. Through this methodology the aim is to create reactive weathered RA, non-reactive weathered RA, reactive non-weathered RA, and non-reactive non-weathered RA. These aggregate types will be used in the different CRA compositions.

Figure 6. Storage of the concrete blocks in a climatic chamber

Figure 7. Storage of the concrete blocks for open-air natural weathering

3 CONCLUSIONS

The research work presented in this paper is still in a preliminary stage of preparation and characterization of material for CRA production with the objective of analyzing ASR. The conditions are now ready to use RA, with various characteristics conditioned by the production and weathering of the different OCs, to simulate several CRA scenarios and study their performance when subjected to ASR.

4 ACKNOWLEDGEMENTS

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Geopolymeric Artificial Aggregates as New Materials for Wastewater

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ABSTRACT: This study evaluates whether artificial aggregates produced from mining wastes geopolymeric binder would be suitable as alternative materials for wastewater treatment processes. Seven types of mineral wastes geopolymeric artificial (WGA) aggregates were produced, using mining waste mud as precursor and sodium silicate and sodium hydroxide as alkaline activators. Seven mixtures were produced for ratios of sodium silicate/sodium hydroxide ranging from 1.25 to 5 and for ratios of precursor/sodium silicate ranging from 4 to 5. 112 samples were studied for different mixing and curing conditions (20ºC and 130ºC) and its structural stability and pH variation after immersion in water was observed during 3 months. Results show that the initial pH in water decreases with the increase of the curing time. A WGA mixture cured at 20ºC during 28 days seems to be suitable to be used as media bed material for fixed-film wastewater treatment processes.

1 INTRODUCTION

The use of new materials in wastewater treatment processes, namely for secondary, tertiary or polishing treatment, has had a great development over the past decade. Several Technologies with fixed-film processes have emerged using vertical flow (e.g. packed beds and the Biofior and the Biostyr processes), horizontal flow (e.g. sub-superficial filters and constructed wetlands) or mobile bed (SBR with fluidized bed and the Captor and the Linpor processes). These processes are able to use different bed materials and have shown to be more efficient and cost-effective over the conventional treatment processes (e.g. percolating filters or biological filters) that use natural beds based on gravel and sand.

The bed material frequently presents clogging problems which causes are not well understood. Several studies have pointed out the properties of the particles (e.g. effective diameter, porosity, water absorption capacity, mechanical resistance, defragmentation capacity and compaction), the operation characteristics (e.g. velocities, flow direction and organic loading), the influent characteristics as well as the excessive growth of biomass, the accumulation of solid material, the formation of precipitates and the development of roots and rhizomes as the main causes of clogging (Wang et al. 1996, Dickenson, Metcalf &Eddy 2003, Mays et al. 2005).

Thus, finding new aggregate bed materials for conventional wastewater processes is na important issue to improve its efficiency, particularly regarding its mechanical resistance and durability.

The term “geopolymers” describe new materials with the ability to transform polycondensed materials and adopt a shape rapidly at low temperatures like "polymers". The polymerisation rocess involves a chemical reaction under highly alkaline conditions in which Al-Si minerals yield polymeric Si-O-Al-O bonds with the empirical formula Mn [- (Si -O2)z – Al - O]n. wH2O, where n is the degree of polymerization, z is 1, 2 or 3 is the order, and M is an alkali cation, such as potassium or sodium (Davidovits 1999). From a chemical point of view, geopolymers can be seen as the synthetic equivalent to natural zeolites having a similar hydrated aluminous-silicate chemical composition, with an amorphous structure which gives it several advantages, mechanical and durability performance, when compared with other materials (Davidovits 2002). Thus, geopolymers obtained from different sources have emerged as new generation inorganic polymeric materials well suited for numerous engineering applications.

Recently, rather extensive laboratory research results have demonstrated that alumino-silicate waste mud from a tungsten local mining exploration has very good reactivity with alkaline activators, after a thermal calcination process and under certain mixing conditions to produce geopolymeric/alkaline activated binders. The results showed that particular waste mud geopolymeric mixes present higher strength, when using 10% calcium hydroxide as well as sodium hydroxide and sodium silicate (waterglass), as activator solutions (Pacheco-Torgal et al. 2008a, b). These mining waste binders also show to have good durability performance regarding abrasion and acid resistance, as well as environmental performance from leaching tests (Pacheco-Torgal 2008). This research work also demonstrated that geopolymers can also be produced from mining waste mud giving it a new utilization.

Finding new applications for alumino-silicate wastes is of particular interest since these types of minerals are the most abundant materials in Earth's crust, as in the Portuguese case, where an underground tungsten mine, located in Panasqueira area, produces tonnes of wastes per day, since the 1980s, resulting in a deposit of several millions of tonnes of alumino-silicate waste mud. Presently, Panasqueira mine produces approximately 100 tonnes of waste per day, and research in utilization of such mining wastes to produce geopolymeric binders will contribute to reduce waste landfill site and environmental impacts (Pacheco-Torgal et al. 2009).

As a consequence, the present research deals with a novel application of mining wastes geopolymeric binder by producing WGA aggregates as new alternative and more durable materials for bed of wastewater treatment process, which can also bring larger perspectives for new applications of waste mining geopolymeric binder based materials.

The objective of this research work consisted in producing WGA aggregates of 2 to 3 cm size using a geopolymeric binder obtained from mining mine waste mud, using as activators, solutions of sodium silicate (S) and sodium hydroxide (H), the last one with concentration of 10M, varying S/H ratios, as well as precursor (P) and sodium hydroxide ratios. The stability in water over time (i.e. behaviour in water without disintegration or dissolution) of different WGA aggregates obtained from different mixing conditions was follow up for a period of 3 months. Simultaneously, water pH variation containing different WGA aggregates was also measured along time. Finally, parameters that affect WGA aggregates structural stability in water as well as water pH variation were studied since they are determinant to accesses its performance as new materials for wastewater treatment processes.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

Waste mud was obtained from Panasqueira tungsten mine located in Portugal's centre region. The chemical composition of the mine waste mud was determined by energy dispersive spectrometry (EDS, Rontech, Germany), as presented in Table 1. It is mainly constituted of silica and alumina and minor percentages of iron and sodium oxide, as found previously [14], although having slight differences in comparison with previous studies. Waste mud was first submitted to a thermal treatment using a static furnace (Termolab, Portugal), for 2 hours at 800ºC, to increase its reactivity during geopolymerization. Temperatures of calcination at 800ºC were found to be adequate to obtain good reactivity, although previous investigation lead to a higher temperature of 950ºC to obtain maximum compressive strength (Pacheco-Torgal et al. 2005), which was not the purpose of this research work. Blaine fineness was determined by Blain's method with air permeability. Chemical composition of sodium silicate as given by supplier is also shown in Table 1.

Table 1. Chemical composition and specific surface

Constituents (mass %)	Mining waste mud	Sodium Silicate (Na_2SiO) activator
SiO_2	68.54	27.80
Na_2O	1.14	8.60
Al_2O_3	18.27	0.40
Fe_2O_3	5.64	-
K_2O	5.24	-
TiO_2	1.17	-
H_2O	-	63.20

2.1 Production of WGA aggregates

For the production of wastes geopolymeric artificial (WGA) aggregates 7 mixtures of waste mud (precursor –P) with different ratios of Na_2SiO (sodium silicate – S) solution and NaOH solution (sodium hydroxide –H) having concentration of 10M were produced. Mixing quantities of each activator solution and waste mud (P) are presented in Table 2, as well as mass ratios of sodium silicate versus sodium hydroxide, R(S/H), and precursor versus sodium silicate, R(P/S). No calcium hydroxide - $Ca(OH)_2$ was added to the mix since its presence can lead to the formation of calcium silicate hydrates which, in turn, can result in strength loss after a certain curing period (Yip et al. 2005a, b).

Table 2. Geopolymeric mix composition and mass ratios R(S/H) and R(P/S)

Mix	Na_2SiO_3 (g) Solution	NaOH (g) Solution	Precursor (g)	R(S/H)	R(P/S)
1	187.5	150	750	1.25	4
2	187.5	62.5	750	3	4
3	187.5	46.9	750	4	4
4*	150	37.5	750	4	5
5**	150	37.5	750	4	5
6 **	150	30	750	5	5
7	150	37.5	750	4	5

* adição de 1% de glicerina relativamente à massa de precursor
** adição de 20% de glicerina relativamente à massa de precursor

In order to produce each geopolymeric mixture alkaline activators were previously mixed together according to each R(S/H) and precursor was added afterwards to the mix, according to each R(P/S) showed in Table 2. In each mixture a small amount of water, about 10%, was added to increase its workability. After mixing for 2 minutes, waste geopolymeric mud mortar was then poured in small moulds of 2x3 cm size and having an approximate shape of natural aggregates. Waste geopolymeric mud mortar was left to cure in moulds at room temperature (20ºC) for approximatly 48 hours. This period of time was found to be appropriate for the initial gepolymeric exothermically reaction to take place and gepolymeric mortar to get initial setting. Mortar samples, designated as WGA aggregates, were removed from moulds after the initial curing period and placed at different curing temperatures to get hardened. For each mix a total number of 16 WGA aggregates were produced in a total number of 112 for all different mixes, whose aspect is presented in Figure 1.

Figure 1. WGA aggregates (2 to 3 cm size) after curing

Two different curing temperatures were adopted (20ºC and 130ºC) to evaluate the effect of curing temperature in accelerating hardening process. Thus, for each mix half of WGA aggregates were cured at room temperature of 20ºC while the other half was cured at 130ºC. Regarding different mixes presented in Table 2, mixes 1 and 2 were the first to be prepared. The proportions adopted for these mixes were based on results of activation reaction and resulting compressive strength after curing. The composition of other mixes, from 3 to 7, were obtained by increasing R(S/H) and R(P/S) of initial mixes to reduce the amount of hydroxide present in WGA aggregates and to obtain a lower initial water pH when aggregates were placed in water, as explained in 2.2 Section. For the same reason mixes 4, 5 and 6 were produced by adding 1% and 20% glycerine since it was initially believed that would contribute to buffer the initial pH of water.

2.2 Structural stability control of WGA aggregates and pH alteration in water

Structural stability of WGA aggregates and pH alteration in water was observed for a curing period of 4 weeks, for each curing temperature.

For the age of 7, 14, 21 and 28 days of curing time, two samples of each mix, for each curing temperatures (20º and 130ºC), were placed in vessels containing 1 L of tap water, resulting in a total of 56 tests, designated from A1 to D14. Half of these tests were cured at the temperature of 20ºC (A1, A3, A5, A7, A9, A11, A13, B1, B3, B5, B7, B9, B11, B13, C1, C3, C5, C7, C9, C11, C13, D1, D3, D5, D7, D9, D11, D13) and the other half was cured at the temperature of 130ºC (A2, A4, A6, A8, A10, A12, A14, B2, B4, B6, B8, B10, B12, B14, C2, C4, C6, C8, C10, C12, C14, D2, D4, D6, D8, D10, D12, D14).

The vessels were operated continuously in fed-batch mode (i.e. the water was replaced each cycle of 24 h). The pH was measured in the beginning (5 minute after the immersion of the WGA or after changing water) and end of each cycle using a SenTix-41 probe connected to a Multi 340i meter (WTW, Germany). The vessels were monitored each day along for several weeks until a water pH of 8 was attained or total disintegration of samples was observed. The water pH variation containing different WGA aggregates was also measured during that time. First, the pH of the tap water before adding the samples was registered for each test, and it was found to vary from 6 to 7,5. The time of beginning of sample defragmentation was also registered.

Statistical analysis was performed using the SPSS program (SPSS Inc., USA; Version 17.0). The data was analyzed through Scheffé test (study of the influence of mixture composition and R(P/S) and R(S/H) ratios in time to achieve $pH \leq 8$) for a statistical significance of differences ($p < 0.05$).

3. RESULTS AND DISCUSSION

The stability in water over time (i.e. behaviour in water without disintegration or dissolution) of different of WGA aggregates obtained from different mixing and curing conditions, in a total of 56 samples, was followed up for a period of 3 months. It was found that most WGA aggregate samples of different mixes would end up disintegrated after a certain period of time in water, particularly samples cured at 20ºC. In Table 3, WGA aggregate samples that end up disintegrating in water are highlighted. WGA aggregates obtained from mix 4 and 7 revealed quite good structural stability in water, either cured at 20º or 130ºC, after the initial curing period.

Table 3. Number of days necessary to obtain pH value lower than 8

Mix	Fed-batch test label	Initial pH	Days to obtain pH ≤ 8	Average days (μ±σ)
1	A2	12.6	49	39 ± 9
	B2	10.5	42	
	C2	10.8	35	
	D2	10.2	28	
2	A4	10.5	49	39 ± 8
	B4	11.0	42	
	C4	9.7	42	
	D3	10.6	28	
	D4	9.4	35	
3	A6	10.6	49	42 ± 7
	B6	10.4	49	
	C6	9.7	42	
	D5	9.5	35	
	D6	9.3	35	
4	A8	9.7	35	27 ± 6
	B7	9.8	21	
	B8	9.8	35	
	C7	9.5	28	
	C8	10.5	28	
	D7	9.3	21	
	D8	9.7	21	
5	A10	9.6	49	35 ± 10
	B10	9.4	35	
	C10	9.4	28	
	D10	9.0	28	
6	A12	9.7	35	16 ± 13
	B12	8.5	14	
	C12	8.4	7	
	D12	8.0	7	
7	A14	10	21	17 ± 4
	B13	10	14	
	B14	10	21	
	C13	9.5	14	
	C14	10	14	
	D13	10	14	
	D14	10	21	

μ: average; σ: standard deviation

The factors which influenced the synthesis and geopolymer formation with alkaline activators and waste mud are not fully understood yet. However, it is believed that increasing R(P/S) might result in higher Si and Al dissolution resulting in better geopolymerisation and consequently a stronger geopolymer structure.

It was verified for the 56 experiments that initial pH values varied from 8 (for test D12) to 12.6 (as found in test A1), decreasing along that time.

According to the Portuguese Law 236/98 (Water quality) the pH of treated wastewater at the discharge point should not be higher than 9. Thus, the number of days needed to obtain a pH value lower than this value was registered for all WGA aggregate samples (pH = 8 was adopted, instead of 9 to increase reliance of results in this study).

The WGA more proper for wastewater treatment processes are the ones which allow to lower pH quickly to values below 8 and which maintain the structural stability in water.

The number of days to obtain a pH value lower than 8 for each sample are presented in Table 4. It was found that average time necessary to get that pH value varied between 16 and 17 days (for mixes 6 and 7) and 42 days (for mix 3).

The results also show that mixes 1, 2 and 3 present both higher initial and final pH water values and the number of days to obtain pH lower than 8 was also higher for those mixes when compared with the others. This circumstance is likely related with the mass ratio percentage of sodium silicate and sodium hydroxide solutions with precursor, which was higher for these three mixes, indicating that part of Na^+ cations that did not combine in the chemical reaction of gepolymerization were dissolved in water, increasing the water pH. This effect was not so evident for mixes 4 to 7 where the mass percentage of alkaline activators with precursor was reduced.

Mixes 5 and 6 show an even lower initial pH which is associated with the presence of 20% of glycerin that might have avoided dissolution of Na+, as well as a little higher stabilization time and higher interval of variation, when compared with others. However, mix 5 took in average more 19 days to stabilize pH below 8.

Mix 4 with 1% of glycerin and mix 7 with the same composition but without glycerin show different values of initial pH and stabilization times (Table 3). The mix 4 presents lower pH in initial days and took more 10 days to achieve pH of 8, when compared with mix 7.

Analysing the results presented in Table 3 it can be seen that the minimum number of days to achieve pH lower than 8 is found in mixes 6 and 7. However, for mix 6, only the samples cured at 130ºC maintained the stability whilst, for mix 7, there are samples cured at 20ºC (B13, C13 and D13) which maintained the stability along the 3 months. Mix 7 also presents much lower standard variation values, which would mean that the time for stabilization observed in each sample were similar.

From an economic point of view, a WGA cured at 20ºC it is more advantageous since it presents low energy consumption. Additionally, the use of WGA promotes the recycling of mining wastes and contributes to minimize environmental impacts.

3.1 Statistical analysis of mix factors versus time to obtain water pH≤8

An analysis of variance and Scheffé test was carried out to study the influence of each factor, i.e. mixture composition and R(P/S) and R(S/H) ratios in time to achieve pH $\leq$ 8. The test aggregates the samples whose averages are statistically equal and in this case created two groups. These tests gave significant differences ($p < 0.05$) to any of the influencing factors.

It was verified that mixes 6 and 7 are the ones that show the lowest length of time to achieve pH $\leq$ 8 and they are significantly different ($p < 0.05$) of mixes 1, 2 and 3. However, the mixture that presents a minor variation interval is the number 7.

Regarding R(P/S) ratio influence it was found that mixes having R(P/S) = 5 present length of time to achieve pH $\leq$ 8 and for lower R(P/S) ratios the time to achieve pH $\leq$ 8 gets higher. Regarding R(S/H) ratio the same conclusion was found, i.e. mixes having R(S/H) = 5 are the ones that present minor length of time to achieve pH $\leq$ 8, however mixes having R(S/H) = 4 (although with higher length of time to achieve pH $\leq$ 8) are statistically equal ($p > 0.05$) to the ones having R(S/H) = 5.

3.2 Analysis of mix factors in the initial water pH

To study the effect of the same factors on the initial water pH, after placing WGA aggregates in water, a non parametric test was carried out as well as a graphical analysis of water pH variation in time.

The Kruskal-Wallis non parametric test indicated that there were statistical significant differences ($p < 0.05$) on the influence of each factor (mix type, R(P/S) and R(S/H)) in the initial water pH, although in all mixes the initial pH decreased with increasing time of cure. As this test does not allow knowing differences between mixes and samples, next analysis on results will try to stress the differences between mixes in order to define the one with more potential to be used in wastewater treatment processes.

From the results of the test and observing the graphs in Figures 5 and 6, mixes may be divided into two groups. The group with mixes 1, 2 and 3 that present high initial water pH and higher mean time to achieve pH ≤ 8 and the group of mixes 4, 5, 6 and 7 showing lower both initial pH and mean time to reach pH ≤ 8.

In the first group, WGA aggregates of mixes 1, 2 and 3, cured at 20°C and immersed in water for 1, 2 and 3 weeks started to disintegrate immediately (all samples). In some cases disintegration process started in first days of immersion and in others started after two to four days. In this group of mixes the immersion tests ended after four to five weeks. WGA aggregates of all mixes cured for different periods (7, 14, 21 and 28 days) at 130°C and mixes cured for 28 days at 20°C remained structurally stable during the 18 weeks of the immersion test.

In the second group, WGA aggregates of mixes 5 and 6 cured at 20°C started to disintegrate immediately after the first and second days and the immersion tests were concluded in four to six weeks. Only the samples cured at 130ºC maintained the structural stability during the 18 weeks of assay. Mixtures 4 and 7 differ between them due to the presence of glycerine in mix 4. Both present 7 samples (3 cured at 20ºC, 4 cured at 130ºC) which maintained the stability along the 18 weeks of immersion test. Both have shown an identical behaviour in terms of pH variation, however, mix 4 took more 10 days to reach pH ≤ 8. In most of these mixes, WGA aggregates did not disintegrate during immersion times with the exception of mix cured for 7 days at 20°C (see Figure 2).

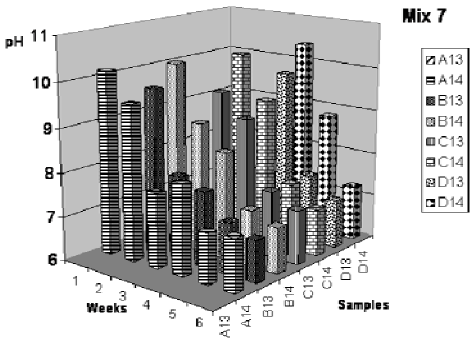

Figure 2. Variation of water pH versus immersion time of WGA aggregates of mix 4 and 7

4. CONCLUSIONS

This work presents a preliminary study to develop alternative aggregates to be used in wastewater treatment processes. These alternative aggregates designated as WGA were produced by using a mining waste mud geopolymeric binder and the parameters that affect its structural stability and pH alteration in water were studied. The WGA should both maintain its structural stability over time and promote the quick reduction of pH in water in order to be suitable for wastewater treatment processes.

In all mixes the initial pH decreased with the increasing time of cure. It was found that the average time necessary to achieve pH ≤ 8 varied between 16 and 17 days (for mixes 6 and 7) and 42 days (for mix 3). It was verified that mixes 6 and 7 are the ones that show the lowest time to achieve pH ≤ 8 and they are statistically significantly different ($p < 0.05$) mixes 1, 2 and 3. However, looking at the samples cured at 20ºC (which less energy consumption) mix 6 samples disintegrated quickly, whilst mix 7 samples maintained its stability during the 18 weeks of immersion test. Mixes having R(S/H) = 5 and R(P/S) = 5 are the ones that present minor times to achieve pH ≤ 8, however mixes with R(S/H) = 4 although having higher times to achieve pH ≤ 8 are statistically equal ($p > 0.05$) to the ones having R(S/H) = 5. In terms of structural stability in water and pH stabilization in a short period of time, mix 7 (cured at 20ºC during 28 days) seems to present good potential for application in wastewater treatment processes and to be a cost effective solution. The initial water pH during WGA aggregates immersion was low (around 10) and the time to achieve and stabilized (pH $\leq$ 8) was relatively short (17 days).

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High Energy Retrofit Module Development

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ABSTRACT: One of the main key sectors to reduce the energy consumption is the existent building stock. The European Union has recognized this issue in 2002 with the entrance into force of the Energy Performance of Building Directive and thus an important step to implement measures to limit building's primary energy consumption was made. Within this context it was initiated the development of a new solution focusing the buildings retrofit – prefabricated retrofit module. This solution is, to some extent, a by-product of the participation on the International Energy Agency project IEA ECBCS Annex50. In order to achieve better support for the solution design and thermal optimization there were applied computational tools to test the design and performance of the several options and also ensure that solution is in accordance to the applicable regulations – Google SketchUp® for 3D modelling and eQuest® for energy performance prediction. Also it is in production a solution prototype to apply on the University of Minho's Test Cells and carry out several "in-situ" thermal performance measurements.

1 INTRODUCTION

Taking in consideration the excessive energy consumption in recent years, one must realize that the building sector is an extremely important sector to intervene. According to Balaras (2005) the European building stock stands for 33% of the final energy consumption and 50% of electricity. Also there are some predictions (Zimmerman, 2006) pointing out that if an significant change of practice does not takes place, in 2050 the buildings stock will represent 80% of the energy consumption. Thus to prevent this situation the building stock should evolve as represented in Figure 1.

With the awareness of the European Union for this problematic, an regulative EU intervention was made by the entrance into force of the *Energy Performance of Buildings Directive* (EPBD, 2002) which objectives are to promote the sustainable development of the building sector and reduce its excessive energy consumption, and also the recent EPBD-Recast (EPBD, 2009) which main goal is so called 20/20/20, i.e., to reduce the greenhouse gases emission in 20%, to reduce the community's, energy consumption in 20% and to increase the share of energy from renewable sources to 20%, all until 2020.

It was compulsory to transpose the EPBD to National Law, in all EU countries. In Portugal this was carried out with the revision of the regulations RCCTE (2006) and RSECE (2006), and the implementation of SCE (2006). The RCCTE objective is to improve the residential buildings thermal behaviour, while the RSECE aims the energy consumption reduction of service buildings and SCE sets the application fields of the regulations, defines the energy labelling and the required qualifications for those who will apply RCCTE and RSECE.

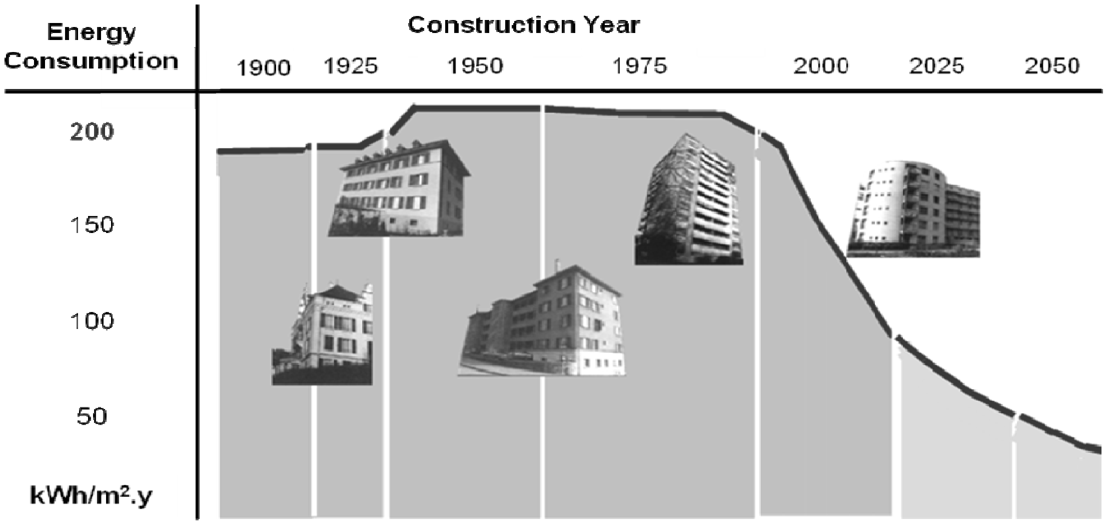


Figure 1. European Building Stock energy consumption through the years (Zimmerman, 2006)

In Portugal the excessive energy consumption scenario is even worse since 77% of the building stock was built before 1990, the year of publication of the first building thermal regulation, thus they were built without any thermal concerns and have high energy consumption in order to guarantee even the minimal comfort requirements. (CENSUS, 2001). Also, the investment made in conservation and retrofit of the building stock is very low – 23%, while the EU average is 45% (Euroconstruct, 2005), since, culturally, the building retrofit in general, and the thermal retrofit in particularly, are not considered as a good alternative compared with new construction.

However the construction companies are starting to be more aware of this problematic, and recognizing a market with high potential, since 41% of the building stock have retrofit needs (CENSUS, 2001) which represents, according to Paes (2009), a market of 74000M€.

Conscious of the market needs, the LFTC – Uminho (Laboratory of Physics and Construction Technologies of the University of Minho) joined an IEA project – Annex 50 – that aims to promote the residential buildings efficient energy retrofit by gathering world specialist in this area and support their exchange of knowledge. In the scope of the latter project and also supported by the Portuguese project financed by FCT (PTDC/ECM/67373/2006) the LFTC – UMinho is developing a prefabricated retrofit module optimized for Portuguese residential buildings.

The evaluation of the system application potential, in terms of design, structural and thermo-acoustic behaviour, etc., will be made with resource of 3D modelling tools, energy simulation and a prototype construction. The computational tools are accompanying the vertiginous technological advancements of the informatics industry, in particular in the processing ability and graphic performance of personal computers. Thus, there are available in the market several tools specifically developed for the construction sector aiming to optimize the design and foresee functional and structural behaviour of different solutions. During the development of the proposed retrofit solution, the applied tools, until this moment, were the 3D Modelling tool – Google SketchUp® (2008) – to verify how the solution can be applied and its visual characteristic, as well as the energy simulation tool – eQuest® (Hirsh, 2003) – with the objective of predict the energy efficiency increase with the application of the solution

2 RETROFIT MODULE DEVELOPMENT METHODOLOGY

2.1 *Initial Premises*

The main objective of the retrofit module in development is to produce a solution that can result in a swift rehabilitation process, causing the least possible inconvenience for building occupants, and with less economical investment compared with the traditional systems.

The guidelines for the module development are the application of an optimized thickness of thermal insulation, in order to increase the energy efficiency of buildings; apply, as much as possible, recycled materials and with low embodied energy (energy necessary for production, transportation and application of the materials); integration of ducts by the interior of the module, since further than improving the final solution aesthetically, it also can provide ducts insulation, what will be added value for the sanitary hot water and for heating / cooling system(s) ducts.

2.2 *Solution Description*

The system in development will be based on traditional discontinuous prefabricated insulating finishing, although with integrated ducts and optimized insulation thickness.

The module composition is (from the exterior to the interior): aluminium composite exterior finishing (6mm); agglomerated cork insulation (20mm); extruded polystyrene insulation (XPS – 120mm); plastic box for the duct filled with injected polyurethane insulation (120mm); agglomerated cork insulation (30mm); air vapour barrier; aluminium composite exterior finishing (6mm).

It is expected that with the application of this retrofit system the exterior envelope walls will increase their thermal resistance by about 4.01 $m^2.^oK/W$, considering the average between the regular and ducts zones. This solution will have a total thickness of 17.7 cm and a total specific weight of, approximately, 12 Kg/m^2.

The application of the solution to the existing wall is going to uphold two phases: 1^{st} placement of the metallic support structure; 2^{nd} application of the module to the support structure due to a system of indentation (module) and gaps (support structure), as shown in Figure 5.

2.3 *3D Modelling*

The aim of the 3D modelling tool is to generate a building's 3D models for a conceptual phase of the projects. Applying Google SketchUp® it was simulated the application of the solution in development to a single-family house with retrofit needs in Braga, Portugal. This study it was carried out in order to optimize the solution design and also to test its application. Therefore the building was modelled and the application of the retrofit system was studied. Also, the building's retrofit consisted not only in the module application, but also the general improvement of the building envelope, i.e., roof slab insulation (XPS - 8cm), ground slab insulation (XPS - 2cm) and replacement of existent windows to double glazings and aluminium frame with thermal break (U_{wdn} = 2.5 $W/m^2.^oK$).

The following figures illustrate some of the 3D models that were executed in Google SketchUp® during the study and development of the retrofit module:

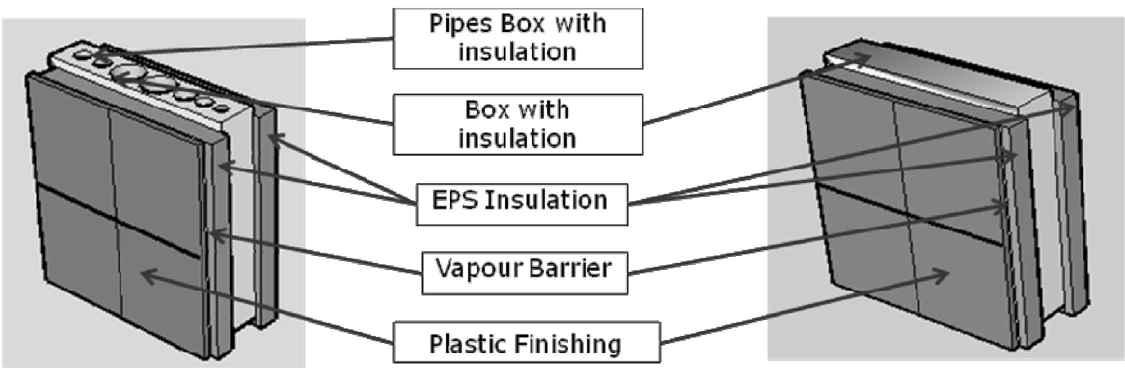


Figure 2. First design of the prefabricated retrofit module - 3D model

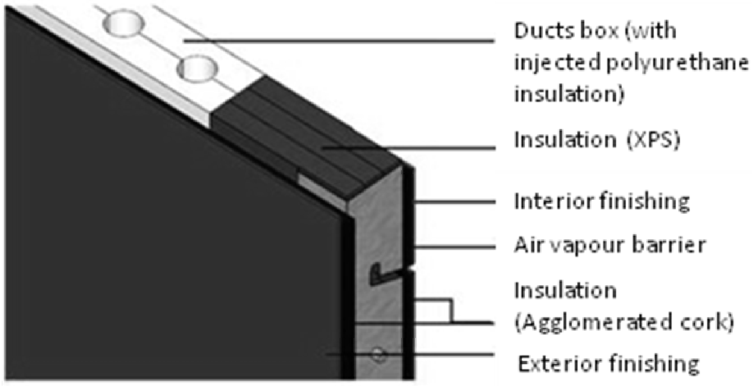


Figure 3. Final design of the prefabricated retrofit module - 3D model

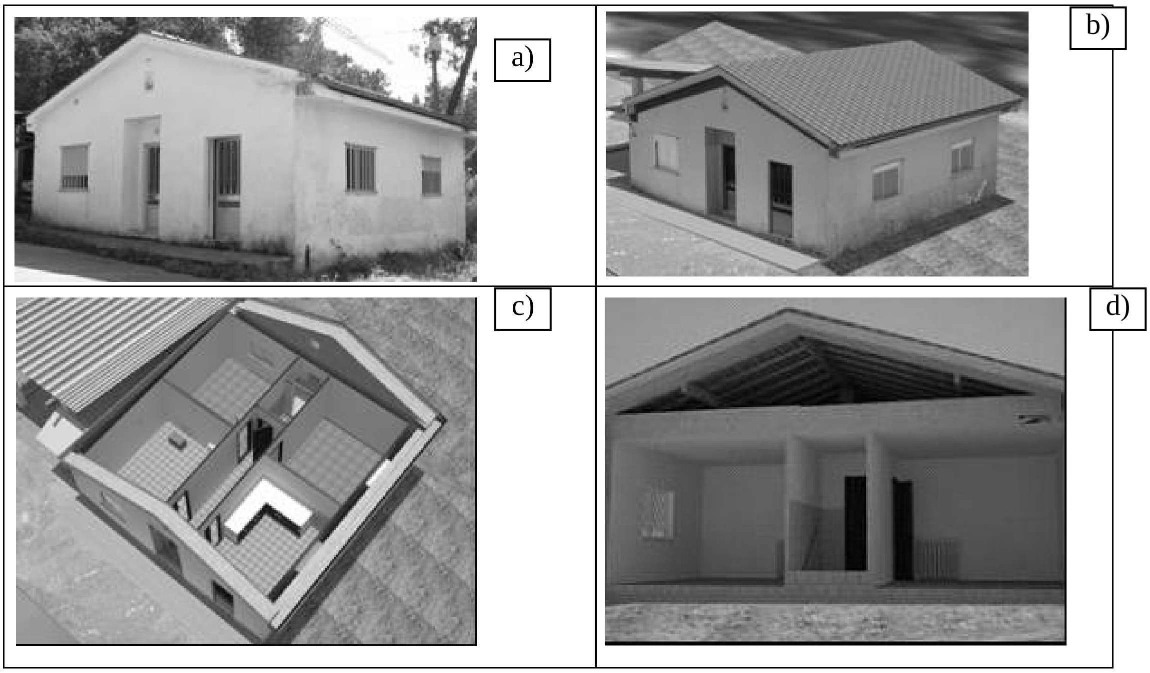
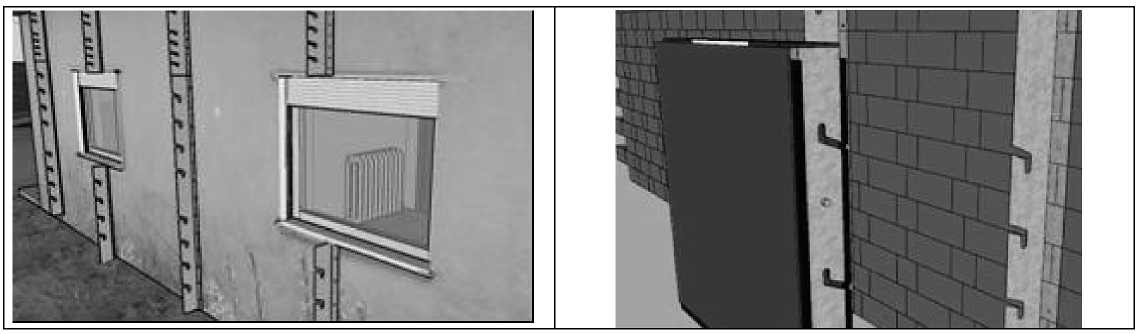


Figure 4. Case study with retrofit needs: a) photograph; b) exterior 3D model; c) interior 3D model; d) 3D model cross-section;



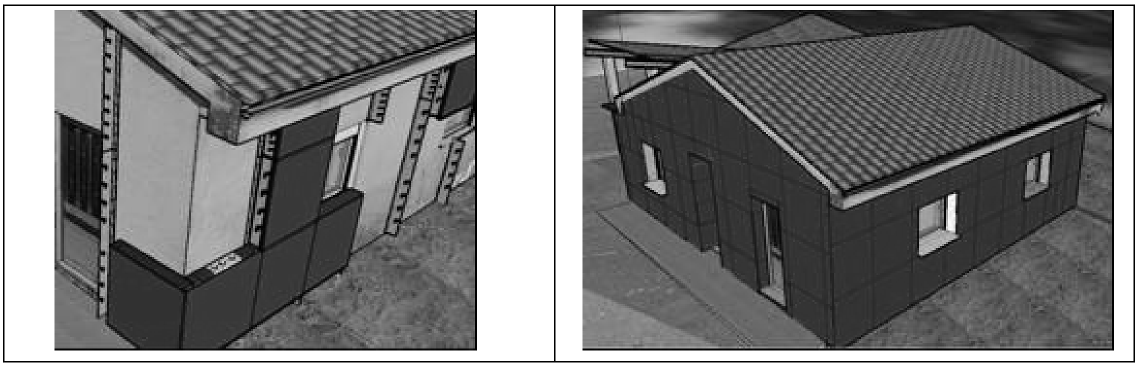


Figure 5. Steps necessary to apply the retrofit module to the case study

By the previous figures it is possible to confirm the large potentialities of the 3D modelling in this type of product development, since it allowed the design optimization of the product, but also to simulate the application of the product in reality, what make possible the study of the necessary support structures and how to apply it in order to be as fast as possible, however guarantying the maximum possible quality of the building retrofit..

2.4 *Dynamic energy simulation*

eQuest® is a free simulation tool developed by the Department of Energy of USA to calculate the buildings energy performance. For example, in the state of California this is a mandatory tool in order to certify the building's energy performance. It is a GUI (Graphical User Interface) of the renowned tool DOE-2.2, which introduced new energetic systems to apply and a faster thermal loads calculation engine. Its new 3D graphical engine makes it easier the editing of building's exterior and interior envelope.

In order to optimize the energy performance of the prefabricated retrofit module in development it was applied this tool to the case study presented before (single-family house in Braga). To simplify the process the Google SketchUp® model shown earlier was exported to a CAD format and imported to eQuest®. Subsequently the envelope characteristics, equipments, occupation and illumination profiles were defined for the original and retrofitted building with the application of the module in development and several scenarios were simulated.

The results obtained with the simulation shown a significant reduction of the energy needs with the final version of the retrofit module, as presented in Table 1. Even thought there was a slight increase in the cooling needs, since with the insulation increase the building requires more days to cool, especially problematic when many consecutive hot days occurs, however the cooling needs are insignificant compared with the total needs.

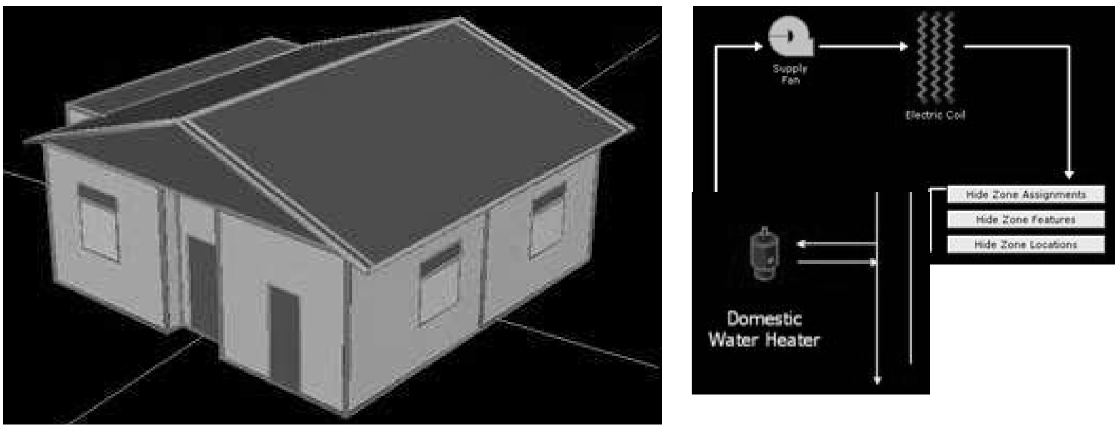


Figure 6. Case study's model, heating and domestic hot water systems.

Table 1 – Simulated energy needs for the case study

Energy Needs (kWh/m^2.year)	Single-family building in Braga		
	Original	Retrofit Module – 1st solution	Retrofit Module – final solution
Heating	318.1	94.1	68.5
Cooling	1.2	10.2	18.3
Total	**319.3**	**104.3**	**86.8**

With the application of eQuest® it was possible to optimize, in terms of thermal performance, the retrofit module in development, testing several options with different insulation thickness and reducing thermal bridges. Thus it also was verified that only with the application of the retrofit module, insulating the roof and floor slab and replacement of the single glazings with double glazings, it was possible to reduce the building's energy needs, for heating and cooling, in about 73%.

2.5 *Future Prototype*

After the retrofit module optimization, in terms of thermal performance, industrialization, quality assurance and economically, it was recognized that in order to further improve the module it was necessary the construction of several prototypes.

At this time the prototypes are in construction and there were schedule two types of assessment to carry out:

Mechanical performance evaluation – for this tests type it will be assessed the module mechanical resistance (torsion, tension, service fatigue, etc.) in order to guarantee the inexistence of problems with desegregation of the module components or the detachment of the module from the existing wall. The tests will be performed in the Laboratory of Civil Engineering of the University of Minho;

Thermal performance evaluation – the main objective of these tests is the determination of the thermal transmission coefficient value (U-value), and also to verify if there are any thermal bridges presented in the prototypes. These tests will be performed in the Test Cells of the University of Minho, School of Engineering campus. The Test Cells are a group of three cells in a rectangular shape, as presented in Figure 7. The non-conventional test cell (CTnc) encompasses non-conventional envelope solutions, like adobe wall. While the conventional test cell (CTC) was built following the most typical Portuguese construction solutions, like double pane brick wall with insulation in the air-gap. In relation to the Passys test cell (CTP), it is a cell with a high insulation thickness in the entire envelope except for the façade in order to test different façade solutions.

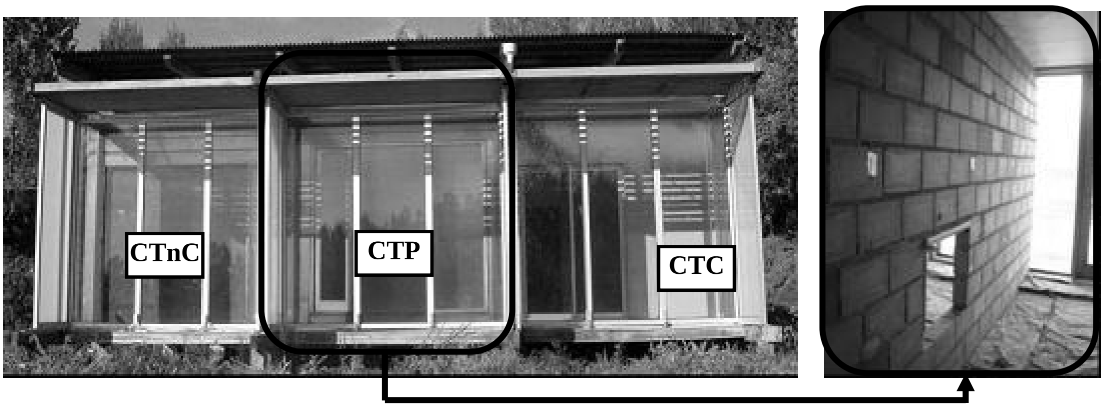


Figure 7. Test Cell's south façade view and interior partition where the retrofit modules will be applied

The prefabricated retrofit modules will be applied in the CTP, in a partition wall, brick masonry wall, executed in the middle of the test cell, as shown in Figure 7. Since only three prototypes will be installed the remaining parts of the wall will be filled with XPS insulation in order to increase the uniformity of the thermal transmission between the two test cell's compartments.

The partition wall was placed perpendicular to the main façade and on the middle of the test cell, while the retrofit modules will be applied top-to-top and side-by-side.

With the application of the prototypes in the Test Cells it will be possible to carry out a more extensive study of the mounting details and its respective optimization, but also to further investigate its thermal properties.

3 CONCLUSIONS

As pointed out in the latest international policies, a drastic reduction of the current energy consumption is necessary. .Having in consideration that the European buildings stock is one of the main responsible for this excessive consumption, representing 33% of the global final energy consumption, the LFCT-UMinho believed essential the development of new retrofit solution that aimed the reduction of the building's energy needs, without overlooking the aesthetic, increase of the thermal and acoustic comfort conditions and indoor air quality.

Thus, the development of a new prefabricated retrofit module for residential building's façades was initiated. For a more supported product development there were applied computational tools – 3D modeling tool Google SketchUp® – for the aesthetical and functional optimization and – energy dynamic simulation tool eQuest® – for the thermal optimization.

At this point it was predicted that with the implementation of this type of solutions a reduction of, about, 73% of the energy needs can be reached, if complemented with the systematic improvement of the building envelope – slabs insulation and windows replacement.

For the final validation of the retrofit module in development it was initiated the construction of several solution prototypes that will be prepared with monitoring equipment and their mechanical and thermal performance certified.

Throughout this paper it was shown the development of a prefabricated retrofit solution that in addition to contribute to the reduction of the building's energy consumption, can also improve their aesthetic with faster, higher quality assurance and less expensive interventions, that can also reduce the occupant disturbance typical in this type of work, thus this is solution with a very high potential of application in the fast growing Portuguese market of building rehabilitation.

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Achieving Sustainability through Energy Efficiency while Assuring Indoor Environmental Quality

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ABSTRACT: Sustainability in the Building sector is nowadays a major concern. Taking in consideration that in the EU buildings account for about 40% of the total energy consumption (35% in Portugal), the EU Directive 2002/91/EU on Energy Efficiency in Buildings (EPBD), recently reinforced with the "EPBD-recast", imposes an increasingly stronger control of the energy consumption in this sector while maintaining, or even improving, their indoor environmental quality (IEQ). But, as buildings are complex systems, where all aspects are interconnected and influence each other, not always in a favourable way, an integrated and comprehensive approach to the buildings design, that enhance indoor health and comfort besides the energy savings, should be followed. In this work it is presented a multi-criteria analysis, suitable for the design phase that balances all these aspects, with the potential of becoming a valuable tool to assist the designer in the most appropriate selection of design alternatives, construction solutions and materials.

1 INTRODUCTION

As EU buildings account for 40% of the total energy consumption, it is important to take measures to reduce these needs and, consequently, reduce the EU energy dependency as well as reducing the greenhouse gas emissions, in accordance with what is prescribed in the EU Directive 2002/91/EU on Energy Efficiency in Buildings (EPBD), recently reinforced with the "EPBD-recast" (EPBD, 1991; EPBD-recast, 2009).

Besides the energy efficiency, buildings must guarantee a healthy and comfortable indoor climate as Men spend about 90% of their time inside closed spaces. Thus, it is mandatory to control the energy consumption in the building sector, while maintaining, or even improving, the indoor environmental quality. But, as buildings are complex systems, where all aspects are interconnected and influence each other, an integrated and comprehensive approach to the buildings design that enhance indoor health and comfort besides the energy savings and environmental sustainability, should be followed. This aim leads to the analysis of several alternative solutions, which differ geometrically, technologically, environmentally and economically, and also in terms of comfort and Indoor Air Quality (IAQ). However, these goals are often in conflict and there is not a unique criterion that describes the consequences of each alternative solution adequately and there is not a single solution that optimizes all criteria simultaneously. Therefore, heating, cooling, daylight availability, Indoor Air Quality, acoustic behaviour and energy reduction strategies should be meshed at an early stage with the other requirements to ensure the buildings overall comfort conditions and energy efficiency. To do so, it is necessary to predict the thermal, acoustic and daylight conditions and also the IAQ behaviour of the buildings, on the design phase, in order to be able to do the right choices, regarding, for instance the geometry, space organization, fenestration strategies, construction solutions and materials, to improve the occupants overall comfort and, at the same time, reduce the energy costs.

Furthermore, to make a conscious selection of the possible design alternatives, it is necessary to balance the positive and negative aspects of each solution into the global behaviour of the building.

Multi-criteria analysis is, in this way, an important tool in such problems, since it employs mathematical models that evaluate alternative scenarios, in this case, design alternatives, that include geometry, construction solutions, fenestration strategies, etc., taking into account both their objective characteristics (like thermal behaviour, daylight factor, energy consumption of the building) and the preferences of the decision makers regarding the objectives and constraints of each project.

The aim of this study was to investigate the viability of the use of multi-criteria analysis to improve the energy efficiency and IEQ in buildings. A simple case study was studied to demonstrate the feasibility of the approach using the multi-criteria analysis method Electre III.

2 METHODOLOGY

To achieve an adequate IEQ it is necessary to consider either the overall comfort conditions (thermal, acoustic, visual and Indoor Air Quality) as well as energy efficiency in buildings. It is then essential to optimize the building envelope, by improving construction solutions and insulation levels, glazing type and shading devices, optimizing the thermal and acoustic behaviour, the natural ventilation and daylighting techniques through an appropriate design. But the solutions adopted in buildings, usually, only optimize no more than one of the necessary comfort requirements. In many cases, the best solutions to accomplish different comfort requirements are not compatible, especially in what concerns natural ventilation and lighting strategies and the acoustic and thermal performance. For instance, the type of window used can have a strong and opposite influence on the thermal and acoustic performance of the building, just not to mention its interference with the IAQ.

The design phase is the ideal moment to mesh and implement all these principals as it is still possible to implement modifications on the project. So, it is during the design phase that the sustainable building concepts should be applied, by a judicious selection of materials, technologies and construction methods to be used.

To test this integrated approach, two dwellings with three bedrooms, representative of the conventional Portuguese buildings, were studied, estimating the heating and cooling needs, the acoustic behaviour of the envelope (estimating the weighted normalized airborne sound insulation index), the daylight factor, the percentage of time considered comfortable by the buildings occupants and the index PPD which means the percentage of people dissatisfied with the IAQ. The analysis considered all the factors that have influence on the behaviour of the buildings, such as glazing type, area and orientation, shading devices, construction solutions, thermal inertia, number of air changes per hour (ach), etc..

To predict the energy consumption and the thermal comfort conditions of the selected dwellings, it was used dynamic simulation. As in Portugal, in general, residential buildings are only acclimatized during occupied periods, the HVAC system was set up to maintain an indoor temperature of 20ºC in winter and 25ºC in summer (in accordance with the Portuguese legislation - RCCTE, 2006) only during this period that is between 7 pm and 8 am.

2.1 *Simulation Tools*

The prediction of the building thermal behaviour was done using the EnergyPlus simulation code, estimating the heating and cooling needs, for different construction solutions for the envelope and for the partition elements. The buildings had mixed ventilation, with air inlets on the windows frames of the main rooms and with mechanical ventilation in the kitchen and in the WCs. In summer, during night periods, the buildings were ventilated to use the cooler outside air to reduce indoor temperature.

The thermal comfort conditions of the occupants were determined according to EN ISO 7730 and EN 15251. The comfort period (number of hours during the occupied period where the occupants were comfortable) was ascertain by EnergyPlus according to ASHRAE 55 - 2004 graph (Section 5.2.1.1) (ASHRAE 55, 2004; EN ISO 7730, 1994; EN 1521; 2007).

The acoustic behaviour was considered estimating the weighted normalized airborne sound insulation index of the façade ($D_{2m,\ nT,\ W}$), using the Acoubat Sound Program, as this is the only requirement that the building elements of single detached family houses have to fulfil (RRAE, 2008).

The visual comfort was accessed through the daylight factor, for the most unfavourable situation, using the Desktop Radiance Tool, for the 21st of December and for the 21st of July considering the existence of a light-colour curtain in every window. The daylight factor is the International Commission on Illumination (CIE from its French title) recommended method to determine the performance of a daylighting system, and is independent on the window design and location, outdoor obstructions, optical characteristics of inner surfaces and windows. It is useful for estimating the amount of glazing needed to illuminate a space.

To assess the Indoor Air Quality it was applied the Fanger method to predict the number of persons dissatisfied with the IAQ, taking into account the number of ach, predicted using Comis studio program, the number of occupants and the materials used (low-polluting or non low-polluting) (Fanger, 1988; CEN CR 1752, 1998).

2.2 *Building Characteristics*

The buildings under analysis, used to test the methodology, have three south oriented bedrooms. The kitchen and the dining and living room are north oriented, in building 1 and South oriented in building 2 (Figure 1).

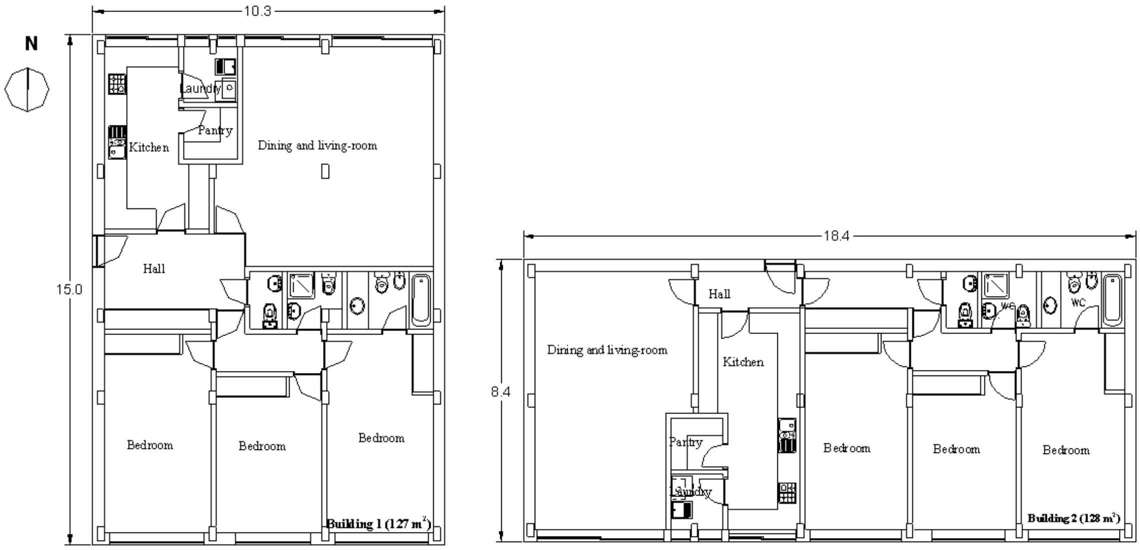

Figure 1 Schematic plan of the studied buildings

The WCs are mechanically ventilated and the windows have adjustable air inlets in the frame to guarantee the ventilation of the dwelling. The glazing area corresponds to 15% of the floor area (30% of the walls area), to optimize the use of solar gains in winter and the daylight availability (3.36 m^2 on the kitchen, 5.15 m^2 on the dining and living room, 2.75 m^2, 2.20 m^2 and 2.75 m^2 for the bedrooms).

2.3 *Construction Characteristics*

The construction solutions analyzed are shown in Figure 2 and listed on Table 1, for the different types of elements of the building envelope. The windows have an adjustable shading system (venetian blinds) on the outside to maximize the solar gains during winter and minimize the unwanted solar gains during summer and at the same time allowing the control of daylight, thus, avoiding the use of artificial lighting.

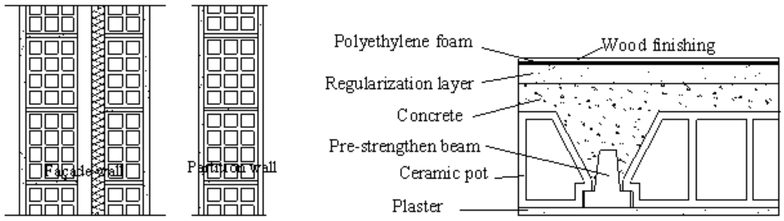

Figure 2 Vertical cross-section of the construction solutions of the walls and floors of the buildings (external and partition elements)

Table 1 Construction solutions characteristics

Element	Construction Solutions (see Figure 2)	
Façade	Double pane wall, hollow brick wall (15cm + 11cm), with 6 cm of mineral wool in plates placed in the air cavity and finished with plaster on both sides	
	Single concrete wall (15 cm), with 4 cm of expanded extruded polystyrene, finished with plaster on both sides	
Partition walls	Single pane hollow brick wall with 11cm, finished with plaster on both sides	
Windows	Metallic window frames with adjustable air inlets, venetian blinds on the outside and overhangs on south windows	Double pane clear glazing (8+10+6) mm
		Double pane Low-e glazing (6+10+4) mm

2.4 *Multi-criteria analysis*

The multi-criteria decision analysis (MCDA) defines flexible approach models to help the decision maker, and/or the design team, selecting the most adequate solutions between a large number of options and possibilities. The problem of the decision maker is a multi-objective optimization problem (Ehrgott & Wiecek, 2005) characterized by the existence of multiple, and in several cases competitive, objectives that should be optimized, taking into account a set of parameters (criteria) and constraints.

This kind of analysis is able to reflect the objectives and limitations of each one of the alternatives to be studied, but it is necessary to be thorough on selecting the criteria that should be exhaustive but not redundant (no more than 12) and must be coherent (which are the criteria to be maximized and to be minimized) (Roy & Bouysson, 1993; Roulet et al, 2002).

The selection of the best options to optimize the sustainability through energy performance, and the IEQ of buildings is a type of problem that fits the purposes of a multi-criteria analysis.

The multi-criteria methodology selected in this work to help the decision maker selecting the most adequate solutions to optimize the building IEQ and energy efficiency was the Electre III model as it may be considered as a decision-aid technique suited to the appraisal of complex civil engineering projects (Papadopoulos & Karagiannidis, 2008). This method requires the definition of weights, which allows the decision maker to provide his scale of values, according to the objective.

2.4.1 *The Electre III method*

Electre III is a multi-criteria decision analysis method (Roy, 1978) that takes into account the uncertainty and imprecision, which are usually inherent in data produced by predictions and estimations. The construction of an outranking relation amounts at validating or invalidating, for any pair of alternatives (a, b), the assertion "**a** is at least as good as **b**". This comparison is grounded on the evaluation vectors of both alternatives and on additional information concerning the decision maker's preferences, accounting for two conditions: concordance and non-discordance.

The Electre III method is based on the axiom of partial comparability according to which preferences are simulated with the use of four binary relations: I, indifference; P, heavy preference; Q, light preference and R, non-comparability. Furthermore, the thresholds of preference (p), indifference (q) and veto (v) have been introduced, so that relations are not expressed mistakenly due to differences that are less important (Roy, 1978).

The model permits a general ordering of alternatives, even when individual pairs of options remain incomparable where there is insufficient information to distinguish between them. Also, the technique is capable of dealing with the use of different units, the mix of both quantitative and qualitative information and when some aspects are “the higher the better” and others are “the lower the better”, as occurs within an engineering project appraisal.

The rank of a building in a series does not change much when the weights given to the various criteria or the threshold levels for veto, preference or indifference are changed within a realistic range (Roulet et al., 1999, Roulet et al., 2002).

The Electre III method does not allow for compensation, which may occur when using methodologies based on performance indexes, due to the use of the veto threshold. Compensation occurs when a criterion with poor rating according to one parameter is compensated by fair results on several other parameters. Using this method, a building which shows too poor results in one criterion cannot be ranked in a higher position (Roulet et al., 1999, Roulet et al., 2002).

3 RESULTS

In the study performed, the Electre III method was applied to the evaluation of five alternatives, based on two types of buildings, with one and two façades with glazing, on the basis of five criteria covering energy needs, comfort period, acoustic insulation, Percentage of People Dissatisfied with the IAQ and Daylight Factor (DF).

Table 2 lists the different criteria, thresholds and weights that are needed to use the Electre III method. The weights and thresholds are presented here just an example. These values must be defined by the project team according to the objectives and constraints of the project.

Table 2 Criteria, weights and thresholds

Category (Criteria)	Units	Weight	Threshold		
			Preference	Indifference	Veto
Thermal Comfort (Percentage of Comfortable Time)	(%)	25	20	10	50
Acoustic Insulation ($D_{2m, nT, W}$, $D_{nT, W}$ and/or $L'_{nT, W}$)	(dB)	22	5	2	10
Indoor Air Quality (Percentage of People Dissatisfied, PPD)	(%)	18	5	2	15
Visual Comfort (Daylight Factor, DF)	(%)	15	0.5	0.2	2
Energy Consumption	kW/(m^2.year)	20	50	10	100

The criteria that were selected are the ones that are related to the sustainability of the buildings, the energy consumption, and the most important characteristics of the IEQ, and also because it is possible to define them in a non subjective way. These criteria are also ones of the few that are possible to predict in the design phase and are under the designer scope.

The weights were defined taking into account the relative importance of each of the criteria. The weight of the energy consumption was established based on the targets defined by the "EPBD-recast" (EPBD-recast, 2009). The weights established for the IEQ criteria were defined according to the relative importance of each one to the occupants based on studies performed in Portugal and according to literature (Monteiro Silva, 2009; Rohles et al., 1987; Kim et al. 2005). These studies showed that the thermal comfort is the most valued criterion, followed by the acoustic comfort and IAQ. The visual comfort is the less valued criterion.

The thresholds were defined according to the criteria characteristics, for example a 2 dB difference is not perceptible to the human ear, but 5 dB is a significant difference.
Five design alternatives were selected, based on two different buildings, shown in Figure 1, Building 1 and Building 2. The buildings have similar areas, but the glazings have different orientations, conducting to different solar gains and energy needs.

The study was performed considering that there are four households and the HVAC system was set up to maintain an indoor temperature of 20ºC in winter and 25ºC in summer, working between 7 pm and 8 am. The ventilation rate was of 0.98 ach. All the options fulfil the regulations.

The construction solutions analyzed, defined in Table 1, were the same for the two buildings. Option A corresponds to a façade with a double brick wall and option B to a single concrete wall. Option C has the same walls as option A, but the painting used is low polluting. In option 1A the occupants are non-smokers, and in option 1B and 1C 20% of the occupants smoke inside the building. In option 2A 20% of the occupants are smokers and in option 2B the occupants are non-smokers.

The acoustic insulation of the façade and the daylight factor shown in Table 3 are from the dining and living-room that is the most unfavourable room of the building. The other criteria are from the whole building.

Table 3 lists the results of the prediction of the building behaviour according to the five criteria selected to outrank the design alternatives.

Table 3 Criteria for the different design alternatives

Options	Energy needs [kW/m^2.year]	Comfort period [%]	Acoustic insulation [dB]	PPD with the IAQ [%]	Daylight Factor [%]
(↓ - lower is better; ↑ - higher is better)	↓	↑	↑	↓	↑
2 façades, with double brick wall, non smokers (1A)	53.3	40	35	20	1.2
1 façade, with double brick wall, 20% smokers, painting used are low polluting (2A)	41.2	35	31	15	1.5
2 façades, with double brick wall, 20% smokers (1B)	23.5	48	33	22	2.0
2 façades, with double brick wall, 20% smokers, painting used are low polluting (1C)	32.3	45	35	15	2.0
1 façade, with single concrete wall, non smokers low polluting painting (2B)	55.6	60	33	13	1.5

Option 1C and 1A are the ones with best behaviour according to acoustic insulation and option 1C and 1B are the ones with best performance according to the daylight factor.

The results of the outranking using Electre III method are presented in Table 4. The dwelling with 2 façades, with optimized construction solutions, option 1C, was ranked as the best action.

Table 4 Credibility degrees matrix

						Non-Dom		Ranking
Options	1A	2A	1B	1C	2B	A	μ(A)	Options
1A	-	0.76	0.75	0.61	0.52	1A	0.52	1C
2A	0.85	-	0.74	0.70	0.75	2A	0.70	2B
1B	1	0.82	-	0.82	0.77	1B	0.82	1B
1C	1	1	1	-	0.88	1C	1.09	2A
2B	1	0.98	0.74	0.78	-	2B	0.91	1A

The best ranked option was not the one that had the best performance in the criteria with highest weights, was in the third position in the highest weighted criterion. This option had the best performance in two of the criteria, but other option had the same performance.

As Tables 3 and 4 show, the option 2B, that has the higher comfort period (which is the criterion that has the highest weight), is not the one best ranked.

This example shows that applying this methodology, due to the use of weights and thresholds, the best action is not the one associated to the highest weight, even if it is the one that has the best performance in that criterion. The methodology is sensitive to small changes, associated to the area of the building, the energy needs, etc..

4 CONCLUSION

This methodology allows, in an easy and quick way, to outrank design options according to a set of criteria pre-established and based on the weight and thresholds assigned to each one.

The possibility to change the criteria, weight and thresholds according to the objectives and constraints of the project enable the use of this methodology to a vast set of possibilities (different areas, selection of construction solutions, materials, etc.).

Using this methodology, the design team can compare design alternatives based on different criteria, for example, the useful area, space organization, glazing area, etc., select and compare materials and construction solutions, considering, for example the U-value, acoustic insulation level, thickness, weight, embodied energy, just to name a few. The criteria, weight and thresholds should be selected by the design team according to the aims of the project.

The design team, once optimized each one of the different components of the building, can compare different design alternatives (using the same criteria, weight and thresholds as the study presented or select other that best adjusts to the study under analysis), compare locations (orientation, shading due to other buildings, amenities, accessibility to public transportation, and so on).

As it is necessary to compare a large set of alternatives, to be able to select the best one, the number of areas under analysis (thermal, acoustic, IAQ, natural lighting behaviour of buildings), the use of detailed simulation methods to increase the rigor of the study, that not all the design teams are acquainted with and also due to the time needed to perform such detailed analysis, are some of the disadvantages of the methodology.

This handicap may be overcome by using simplified methods to estimate the energy needs, for example the national energy codes based on the EPBD. The study may also be carried out in phases, in a first phase, with many alternatives, are used simplified analysis to select the most suitable ones and afterwards the best ranked solutions are object of a detailed analysis.

Thus, the use of a multi-criteria decision analysis is a way to help the decision maker to select the most suitable design alternative regarding different aspects that affect Indoor Environmental Quality (IEQ) and energy performance of the buildings.

The example here presented allows a robust analysis of the buildings as it comprise a detailed study of each alternative through a detailed simulation and analysis of the main factors that affect the IEQ and also the sustainability, based on the energy needs of the buildings.

Throughout the multi-criteria analysis performed, it was possible to verify that the overall comfort exigencies are not restrictive, because there are a large number of constructive solutions that, when adequately used, will assure all the needs, being only necessary to integrate the exigencies of all the different requirements.

The proposed multi-criteria method, which can easily be applied using building simulation software, allows buildings to be rated according to their energy use and comfort conditions, or by using a more complete set of parameters involving environmental factors. This methodology may be used in the design phase or to evaluate rehabilitation or retrofitting scenarios.

Using the Electre III, buildings, design alternatives or retrofit scenarios can be ranked according to several criteria and weights representing the preferences of the decision maker.

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Self-compacting concrete (SCC) - Contribution to Sustainable Development

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ABSTRACT: This paper intends to demonstrate how self-compacting concrete can contribute to reduce the effects of the construction industry in terms of sustainable development. The impact of the construction industry on the environment is significant and it can not be overlooked when analysing the issue of sustainable and balanced development of the planet with an emphasis on the greenhouse effect and the consumption of limited natural resources. This paper highlights how the use of self-compacting concrete (SCC) can be an important contribute to reach a better sustainable development, namely by incorporating significant quantities of sub-products of other industries and recycled materials in its composition, and by potentially increasing the structures durability which will lead to longer life cycles.

1 INTRODUCTION

Concrete, as it is known nowadays, has been used for thousands of years. Concrete is constituted by a composite of coarse aggregate kept together by a paste of hydraulic binder, which was already used by the Romans in the construction of part of their structures, some of which survived to the present days.

With the invention of normal Portland cement (NPC) in the first half of the 19^{th} century, concrete as it is known today appeared, which became in modern times the most important construction material in the world. Nevertheless, and despite the popularity of its use, concrete is associated with several anomalies observed in infra-structures currently in use, usually linked to problems related to the mixes, to poor casting at the construction site or to inadequate or even inexistent maintenance processes, which may lead to permanent deterioration of the structures and to the consequent loss of usability conditions.

The increase of worldwide social empathy towards the planet's sustainability problems has, nowadays, led to a greater concern of the environmental impact of the use of concrete in construction. This is now one of the major concerns, if not the main concern of the concrete industry. Naturally, the search for sustainability solutions is (or should be) causing significant changes to the current living standards, leading to the identification of the most "problematic" sectors. Recognising the concrete industry as one of the main consumers of natural raw materials and energy resources, therefore constituting one the main contributors to the worsening, for example, of the planet's greenhouse effect (Meyer, 2002), comes up, as a logical consequence, the need to develop and test new solutions.

Therefore, the new challenge faced by the construction industry, and already acknowledged by many, is that of providing more efficient answers in terms of development and use of new techniques and materials that can respond to a higher and tighter level of requirements in terms of environment and that may, simultaneously, achieve superior performances with lower costs. In other words, it will be necessary to produce concrete with excellent mechanical properties in parallel with high durability levels and controlled costs.

2 CURRENT STATE OF CONCRETE TECHNOLOGY

The improvements that need to be implemented in the concrete technology to contribute to an effective decrease of the environmental impact of the construction industry will have to involve not only the analysis of its impact on nature, the use and consumption of different constituent raw-materials, but mostly a change in the way the process itself is viewed by the different actors (from the owner to the contractor). Only then will it be possible to implement new construction techniques as well as the use of new materials (and/or combinations of both) so that, through a decrease of the construction industry's environmental impact, the industry can contribute to a sustainable development.

It is urgent to understand the causes of the current problems of hardened concrete, that is, to directly associate the occurrence of anomalies to either the construction process or to the conception of concrete in itself. Baalbaki (2006), in the *technical report of the Cementos Minetti group* (Buenos Aires - Argentina), presents a set of reflections on the reasons for a less satisfactory form that concrete occasionally evidences.

2.1 *Sometimes wrong idea of the concrete technology by the different actors*

The construction sector is very competitive and that, in many cases, leads to awarding projects exclusively on the basis of economical factors without any concern with the technical capacity for the execution of the awarded work and, as a consequence, allowing that it be done without any quality guarantee.

The mechanical resistance can not be the only factor to be considered in the verification of the concrete's final quality and in the evaluation of its performance. In other words, it is true that the concrete technology is seen as something simple, which leads many actors to "abuse" the properties of concrete, either by ignorance or even by dishonesty. Baalbaki (2006) mentions that *"…many people thing they are specialists because having 20 years of experience doing things right or wrong is still having 20 years of experience…"*.

2.2 *Incorrect concrete specification*

According to what was just mentioned, the methodology to specify concrete does not depend exclusively on the indication of the mechanical resistance at 28 days. According to the NP EN 206-1: 2007 (IPQ, 2007), to ensure an effective performance of concrete's structural functions and durability requirements, it is necessary to provide a set of elements beyond the class of compressive strength, such as:

- Class of environmental exposure and class of chloride levels;
- Maximum-size of aggregate;
- Class of consistency.

2.3 *Generalized lack of interest for the quality of concrete and inadequate control at the construction site*

The process of casting concrete into the moulds represents an important factor for its final quality. Failures during transportation and casting of concrete, inadequate compacting (by excess or by omission), inexistent or inadequate curing process are all factors that, despite concrete being correctly specified, may lead to a material with an inadequate behaviour, therefore compromising the final quality of the structure to which it is destined.

3 CONCRETE TECHNOLOGY VS SUSTAINABLE DEVELOPMENT

The effect of the construction industry on the environment is significant given that it has an environmental impact that can not be despised when considering a sustainable and balanced development of the planet with emphasis on the greenhouse effect and on the consumption of limited natural resources.

From the process of obtaining the different raw materials until the end of the structures service life (which corresponds to demolition), all intermediate phases contribute in some way to the effect mentioned above. By observing Figure 1, it is possible to identify many of the factors that contribute to the effect of construction on the environment and consequently on a sustainable development closer to ideal. It is not possible to ignore the important contribution of concrete to the effects mentioned. From the extraction process of its several components, to its production, to the structure's use and maintenance and to the recycling of the waste resulting of demolitions, concrete is present and represents a significant percentage of those effects.

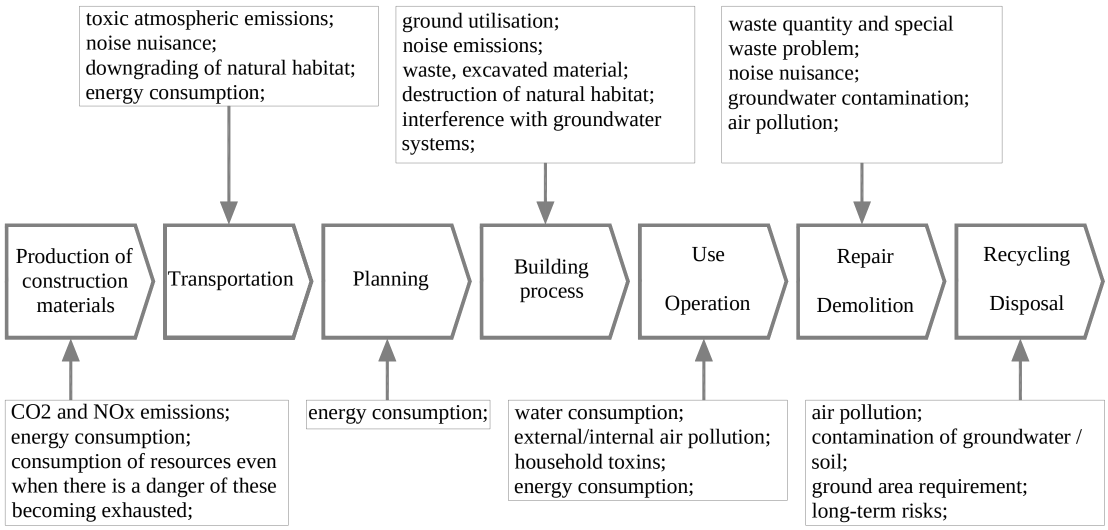

Figure 1. Effect of construction on the environment - from construction to demolition (adapted from Jacobs & Hunkeler, 2001, Camponovo et al., 2006 and Young et al., 2002)

Despite not being fair to impute the environmental impact of the use of concrete exclusively to the use of Portland cement, it is nevertheless one of the most relevant factors. Mehda (2001) mentions that the annual production of NPC (worldwide) causes an approximately 7% increase of the total CO_2 in the atmosphere. This amount is attributable not only to the fabrication process/transformation of NPC but also to the activities of extracting raw materials such as limestone and clay.

Furthermore, concrete uses large quantities of both coarse and fine aggregate that, in conventional concrete, may represent up to 80% of the concrete's volume. The need for such quantities of aggregate results in extraction processes, treatment and transportation at large scale which necessarily consume considerable amounts of energy (essentially fossil fuels) (Mehta, 2001).

The consequences that the lack of concrete's durability has on concrete's environmental impact should also be mentioned, namely decreasing the structures life cycle and causing significant repairs, most of which long before their due date, considering that the design, in most structural regulations, implies, for ordinary situations, a life span of 50 years. It is nonetheless frequent to see structures with signs of deterioration with just 20 to 30 years of use. The increase of structures life span to 100 or even 150 years would bring benefits not only associated with the decrease of costs related to the increase of the life cycle ("replacing" a certain structure in cycles of 100 or 150 years instead of 50) but also with the reduction of natural resources consumption. If one adds the re-use of demolition waste in the production cycle, that impact can be even more significant (Mehta, 2001).

It is nevertheless recognised that the evolution and the investigation effort that occurred during the last 30 years, has led to significant progress both at the level of concrete's constituent materials and of the technology involved. One has moved from a situation in which the technical know-how was mainly based on empirical knowledge associated with cycles of "experiment, error, correction", to another in which the study, selection and application, both of materials and technologies associated with concrete, can be properly calculated as a function of the knowledge and requirements.

Nowadays, with an emphasis on sustainable development demands, a new approach regarding concrete's technology is imposed: search for production and construction methods with lower energy consumption, improvement of the structures durability and a higher degree of construction waste recycling, namely with its re-introduction (re-use) in the construction process, among others. In other words, the way concrete can contribute to a more sustainable construction implies essentially acting in 3 areas, which are (Mehta, 2001):
Minimising the use of raw materials (meaning natural resources) by increasing both the efficiency of the different components in themselves and the use of recycled materials after being incorporated in the final product;

- Maximising the structures durability increasing considerably their useful life with minimal needs for maintenance;
- Reducing maintenance costs not only through a direct increase of durability but also by changing the way construction is regarded by the different actors, that is to say, a structure's service life cannot be different in function of the individual view of each of them, since it is effectively (and legally) the same to all: the owner, project designer, contractor or inspector. Nonetheless, regarding concrete technology, the decrease of maintenance costs can be directly associated to the increase of structures durability leaving the remaining factors to other more wide approaches on the subject.

Figure 2 presents a simple flowchart of the approach mentioned before.

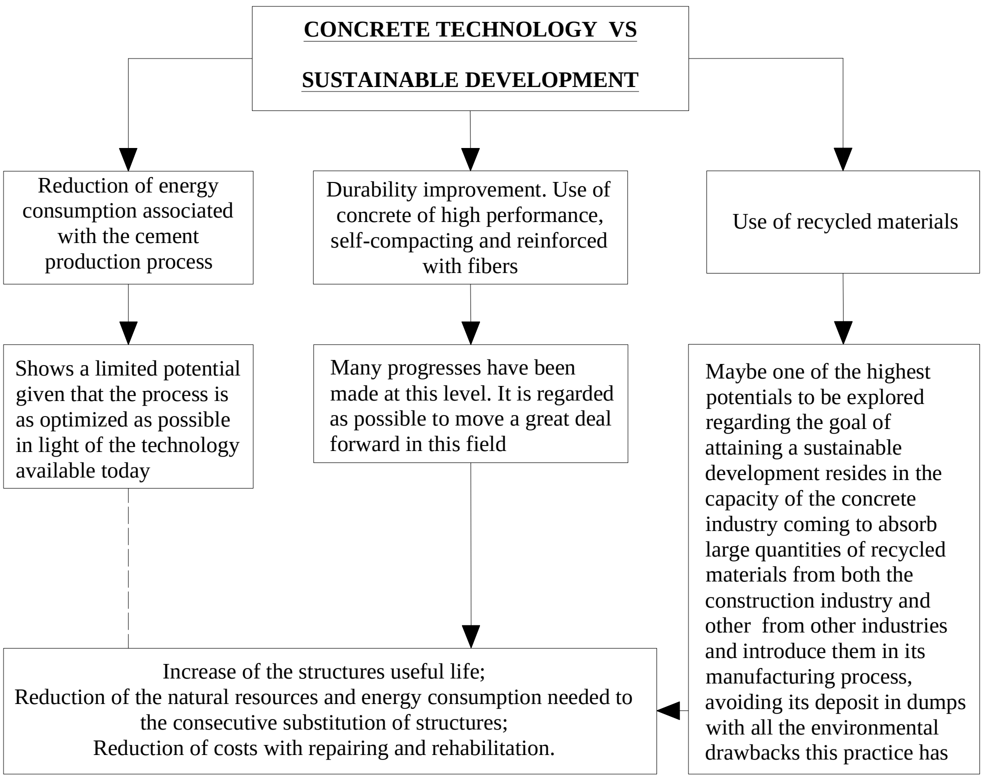

Figure 2. Concrete technology *versus* sustainable development

Regarding "concrete technology *versus* sustainable development", from the 3 possibilities considered, one concludes that, in terms of the main intervention field for future development, the use of concrete with improved performance and the incorporation of recycled materials in the fabrication of concrete are the fields that possess the highest potential impact on development with significant effects.

Related to this last field of intervention, i.e. the use of recycled materials in the construction industry, some very promising steps have already been given for example at the level of R&D where interesting results have been obtained, namely in Portugal, where the current state of knowledge clearly demonstrates the interest on the subject. There is a set of specific normative references on the matter, namely the specification LNEC E 471 (LNEC, 2006), which demonstrates its' importance at the level of the organisations involved with the construction industry.

Regarding the concern with the environment and the natural resources management as a way to achieve a sustainable development, one should highlight the creation of the European Construction Technology Platform (ECTP), whose goal is to contribute to the improvement of competitiveness and sustainability of the construction sector in Europe.

Through the guidance of ECTP, it is possible to identify the importance given to the search for the factors that may contribute to a more sustainable development, looking for the mobilization of the different actors in the construction sector, namely contractors, official organizations, architects and engineers, among others. The intervention of the ECTP focuses mainly on the promotion and incentive to R&D in the sector, mostly directed to the following fields:

- Technology and materials;
- Industry and transformation;
- Services.

In the document "Challenging and changing Europe's built environment - A vision for a sustainable and competitive construction sector by 2030" from February 2005(ECTP, 2005a), ECTP proposes a set of goals in terms of development for Europe, which aim, as a final goal, at the improvement of the citizens quality of life.

The design, construction and maintenance of buildings and infra-structures are shown as essential elements to the economic development, the sustainable growth and the citizens' quality of life. As such, ECTP considers essential the contribution that the construction sector will have to achieving its goals. ECTP (2005a) also considers that the way to respond to the high levels of energy consumption - just the construction sector is responsible for 40% of the natural resources consumed in Europe - should involve the possibility of a higher use of modular constructions through the introduction of prefabricated elements, the use of construction materials incorporating recycled products, the use of new materials and the improvement of the construction processes themselves.

Nowadays one can expect to obtain a reduction of approximately 30% of the cost associated with the life cycle of constructions and a reduction of 50% of the work accidents, solely with the change and consequently improvement of the construction processes.

In the document "Materials-vision 2030 & Strategic Research Agenda" (ECTP, 2005), in the chapter "Need of R&D", where SCC is highlighted, included in the group of "Composite cement-based materials", ECTP mentions that "*the methodologies for the optimisation of the mix proportions, together with the economical viability and especially with the improvements of the working environment and the environmental impact are aspects to take into consideration in the forthcoming years*". Regarding the use of new concrete (namely SCC) big progress has been made which has clearly contributed to obtaining concrete with performances that were unthinkable 40 or 50 years ago.

The subject (SCC) is nowadays of great interest since it evidences clear positive effects both in the improvement of working conditions and of the environment surrounding the construction site, despite the fact that its initial development was linked to the search for an answer to the problems of reinforced concrete structures.

SCC was also initially linked to the growing scarceness of specialised labour force in Japan which, in the beginning of the 1980s, motivated a search for the improvement of structures durability, independently of the quality of the compacting process, therefore intensifying the studies to obtain concrete that exempted any compacting method. This is the concrete currently known as self-compacting (SCC).

Therefore, SCC can be defined as a concrete which, by its own weight and with the kinetic energy produced by its application, is capable of flowing without segregating, fulfilling all the voids, independently of the presence of reinforcement and the geometry of the formwork that constitute important obstacles.

Some consider this to be the most revolutionary development of the last decades in the civil construction sector, mostly due to the fact this it involves a new production process and a new process of casting the concrete on the work site, which, based on the elimination of vibration, allows increasing the final product's quality with possible benefits related to the decrease of the global casting cost.

Since several of the problems with hardened conventional vibrated concrete in structures are related to the work force interference at the moment of casting, a concrete that exempts work force intervention at that stage provides a real contribute to the reduction of those problems.

4 SCC'S ENVIRONMENTAL IMPACT

The use of SCC adds value in various ways, namely because of the decrease of the time associated with the casting task due to the decrease of the amount of work needed and of the need for compacting devices, as well as due to new construction systems. One should also mention the added ease with which concrete is cast in densely reinforced structures and areas of difficult access, the noise reduction on the work site and, consequently, on the surrounding environment, as well as the decrease of injuries associated with the compacting process by vibration and the significant improvement of the final quality of the concrete finishing surfaces.

The use of SCC can also give an important contribute to achieve a more sustainable development, namely through the incorporation of significant quantities of sub-products from other industries (such as mineral additions), the possibility of incorporating recycled materials in its composition in substitution of natural aggregate and the potential increase of the structures durability that will lead to longer life cycles with a consequent decrease of the structures global costs and of the material associated with demolitions.

Regarding its composition and when compared with conventional concrete (CC), SCC contains higher quantities of ultra fine materials (cement and mineral additives) as well as of superplasticizer and sometimes of viscosity modifying agents. On the other hand, SCC contains significantly lower quantities of coarse aggregate.

The use of superplasticizers is needed as a way to increase fluidity while the ultra fine material, as well as the viscosity moulders, contribute to maintaining the viscosity needed for a correct self compacting without the occurrence of segregation, bleeding or particles flocculation. On the other hand, the lower quantities of coarse aggregate contribute to reducing the blocking phenomena allowing SCC to fulfil the moulds and to move through densely reinforced zones.

Due to the differences in composition (and material consumption), SCC emerges as a material with properties, in both fresh and hardened states, very distinct from those of CC, namely at the level of materials consumption and durability.

There is still little precise information on the effect/contribution of concrete to the environmental impact of the construction industry and the existing information is very dispersed in loose publications difficult to link.

Jacobs & Hunkeller (2001) present an interesting comparison between one reference CC and 3 SCC (with distinct compositions) based on several possible environmental impacts (greenhouse effect, acid rain, eutrophisation, oxidant generation and renewable energies) and considering all phases of the process from component extraction, to concrete production and to its delivery in the working site. Nevertheless, the phases of casting, compacting and the possibility of recycling were not considered in the study mainly due to the lack of sufficient data and because it was considered that these stages would have a lower environmental impact when compared with the remaining phases. Still regarding the casting, compacting and recycling possibility after demolition in terms of their environmental impact, the authors consider that the differences would be minimal between SCC and CC. Some elements of the composition of the CC and the 3 SCC that served as the basis to the referred study as well as the evaluated properties at 28 days are presented in Table 1.

Table 1 - Composition and properties of the considered SCC (adapted from Jacobs & Hunkeler, 2001)

COMPOSITION		$CC_{reference}$	SCC 1	SCC 2	SCC
Cement CEM II/A-L	[kg/m^3]		450	430	
Cement CEM I		300			350
Blast furnace slag					110
Silica dust				20	
Superplasticizer			7,2	7,2	14,7
(water) / (ultra fine material)		0,62	0,47	0,41	0,37
28 DAYS PROPERTIES					
Compressive strength	[n/mm^2]	40,1	61	59,3	56,9
Chloride diffusion coefficient	[10-12 m^2/s]	19,7	16,3	8,9	7,5
Capillary suction	[g/m^{2}h]	6,6	4,9	4,7	6
Gas permeability	[10-16 m^2]	0,49	0,44		

Based on the values illustrated in Table 1, Figure 3 presents the correlation between the properties of the SCC and the CC individually analysed and with the higher results corresponding to the best results. It is possible to observe the differences in terms of durability between the SCC and the CC. Regarding the mechanical resistance, significant changes can be observed mainly due to the difference in the water to cement ratios. Concerning the values of the chloride diffusion coefficients, the use of ultra fine material, essentially of mineral additions, contributes heavily to the results improvement.

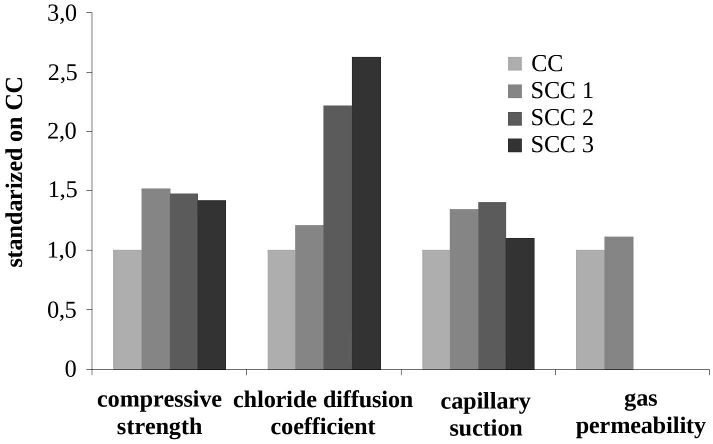

Figure 3. Correlation between the properties of SCC and CC (adapted from Jacobs & Hunkeler, 2001)

The impact of the SCC in each category analysed and in relation to the CC is shown in Figure 4, the higher values being those with a potentially greater negative effect. In this case, the substantially higher quantities of cement (despite the use of mineral additions) and of chemicals, namely superplasticizer, are clearly the most unfavourable factors which reflects in the results shown. Nonetheless, it should be mentioned that the optimization of the mix quantities can contribute significantly to the improvement of the results shown. In the study case presented, despite being only a relatively simple analysis, one can see a positive influence of the use of sub-products from industries such as the blast furnace slag and the silica dust.

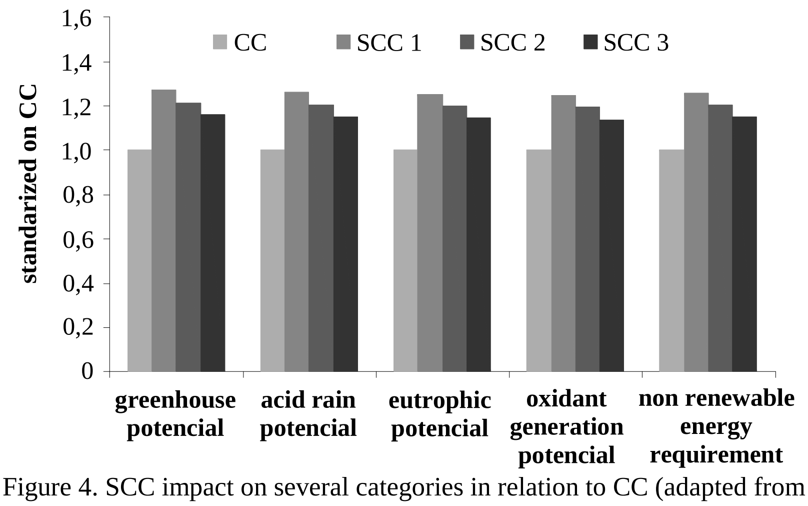

Figure 4. SCC impact on several categories in relation to CC (adapted from Jacobs & Hunkeler, 2001)

The analysis integrated in Figures 3 and 4 allows a more precise evaluation of the "ecological performance" of SCC in which, relatively to SCC 1 and 2, the differences to CC shown in the values of the mechanical resistance, chloride diffusion and water absorption, when compared to the impact on different categories allows the statement that they present a reasonable "ecological profile" (correlation between advantages/disadvantages of different parameters in terms of ecological performance).

In the case of SCC 3, if the comparison mentioned is based on the analysis of the mechanical resistance values and the chloride diffusion coefficient, it has a more favourable “ecological profile” than SCC 1 and 2. If the analysis is made in terms of capillary suction, SCC 1 has a worst behaviour even though with very acceptable levels and lower than those of CC.

Regarding the impact of SCC on global construction costs, it is possible to obtain a reduction of between 2 to 5%, when compared to a CC with an equivalent performance. Nevertheless, the direct production costs are higher in 20 or even 25% when compared to the CC mentioned (Silva et al., 2008).

The conclusion is that the main contribution to the reduction of global construction costs due to the use of SCC in substitution of CC is related to the improvement of the final product’s quality obtained when it is necessary to cast in densely reinforced areas or in moulds with less conventional forms. The potential durability improvement equally constitutes an important contribution to the reduction of global construction costs. One can also mention the increase in productivity, the decrease of the number of workers associated with the casting task and the general improvement of working conditions as well as of the environment in the area surrounding the construction site.

5 CONCLUSIONS

To quantify the technical and economical characteristics of a construction is relatively simple. However, the same evaluation from an ecologic view point is clearly more difficult to perform.

The cement industry is nowadays identified as one of the larger contributors to the increase of gas emissions that lead to the greenhouse effect. While that industry can and should act to diminish those effects, the actors should also contribute through a correct specification of the materials to be used including the increment of the use of sub-products, either the different mineral additives already available in the market with proven results or the recycled materials in substitution of conventional ones.

The improvement of concrete’s durability is clearly one of the paths to follow to attain a sustainable development and SCC can, in that way, give a significant contribution given its potential to improvement that durability, as well as the quality of the final product while incorporation significant quantities of construction’s sub-products and the use of recycled materials.

The opinion of Aïtcin (2000) on the correlation between the construction industry and the search for a sustainable development must be mentioned: *The binders of tomorrow will contain less and less clinker composed by natural materials, therefore containing lower quantities of C3S (tricalcium silicates), will be produced using more and more alternative energies and will have to answer to ever higher demands, showing more consistent characteristics given that the clinker quantity will in the mix be less and less. The binders of tomorrow will be compatible with mixes of more complex structure and its use will result in concrete ever more durable instead of simply more resistant concretes. The binders of tomorrow will have lower and lower W/C ratios, will be more durable and will have distinct characteristics one from the other depending on their application. The time for concrete to be considered a standard product as to end and time will come for concrete a la carte. Owners, contractors and designers have to understand that what matters is not the cost of 1* m^3 *of concrete but the cost of 1MPa or of 1 year of the structure’s life cycle* (adapted from Aïtcin, 2000)).

In summary, the world has clearly to move forward in order to attain a sustainable development. Due to the construction using materials and energy from ever scarcer resources, the construction industry (including all its actors, without exception) have an added social responsibility and an essential role in the implementation of that sustainable development, with the use of SCC being able to contribute significantly to that goal.

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Chapter 5

Monitoring and evaluation

Life cycle assessment (cradle to gate) of a Portuguese brick

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ABSTRACT: The ceramic industry is a traditional sector in Portugal, with a typology of products adapted to the diverse habitat requirements. Brick is one of the most widely used materials in construction. The ceramic industry, like other sectors, generates impacts over its life cycle (from the extraction of resources until the final disposal of waste ceramics, ie from "cradle to grave"), such as consumption of resources, water and energy, air emissions, emissions to water, waste, noise, etc.. This Life Cycle Assessment (LCA) examines the stages of the brick from cradle to the customer's gate, including the process of mining and mining facilities, transport, production in factory and its later distribution to end users (base on scenarios). The methodology takes into account the ISO14040, ISO 21930 and the EPD (environmental product declaration) rules. In general, the impacts are mostly focused on air quality, particularly at the production level in the firing operation.

1 INTRODUCTION

Building materials represent an important research field in the context the sustainability of construction works. Nowadays is important to know the environmental behaviour of building materials that plays an important role on the environmental responsible architecture and design of a building.

The Green Paper on Integrated Product Policy (2001) proposes the use of methodologies for assessing the environmental behaviour of products that take into account their life cycle (from the mining of the raw materials, production, distribution utilisation and the management of waste).

Also the CEN TC 350 is working in the development of the methodology for calculation of the sustainability of the buildings, based, in the environmental performance of the buildings, and in the EPD.

The ceramic industry is a traditional sector with a significant contribution to the national economy, and a typology of products adapted to more diverse habitat requirements.

Given its geological characteristics of Portugal, a soil rich in quantity and quality of raw materials, as clays and fluxes, the industrial ceramic activity was developed with many valences and diverse products, covering and flooring tiles, giving acoustic and thermal comfort inside the house. Recent developments transformed old products in multifunctional products that can incorporate other resources as organic wastes or incorporate nanomaterials so called "advanced materials".

Brick is the basic ceramic product most used in the Portuguese masonry construction of buildings.

The life cycle of ceramic construction products is long, due to the high durability of the products, and suitable for recycling.

The Life Cycle Assessment (LCA) consists in the systematic analysis of the environmental impacts of products (any change in the environment, both adverse and benefic, overall or in part resulting from the product) at all stages of their life cycle, from extraction or synthesis of natural resources, through production, transportation, use and disposal of products (ie "cradle to grave").

In this paper the LCA methodology is applied to examine the environmental impacts associated to the brick production chain from cradle to the customer's gate, including the process of mining and the mining facilities, transport, brick production in factory and its later distribution to end users (base on scenarios) ie “cradle to gate”. The methodology takes into account the ISO14040, ISO 21930 and the EPD (environmental product declaration) rules and some databases like “Ecoinvent” [6], and the “SimaPro” software (Preconsultants, 2009).

The brick selected is produced in Central region of Portugal.

The ceramic industry, like many other sectors, generates over its life cycle, a series of environmental impacts (Almeida et al, 2004, 2009, Bovea et al, 2007; Timellini et al, 1998, BREF, 2008).

The impacts in the production phase are related to:

- Emissions to air resultant from the thermal processes (drying and firing) and colt emission;
- Consumption of natural resources and others, energy and water;
- Emissions of industrial and domestic effluents;
- Production of waste;
- Noise.

At the same time, the goal is to use this LCA study (cradle to gate), as the basis to obtain the Environmental Product Declaration (EPD) (ISO 14025) for this brick.

The EPDs are intended to provide information for planning and assessing the sustainability ofbuildings. The declarations can also be used by the user/purchaser to compare the environmental impacts of products under certain conditions.

2 CERAMIC BRICK PRODUCTION

The manufacture of bricks process goes through several stages: The first one is the mining/quarrying of raw materials, followed by the storage of raw materials, raw materials preparation, shaping, drying, firing, packing and subsequent treatment.

Dry preparation and semi-wet preparation are used in the manufacture of bricks. The combined processes of mixing and kneading bring about a homogenisation of the mass to obtain a good plasticity. The prepared mixed clay are stored in large volume facilities, ageing and souring for further homogenisation. Water may be added in this stage.

Then the mixed clay is submitted to a shaping process such as, extrusion, and soft-mud moulding, depending on the kind of clay, the water content and the desired product.

After this stage, the green brick goes to the drying process. This operation occurs in tunnel and fast dryers, during 8 up to 72 hours at a temperature of 75 up to 90 ºC.

One of the most important operations of the brick making process is the firing. This operation is done in tunnel kilns mainly in an oxidising atmosphere. The ware to be fired passes through the kiln on a series of kiln cars. Dried bricks are placed directly on the tunnel kiln car. The ware to be fired is heated up to a maturing temperature of between 800 and 900 ºC. Following the necessary body formation time of between two and five hours at maturing temperature, the ware is cooled down according to a plan to 50 ºC. The firing time of brick is 17 to 25 hours.

In the final stage the bricks are sorted during the unloading of the kiln or the tunnel kiln car automatically or manually, packed and palletised for transportation to a shipping unit.

3 LCA METHODOLOGY AND RESULTS

3.1 *Goal and scope definition*

The aim of this work was to identify and assess the environmental impacts associated with extraction, production, and distribution (based in scenarios) of ceramic brick produced in Portugal (from cradle to gate).

All inputs to the system related with energy consumption (fuel and electrical power) and natural resources (clay and water) were included. The system outputs comprise emissions into the atmosphere and into water and the generation of waste (hazardous and non hazardous waste) from the processes (extraction, transport and production).

The end of life and the impacts of the waste management transport and treatment were not in the scope of this study.

3.2 *Functional Unit and system boundaries*

The functional unit used was 1 kg of brick ready to be sold (for a brick 11 (dimensions 30*20*09 cm), 1000 kg is equivalent to 14,6 m^2).

The phases included in the system are the extraction of raw materials, brick production and distribution of the final product to customers (scenario 100 km).

A cut-off rule was established in order to decide which materials associated to these phases should be included within the boundaries. Thus, the materials that represented less than 0.5% of the functional unit were left outside the boundaries.

The phases corresponding to consumer use and final disposal of the product were also excluded, as well as transport and final disposal of industrial waste. The construction phases of the plant and remaining infrastructure, production of manufacturing equipment, personal activities were also excluded.

The figure 1 represents the life cycle phases and system boundaries of the Portuguese brick material under study (the dashed boxes were not included in the study).

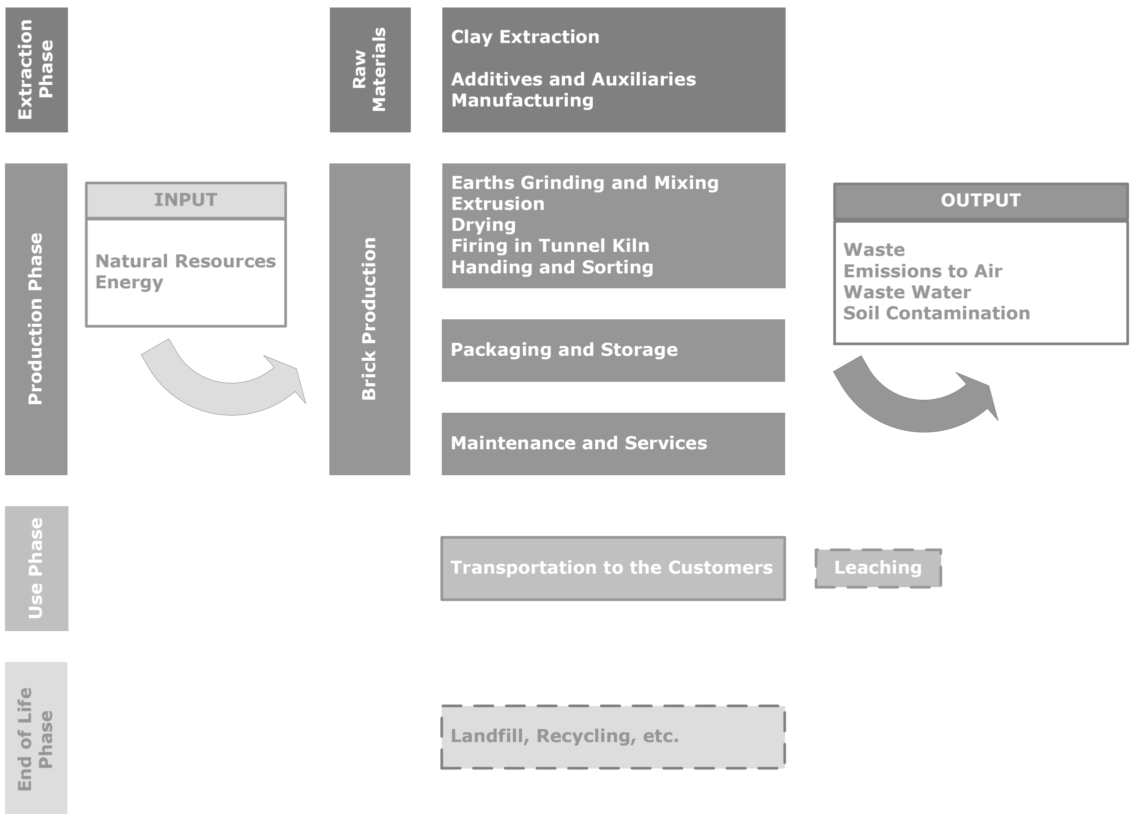

Figure 1. The life cycle phases and system boundaries of the brick material

3.3 *Quality of the data*

Data for the brick production process refer to the year 2008 and were collected by the Technological Center of Ceramic and Glass (CTCV) from industrial companies located in central Portugal. Data from literature sources and from the database "ecoinvent” were used for the remaining processes included in the boundaries.

The "cut-off rules" were also used for the processes and activities that don’t contribute more than 0.5% for the environmental impact.

3.4 *Inventory analysis*

The parameters used to describe the environmental burdens of the processes were divided into inputs and outputs.

Inputs include materials/products, chemical substances and preparations, fuels, resources (used as raw material or energy) and electricity.

The outputs include materials/products, energy, air emissions, waste water emissions and waste.

The processes, inputs and outputs had been modelled with the SimaPro software application following the guidelines set out in the ISO 14040 and ISO 21930 standards.

The environmental burdens during the stages (extraction, manufacturing and transport) vary depending on the type of material production, and are generally distributed as shown in Table 2 and 3, which present respectively the inputs and the outputs for the production of 1 kg of brick.

Table 2. Primary LCI data in terms of inputs (data for the functional unit: 1 kg of brick)

		Units
Inputs		
Clays	1.22	kg
Water (well)	9.55E-05	m^3
Domestic water	2.25E-06	m^3
Electricity	3.38E-02	kWh
Natural gas	1.10	MJ
Diesel	2.14E-02	MJ
Lubricating oils	2.92E-06	kg
Packing film	1.14E-04	kg
EUR pallet	1.61E-05	p
Steel castings	9.55E-06	kg
Product transport	100	km

Table 3. Primary LCI data in terms of outputs (data for the functional unit: 1 kg of brick)..

		Units
Outputs		
CO	5.71E-04	kg
CO2	6.50E-02	kg
NO	4.35E-05	kg
SO2	3.56E-05	kg
F	7.67E-07	kg
As	1.55E-08	kg
Cd	7.51E-09	kg
Cr	2.55E-08	kg
Cu	4.21E-10	kg
Hg	3.75E-09	kg
Ni	3.60E-08	kg
Pb	7.50E-08	kg
Zn	1.44E-08	kg
HCl	7.49E-07	kg
PM10	1.93E-05	kg
NMVOC	1.97E-05	kg
CQO	5.31E-09	kg
SST	1.81E-08	kg
Oils	1.38E-09	kg

The full inventory also includes the transport of the final product – brick to consumer consider a scenario of 100 km.

3.5 *Life cycle impact assessment*

Environmental indicators were obtained for the impact categories shown in Table 4, together with the indicator that quantifies them. The impact categories correspond to the proposals of the EPD (www.environdec.com) and the characterization factors were those suggested by CML method [www.cml.leiden.edu].

Table 4. Impact categories and units considered in the study (data for the functional unit: 1 kg, including 100 km distribution to the customer)

Impact category	Unit	Total
Global warming (GWP100)	kg CO2 eq	1.41E-01
Ozone layer depletion (ODP)	kg CFC-11 eq	1.67E-08
Photochemical oxidation	kg C2H4	7.50E-05
Acidification	kg SO2 eq	5.44E-04
Eutrophication	kg PO4--- eq	7.24E-05

3.6 *Interpretation*

In the category global warming, the main contribution comes from the production phase namely the burning of natural gas in the stage of drying and firing. Transport and the clay mine process are less relevant.

In the category of the ozone layer depletion, the profile of contributions seem to be mainly due to the emissions from the combustion of diesel in the transports associated to clay consumption, brick storage and brick distribution.

The category photochemical oxidation is predominated by drying and firing processes in brick production that emit nitrogen oxides (NOx), sulphur oxides (SOx), carbon oxides (COx) and hydrocarbons during the combustion of natural gas and also by combustion of diesel in the transport. The emissions of SOx given off during the production of the electrical power used by the machinery in brick production play also an important role for this impact category.

Acidification is mainly due to NOx and SO2 emitted during the drying and firing of the ceramic brick and in the combustion of fuels in transports.

Eutrophication is mainly due to NOx emitted during the combustion of the natural gas used in drying and firing of the ceramic brick and in the combustion of fuels in transports.

4 CONCLUSIONS

This LCA study reports inventory data and impact assessment associated with the manufacture of ceramic bricks from cradle to gate, including ceramic brick distribution. (with a scenario of 100 km).

Many of the impacts of the brick manufacture are associated to the air emissions in the production stage.

The reduction of mass and the temperature of firing of ceramic bricks, using specific clays and organic mass additives, is one possibility to reduce the environmental impacts and improve the sustainability of the ceramic bricks.

The building construction industry will be, in the next future, focused on the Environmental Product Declaration (ISO 14025) for the different materials used in building. This is the case of the Portuguese Ceramic Industry Association, promoting decisions based in the life cycle of products, in order to build more environmental friendly constructions.

5 ACKNOWELEGEMENTS

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The LT-Portugal software: a design tool for Architects

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ABSTRACT: In Portugal, there is a critical need for architects to incorporate energy-conscious strategies on the process of refurbishment design. Passive design technology is still widely unknown or misused by Architects, to a large extent because information on these issues is scarce, mostly referring to foreign climatic and building contexts. There is also a great need for user-friendly tools, like the LT method, particularly for demonstrating and validating its use in the Portuguese context. This paper presents the LT-Portugal software, which is an energy design tool that can quickly assess the energy use (lighting, cooling, ventilation and heating) and thermal comfort implications of design options – both in existing projects and also to inform design decisions. Despite the complexity of the analysis, the LT Method is easy to use and to apply to a range of situations. It is thus an ideal to assess refurbishment strategies, to which it has been applied before, and to make comparisons between various refurbishment options.

Keywords: Software simulation tool, Energy use in buildings, Design process

1. THE LT METHOD: INTRODUCTION

The mechanism of energy use in buildings is complex, involving three main factors: the physical building itself; the efficiency of the energy-using equipment such as cooling plant and lighting; and the way in which the occupants control the building and systems. Different combinations of these factors lead to a wide variance in energy use. For example, poor fabric insulation, and inefficient cooling system, and occupants controlling excess heat by opening windows, may all contribute to high-energy use.

Refurbishment provides the opportunity to directly improve the building fabric and systems, and these improvements may promote better occupant satisfaction and performance. For example, the fitting of room thermostats would remove the need for occupants to open windows to control overheating in winter.

In developing a strategy, it is useful to be able to rank the impact of various refurbishment measures. Savings are not simply additive – for example the value of cooling energy saved by applying a shading system is dependent on the efficiency of the air conditioning system.

In Portugal, there is a critical need for architects to incorporate energy-conscious strategies on the process of refurbishment design, particularly in the case of office buildings, which is a building sector associated to higher ratings of energy consumption. Passive design technology is still widely unknown or misused by Architects, to a large extent because information on these issues is scarce, mostly referring to foreign climatic and building contexts. There is also a great need for user-friendly tools, like the LT method, particularly for demonstrating and validating its use in the Portuguese context.

The LT method was originated as a manual method to predict energy consumption in buildings (heating and lighting) from a very simple description of the building at an early stage in the project. It has been developed by Baker and Steemers, from the Martin Centre for Architectural and Urban studies, University of Cambridge, since 1988. It has been extensively and independently validated (including by the UK's Building Research Establishment), and applied to real projects and design competitions throughout Europe and beyond.

Using the LT-Method algorithms, a software - LT Europe - was subsequently developed, incorporating a graphical tool that allows the design of the building. The LT Europe was developed by an international team coordinated by Martin Center (Nick Baker, David Hoch, Koen Steemers, Renaud, Runming Yao, Simmon Ruffle, Joe Ashmore and Nabeel Shaikh) involving the following institutions: Gefosat (France) Instituto de Engenharia Mecanica, Polo FEUP (Portugal), Center for Renewable Energy Sources (Greece), University College Dublin (Ireland) and EDAS North, University of Sheffield (UK).

Despite the complexity of the analysis, the LT Method is a user-friendly tool, applicable to a range of situations. It can also assess refurbishment strategies, and to make comparisons between various refurbishment design options.

2. The LT-PORTUGAL SOFTWARE

The LT-Portugal is a development of LT-Europe, providing greater accuracy in terms of the contextual specifications for the Portuguese territory, such as climatic data, and other general improvements. It calculates the annual energy consumption and related CO2 emissions related to heating, cooling and lighting, and indicates the frequency of overheating in buildings with natural ventilation. This assessment is based on building input variables ranging from the site context (e.g. surrounding building obstructions) to detailed constructional considerations (e.g. wall construction, window size, etc.), for different building types (office, educational, institutional or domestic). The software is in Portuguese Language.

In terms of climatic data, the program considers combinations of the climatic regions identified for Portugal, based on the reference climatic zones considered by RCCTE (2005): four winter zones and four summer zones.

The main added value of software is to demonstrate the sensitivity and interaction of several variables in building design. Developed in the context of the LT-Portugal Project, at the Instituto Superior Técnico (Technical University of Lisbon) and Martin Center for Architectural and Urban Studies (University of Cambridge, UK), it was supported by the Foundation for Science and Technology (FCT). The research team was constituted by Dr. Nick Baker (Univ. Cambridge), Manuel Correia Guedes (IST), Nabeel Shaik (Univ. Cambridge), Luis Calixto (IST) and Ricardo Aguiar (LNEG).

The LT Method is primarily a building energy modeller. However, because it is sensitive to the availability of daylight and the benefit and dis-benefit of solar gain, the effect of site obstructions is also taken into account. The user works through a series of stages (screens), the first 4 for data input, and the following 3 for data output. These are described below:

2.1 Inputs

Input Screen 1: Context. The project is placed on a map of Portugal and a building type is selected (new construction or refurbishment; building type – office, housing, institutional or school). This selects longitude and latitude (for solar geometry) climate data (hourly temperature and radiation), and default values for building fabric and systems appropriate to the country. The screen maps LT Climate Zones (a total of 9 climatic combinations), zones of similar energy consumption, individually for winter and summer.

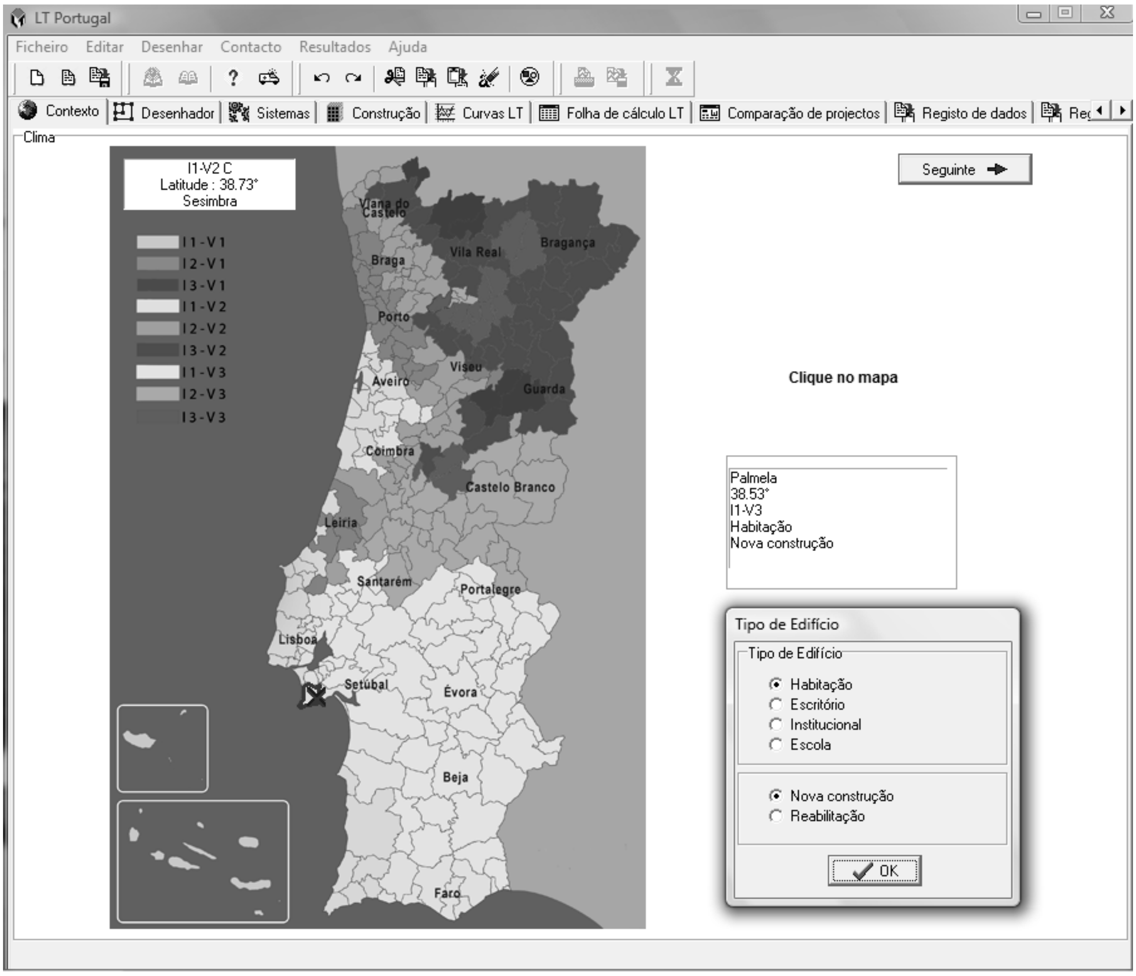

Figure 1: Input screen 1: Context.

Input Screen 2: Sketcher. A simple drawing tool with the usual drawing functions (line, rectangle, drag, rotate etc) allows the user to make a sketch plan. This is given a default floor-to ceiling height and becomes a 3-d object, i.e. a building. Walls can be given attributes - in particular windows, entered as a glazing ratio. The application of glazing to an external wall immediately designates the zone adjacent to it as *passive* zone (i.e. able to benefit from daylight and natural ventilation etc), as distinct from *non-passive* zone which needs artificial lighting and mechanical ventilation. Passive zones are designated according to their orientation. Zones in the plan can also be designated *normal interior* (i.e. heated and lit), *buffer space* (unheated atrium or conservatory), *roof lit*, or *open to the sky* (e.g. light well). Floors (storeys) can be duplicated and their attributes edited. Polygons drawn on the plan can be designated obstructions and given a height. They can be positioned by tracing over an imported site plan, and then scaled correctly.

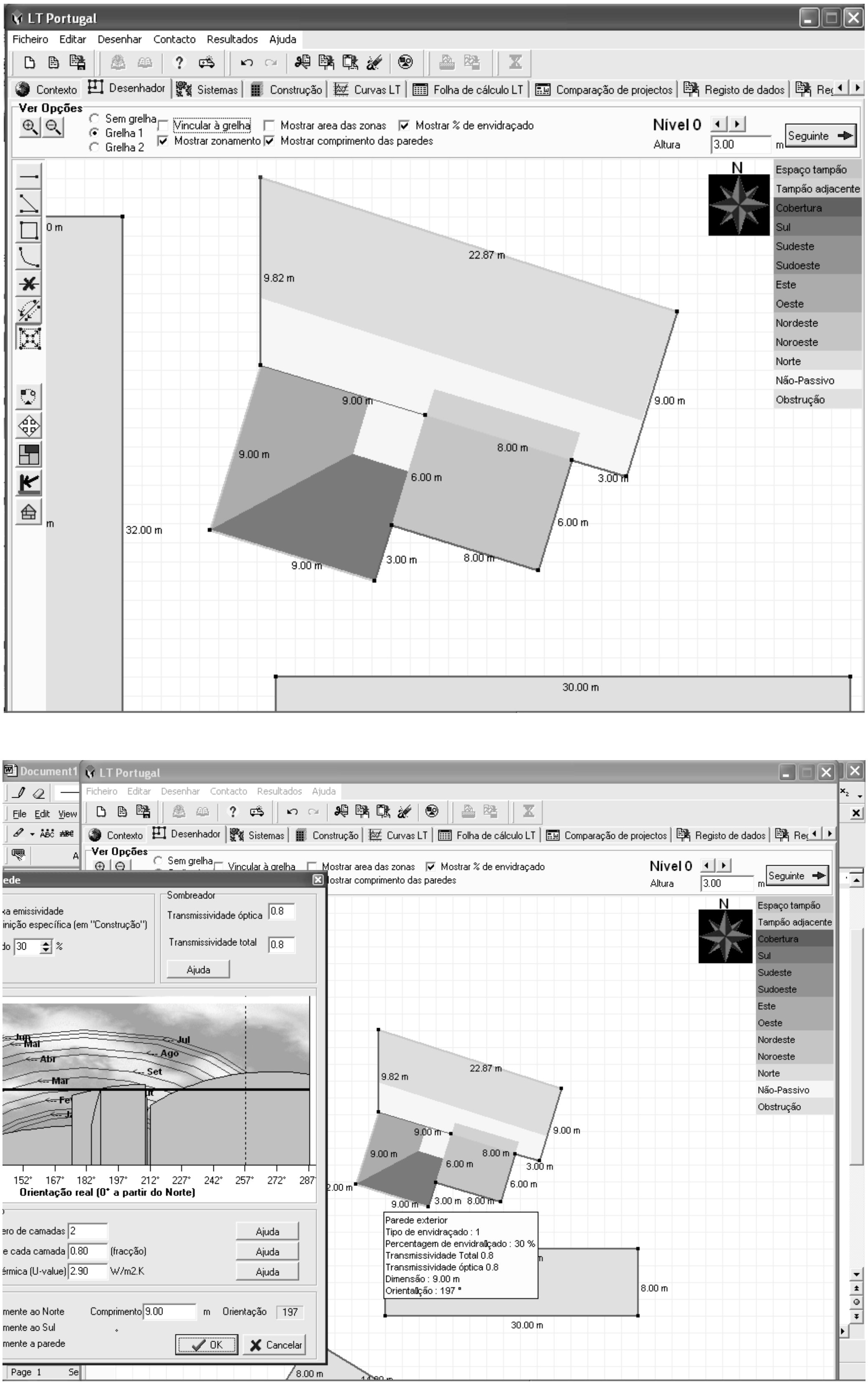

Figure 2: LT Sketcher screen showing plan of building with atrium [in blue] (green house or buffer space). The yellow area is the non-passive zone, and the tinted zones are passive zones of varying orientation, as indicated by the key top right The grey blocks are obstructions - e.g. other buildings, and the dialog box for the glazing specification shows the sunpath diagram and obstructions as seen from the part of the wall being specified.

Input Screen 3: Systems. The following data are input:

- Heating boiler efficiency
- Internal gains
- Winter ventilation rate
- Cooling coef. performance (COP)
- Installed fan power for fresh air
- Installed fan power for air-con.
- High summer ventilation (on/off)
- Night ventilation (on/off)
- Lighting switch-on datum
- Useful artificial lighting datum
- Occupants hourly pattern
- Occupants daily pattern (per week)
- Occupants monthly pattern (per year)

All have default values appropriate to the building type and location have been selected in the Context screen

Screen 4: Fabric. The following data are input: Wall U-value, Roof U-value, Floor U-value and type of Construction – (light, medium, heavy).

2.2. Outputs

Output Screen 5: LT Curves. Annual energy consumption per square metre is displayed as a function of glazing area and orientation for the uses – lighting, heating, and cooling. Two graphs can be displayed simultaneously for comparison. Overheating as a function of glazing ratio is also displayed.

Output Screen 6: Worksheet. Energy consumption /m2 and totals are given for the passive zones (defined by orientation) and the non-passive zone, floor by floor. Overheating (days with more than 2 consecutive hours above 27^{o}C) is also given. Zone values are summed to give a building total and an area-weighted overheating hours is also given. CO2 emissions are also given. The thermal contribution of an unheated atrium is shown. There is a review of current input data values.

Output Screen 7: Case Comparison. The normal use of LT involves the modification of a Base Case in order to achieve better energy performance, and less overheating if a naturally ventilated option is being explored. This screen allows a series of cases to be compared in both and air-con and naturally ventilated version. In the air-con case it is assumed that there is no overheating, whereas in the nat vent case the free-floating hourly temperature is modelled and output in the form of an area- weighted average of hours during occupancy above 27^{o}C. The display consists of stacked bars, each representing one component of energy use – e.g. lighting, heating, etc. Energy units are in KWh Primary, an energy unit taking account of the energy value at source before conversion and distribution losses. It closely relates to CO_2 emissions.

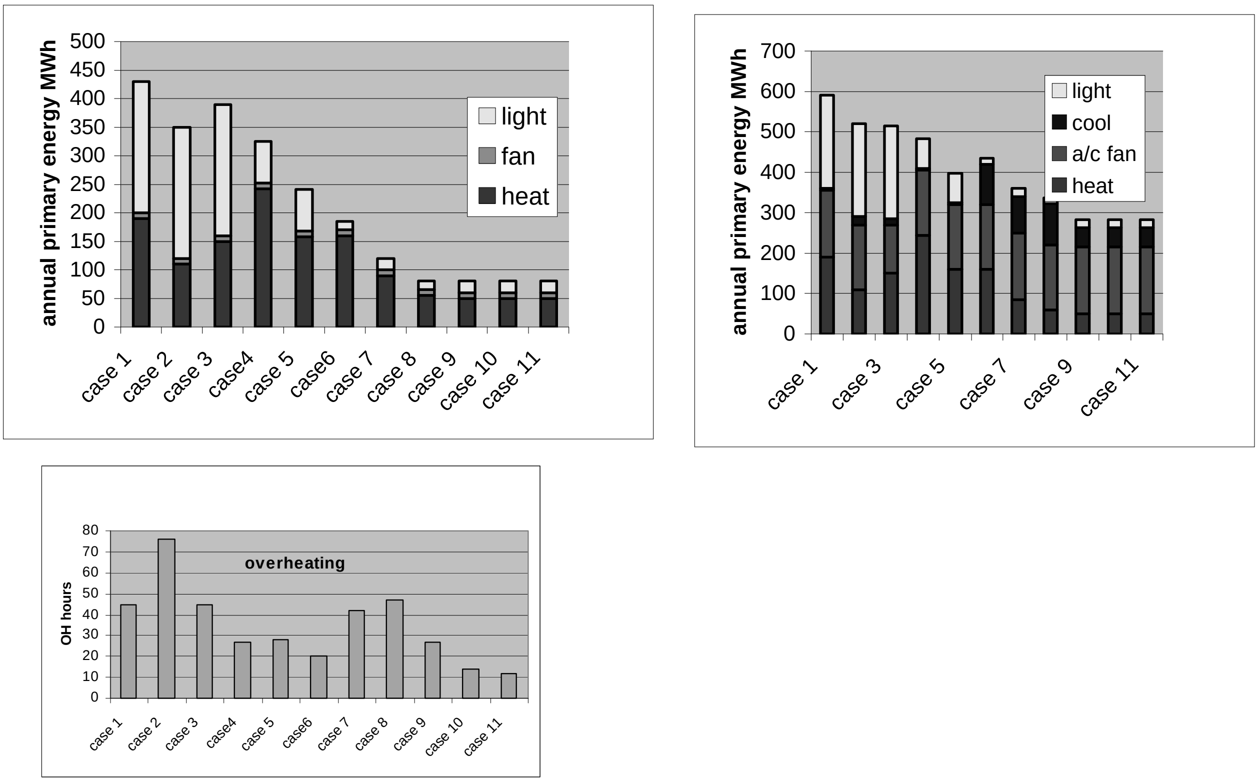

Figure 3: Outputs for energy consumption and overheating hours, for 11 different design options.

2.3 Notes on the internal structure of LT

The software consists of a solver (written in VB) and an interface written in Delphi, a derivative of Pascal. The solver simulates the annual energy consumption and free floating temperature of a 9m x 9m cell, to cover all conditions of glazing ratio, orientation and overshadowing found in the building sketch. It outputs these to the interface in the form of annual primary energy consumption/m^2 for each zone type. The interface then applies these specific energy consumptions to the zone areas obtained from the Sketcher screen, and sums them for the whole building. Note that, although there may be some loss of accuracy, this has the advantage of not having to form a thermal model of a complex building.

3. CONCLUSIONS

The LT-Portugal is a user-friendly software for building designers, allowing one to compare and optimise design solutions, in terms of energy and comfort performance, for different building types and climatic contexts existing in Portugal. It is currently on the process of being distributed to students of schools of Architecture in Portugal, and will, on the short term, be available to the general public.

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Regulamento das características do Comportamento Térmico de Edifícios - RCCTE, Decreto-Lei n.º 40/90.

LCA Database for Portuguese Building Technologies

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ABSTRACT: The aim of this paper is to present one solution to integrate more accurate environmental assessment methods in rating systems and that could be used to support the design teams' decisions that aim the implementation of low impact building solutions. The solution is the development of a LCA database that is based in the EPD's (Environmental Product Declarations) approach and that gathers the quantification of several environmental impact categories of the most common building solutions used in Portugal. This database is in continuous update and now covers about 50 building solutions for floors and exterior walls, 40 building materials and the impacts related to the use of 12 systems for acclimatization and hot water.

1 INTRODUCTION

1.1 *State-of-the art and goals*

The use of improved materials and building technologies can contribute considerably to better environmental life cycle and then to the sustainability of the constructions.

LCA is as a usable approach to evaluate the environmental impacts of products or processes during their whole life-cycle. It is basically quantitative, and it considers the material and energy flows. The methodology has been developed and used for tens of years, but it was only standardized in the mid-to-late 1990s', by the International Organization for Standardization (ISO14040-42). The LCA fits at best to the level of single product or material, but it is generally accepted to be applied for construction products and whole building, too. Environmental performance is generally measured in terms of a wide range of potential effects, such as:
- global warming potential;
- stratospheric ozone depletion;
- formation of ground level ozone (smog);
- acidification of land and water resources;
- eutrophication of water bodies;
- fossil fuel depletion;
- water use;
- toxic releases to air, water and land.

It is widely recognised in the field of Building Sustainability Assessment that Life Cycle Assessment (LCA) is a much more preferable method for evaluating the environmental pressure caused by materials, building assemblies and the whole life-cycle of a building. Although of existing several recognized LCA tools, these tools are not extensively used in building design and most of building sustainability assessment and rating systems are not comprehensive or consistently LCA-based. Reasons for this failure are above all related to the complexity of the stages of a LCA. Besides of being complex, this approach is very time consuming and therefore normally used by experts at academic level. For these reasons most of the building sustainability assessment methods are relied on singular material proprieties or attributes, such as recycled content, recycling potential or distances travelled after the point of manufacture (Carmody, et al, 2007).

The adoption of environmental LCA in buildings and other construction works is a complex and tedious task as a construction incorporates hundreds and thousands of individual products and in a construction project there might be tens of companies involved. Further, the expected life cycle of a building is exceptionally long, tens or hundreds of years. For that reason LCA tools that are currently available are not widely used by most stakeholders, including those designing, constructing, purchasing or occupying buildings. Due to its complexity most of them are used and developed only by experts, most times only at academic level.

In order to overcome this situation, most popular rating systems simplified LCA for practical use. The simplified LCA methods currently integrated in rating systems are not comprehensive or consistently LCA-based but they are playing an important role in turning the buildings more sustainable. Nevertheless, the LCA approach is not the same in the different sustainability assessment methods and therefore the results of the environmental performance assessment are not the same nor comparable. The integration of more accurate environmental assessment methods is needed to verify if the required performance has really been achieved, to accurate compare solutions and to compare the results from different rating systems (Bragança et al, 2008).

In order to standardize, facilitate the interpretation of results and comparison between different building sustainability assessment methods developed within the European Countries, CEN (European Centre of Normalization) started on the Technical Committee 350 (CEN/TC 350). The working document (TC 350 WI 002) is a part of the a suite of European standards, technical specifications and reports written by CEN TC 350 that will assist in evaluating the contribution of buildings to sustainable development through the assessment of the environmental performance of the building. In these standards the assessment methodology is based on a life cycle approach for the quantitative evaluation of the environmental performance of the building. For now these standards are specific for buildings but, with the necessary adaptation, their approach could be adopted to any type of constructions.

Based in the work of CEN TC 350 and in the work of iiSBE Portugal in the development of the Portuguese rating system SBTool^{PT}, this paper will present and discuss the development of an LCA database with the environmental data for conventional and non-conventional Portuguese building solutions

1.2 *The LCA approach*

Life cycle assessment (LCA) is a systematic approach to measuring the potential environmental impacts of a product or service during its lifecycle. LCA considers the potential environmental impacts throughout a product's life cycle (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal.

LCA is very important to compare several possible alternative solutions, which can bring about the same required performance but that differ in terms of environmental consequences. For constructions, such bridges, the embodied environmental performance of the building materials as well the construction impacts on landscape and biodiversity will often dominate the construction's life-cycle environmental impacts. For buildings, such as dwellings and offices, life-cycle environmental impacts are often dominated by energy consumption, in space heating or cooling, during the operation phase: it is estimated that the operation phase in conventional buildings represents approximately 80% to 94% of the life-cycle energy use, while 6% to 20% is consumed in materials extraction, transportation and production and less than 1% is consumed through 1% end-of-life treatments (Berge, 1999). In buildings, design teams should seek for more energy-efficient alternatives, while in other constructions, like for instance dikes and bridges, priority should be given to eco-efficient materials. Nevertheless, with the development of energy-efficient buildings and the use of less-polluting energy sources, the contribution of the material production and end-of-life phases is expected to increase in the future.

There are two combined standards developed specific to set the framework and requirements of a LCA that replaced the former four LCA standards (ISO 14040, ISO 14041, ISO 14042, ISO 14043) in 1st July 2006: ISO/FDIS 14040 2006-07-01 Environmental management – Life cycle assessment – Principles and framework; and ISO/FDIS 14044 2006-07-01 Environmental management – Life cycle assessment – Requirements and guidelines.

According to ISO 14040, framework for LCA includes:

- Goal and scope definition of LCA;
- Inventory analysis (LCI);
- Impact assessment (LCIA);
- Interpretation;
- Reporting and critical review;
- Limitations;
- Relationships between the LCA phases, and
- Conditions for use.

As presented in Figure 1, LCA is essentially an iterative process.

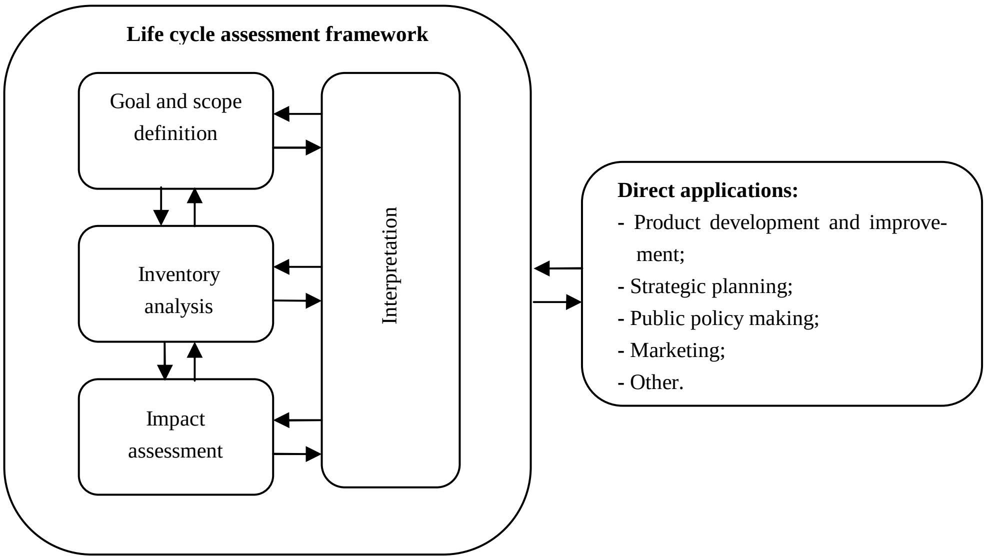


Figure 1. Stages of an LCA in ISO 14040:2006.

LCA can be applied to a single product or to an assembly of products, such as a building. For building and other constructions (B/C) the general framework for LCA involves the following goals and LCA steps (Kotaji, Schuurmans & Edwards, 2003):

1) The lifecycle of the B/C is described. What is included in the study will depend on the scope. It may include how the B/C is constructed, used, maintained and demolished and what happens to the waste materials after demolition. These are processes that contribute to the life-cycle performance of a B/C, but which will not be included in all studies.
2) The B/C is "broken down" to the building material and component combinations (BMCCs) level. This is the composition of the B/C to be analysed. The way in which the BMCCs are defined is not necessarily important; what matters is that the B/C is completely described through the addition of the BMCCs.
3) For each BMCC, the LCA of the production process (cradle-to-gate) is carried out. Their LCAs may include the transport processes to the B/C site, the construction process, the operation and maintenance processes, the demolition processes, and the waste treatment processes for each of the waste materials defined in the B/C model. This would be a cradle-to-grave analysis.
4) The BMCC-LCA results are added together, resulting in the LCA of the B/C. The various BMCC-LCAs should be carried out consistently according to the goal and scope.

2 THE DEVOLOPMENT OF THE LCA DATABASE

2.1 *Environmental impact categories*

The number and type of environmental impact category indicators are different in the several sustainable assessment methods. There is a wide range of impact category indicators, normally categorized according to the endpoints or the midpoints. Endpoints are also known as damage categories and express the effect of the product in the Human Health, Ecosystems Quality, Climate Change and Resources. LCA methods that use this type of impact categories are damage oriented and they try to model the cause-effect chain up to the endpoint, or damage, sometimes with high uncertainty. The midpoints, also referred as indicators, are the measures between the emissions and resource extraction parameters from life-cycle inventory (LCI) and the damage categories. These impact categories are used in the classic impact assessment methods to quantify the results in the early stage in the cause-effect chain to limit the uncertainties. Midpoints uses to group LCI results in the so-called midpoint categories according to themes as “destruction of the stratospheric ozone layer”, “acidification of land and water resources” or “global warming”.

LCA can be incorporated into rating systems for buildings to quantify environmental burdens associated with the manufacture of building products. Such burdens include the consumption of primary resources and the output of gaseous, liquid, and solid wastes. Most of the rating systems use midpoint impact categories but do not assess the B/C’s environmental performance in a LCA consistent way, because they do not include LCA-based indicators.

Three examples of rating tools that integrates LCA-based Environmental Performance Criteria are: SBTool, Green Globes and Code for Sustainable Homes. Nevertheless, they use a simplified LCA approach to promote its practical use.

SBTool incorporates LCA into its criteria as referred in Table 1. The environmental performance is based on the embodied energy of building products and assemblies, quantified per unit floor area (iiSBE, 2007). User can both select the LCI data or an external LCA tool to calculate the embodied energy (Larsson, 2007).

Green Globes incorporates LCA into several of the used criteria, as outlined in Table 1. LCI data for building materials are developed by the ASMI (GBI, 2008). However, documentation describing the methodology in which points are awarded based on LCI data is not publicly available.

Code for Sustainable Homes encourages the use, in housing construction, of materials that have less impact on the environment, taking account of the full life cycle (BRE, 2008). The credits are obtained for choosing a specified proportion of major building elements that have a high environmental performance. To assist the user, the system integrates a handbook that provides a “green” guide to specification of construction materials for housing which is both easy to use and soundly based on LCA studies of the environmental impacts of different materials (Anderson & Howard, 2006).

Unlike the three presented rating systems, an example of a popular rating tool that does not incorporate LCA criteria is LEED. Rather, the criteria for building products are based on percentage requirements established through pilot projects conducted in the late 1990s (Brown, 2008).

The differences between the environmental impact assessment approach in the several rating methods – because some of them are not LCA-based, not based in a reliable LCA method (because do not integrate the most common impact categories) or do not share the same impact categories – difficult the comparison of results from different rating systems.

The goal of the work undertaken by CEN/TC 350 standardization mandate is to overcome this problem at the European level, through the development of an approach to voluntary providing environmental information for supporting the sustainable works on construction. The working document (TC 350 WI 002) sets the environmental indicators that should be used in the European building sustainability assessment methods. The aim of the list of the impact categories is to represent a quantified image of the environmental impacts and aspects caused by the object of assessment during its whole life cycle. As referred in Table 2, according to the future CEN standard the assessment of the environmental performance of an building should be made through the evaluation of five quantified indicators for environmental impacts expressed with the impact categories of the life cycle impact assessment (LCA) and nine quantified indicators for environmental aspects expressed with data derived from LCI and not assigned to the impact categories of LCA.

The assessment approach of this future CEN standard is applicable to new and existing buildings. It provides a calculation method that covers all stages of the building life cycle (assembly, operation and disassembly phases) and the list of environmental indicators is developed in such way that potentiates the use of the LCI data issued from Environmental Product Declarations (EPD).

Table 1: SBTool, Green Globes and Code for Sustainable Homes LCA-based Environmental Performance Criteria (Optis, 2005).

Rating system	Category	Aim	Criteria
SBTool	Non-renewable primary energy embodied in construction materials	To minimize the embodied primary energy used in the building	Meet threshold for embodied energy of structure, envelope and major interior assemblies, as determined by LCA
Green Globes	Low Impact System and Materials	To select materials with the lowest life cycle environmental burdens and embodied	Select materials for structural, roof and envelope assemblies that reflect the results of a 'best run' LCA
	Minimal Consumption of Resources	To conserve resources and minimize the energy and environmental burdens of extracting and processing non-renewable materials	Specify materials from renewable sources that have been selected based on a LCA Specify locally manufactured materials that have been selected based on a LCA
Code for Sustainable Homes	Environmental impact of materials	To encourage the use of materials with lower environmental impacts over their lifecycle.	Credits are awarded depending on the LCA performance profiles of the building materials and components used in the building.

Table 2. Quantified indicators for environmental impacts/aspects assessment according to CEN TC 350 WG1 N002 – Working Draft.

Environmental impacts expressed with the impact categories of LCA	Environmental aspects expressed with data derived from LCI and not assigned to the impact categories of LCA
• Climate change expressed as Global Warming Potential; • Destruction of the stratospheric ozone layer; • Acidification of land and water resources; • Eutrophication; • Formation of ground level ozone expressed as photochemical oxidants.	• Use of non-renewable resources other than primary energy; • Use of recycled/reused resources other than primary energy; • Use of non-renewable primary energy; • Use of renewable primary energy; • Use of freshwater resources; • Non-hazardous waste to disposal; • Hazardous waste to disposal; • Nuclear waste (separated from hazardous waste).

In future, all standardized European sustainability assessments should consider the same list of indicators, the new sustainability rating systems should be consistent with it and it is expected that the existing ones will be adapted to this new approach. The Portuguese building sustainability assessment method ($SBTool^{PT}$) it is already updated according to the requirements of this future standard. Therefore the developed LCA database covers the five environmental indicators expressed with the environmental impacts of LCA together with the embodied energy in the materials and construction technologies.

2.2 *Considered life-cycle phases*

A typical life cycle of a building can be separated into three distinct phases, each consisting of one or several life cycle stages, as illustrated in Figure 2. The assembly phase refers to the collection of raw materials through resource extraction or recycling, the manufacture of these raw materials into products, the assembly of products into a building, the replacement of building products and assemblies, and intermediate transportation. The operation phase refers to heating and electricity requirements, water services and other services excluding material replacement. The disassembly phase refers to the decommissioning and demolition of the building, the disposal/recycling/reuse of building products and assemblies, and intermediate transportation steps. Each life cycle stage can consist of many unit processes.

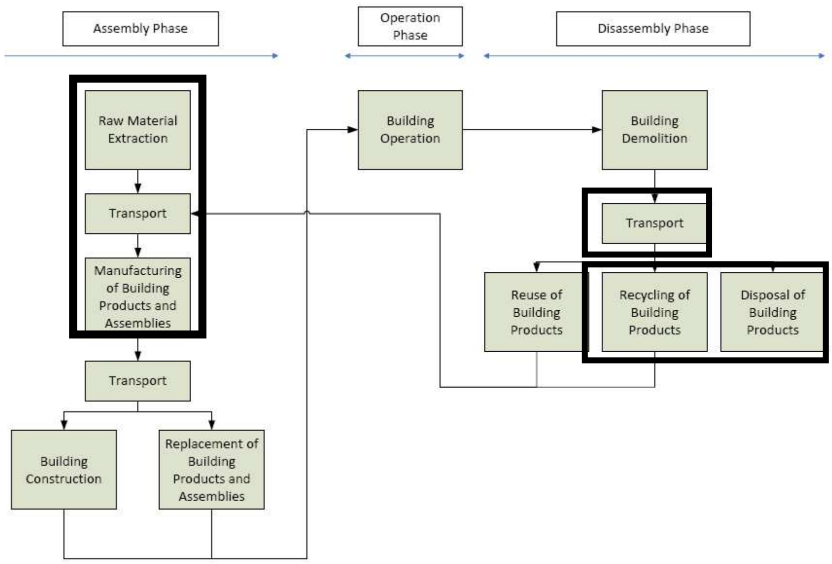


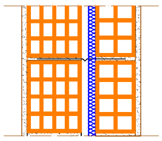
Figure 2. Life cycle of a building (Optis, 2005).

The LCA database for building technologies covers the "cradle-to-gate" impacts, i.e. the environmental impacts from the raw material extraction to the manufacturing of building products and assemblies and the disassembly phase. Additionally the database covers the environmental impacts derived from the transport of the demolition waste to the treatment units and with its treatment. The considered processes are highlighted in Figure 2.

2.3 *Quantification of the environmental indicators*

The two most important barriers to the quantification of the environmental indicators and therefore to the incorporation of LCA in rating systems are: a lack of LCI data for all building products and the inherent subjectivity of LCA. Environmental Product Declarations (EPD) are a good source of quantified information of LCI environmental impact data. In order to potentiate their use, rating systems should be based in the same LCA categories, as stated in the future CEN standard. Nevertheless, at the moment, there are important limitations on this approach, since there is only a small number of companies either having or making publicly the EPD of their products. The solution proposed to overcome this problem is to develop and use databases with the LCA data of the most used building materials and components. The developed database is continuously updated and covers common building technologies for each building element (floors, walls, roofs and windows, doors), the most used building materials and the impacts of operating most common acclimatization equipments.

The environmental indicators were quantified using the SimaPro software and several LCI databases with the average environmental impacts of each used building material (e.g. EcoInvent, IDEMAT 2001, etc.). Figure 3, presents how the information is organized in the LCA database for a building component and the list of environmental indicators and LCA methods used to quantify it. In the database of the building components the quantification is presented per each component's unit of area (m^2) and in the materials database values are available per each unit of mass (kg). Quantification is presented for two life-cycle stages: "cradle to gate" and "demolition/disposal". SBTool^{PT} uses a bottom-up up approach in the quantification of the whole building environmental performance. The quantification begins at the level of the embodied environmental impacts in building materials and ends at the whole building scale. Table 3 illustrates the principle of calculation of the total environmental of the building life cycle using the data issued in the SBTool^{PT} LCA database.

Building component:	Hollow brick cavity wall (15cm+11cm) with thermal insulation in the air cavity								Ref: Wall 1
	Life cycle stages	Environmental impact categories of LCA						Embodied energy	
		ADP[1]	GWP[2]	ODP[3]	AP[4]	POCP[5]	EP[6]	NR[7]	R[8]
	Cradle-to-gate	3.70E-01	9.53E+01	1.02E-04	1.91E-01	1.13E-02	2.54E-02	8.68E+02	1.01E+02
	Dismantling and disposal	2.08E-01	3.17E+01	5.00E-06	1.42E-01	5.40E-03	2.95E-02	4.75E+02	2.83E+00
	Total	5.78E-01	1.27E+02	1.07E-04	3.33E-01	1.67E-02	5.49E-02	1.34E+03	1.04E+02
	Comments:	**Considered materials:** Hollow brick, XPS (thermal insulation) and Portland cement mortar **LCA methods:** CML 2 baseline 2000 method (version 2.04, to quantify the environmental impact categories of LCA) and Cumulative Energy Demand (version 1.04, to evaluate the embodied energy) **LCI librarie(s):** Ecoinvent system process							

Notes:

[1]Abiotic depletion potential in kg Sb equivalents;

[2]Global warming potential in kg CO_2 equivalents;

[3]Ozone depletion potential in kg CFC-11 equivalents;

[4]Acidification potential in kg SO_2 equivalents;

[5]Photochemical ozone creation potential kg C_2H_4 equivalents;

[6]Eutrophication potential in kg PO_4 equivalents;

[7]Non-renewable embodied energy in MJ equivalents;

[8]Renewable embodied energy in MJ equivalents.

Figure 3. Part of the SBTool^{PT} LCA database.

Table 3. Principle of the quantification of the whole building's life cycle environmental impacts.

Building Component (C_i)	Area (m^2)		LCA indicators							
C_1	A_1	x	ADP_1/m^2 +	GWP_1/m^2 +	ODP_1/m^2 +	AP_1/m^2 +	$POCP_1/m^2$ +	EP_1/m^2 +	NR_1/m^2 +	R_1/m^2 +
(...)	(...)	x	(...) +	(...) +	(...) +	(...) +	(...) +	(...) +	(...) +	(...) +
C_n	A_n	x	ADP_n/m^2	GWP_n/m^2	ODP_n/m^2	AP_n/m^2	$POCP_n/m^2$	EP_n/m^2	NR_n/m^2	R_n/m^2
			=	=	=	=	=	=	=	=
Whole building embodied environmental impacts			ADP'_e	GWP'_e	ODP'_e	AP'_e	$POCP'_e$	EP'_e	NR'_e	R'_e
			÷	÷	÷	÷	÷	÷	÷	÷
			Time boundary of the LCA assessment							
			÷	÷	÷	÷	÷	÷	÷	÷
			Net floor area of the building							
			=	=	=	=	=	=	=	=
Whole building embodied environmental impacts /m^2.year			ADP_e	GWP_e	ODP_e	AP_e	$POCP_e$	EP_e	NR_e	R_e
			+	+	+	+	+	+	+	+
Environmental impacts of the maintenance scenario /m^2.year			ADP_m	GWP_m	ODP_m	AP_m	$POCP_m$	EP_m	NR_m	R_m
			+	+	+	+	+	+	+	+
Environmental impacts of the operational energy use for heating and cooling /m^2.year			ADP_o	GWP_o	ODP_o	AP_o	$POCP_o$	EP_o	NR_o	R_o
			=	=	=	=	=	=	=	=
Total life cycle impacts of the whole building /m^2.year			**ADP**	**GWP**	**ODP**	**AP**	**POCP**	**EP**	**NR**	**R**

3 CONCLUSIONS

Although, LCA is considered the best method available to assess the environmental performance of a product, its application in construction is very complex. This is because the huge number of different materials, actors, processes and also the wide life cycle span of a construction product.

Based in the work of CEN TC 350 and in the development of the Portuguese sustainability rating system (SBTool^{PT}), this paper presented some solutions to overcome the difficulties in the integration of more accurate LCA-based approaches is the assessment of the environmental performance in rating systems. The development by experts of databases with the LCA data of the most used building technologies and materials is a good solution to integrate more accurate and LCA-based approaches, without turning the rating systems too complex for practical use.

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Portal de Construção Sustentável (PCS): an online tool for sustainable designers

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ABSTRACT: Sustainable development requires new strategies for the construction industry like more information, additional tools and more emphasis on rehabilitation of buildings. The sustainable construction market is growing fast due to new legislation on energy, waste management, water and materials. In order to cope with new requirements, professionals have to keep informed regularly and efficiently in order to make decisions on crucial design solutions and also on how to select available technologies and materials on the market. But a problem is arising: green washing is a phenomenon that is growing and requires quick action. One way to avoid that is thru credible information and labeling. In order to combine information, formation and databases, a site on the internet was created in early 2009 for the Portuguese market- the Sustainable Construction Site (PCS). The site has 3 goals. The first one is to provide up to date data that is free to be used. The second is to promote rehabilitation instead of new construction. The third is to create a link between the sustainable construction industry and design professionals.

1 INTRODUCTION

Project Designers are aware of the importance of the sustainable construction in the European Union. Design sustainable architecture means to create buildings with a longer life cycle, more versatility, but it can also mean to rehabilitate existing buildings thru its adaptation or simple maintenance.

Building's operation consumes about 50% of available natural resources and is responsible for approximately 40% of the total amount of solid waste. Buildings energy consumption can reach high levels (although 50% inferior to the levels attained in the most industrialized countries), which are the source of most gas emissions which affect the environment.

The emission of CO_2 and other gases with green house effect causes global heating and climate changes. The bet on the new construction versus preservation, requalification and refurbishment of existing, causes a bigger environmental impact due to a bigger energetic consumption during construction including materials embodied energy and is responsible for significant extraction of rocks causing terrestrial, marine and river impacts.

Further more, new construction occupies and creates significant impervious areas that are important for maintaining natural assets and balances off other human activities impact.

The civil construction sector and Public Works (CC&OP), is greatly represented by new construction, followed, though of minor importance by the refurbishment of buildings, and less portion by maintenance work and restoration of historical monuments.

In the E.U., retrofitting and refurbishing buildings represents roughly half of the activity of the sector of construction.

2 THE IMPORTANCE OF REFURBISHMENT

Aware of the importance of the refurbishment in a country where the Patrimony already built surpasses the dwelling needs and where the urban centres are, partly, vacant (In Lisbon there are about 40.000 vacant homes, in 2001), having the city lost about 30.000 inhabitants in thirty years, due to the exodus towards the suburbs, it is our goal, with this cooperation to bring attention from the authorities to the issue of refurbishment of the patrimony which can contribute to a more sustainable construction.

The refurbishment market is now considered to be emerging and it is the reflex of an international tendency. In Europe this market represents 36% of the construction sector, and in Portugal is only 6.5%. The statistics also show that the number of classified buildings is about 4500, according to the data from the IGESPAR (Institute for the management of Architectural and Archaeological Patrimony). On the other hand this market of refurbishment has proved to be a way of fighting crisis not only by creating new jobs, but also for its contribution to a more sustainable development.

The Sustainability of the refurbishment has got several aspects:

- Firstly the refurbishment means a non-increasing of the area of construction contributing to keep the existing area impermeable, avoiding the “heat island effect”.
- Secondly refurbishing a building implies the reuse of the existing infrastructures, mainly roads and gutters, and when the refurbishment is done in the urban areas it contributes to decrease the pendulum movements, increasing the security in the vacant urban centres.
- Thirdly refurbishing a building is a mean of reusing a meaningful part of existing materials (structure, roof and façade).

The refurbishment allows adding the characteristic of sustainability to the existing buildings, i.e., to adapt them with solar passive or hybrid technologies and also including concepts, such as the reuse of recycled material of low impact, etc. Thus the environmental impact of the building is significantly decreased thanks to the implementation of the passive measures together with reuse of great part of existing materials.

These questions were arisen as a result of the experiments of two architects.

In the authors practical work great potentials were detected, related to the introduction of concepts of sustainability in refurbishment.

3 THE SUSTAINABLE CONSTRUCTION SITE (PCS)

portal da construção sustentável

Figure 1. The PCS site logo

The best way to convey information to a mass audience in a way that is not yet provided (organized and complete) on sustainable construction, was to create a free access site where information would be selected but referred to all aspects of sustainability.

The existing sites in Portugal were a starting point but soon became very limited and outdated. Sites on sustainable construction are available in a significant number but commonly approach specific themes like: architectural projects, generalities, glossaries or non usable. There isn`t one that provides all the information including recent research information, databases or retrofitting projects.

The Sustainable Construction site (www.csustentavel.com) aims to be a tool for the construction sector to move forward in a more sustainable way. Thus it is based on the resource and availability of information on the Construction sector in Portugal, promoting good practices in construction and refurbishment. The site is the visible face of the Sustainable Refurbishment Movement whose contribution is to turn around the actual tendency of the sector which privileges the construction versus refurbishment. Its other goal is to become an open data base for sustainable techniques, materials and tools.

It also aims to create a network between sustainable designers and the sustainable construction industry, involving all stakeholders like municipalities, banks and universities.

The site is also meant to demonstrate the plus value of a more sustainable construction and that it may become an incentive to the sustainable refurbishment and a contribution for a better future.

The info addresses themes like Water, Air, Comfort, Construction, Energy, territory management and Waste. The site is presented as follows:

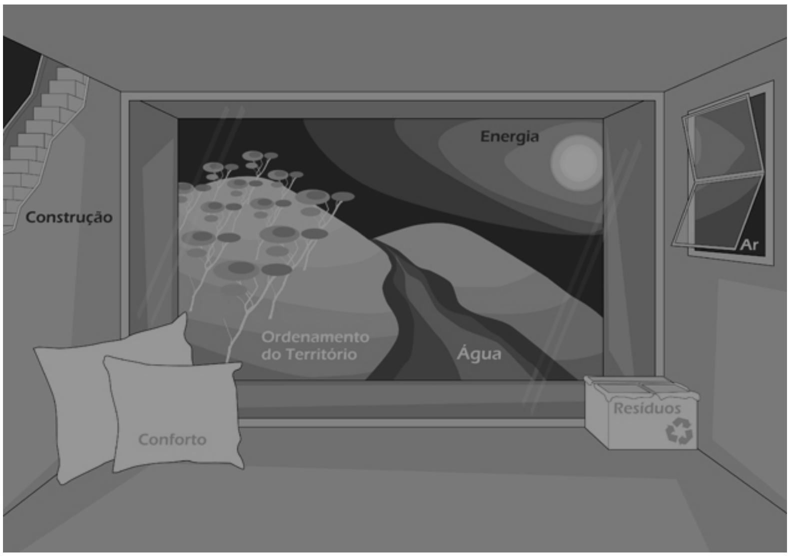

Figure 2. The PCS site main page

Each theme contains several topics including 5 common items:

- good practices,
- environmental impacts,
- questionnaires,
- legislation and
- links to products

Besides that, each theme can include one to three specific items like shown on table 1.

Table 1.

water	air	comfort	construction	energy	Territory management	waste
storing	Contami tami-nants	Acoustics	Life cycle	passive	Mobility	Construction management
Reuse	Natural ventilation	hydro-thermal	materials	renewable	Occupation	Operation management
		visual		Construction techniques	Urban planning	

The site also provides:

- a glossary,
- some published scientific documents,
- architectural examples,
- FAQ`s,
- news,
- events and
- partners and sponsors.

The site is for free access but in order to get feedback from users, there will be a questionnaire for users to complete. The questionnaires are related to a theme: water, air, comfort, construction, energy, territory management and waste. They are meant to gather information on the market, the user profile and assess the way the site is helping the user. During 2009 the site was monitored on access frequency, time of use and user origin. During 20010 the questionnaires will provide more complementary information.

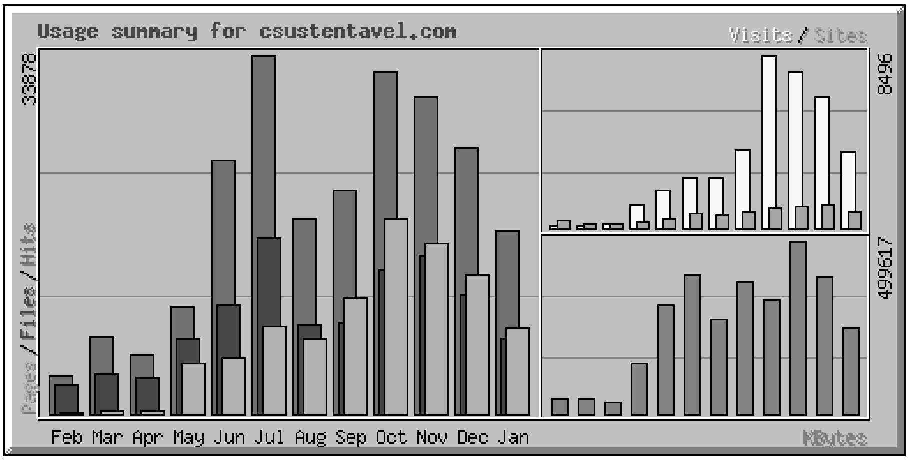

Figure3. The PCS site access during 2009

4 THE SUSTAINABLE REFURBISHMENT MOVEMENT (MRS)

The MRS movement proposes a sensitization for the refurbishment all over the country by the municipalitiess, companies, banks and universities. Our goal is to create partnerships with the key entities to promote this type of approach to the built patrimony.

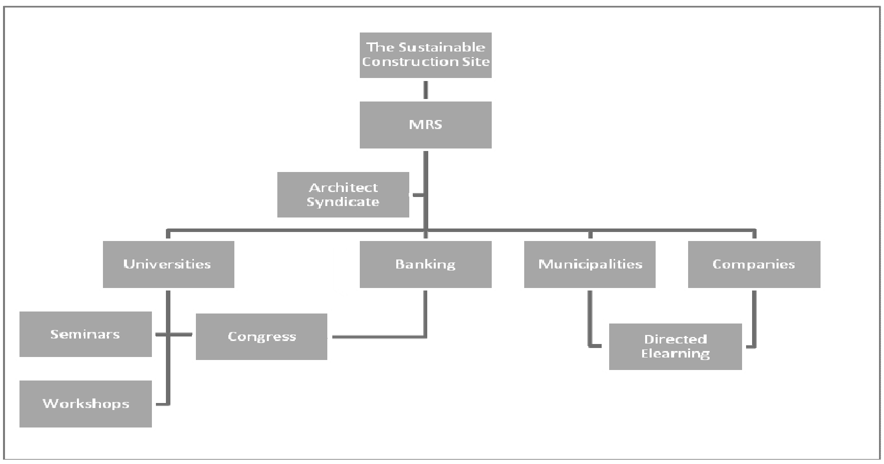

Figure 3. The PCS site and the stakeholders to be involved

5 ENTITIES TO BE ADDRESSED

5.1 *Municipalities*

The goal is that Town Councils become promoters of the necessary change of attitudes, through actions of formation, which contribute to the spreading, awareness and information on urban refurbishment for a more sustainable development. In order to achieve that it will be crucial to first get the attention from the Town Councils to this new vision in order to understand this reality and give their contribution not only concerning the public works but also the info and projects license where more plus values may be applied such as: reduction of taxation for the refurbishment projects (as in the case of LiderA certified buildings which determine 50% IMI tax reduction in CML) and priority to licensing of refurbishment works.

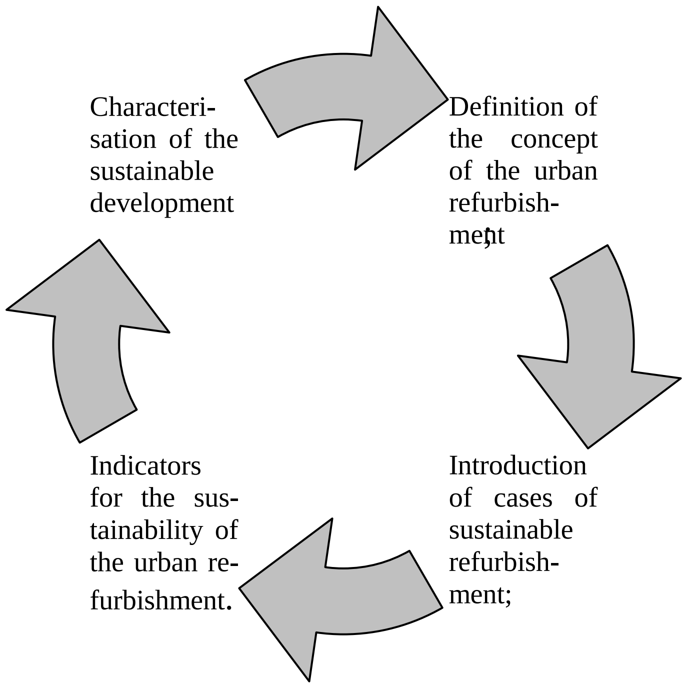

Figure 4. The Diagram Learning for Municipalities

5.2 *Banks*

The Banks should be informed on sustainability issues in order to play better their role as mediators on housing acquisition, explaining the concept of sustainable refurbishment, emphasizing the environmental advantages of reusing and recycling of Energy Efficiency, Conservation of the Energy and Renewable Energies (like CGD, BPI, BCP, BES promoting programs on renewable energy installations) This awareness should be made through:
Creation of a brochure's contents for the bank to include in the documents for the housing funding, where the following is included:

- Advantages of building's refurbishment and their location in the urban centres;
- Advice for the purchase of a house regarding energy efficiency and thermal comfort, keeping in mind that sustainable construction strategies and use of renewable energy can become assets in the investment;
- Brief introduction to the concepts of sustainable and bio-climatic construction and also a brief description of renewable energy that can be applied in a residence;
- Placement of above contents on the Bank site under house financing while referring to specific factors to be taken into consideration during housing acquisition/refurbishment
- Advisory and formation on the advantage of building's refurbishment, stressing issues like energy efficiency, energy conservation and reuse of urban patrimony;
- Lectures and advisory for the real estate agents who depend on the house financing;

- Acts to sensitize, to give advice and to debate with real estate agents the importance of the urban refurbishment and the rationing of resources;
- Formation for banks evaluators, which would provide info about the inherent plus values to the questions related to the refurbishment of buildings.

5.3 *Universities*

The Universities, mainly the Colleges of Civil Engineering and Architecture are responsible for the professional skilful of the agents of this area. So the teaching of sustainability in the construction should be transversal to the academic course and it is necessary to include at least a discipline on urban rehabilitation. To fulfil this gap Universities would be proposed to organize lectures or seminars where themes like the sustainability in a wider level and refurbishment as a need to improve construction in a more sustainable way, would be discussed. These actions would impel new curriculum and disciplines based on topics like:

- Our role in the consumption of energy: the consumptions at home, the using of transports, the goods and services available for the consumption;
- The main spring of energy in Portugal: The dependence of the oil and the environmental problems, which are associated;
- Climate change: The green house effect and the changes introduced by man in this balance;
- The Man and Nature: Before the industrialization Man could get the profit of the energy of the nature;
- Vernacular architecture: the way man could get profit of the available materials;
- The actual society: The actual needs of energy, which man should face;
- The renewable energies: the sources of energy which we have available and the profit they represent;
- The construction: The quality in the construction and the use of the climate as a way to reduce the energy needs;
- The sustainable refurbishment of buildings.

5.4 *Companies*

With expectation of impelling the companies connected with the construction sector to act in the area of sustainability, in the PCS site, info may be found.

Starting with those enterprises which use ecological materials to those which in their working practice include an environmental preservation in the enterprising policy, small texts and direct links will be sent to their pages. Thus a net of info will be created, to show the available materials in our market, within the area of sustainability, concerning the urban construction and refurbishment. The database will provide information on eco-labelled materials or materials with EPD`s. Some consulting companies on sustainable construction will also be available on the database.

6 CONCLUSIONS

The PCS site (www.csustentavel.com) which is presented in this paper contains two pioneering initiatives: the Movement for Sustainable Rehabilitation (MRS) and a information and technical database that supports that Movement. Its goal is to promote adequate, reliable and update information for all that are interested in turning construction into a more sustainable industry. The site was developed on information available in the market, professional experience and recent research . The site has been monitored and its impact will be discussed in future research.

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Energy Performance Certification in Portugal as a tool to achieve real energy savings in buildings

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ABSTRACT: The National System for Energy and Indoor Air Quality Certification of Buildings (SCE) came into force on 1st July 2007. This marked a new phase in the current legislation on energy efficiency of buildings in Portugal and was a direct result of the national transposition of Directive 2002/91/EC. By the end of June 2009, more than 100 000 energy certificates were registered on a web based central registration system that qualified experts must access and use to issue certificates. About 80% of these certificates are of existing buildings and were issued in the first six months of 2009. Around 3 000 certificates for new buildings and 15 000 certificates for existing buildings are issued every month, covering nearly all the licensing and selling processes that take place in the country. This way, a national database of certified buildings is being fed with information that is being useful to monitor progress of different aspects of the implementation of the Directive, from basic statistics such as the number of certified buildings, to impact assessment, including estimated savings. By analyzing the certificates issued in Portugal for existing buildings in the first 6 months of 2009, we can see that about 40% are rated above the threshold for new buildings (B-). If all the recommendations for improvements made by the experts in each certificate were actually implemented, then about 86% of the existing buildings would have, at least, the same energy performance as new buildings (in terms of primary energy consumption per square meter of floor area). For that, an average investment between €1250 and €6500 per building would be required, for an average payback period for investment of 6 to 11 years. And, in this scenario, Portugal could save about 0,4 toe of primary energy per building per year. Although theoretical, this analysis emphasizes the importance of implementing the recommendations made by the experts in the certificates and how these measures need to go from paper to practice. Therefore, it's now time to move from paper to practice. A number of programs and actions are being prepared to take real action and lead to actual implementation of the expert's recommendations, particularly in the framework of building's rehabilitation. Only through these actions the -/goals of the Directive will be reached and real energy savings -/can be achieved.

1 INTRODUCTION

1.1 *Energy Analysis*

In recent years it has been observed an increase of final energy consumption to a very high rate, particularly in the areas of residential buildings and services. Currently, the buildings (residential plus services) account for about 30% of global energy consumption in the country.

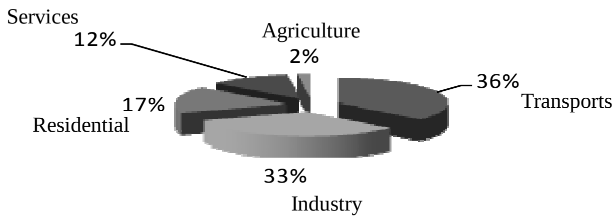

Figure 1. Energy consumption in Portugal

In the European context, it is also the general consensus the need to improve the energy efficiency of buildings. This results of the common concerns of compliance with the Kyoto protocol and the security of energy supplies, in a scenario where buildings account for 40% of global energy consumption. This led the European Commission to move forward in 2002 with the publication of an EU Directive on the energy performance of buildings (EPBD).

Under this Directive, the commission requires that an energy certificate (EC) is issued when applying for the license of a new building, and whenever there is a commercial transaction, sale or lease of an existing building. The certificates should be valid for 10 years and the certification must be provided by qualified experts.

1.2 *EPBD implementation in Portugal*

The partial transposition of the Directive has been put into force in Portugal in April 2006 with the introduction of new legislation that included a review of two existing regulations regarding buildings the RCCTE - Regulation Characteristics of Thermal Behavior of Buildings (DL 80/2006) and the RSECE - Regulation of Energy Systems of Energy in Buildings (DL 79/2006) and the publication of a new decree concerning the certification system for energy and indoor air quality (SCE). For the latter there were published two ordinances, one that sets the timing of the implementation of the SCE (No 461/2007) and the other that defines the registration fees for issuing the EC buildings for housing and buildings services (No 835/2007).

Regarding the scope of application, RCCTE covers all new residential buildings (single-family and multifamily) and small service buildings without HVAC systems or systems with an installed power in air exceeding 25kW. RSECE covers all major commercial buildings, with more than $1000m^2$ and $500m^2$ in the case of certain specific types such as supermarkets, hypermarkets, shopping centers and buildings with indoor pools and even small commercial buildings and housing with an installed power in air exceeding 25 kW.

The two regulations are in force since July 2006, requiring that new building projects have, on licensing procedures, to integrate the chips and annexes provided, by both RCCTE and RSECE.

The timetable to implement the SCE in the different types of buildings was divided into three phases, starting with new buildings:

- In a first stage, certification was only required for all new residential and non-residential buildings with a floor area larger than 1,000 m^2 and that had construction permits requested after July 1, 2007;
- The second phase included all new buildings, regardless of their floor area, and that had construction permits requested after 1st July 2008;
- The third phase started in January 2009 and meant full implementation of EPBD, that is, all buildings are now included in the certification system: new buildings, major renovations, public buildings and all buildings when sold or rented.

The Energy Certificate (EC) is the most visible aspect of the SCE. This document will give an energy performance (EP) label to residential and non-residential buildings and it may list measures for improving their energy performance.

The energy label in the certificate classifies the buildings on an efficiency scale ranging from A+ (high energy efficiency) to G (poor efficiency). This is similar to the scale currently used for some domestic appliances and equipment (although classes A and B are evenly subdivided in to classes A+, A, B, B-, to improve the distinction among new buildings – all new buildings must be in the A+ to B- classes) and it allows for easy reading and interpretation by the consumer.

ADENE is the managing body of the SCE in Portugal, which is being supervised by the Directorate-General of Energy and Geology and the Portuguese Environmental Agency, and developed a mechanism that allows qualified experts to issue certificates on-line, thus creating a database of all certificates issued. The following is an analysis of that database on the certificates issued until the end of the first half of 2009 relating to residential buildings only.

2 DATA BASE ANALYSIS

Since July 2007 until the end of June 2009, more than 100 000 energy certificates were registered on a web based central registration system that qualified experts must access and use to issue certificates. About 80% of these certificates are of existing buildings and were issued in the first six months of 2009. Currently, around 3 000 certificates for new buildings and 15 000 certificates for existing buildings are issued every month, covering nearly all the licensing and selling processes that take place in the country.

This way, a national database of certified buildings is being fed with information that will be useful to monitor progress of different aspects of the implementation of the Directive, from basic statistics such as the number of certified buildings, to impact assessment, including estimated savings. Such database will also be used to produce information that is useful for the soon to be started process of periodic revision of the technical regulations, where a possible tightening of minimum requirements, as well as a change or optimization of some operational rules, is likely to take place.

ADENE studied the EC issued on the first semester of the year, and concluded that the majority of the dwellings have a C class or lower accordance with the following distribution.

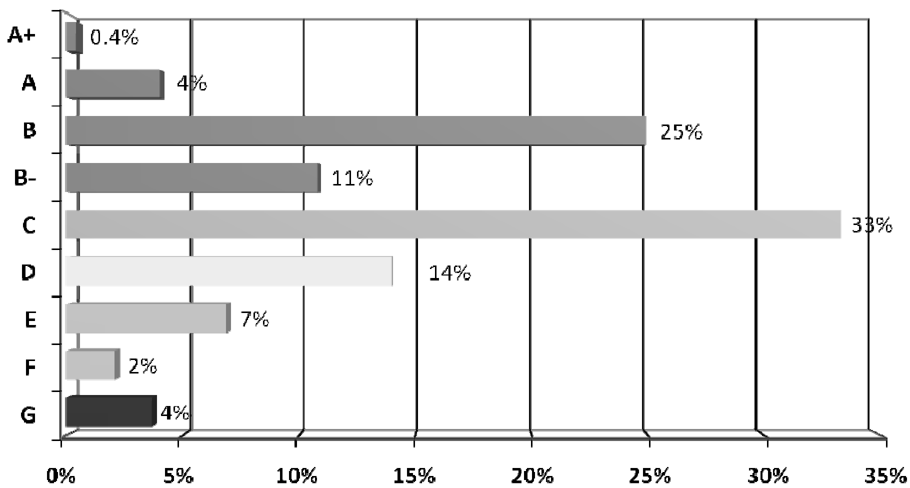

Figure 2. Energy Certificates in Portugal in existing dwellings

As already stated, the new buildings have requirements and are subject to rigorous scrutiny by technical experts, and have to ensure a minimum energy class, contrary to what happens to existing buildings where tenants are responsible for the maintenance and to ensure adequate living conditions. It is thus necessary to examine the reality constructed before the entry into force of this new legislation, to see which buildings have a greater inefficiency.

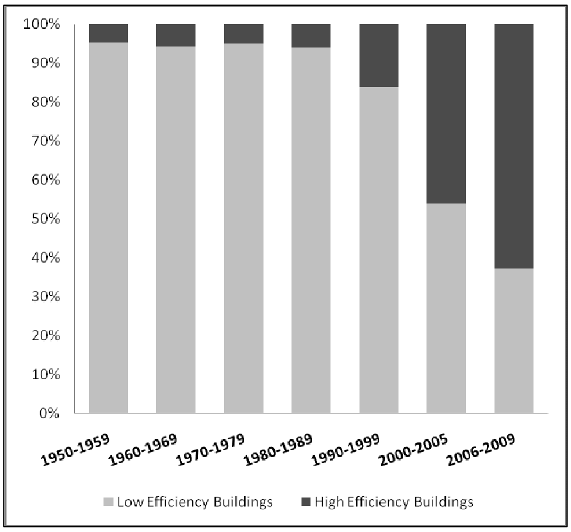

Figure 3. Energy Class Distribution by Decade

Analyzing the different decades, we observed that since 1990 there has been a slight improvement in the energy class caused by the introduction of legislation on the thermal quality in residential buildings, and that the decade with more buildings constructed with lower efficiency is the 70's which is also the decade with more buildings constructed, according to information available in INE - National Institute of Statistics.

Based on this information there is the need to make changes that enable energy savings in homes built in the decades before the implementation of the legislation and to promote improvements in the constructions made in the following decades, in order to get higher ratings than the limit set for new buildings of B-.

One of the most important aspects of the energy performance certificates is the recommendation of improvement measures by the qualified expert. Analyzing the improvement measures recommended by qualified experts in the 1st half of 2009, it appears that the main improvement measures are related to the replacement of equipment for the production of hot water (DHW), heat pumps, glazing, installation of solar thermal collectors and the introduction of insulation in floors, roofs and piers according to distribution presented in the following table.

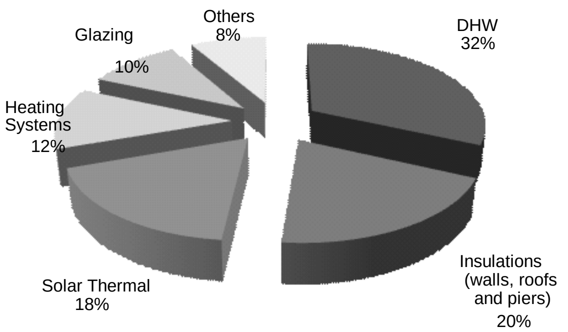

Figure 4. Efficiency measures proposed by the experts

From the database information it was obtained the perception that buildings constructed during the twentieth century require higher measures to become efficient dwellings than those constructed during the present century.

With these measures recommended by experts is possible to obtain significant savings. But how can this be done and move from paper to reality?

3 ENERGY SAVINGS

3.1 *Achieving Real Energy Savings*

The EP requirements for new buildings and major renovations will certainly bring important energy savings in the near future. Maintaining thermal comfort and indoor air conditions will require less energy, as new and renovated buildings become more and more efficient.

But new and renovated buildings only make up a small share of the entire building stock in Portugal (around 5.5 million homes). Currently, less than 50 000 new buildings are built each year in Portugal and, despite the recent growth in the rehabilitation market, major renovations still don't have a significant expression. Therefore, the impact of applying EP requirements in new and renovated buildings is obviously limited and will not lead, in useful time, to a relevant reduction in energy consumption in the building sector.

So, to achieve real energy savings in this sector, there has to be good incentives to the improvement of existing buildings. And certification can play a crucial role in this matter. The recommendations made by the experts in the certificates are important guidelines that the owners of the buildings can make good use of, either in the context of a renovation, or as individual cost-effective measures.

If all the recommendations for improvements made by the experts in each certificate were actually implemented, then about 86% of the existing buildings would have, at least, the same energy performance as new buildings (in terms of primary energy consumption per square meter of floor area). For that, an average investment between €1250 and €6500 per building would be required, for an average payback period for investment of 6 to 11 years. And, in this scenario, Portugal could save about 0,4 toe of primary energy per building per year.

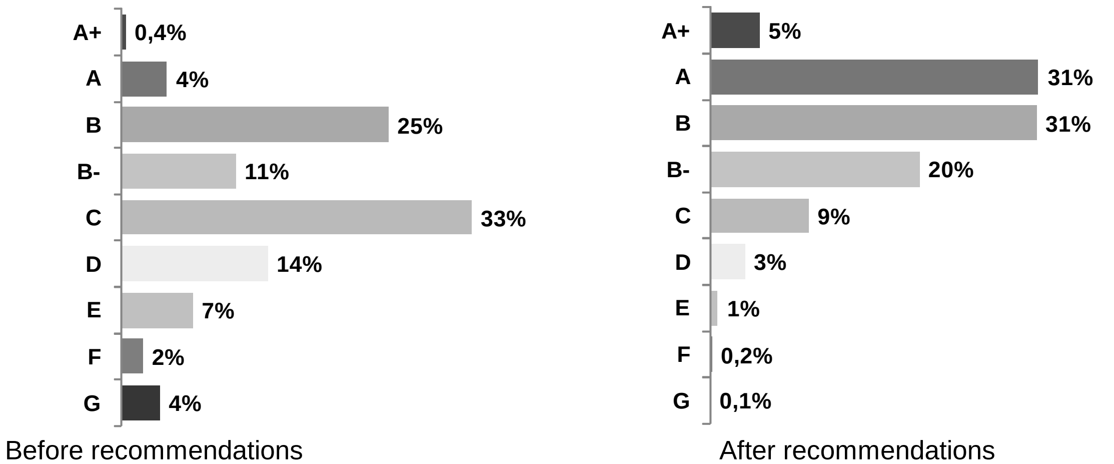

Figure 5. Energy Class Distribution Before/After Recommendations

Although theoretical, this analysis emphasizes the importance of implementing the recommendations made by the experts in the certificates and how these measures need to go from paper to practice.

For that purpose, the National Action Plan for Energy Efficiency (PNAEE), defined by the Portuguese government under the Directive 2006/32/EC, has established the general framework for financial support to specific measures. The exact measures to be supported, as well as the detailed terms and conditions to access that support, are now under definition, taking into consideration the data already available from the database of the certification system.

3.2 *Energy Performance Measures*

We have described the major improvement measures recommended in general terms; however, it is possible to describe the recommendations in more detail. We present some of the improvement measures for each group of application.

Domestic Hot Water Systems
- Hot Water Pump
- High Efficiency Boiler

Insulation
- Thermal insulation on the exterior applied in exterior walls
- Thermal insulation on the inside applied in exterior walls/rooftops/floors

Renewable Energy
- Solar Thermal Collectors

Heating System
- High efficiency boilers for central heating
- High efficiency heat pumps

Windows/Glazing
- Replacement of existing frames maintaining the glass
- Replacement of the glass maintaining the frame
- Replacement of the frame/glass
- Placing an additional frame

These are some of the measures that ensures the increase of the efficiency in residential buildings.

4 DISSEMINATION AND PROMOTION OF ENERGY EFFICIENCY

4.1 *Incentives to promote energy efficiency*

In Portugal the most direct incentives regarding the adoption of energy certification system are fiscal benefits, namely:
- a 10% increase in the deduction related to house loans in the Individual Income Tax for class A/A+ level homes; (national incentive)
- a reduction of 25 to 50% of the Municipality Tax on properties for class A/A+ level homes (until now only in force for houses in the municipality of Lisbon, but others may follow)

Besides energy certification, another incentive promoted by the Portuguese government is the installation of solar thermal collectors. Portuguese government grants a 30% tax credit for investment in renewable energies with a maximum of 796 €, therefore an excellent incentive for reducing energy bills. The micro-generation also has success by ensuring very advantageous electricity tariffs, thus creating a large number of micro-energy producers.

Other measures are being considered such as replacement of glazing and the inclusion of thermal insulation in walls, floors and roofs; however, they all have to be carefully decided, considering they will need an average investment of € 3800. Taking into account the economic period in which we live in, it is difficult for the majority of Portuguese families to support that investment, so financial incentives promoted by the Portuguese government become of vital importance.

In the study promoted by ADENE regarding the improvement measures, the current practices in some countries within the European Union were analyzed, as well as in other developed countries outside EU, such as the United States and Australia. According to the information gathered the following two tendencies were observed: a) Subsidies are the most common incentive applied by the European countries, representing more than 59% of the programmes evaluated; and b) Insulation and heating were the main frequent focuses of the programmes. Within the subsidies it appears that the solutions adopted are subsidized loans and tax incentives, which may take into account the different segments of society benefiting the owners with worst financial situation. Some of these measures are set in PNAEE.

4.2 *Dissemination of energy efficiency*

Although today the consumer is aware of the need to reduce the energy bill and that small gestures provide some reduction of energy consumption, it appears that background action is necessary to rectify the situation more effectively.

One of the problems already identified is the financial issue, due to the need for an initial investment by the owners. Another problem is the need to spread the support programs provided by the Portuguese government and its benefits. This major release should not only be taken by public authorities, but promoted by independent entities with sufficient reliability to the public such as DECO - Portuguese Association for Consumer Protection for example.

Another key player is the qualified expert that relates very closely with the consumer, and can easily advise owners on the best incentives to put into practice the improvement measures he recommends.

Another problem is the lack of knowledge of technologies that despite already being used for a long time in other countries, only now is beginning to have massive use in Portugal. This is a problem for manufacturers and distributors of the product. They have to close this gap and catch up with consumers, providing them with the reliability before and after selling the product.

5 FINAL STATEMENTS

Portuguese household consumers are aware of the current needs on Energy Efficiency and CO_2 emissions and know that there are actions that they can take that will have a considerable impact on those issues.

An important challenge to develop, is training the public to measure the energy use. Recent surveys conducted by leading research agencies point towards the consumer’s vulnerability to costs and their lack of awareness as big constraints for the promotion of energy efficiency and renewable solutions in Portugal. Portuguese consumers are very cost oriented and prefer to invest in cheaper technologies, that aren’t more environment friendly technologies. Lack of awareness is another big hurdle. Lack of awareness is shown generally in two fronts: 1) consumers are not aware of the amount of energy they are currently consuming in their houses. This makes it difficult for them to understand the benefits of renewable technologies and 2) consumers are not aware of the renewable technologies. This however is slowly reducing due to the government’s promotion of these technologies.

On the other hand, additional training should be offered for qualified experts, focusing on issues such as energy audits and best economic and technologic building improvement solutions. The main target is for these agents to stress among citizens that energy certification should not be viewed simply as a cost, and make evidence of the whole idea that making buildings more efficient, results in energy savings and consequently in reduced costs and hence offset the investment.

The impact of applying energy performance requirements in new and renovated buildings is obviously limited and will not lead, in useful time, to a relevant reduction in energy consumption in the building sector. If all the recommendations for improvements made by the experts in each certificate were actually implemented, then about 86% of the existing buildings would have, at least, the same energy performance as a new building, and in this scenario, Portugal could save about about 0,4 toe of primary energy per building per year, what migh, in a best case scenario, represent a 8% reduction of global primary energy consumption.

"One day, all buildings shall be green".

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Use of PCM in Mediterranean building envelopes

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ABSTRACT: This work presents the results of an experimental set-up to test phase change materials in building envelopes with various typical insulation and construction materials for Mediterranean construction in real conditions. Several cubicles were constructed (using conventional and alveolar brick) and their thermal performance throughout the time was measured. Macroencapsulated PCM is added in one conventional brick cubicle and in one alveolar brick cubicle (CSM panels, containing RT-27 and SP-25 A8, respectively). The cubicles have a domestic air conditioner as a cooling system and an electrical radiator as a heating system; the energy consumption of both systems is registered.

In summer 2008 and 2009 the energy consumption of the air conditioner in the cubicle with polyurethane insulation and PCM was lower than the energy consumption of the PU cubicle for set points higher than 20 ºC. Lower set points decreased the effect of the PCM since it is not melting properly.

1 INTRODUCTION

Energy consumption for thermal comfort in buildings has grown a lot in few years, resulting in higher CO_2 emissions. The main reasons are the increasing users demand for comfort conditions and the market penetration of cooling systems. This new scenario significantly contributes to global problems such us greenhouse effect. The new approach to this problem includes more sustainable buildings and a more efficient energy management.

Phase change materials (PCMs) have been studied for thermal storage in buildings since before 1980. Several constructive solutions incorporating PCM, such as concrete and gypsum, have been tested (Cabeza et al. 2007, Hauer et al. 2005, Khundhair and Farid 2004, Schossig et al. 2005, Zalba et al. 2003). However, no work was found in the literature were macroencapsulated PCM was experimentally tested, under real conditions, in brick constructive solutions.

This work presents a new experimental set-up to test the effect of the inclusion of PCM in buildings. For this purpose, several cubicles were constructed using traditional brick and alveolar brick. Macroencapsulated PCM is added in one traditional brick cubicle and in one alveolar brick cubicle (CSM panels, containing RT-27 and SP-25 A8, respectively).

2 DEMONSTRATION CUBICLES

The cubicles were built with Mediterranean typical constructive solutions. To be able to compare the results obtained with the concrete cubicles studied previously (Cabeza et al. 2007), the internal dimensions of the new cubicles are the same as the old ones (2.4x2.4x2.4 meters). For comparison purposes, the new cubicles have no windows. One door in the northern wall is the only opening of the new cubicles. Figure 1 shows the demonstration cubicles located in Puigverd de Lleida.

Figure 1. Demonstration cubicles in Puigverd de Lleida.

The structure of the conventional brick cubicles (Reference, PU and RT27+PU) was done using 4 mortar pillars with reinforcing bars, one in each edge of the cubicle. The base consists of a mortar base of 3x3 meters with crushed stones and reinforcing bars. The walls consist of perforated bricks (29x14x7.5 cm) with an insulating material (depending on the cubicle) on the external side and plaster on the internal side. The external finish was done with hollow bricks and a cement mortar finish. Between the perforated bricks and the hollow bricks there is an air chamber of 5 cm. The roof was done using concrete precast beams and 5 cm of concrete slab. The internal finish is plaster. The insulating material is placed over the concrete, protected with a cement mortar roof with an inclination of 3% and a double asphalt membrane.

For the alveolar cubicles (Alveolar and SP25+Alveolar) the structure of the wall consisted of alveolar brick with plaster as internal finish and cement mortar as external finish. The structure of the roof was the same as for the conventional brick cubicles. An explanation of the nomenclature used for the cubicles is given as follows:

1. Reference cubicle (Reference): This cubicle has no insulation.
2. Polyurethane cubicle (PU): The insulation material used is 5 cm of spray foam polyurethane.
3. PCM-PU cubicle (RT27+PU): The insulation used is again 5 cm of spray foam polyurethane and an additional layer of PCM. CSM panels containing RT-27 paraffin are located between the perforated bricks and the polyurethane (in the southern and western walls and the roof).
4. Alveolar cubicle (Alveolar): The alveolar brick has an especial design which provides both thermal and acoustic insulation. No additional insulation was used in this cubicle.
5. PCM-Alveolar cubicle (SP25+Alveolar): Several CSM panels containing SP-25 A8 hydrate salt are located inside the cubicle, between the alveolar brick and the plaster plastering in order to increase the thermal inertia of the wall (in the southern and western walls and the roof).

The most important properties of the polyurethane, the alveolar brick and the PCM (RT-27 and SP-25 A8) are shown from Table 1 to Table 3. Figure 2 to Figure 5 show the demonstration cubicles built with brick, polyurethane, RT-27 PCM and polyurethane, and alveolar brick respectively, during construction.

Table 1. Physical properties of polyurethane.

	Polyurethane
Thermal conductivity (W/m·K)	0.028
Density (kg/m^3)	35
Maximum temperature (ºC)	80

Table 2. Physical properties of the alveolar brick.

	Alveolar brick
Heat transmittance (W/m^2·K)	0.66
Thickness (mm)	290

Table 3. Physical properties of used PCM.

		RT-27	SP-25 A8
Melting point (ºC)		28	26
Congealing point (ºC)		26	25
Heat Storage Capacity (kJ/kg)		179	180
Density (kg/L)	solid	0.87	1.38
	liquid	0.75	
Heat capacity (kJ/kg·K)	solid	1.8	2.5
	liquid	2.4	
Heat conductivity (W/m·K)		0.2	0.6

Figure 2. Brick cubicle.

Figure 3. Brick cubicle with polyurethane.

Figure 4. Brick cubicle with RT-27 and polyurethane.

Figure 5. Alveolar brick cubicles.

To evaluate the thermal performance of each material the following data were registered for each cubicle.

- Wall temperature (east, west, north, south internal, south external, roof and floor).
- Internal ambient temperature (1.5 m) and humidity.
- Heat flux at the south wall (inside and outside).
- Electrical consumption of the heat pump.
- Solar radiation.
- External ambient temperature and humidity.

The experimental set-up offers the possibility to perform two kinds of tests. In this work only controlled temperature results are presented.

- Free-floating temperature, where no heating/cooling system is used. The temperature conditions in the cubicles are compared. The ones with PCM are expected to have better behavior.
- Controlled temperature, where a heat pump is used to set the ambient temperature of the cubicle. The energy consumption of the cubicles is compared using different set points. The cubicles using PCM are expected to have lower energy consumptions.

3 RESULTS AND DISCUSSION

For the summer period, the energy consumption of the cubicles was studied. Different weeks with similar weather conditions were tested with different set points. Figure 6 and Figure 7 shows the comparison of PU and RT27+PU cubicles for the first week of June, where a set point of 16 ºC was used.

From the beginning of the week the energy consumption of the Reference cubicle is higher than the one from the PU and RT27+PU cubicles. The PU and the RT27+PU cubicles have almost the same energy consumption, presenting no improvements the cubicle with PCM. On the other hand, the Alveolar cubicle consumption is significantly lower than that of the SP25+Alveolar cubicle.

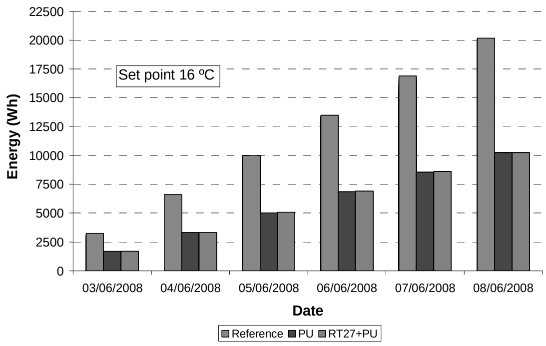

Figure 6. Accumulated energy consumption – brick cubicles. Set point 16 ºC.

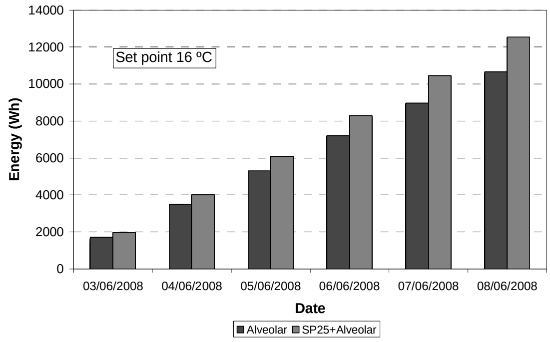

Figure 7. Accumulated energy consumption – alveolar cubicles. Set point 16 ºC.

Very low set points (like 16 ºC) do not favour the PCM operation since the phase change range is much higher than the set point and the PCM is sensitive to the inside temperature due to its location inside the wall. In these cases the energy consumption of the cubicles is not improved by the use of PCM (Table 4).

The energy consumption in the PU and RT27+PU cubicles is practically the same, which demonstrates that both heat pumps have very similar COP. On the other hand, the energy consumption of the SP25+Alveolar cubicle is significantly higher than the one of the Alveolar cubicle, probably due to a lower COP which results in higher energy consumptions.

Table 4. Accumulated energy consumption and savings for the different cubicles.

	Energy Consumption[1] (Wh)	Energy Savings[2] (Wh)	Energy Savings[2] (%)	Improvement[3] (%)
Reference	20162	0	0	-
PU	10244	9918	49.19	0
RT27+PU	10227	9935	49.28	0.17
Alveolar	10650	9512	47.18	0
SP25+Alveolar	12536	7626	37.82	-17.71

[1]Set point of 16 ºC during 6 days

[2]Referred to the Reference cubicle

[3]Referred to the cubicle with analogue constructive solution and without PCM

The results for the experiments with a set point of 20 ºC are presented in Figure 8 and Figure 9. For the conventional brick cubicles, an important difference in the energy consumption between the Reference and the PU and RT27+PU cubicles is observed. Both insulated cubicles prevents the heat pump to start for the first two days of the experiments, while the heat pump of the Reference cubicle is working during all the experiment, reaching an energy consumption about 3 times higher. Moreover, the RT27+PU cubicle achieves a reduction of the energy consumption of about 5 % compared to the PU one (Table 5).

On the other hand, for the alveolar brick cubicles the energy consumption in higher in the SP25+Alveolar cubicle than in the Alveolar one (Table 5). This may be caused by the different COP of the heat pumps already observed in the experiments with a set point of 16 ºC. A COP correction can be done forcing the same energy consumption for both Alveolar and SP25+Alveolar cubicles when using a set point of 16 ºC. In that case the results for the experiment using a set point of 20 ºC show a reduction of the energy consumption in the SP25+Alveolar cubicle of about 5 %.

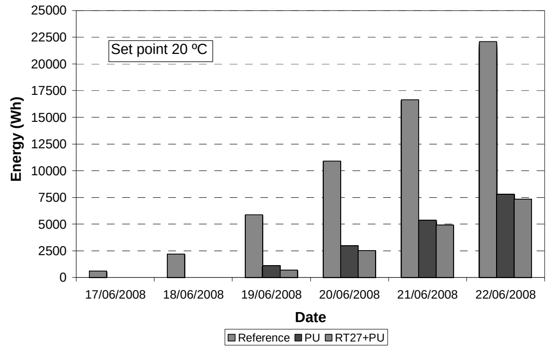

Figure 8. Accumulated energy consumption – brick cubicles. Set point 20 ºC.

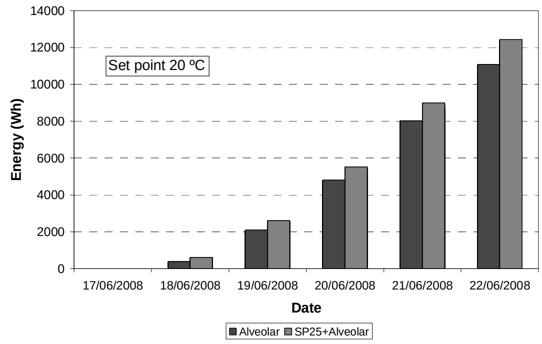

Figure 9. Accumulated energy consumption – alveolar cubicles. Set point 20 ºC.

Table 5. Accumulated energy consumption and savings for the different cubicles.

	Energy Consumption[1] (Wh)	Energy Savings[2] (Wh)	Energy Savings[2] (%)	Improvement[3] (%)
Reference	22096	0	0	-
PU	7799	14297	64.70	0
RT27+PU	7343	14753	66.77	5.85
Alveolar	11074	11022	49.88	0
SP25+Alveolar	12438	9658	43.71	-10.97

[1]Set point of 20 ºC during 6 days

[2]Refered to the Reference cubicle

[3]Refered to the cubicle with analogue constructive solution and without PCM

Figure 10 and Figure 11 present the results of the controlled temperature experiments using a set point of 24 ºC. The accumulated energy consumption of the Reference cubicle is higher than all the other ones. The RT27+PU cubicle is the one with the lowest energy consumption while the SP25+Alveolar cubicle is the second one, consuming even less energy than the PU cubicle. Finally, the Alveolar cubicle is the one that more energy consumes after the Reference one.

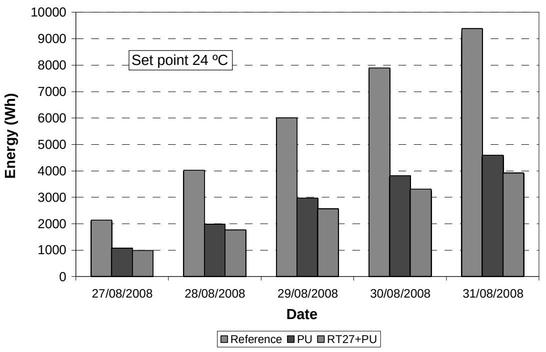

Figure 10. Accumulated energy consumption – brick cubicles. Set point 24 ºC.

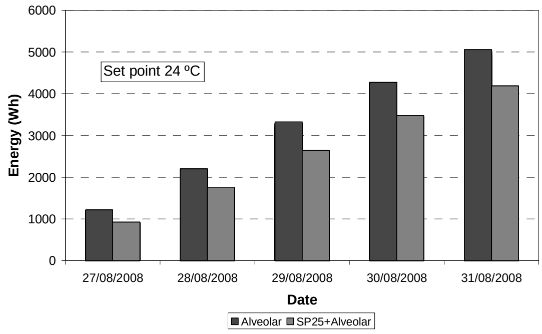

Figure 11. Accumulated energy consumption – alveolar cubicles. Set point 24 ºC.

A moderate set point (like 24 ºC) favours the PCM working conditions, since the inside temperature is close to the phase change range. Both PCM cubicles reduced the energy consumption compared with the same cubicle without PCM. The RT27+PU cubicle achieved a reduction of 15 % compared to the PU cubicle, while the SP25+Alveolar cubicle reached a 17 % of energy savings compared to the Alveolar one (Table 6). If the COP correction is done for the SP25+Alveolar cubicle, the improvement in the energy consumption increases up to 30 %.

Table 6. Accumulated energy consumption and savings for the different cubicles

	Energy Consumption[1] (Wh)	Energy Savings[2] (Wh)	Energy Savings[2] (%)	Improvement[3] (%)
Reference	9376	0	0	-
PU	4583	4793	51.12	0
RT27+PU	3907	5469	58.33	14.75
Alveolar	5053	4323	46.11	0
SP25+Alveolar	4188	5188	55.33	17.12

[1]Set point of 24 ºC during 5 days

[2]Referred to the Reference cubicle

[3]Referred to the cubicle with analogue constructive solution and without PCM

4 CONCLUSIONS

In this work the benefits of using PCM in conventional and alveolar brick construction are studied. Energy consumptions are analyzed for summer period.

The set point used plays a key role in the working conditions of the PCM and therefore in the thermal behavior and the energy consumption of the cubicle. The location of the PCM, closer to the inside, makes it more sensitive to the set point used. For very low set points (16 ºC) no improvements were observed in the PCM cubicles, since the phase change temperature of the PCM is much higher than the set point (about 27 ºC). When using low set points (20 ºC) a small reduction of the energy consumption was observed (about 5 %), while moderate set points (24 ºC) improve the working conditions of the PCM since the temperature is much closer to the phase change range. In that case a reduction of the energy consumption about 15 % is achieved.

ACKNOWLEDGEMENTS

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Experimental study on the performance of buildings with different insulation materials

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ABSTRACT: It is well known that it is necessary to insulate buildings to decrease their thermal demand. Different insulation materials are available in the market, but also different constructive solutions appear, claiming high insulation properties. Those systems are usually compared by their theoretical values, but never compared side-by-side in real constructions. This work presents an experimental comparison of two different constructive solutions: conventional brick and alveolar brick. For this purpose five cubicles were built: four of them built with conventional brick and different insulation materials, and one built with alveolar brick, which is supposed to provide enough thermal insulation by itself. The cubicles have an electrical heater and an air conditioner as the heating/cooling systems and the energy consumption is registered.

The results show a significant improvement when comparing the alveolar brick cubicle with the reference one (conventional brick with no insulation). However, the thermal performance is even better for the cubicles with conventional brick and 5 cm of insulation.

1 INTRODUCTION

Thermal insulation is a key parameter for energy efficiency in buildings. By correctly insulating buildings one can reduce operational costs and also reduce air pollution and environmental problems such as CO_2 emissions. Considering a broader perspective, the building sector accounts for 40% of Europe's CO_2 emissions. Insulation techniques can mitigate climate change cost-effectively and also reduce the dependence on external primary energy supplies.

New insulation materials are used nowadays to improve the thermal behavior of buildings. Inorganic fibrous materials, glass wool and stone wool are widely used as for building insulation, as well as organic foamy materials, expanded and extruded polystyrene and polyurethane. In Spain the three most common insulation materials used in buildings are polyurethane, mineral wool and polystyrene. However, new insulation techniques are developed everyday, for example alveolar bricks. The new design of alveolar brick is presented as a material that will provide structural, thermal and acoustical properties altogether.

Thermal performance of insulation materials has been studied widely all over the world. Most of those studies are numerical, simulating the heat transfer mechanisms or obtaining expressions for the thermal conductivity and diffusivity (Bankvall 1973, Beck 1966, Hokoi & Kumaran 1993, Langlais & Klarsfeld 1984, Larkin & Churchill 1959, Rennex 1979, Tong et al. 1985, Veiseh et al 2008).

Looking at experimental works, all of them focused on laboratory scale tests, where different insulation materials were tested and their thermal conductivity and diffusivity characterized (Soubdhan et al 2005, Swinton et al 2006, Karamanos et al 2008). Nevertheless, no experimental study comparing the thermal behavior of alveolar brick with different insulation materials in real conditions is found.

Recent research has focused in vacuum panels (Ghazi et al. 2004, Nussbaumer et al. 2006, Simmler & Brunner 2005), with the main drawbacks of price and durability, and phase change materials to increase the thermal inertia (Cabeza 2007, Castell 2009, Castellón 2009, Sarier & Onder 2007).

The goal of this work is to experimentally compare the thermal performance of five house-like cubicles built with typical Mediterranean constructive solutions with different insulation materials and technologies, especially comparing the alveolar brick concept. The energy consumption of the air conditioning and heating systems are measured to be able to analyze the real energy savings achieved by each system.

2 EXPERIMENTAL SET-UP

Figure 1 shows 9 demonstration cubicles located in Puigverd de Lleida (Lleida, Spain), built with different constructive solutions (Cabeza et al. 2007, Cabeza et al. 2009, Castell et al. 2009, Castellón et al. 2009). Two concrete cubicles were built in 2002 and seven brick cubicles were built in 2007, presenting all of them the same internal dimensions (2.4x2.4x2.4 m). In this paper two different constructive solutions are studied: conventional and alveolar brick. For this purpose five cubicles are compared:

1. Reference cubicle (Reference): This cubicle has no insulation.
2. Polyurethane cubicle (PU): The insulation material used is 5 cm of spray foam polyurethane (from Synthesia).
3. Mineral wool cubicle (MW): The insulation material used is 5 cm of mineral wool (from Rockwool).
4. Polystyrene cubicle (XPS): The insulation material used is 5 cm of extruded polystyrene (from URSA).
5. Alveolar cubicle (Alveolar): The alveolar brick itself provides both thermal and acoustical insulation.

Figure 1. Experimental set-up located in Puigverd de Lleida.

The structure of the 4 cubicles built with conventional brick was made of 4 mortar pillars with reinforcing bars, one in each edge of the cubicle. The base consists of a mortar base of 3x3 meters with crushed stones and reinforcing bars. The walls consist of perforated bricks (29x14x7.5 cm) with an insulating material (depending on the cubicle) on the external side and plaster on the internal side. The external finish was done with hollow bricks and a cement mortar finish. Between the perforated bricks and the hollow bricks there is an air chamber of 5 cm. The roof was done using concrete precast beams and 5 cm of concrete slab. The insulating material is placed over the concrete, protected with a cement mortar roof with an inclination of 3% and a double asphalt membrane. In these cubicles there are no windows. One door in the northern wall is the only opening.

For practical reasons, the same insulating material thickness was taken for the three cubicles with insulation, instead of having the same thermal resistance with different and non-standard thicknesses. A thickness of 5 cm was chosen as it is the minimum thickness which complies with the Spanish new building code (Spanish Building Code 2006) for Lleida climate zone and, therefore, will likely be the mostly used for new construction.

The cubicle built with alveolar brick only had the internal and external finishing (plaster and mortar, respectively). The roof was build with the same solution as the PU cubicle.

The most important properties of the construction materials are shown in Table 1. Both polyurethane and polystyrene present a very similar thermal diffusivity, while mineral wool presents a lower one. For the air chamber, the effective thermal resistance is 0.18 m^2K/W. Figure 2 presents a section of the Reference cubicle (no insulation in the walls), the PU cubicle (as an example of cubicle with insulation), and the alveolar cubicle.

Table 1. Thermo-physical properties of construction materials.

	Specific heat (J/kg·K)	Thermal conductivity (W/m·K)	Density (kg/m^3)
Cement mortar	1000	0.700	1350
Hollow brick	1000	0.375	930
Polyurethane	1000	0.028	35
Perforated brick	1000	0.543	900
Alveolar brick	1000	0.270	1080
Plastering	1000	0.570	1150
Concrete precast beam	1000	0.472	760
Concrete	1000	1.650	2150
Double asphalt membrane	1000	0.700	2100
Crushed stones	1050	2.0	1450

To evaluate the thermal performance of each material the following data were registered for each cubicle at five minutes intervals:

- Internal wall temperatures (east, west, north, south, roof and floor) and also external south wall temperature.
- Internal ambient temperature and humidity (at a height of 1.5 m).
- Heat flux at the south wall (inside and outside).
- Electrical consumption of the air conditioner or the electric heater.
- Solar radiation.
- External ambient temperature and humidity.

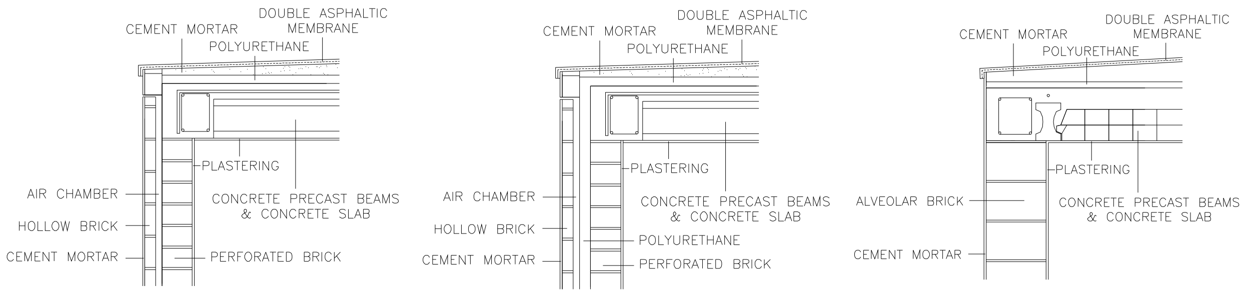

Figure 2. Section of the cubicles analyzed. Left: Reference; Middle: Insulated; Right: Alveolar.

All temperatures are measured using Pt-100 DIN B probes, calibrated with a maximum error of ±0.3 ºC. The air humidity sensors are ELEKTRONIK EE21FT6AA21 with an accuracy of ± 2 %. The heat flux sensors used are HUKSFLUX HFP01 with an accuracy of ± 5 %.

The experimental set-up offers the possibility to perform two kinds of tests:

- Free-floating temperature, where no heating/cooling system is used. The temperature conditions in the cubicles are compared.
- Controlled temperature, where an air conditioner system is used in summer and an electrical oil radiator is used in winter to set the internal ambient temperature of the cubicle. The energy consumption of the cubicles is compared.

3 RESULTS AND DISCUSSION

The experimental set-up was built in spring 2007. Many data has been registered during the last years. A week of July (July 22st to 29th, 2008) is presented were the set point in the air conditioner system was set to 24 ºC, and the average temperatures inside all the cubicles were always within the range 24 ±0.5 ºC. Outside temperatures present daily oscillations in the range of 15-35 ºC. Outside temperature patterns are very similar during the week, being the first day a bit colder than the rest of the week days; solar radiation is between 800 and 900 W/m^2 every day.

Figure 3 shows the accumulated electrical consumption of the air conditioners. The energy used to cool the reference cubicle is much higher than that of the insulated and alveolar cubicles. The differences among insulated and alveolar cubicles are smaller, being the consumption of the polyurethane cubicle the lowest one (49 % less than the Reference cubicle). On the other hand, the Mineral Wool and Polystyrene consumes 46 % and 45 % less energy that the Reference cubicle, respectively. Finally, the Alveolar cubicle consumed 41 % less than the Reference one.

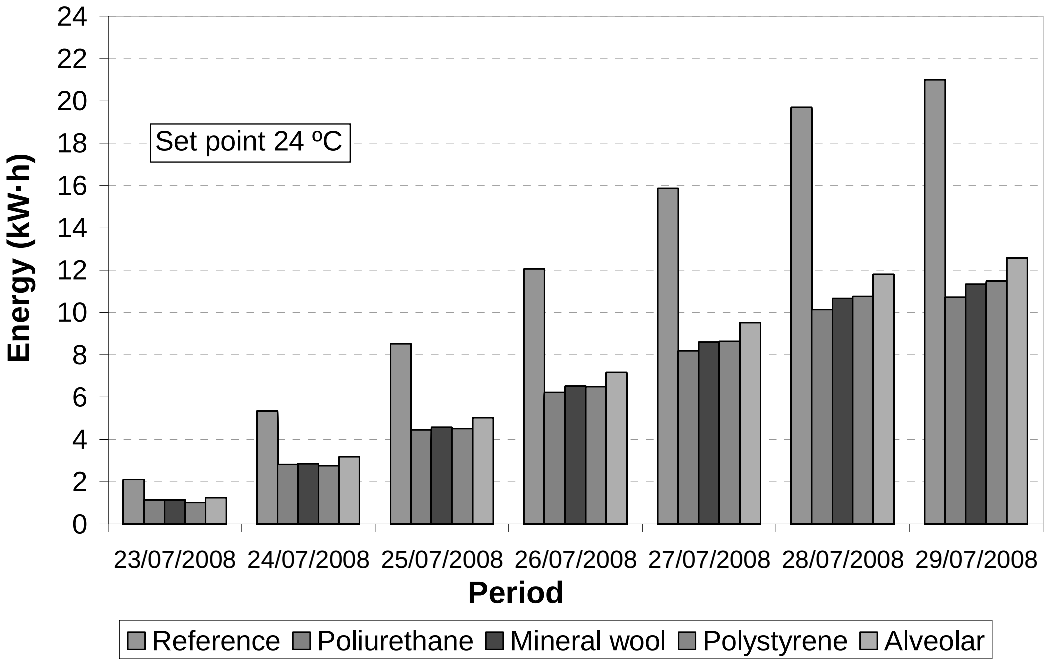

Figure 3. Accumulated energy consumption of the different cubicles during one week of summer. Set-point of 24 ºC.

3.1 *Extrapolation of monthly consumptions*

Figure 4 presents the comparison of the estimated monthly energy consumption for the five different cubicles in summer period. The inclusion of the thermal insulation leads to an important decrease in the energy consumption for air conditioning (reductions of 49-41 %). The PUR cubicle presents the lowest energy consumption (6 to 14 % lower than the other insulated and alveolar cubicles). On the other hand, the Alveolar cubicle presents an energy consumption 7-14 higher than the insulated cubicles but 41 % lower than the Reference one.

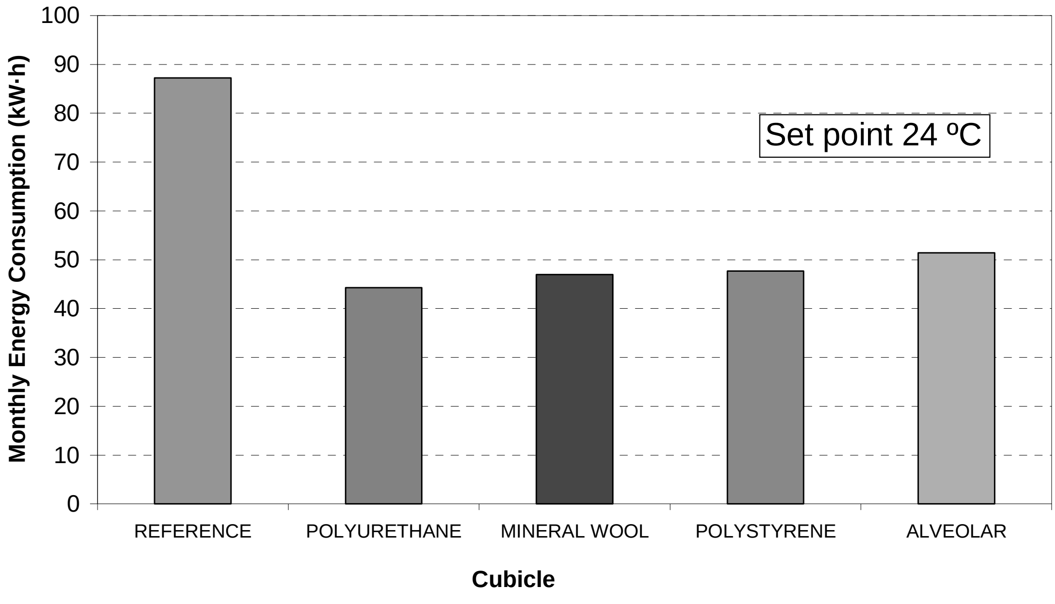

Figure 4. Extrapolated energy consumption of the different cubicles during one month of summer. Set-point of 24 ºC.

4 CONCLUSIONS

In this paper an experimental set-up to evaluate the influence of different insulation materials in buildings is presented. Several cubicles were constructed and instrumented to measure the energy consumption during the year. Results show that insulation is required to dramatically reduce the energy consumption in buildings, and therefore the associated CO_2 emissions.

The comparison between insulated cubicles shows a better behavior of the polyurethane cubicle. However, the alveolar cubicle, which only has alveolar brick to provide insulation and as structural material, presents a behavior much better than the Reference cubicle (about 40 % of energy reduction) and slightly worst than the insulated ones (7 to 14 % higher energy consumption). This demonstrates the good behavior of such a constructive solution, which allows reducing the construction time, since only one layer is necessary. Also thermal bridges due to bad installation of the insulation can be avoided.

New experiments will be performed and dynamic thermal conditions will be evaluated in the future to determine the effect of the thermal inertia in the comfort conditions inside the cubicle.

ACKNOWLEDGEMENTS

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National portal for the energy certification of buildings: DOCET

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ABSTRACT: European Directive 2002/91/CE on the energy performance of buildings provides that "[…] Member states shall apply the methodology for the calculation of the energy performance of buildings […]", Article 3, and provides for the definition of simplified methods for energy certification purposes in order to reduce the costs to be borne by final users.

In Italy, the regulatory framework on the energy performance of buildings has been transposed through UNI TS 11300-1/2 Technical Standards; thanks to the recent publication of National Guidelines for the Energy Certification of Buildings, Ministerial Decree 26 June 2009, the procedures for the issuing of the energy certificate for buildings have been regulated at national level. Article 5, Annex A of the above mentioned Decree provides for the use of the calculation method implemented in the DOCET software, for the calculation of the energy performance index for heating and for the production of domestic hot water in case of asset rating calculation method.

DOCET is a calculation tool for the energy certification of buildings developed and implemented by ITC-CNR, the Construction Technologies Institute of the Italian National Research Council and ENEA, the Italian National Agency for New Technologies, Energy and the Sustainable Economic Development. These two bodies are in charge, at national level, of the research activities carried out in the field of energy efficiency of buildings.

The idea behind the DOCET software is to create a calculation tool with a simplified interface for the energy certification of existing residential buildings. Its objective is to act as a national reference portal for the energy certification of buildings as well as to effectively support the identification of the main energy criteria to be used for the evaluation of the environmental sustainability of buildings.

1 CONTEXT

The Italian Guidelines for Buildings Energy Certification (DM 26/06/09) define the assessment of buildings performances; they identify DOCET as the national tool for the calculation of primary energy for heating (EP_i) and for DHW (EP_{ACS}), according to national standards. The software is free of charge available on the website www.docet.itc.cnr.it. DOCET involves standard energy rating calculated with actual data for the building and standard use data set. It represents the intrinsic annual energy use of a building under standardized conditions. This is particularly relevant to the certification of standard energy performance.

2 SOFTWARE ARCHITECTURE

The tool is based on the monthly balance method, aimed at the energy certification of buildings, according to different uses.

DOCET comes out from the research of simplified approaches to facilitate data entry by users without special expertise, defining an interface that qualifies existing buildings, and is easily reproducible. Actually this tool is characterized by high simplification of input data and the reproducibility of analysis, but without disregarding the accuracy of the result.

The calculation of the net energy for heating is carried out according to the UNI TS 11300 part 1, which defines the net energy as the balance of heat losses and heat gains.

The primary energy for heating is calculated according to the methodology laid down in UNI TS 11300 part 2, which defines the primary energy as the balance of heat loss and heat and electrical recovery for every subsystem of the heating and domestic hot water system.

DOCET evaluates the energy buildings performances according to the methods and indicators developed within CEN, allowing three steps of calculation:

- Net energy, defined as the energy needed to meet comfort criteria, taking into account the thermal losses and gains; this parameter varies depending on the thermal transmittance, orientation, shape factor, profiles of use, etc., and basically indicates that the architectural and construction solutions are fit for the building envelope;
- Delivered energy, defined as the energy actually measurable at the "power meter"; the calculation depends on the type of technological systems installed, their efficiency and the performance factor, and gives comprehensive information on the efficiency of the "building-plant system";
- Primary energy, defined as the actual consumption of non-renewable resources, depending on the fuel used and the actual use of renewable energy sources.

According to the European EPBD (Energy Performance of Buildings Directive) normative framework the energy certificate must be accompanied with recommendations for the improvement of the energy efficiency of the building. DOCET contains a section devoted to the cost-benefit analysis, in which possible energy-efficiency refurbishment actions are evaluated from the point of view of improving performance and the economic and financial impact; to this end, the simple payback time of investment is calculated.

The overall structure of the software is designed and developed according to criteria of simplicity, clarity and intuitiveness.

The tool quantitatively automatically defines all qualitative data entered.

2.1 *Net energy*

The net energy for heating, $Q_{H,nd}$, and for cooling, $Q_{C,nd}$, expressed in kWh, is determined by the balance of losses (transmission and ventilation) and gains (internal and solar gains), according to the following formulas:

$$Q_{H,nd} = \left(Q_{H,tr} + Q_{H,ve}\right) - \eta_H \cdot \left(Q_{int} + Q_{sol}\right) \quad (1)$$

$$Q_{C,nd} = \left(Q_{int} + Q_{sol}\right) - \eta_C \cdot \left(Q_{C,tr} + Q_{C,ve}\right) \quad (2)$$

where: $Q_{H,tr}$ = total heat transfer by transmission for heating; $Q_{C,tr}$ = is the total heat transfer by transmission for cooling; $Q_{H,ve}$ = is the total heat transfer by ventilation for heating; $Q_{C,ve}$ = is the total heat transfer by transmission for cooling; Q_{int} = is the sum of internal heat gains over the given period; Q_{sol} = is the sum of solar heat gains over the given period; η_H = is the dimensionless gain utilization factor; η_c = is the dimensionless utilization factor for heat losses.

In this section the users can enter the characteristics of the building envelope, such as: geographical location (province, municipality, degrees/day, latitude, altitude, etc.); geometry of the building; thermo-physical features of opaque and transparent technical elements (thermal transmittance, surface colouring, solar factor, etc.). From limited data, the software recognizes and defines the dimensions and the physical characteristics of the envelope; the users can modify these intermediate results.

2.2 *Delivered energy*

The energy delivered for heating and/or for the production of hot water for domestic use depends on the technological systems installed. The heat producing systems can be divided into the following subsystems:

- Heating: emission, regulation, distribution, stoke, generation;
- DHW production: emission; distribution; stoke; generation.

For each subsystem the following shall be determined:

- Total amount of energy entering the subsystem;
- Total auxiliary energy of the subsystem;
- Losses.

The tool is also able to assess the contribution obtained by applying solar collectors and photovoltaic panels.

2.3 *Primary energy and certification tool*

The primary energy is defined as the energy potential presented by carriers and energy sources in their natural form, i.e. energy that is not subject to any conversion or transformation process; the tool adds different forms of energy such as fuel (natural gas, oil, biomass, etc.), self-produced or purchased electric energy, derived from renewable sources (geothermal, hydroelectric, wind, etc.) or fossils.

DOCET is a software dedicated to energy certification of residential buildings; the analysis of net and primary energy defines the energy performances of the building. The inputs and outputs calculated by DOCET are entered in the energy certificate, according to the National Guidelines for Buildings Energy Certification.

2.4 *Energy diagnosis*

In the last section of the tool, it is possible to define improvements of performances of the building, modifying some thermal indicators such as thermal transmittance and heating system efficiency, according to the Italian Decree Law 192/2005 which defines the minimum requirements on the energy performance of buildings.

DOCET involves “Recommendations” to evaluate energy-efficiency refurbishment actions by a quantitative point of view, and “Parametric analysis” to evaluate energy behavior of the building depending on the variation of some physical quantities, such as thermal transmittance and plant efficiency.

The “Recommendations” section verifies in real time the improvement of energy performance, in terms of net energy, primary energy, delivered energy, CO_2 emissions and energy performance classification of the building, as specified in National Guidelines. In this section, it is possible to improve thermal transmittance of building elements, plant efficiency and DHW pipe insulation with values corresponding to the limits imposed by Italian Decree Law 311/2006 (see figure 1).

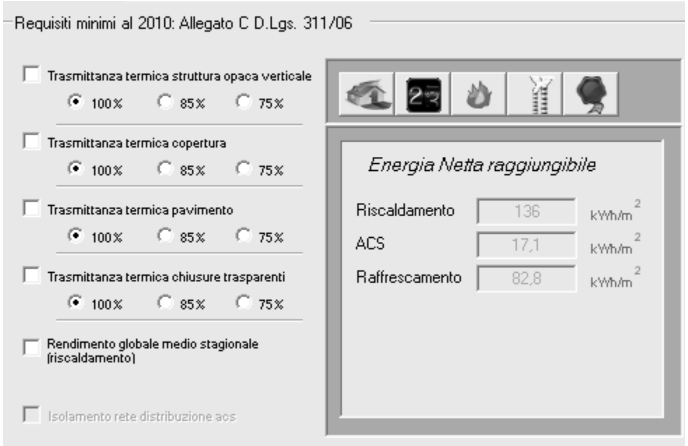


Figure 1. Recommendations

"Parametric analysis" evaluates the thermal performances (net energy for heating and cooling) of buildings, as the thermal transmittance of opaque or transparent components changes, as defined in figure 2.

This section also contains the "sensitive analysis" that identifies the most sensitive parameters among thermal transmittance of vertical walls, roof, ground and doors, g-value of the transparent elements and plant efficiency, and allows to compare them in a radar diagram, as defined in figure 3. The highest values correspond to a high priority for refurbishments.

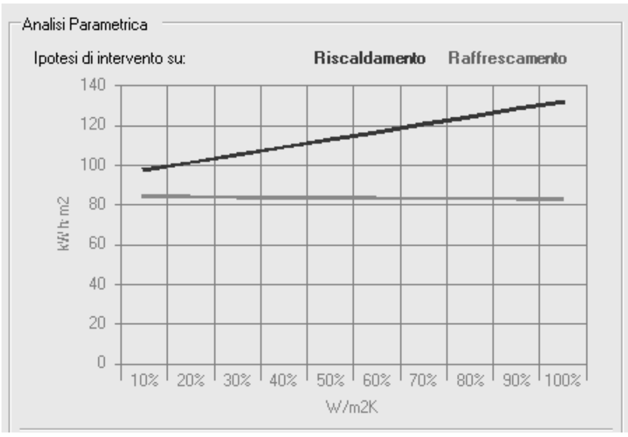
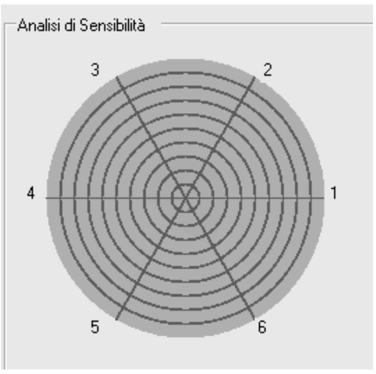


Figure 2. Parametric analysis



Legend:
1. thermal transmittance of walls;
2. thermal transmittance of roof;
3. thermal transmittance of floor;
4. thermal transmittance of windows;
5. g-value;
6. heating system efficiency.

Figure 3. Sensitive analysis

3 CONCLUSIONS

According to promotion activities and awareness of users of the European Union about the energy performance and certification of buildings, the Italian regulatory framework (D.Lgs 192/2005, D.Lgs 115/2008, DPR 59/2009 and National Guidelines for energy certification) is aimed at containing costs for end users, to have simplified calculation methods and to simplify procedures.

The idea behind the DOCET software is to create a calculation tool with a simplified interface for the energy certification of existing residential buildings.

Its objective is to act as a national reference portal for the energy certification of buildings as well as to effectively support the identification of the main energy criteria to be used for the evaluation of the environmental sustainability of buildings.

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Ecological Footprint: a “switched on”, a “switched off” and “on the move” indicators for ecocompatibility building assessment

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ABSTRACT: Ecological Footprint (EF), fitted for building sector, might be considered an effective tool within monitoring and evaluating activities estimating the “ha/per capita” needing to build up, use and pull down a building, thanks to only one indicator. The paper deal with the results of research aimed at summarizing and putting into practice the environmental performances of a building through an integrated approach: the “switched on” Ecological Footprint, related to energy consumption for heating, cooling and lighting the building; the “switched off” Ecological Footprint, related to ecocompatibility of production, construction and maintenance stages, finally the “on the move” Ecological Footprint related to transport stage. Further the research has developed a database and a simplified tool with the aim of “speeding up” the assessment process.

1 INTRODUCTION

The building and construction sector is a key sector toward sustainability. The life cycle of a buildings produce social and economic benefits to society, specially for developing countries, but at the same time buildings may have a serious negative impact on the environment.

Although more then 160 countries subscribed the Kyoto Protocol and several continents have promote betters environmental performances in production and building sectors, world wide the fossil fuel energy needs still increase, as well as dioxide carbon (CO_2)emissions.

With regard of building life cycle, “use” can be assumed as the most relevant stage. The energy demand for heating and cooling, for lighting and for the warm water consumption causes the largest energy and environmental impact if compared with other life cycle stages, such as production, maintenance and final disposal.

The European Directive 2002/91/CE and 2006/32/CE are two important example of the EU statement within the “use stage” in order to reducing energy needs of a building.

In the other building life cycle stages it is not usual finding compulsory regulations with the exception of the EU Directive 2005/32/CE and the newest 2009/125/CE. In any way in Europe there are not thresholds concerning the environmental impact of building materials even only for production stage.

If compared with energy consumption in use stage, production of building materials is not a negligible. Each year about three billion tones of raw materials (40-50% of total flow extracted) are used worldwide to manufacturing building products and components. Furthermore raw materials when processed into building products need energy resources and realize emissions - even harmful – to air, water and soil.

In particular, building products are heavy consumers of high embodied energy content, such as aluminum, steel, polyurethane, cement, etc.

Finally raw materials and building products need to be transported adding further energy consumption and emissions, especially when extracted and processed faraway from manufacture and construction sites.

In order to assess the environmental impact of a building in its whole life cycle an increasing numbers of models and tools have been developed in the last fifteen years, such as BREEAM, LEED, GBC, etc.. Each one of the mentioned model and tool is based on indicators and on a corresponding score system.

For some indicators the scoring can be assessed through methodological approach resulting from building regulations, code and certification systems. Thus the assessment procedure is not particularly tricky and the data information system is usually well organized and defined within technical standards (e.g. UNI EN standards). For some other indicators the scoring can not be easily evaluated.

In production and transportation stages Life Cycle Assessment is the reference framework for assessing energy and environmental impacts. Nowadays several LCA models can be adopted by designers but often they are not consistent to architecture and civil engineering needs, or they are customized for building systems only suitable in some countries. (e.g. Europe, USA and Japan build up a building with different elements, components and systems).

The main object of the research carried out by the team of Polytechnic of Turin was to develop a simplified model aimed at harmonizing the methodological approaches characterizing the several life cycle stages of a building with particular reference to use and production by means of the Ecological Footprint Account tailored to building and building systems as well.

2 ECOLOGICAL FOOTPRINT ACCOUNTING

The Ecological Footprint (EF) is an indicator, measured in equivalent hectare, generally used to indicate, in a synthetic way, the level of sustainability of a process, an activity or a service.

The term “Ecological Footprint” was coined at the end of the 1980s by Canadian researchers - Mathis Wackernagel and William Rees - who studied the amount of land needed by cities to support their populations. An Ecological Footprint represents the bioproductive land and marine area needed to produce everything consumed by an individual or a population and to absorb the emissions that result from this consumption, using prevailing technology.

The Ecological Footprint is obtained combining different factors:

- crop area;
- pasture area;
- fisheries area;
- forest area;
- built up area;
- sequestration area or energy biomass accumulation area.

EF accounting compares human demand on nature with the biocapacity, the biosphere's ability to regenerate resources and provide services. The biocapacity measures the productive capacity of the areas that are available in the world as a whole, in a country or in a smaller area. If the value is lower than the one of the Ecological Footprint, it means that there is an ecological deficit, if, instead, the value is superior than the one of the Ecological Footprint, this means that there is an ecological surplus.

Thus EF accounting shows how much nature people use. This resource accounting is similar to life cycle analysis wherein the consumption of energy, biomass (food, fiber), building material, water and other resources are converted into a unique value, a normalized measure of land area called “global hectares” (gha).

The EF accounting method can be used at different level: at global and national level, as described in the Living Planet Report, or at local level, e.g. within Agenda 21 program developed by public body.

Thanks to researches carried out in several countries, EF has shown its suitability of being applied in building sector within assessment and design processes. In this specific field EF accounting does not take into account each above mentioned area but only the most appropriates. In particular: the “built-up area”, the “forest area”, due to eventually timber needs, and “sequestration area", due to primary energy consumption for heating and lighting needs and primary energy content for production building products and building systems as well.

The EF accounting split up the assessment in three calculations with a common theoretical approach and with a common unit aimed at adding the results got. The three specific indicators are:

- the "switched off" building EF;
- the "switched on" building EF;
- the "on the move" EF.

3 BUILDING ECOLOGICAL FOOTPRINT: "SWITCHED OFF"AND "ON THE MOVE" INDICATORS

The "switched off" Ecological Footprint accounting is connected to the amount of building products and building systems used in the construction stage. For the mainly categories of products it is necessary quantify the primary energy content and it is necessary taking into account the numbers of replacements due to maintenance activities.

The primary energy content is closely related to the gross energy requirements within the inventory analysis of a Life Cycle Assessment study. Database or exhaustive inventory analysis carried out before the accounting of the EF is required and it is time consuming.

In order to simplify the analysis and the assessment process several research centre have developed database and ecotool, such as IBO- IBN or Ecoinvent. Some tools are quite expensive, some others do not take into account the energy mix of the country where the EF account should be carried out.

3.1 *The EF database*

According to the above mentioned environmental requirements, as a result of the survey carried out, part of the research activities was aimed at developing a database where information aimed at characterizing the environmental performance of building systems are gathered.

The total amount of building materials selected for the data gathering procedure are about seventy. The work was focused on the most common building products nowadays used in construction sector and was based on the following main references:

- technological manuals and environmental reports;
- mandatory regulations and voluntary standards available;
- chemical safety cards for building products and substances;
- database for inventory analysis and focused software and tools for impact assessment calculations.

Furthermore in several cases data were collected and completed thanks to the close cooperation with manufacturers enterprises. Data gathering procedure implied more then three years activities and the research team is now committed in increasing the number of building products in order to establish a reference data base for designers and public bodies.

Once carried out the data collection, the inventory analysis and impact assessment calculations, a datasheet frame was drawn up. The main goal of datasheet is to summarize all the gathered information in a proper format. In such a way an environmental comparison among products aimed at providing a specific function within a building element (e.g. insulation) is possible (Figure 1).

Each datasheet is organized as follows:

- Part 1 – General Information;
- Part 2 – Thermal and Physical Information;
- Part 3 – Environmental Potential Scenarios;
- Part 4 – Energy and Environmental Performances.

An Italian version is now available, a further implementation with an English one will be worked out soon.

Caratteristiche tecnologico-ambientali						
Modalità di posa in opera	0		3		5	
	Sistema umido/Adesione/ Saldatura		Incastro/Serraggio		Accostamento	
Durata stimata (anni)	0	1	2	3	4	5
	2-10	11-25	26-40	**40-55**	56-70	> 70
Indicatore di ricilabilità	0	1	2	3	4	5
	Discarica rifiuti speciali	Discarica inerti	**Incenerimento**	**Riciclabile con bassa capacità prestazionale**	Riciclabile con alta capacità prestazionale	**Biodegradabile e/o riutilizzabile**

Caratteristiche energetico-ambientali unità funzionale [1 kg di prodotto]								
Contenuto Energia Primaria [MJ/kg]			0	1	2	3	4	5
	Granuli	Pannelli						
CEP totale	**30,50**	**38-4**	> 70	56-70	40-55	**26-40**	10-25	< 10
CEP non rinnovabili	11,31	15,39						
CEP rinnovabili	19,19	23,07						
Anidride Carbonica [CO_2/kg]			0	1	2	3	4	5
	Granuli	Pannelli						
CO_2 totale	-1,15	-1,27	> 3,75	3,01-3,75	2,26-3,00	-,51-2,25	0,75-1,50	**< 0,75**
CO_2 diretta	< 0,01	< 0,01						
CO_2 indiretta	-1,15	-1,27						

Figure 1. Example of datasheet for assessing the “switched off” EF concerning cork insulation material. (Part 3 - Environmental Potential Scenarios and Part 4 – Energy and Environmental Performances).

Datasheet Part 1 gives information about:

- building products commonly used in building elements (e.g. bricks for facade);
- specific function performed within the building elements (e.g. insulating, water-proofing, finishing, etc.);
- functional units assumed for the energy, environmental and thermal characterization (according to Life Cycle Assessment methodology – ISO 14040);
- boundary system assumed for inventory analysis and the environmental impacts assessment calculations.

Datasheet Part 2 gives necessary information for the U-value and thermal inertia calculation.

Above-given indicators might not be the only ones necessary for a comprehensive assessment of energy and environmental performances at use stage, but certainly very important if related EU Directive.

Datasheet Part 3 basically gives information about the attitude of a building element or a building product of being re-manufacturable, appropriately durable and recyclable. The evaluation of the performance of a building element or product is carried out on the basis of pre-defined classes of performance values to be applied to the Ecological Indicator. The number of classes is 5, ranging from 1 to 5.

Datasheet Part 4 provides - for a building product - the Gross Energy values and Global Warming Potential, the former according to life cycle inventory analysis, the latter to life cycle impact assessment. Input streams of the product system affect the Gross Energy quantification as sum of the following energy carriers: energy production and delivery, fuels’ energy content, energy transport, feedstock energy and biomass energy. Output streams of a product system are related to the total amount of air emission contributing to Global Warming Effect.

A characterization of the most important greenhouse gasses was carried out, as well as the impact assessment based on weighting factors. Estimation of the environmental effect was performed on Global Warning Potential of equal mass emissions over a period of 100 years.

Finally some information about human health and safety effects are provided. Such impacts are usually achieved on the basis of information about:

- hazardous substances identification;
- frequency and duration of the exposure;
- estimation of the risk from exposure to a particular agent or substance.

At design stage such determination can be very difficult. Thus the information given and the simplified assessment procedure proposed are mainly referred to Chemical Safety Cards gathered in the research activities.

3.2 *The "switched off" and the "on the move" EF assessment*

The "switched off" EF accounting as above mentioned is based on the primary energy content of production stage and taking into account the necessary replacements due to maintenance of building products and components during the building life cycle.

Primary energy content can be converted in a Sequestration Area (SA_E) value as follows:

$$SA_E = Q \text{ x } fc \text{ x } Ep \text{ [ha]} \tag{1}$$

Where:
Q = total amount of selected building products within the EF account [t or t/km];
fc = EF conversion factor obtained by the "Ecological Footprint Manual" [ha/GWh];
Ep = primary energy contents of selected building products [GWh/t].

The "switched off" EF account for a building product (EF_{BP}) is calculated as follow:

$$EF_{BP} = \frac{(SA_E + S_f) \times f_{qz}}{D} \text{ [ha]} \tag{2}$$

Where:
S_f = forest area due to timber used in the building – 1 ton means 2,4 ha of forest – [ha];
f_{qz} = frequency of replacements due to maintenance activities [1/years];
D = building product life span.

Once carried out the calculation of the "switched off" EF account for the building products taken into account for the assessment, it is possible quantify the "switched off" EF_{SOFF} account for the building as whole as follow:

$$EF_{SOFF} = \Sigma\, IE_{elem} + S_d \text{ [ha]} \tag{3}$$

Where S_d is the built-up area defined as follows:

$$S_d = \frac{\text{Land covered by the building}}{\text{Expectd life span of the building}} \text{ [ha/anno]} \tag{4}$$

The "on the move" EF account is based on analogous methodological approach. The energy impact of transport can be assessed with equivalence factors where the distances from manufactures to the construction site are expressed in MJ as it is shown on table 1.

Table 1. Energy consumption related to two types of commercial vehicle.

Type	Journey	Energy consumption [Mj/vehicle km]
Diesel < 3,5 t (EEC Euro 0)	Urban	5.27
	Extra-urban	2.97
	Highway	3.92
Diesel < 3,5 t (EEC Euro 1)	Urban	4.79
	Extra-urban	2.62
	Highway	3.48

The “on the move” EF accounting is completed through the conversion factors obtained by the “Ecological Footprint Manual” [ha/GWh].

4 BUILDING ECOLOGICAL FOOTPRINT: “SWITCHED ON” INDICATOR

The “switch on” EF accounting is based on the assumption that with the calculation system is possible to define the consumptions, and the resultant footprint, due to the use of different equipments (specially electrical and thermal systems) even though it becomes necessary to make conceptual simplifications, because of the hardness to assess the costumers’ behaviors concerning the use of plant technologies.

The assessment can be given using software and tools able to calculate the amount of heat needed to cover the heating and electrical requirements of the buildings, for each month of the year.

Considering the Ecological Footprint of the “switched on” building, to calculate the monthly heat requirements that the heating system has to supply, is necessary to sum up the value of free heat gains due to internal metabolism, to passive systems and the value due to thermal losses of the building.

In this case the factors having an influence on the calculation of annual consumption of primary energy are:

- local climatic conditions;
- buildings’ shape and façades’ orientation;
- typologies of opaque and transparent envelope systems;
- use of shielding systems;
- thermophysical properties of elements;
- heating system efficiency;
- effect of ventilation flows;
- effect of free solar gains;
- cooperation of buffer spaces (closed and unheated spaces placed as a separation between heated rooms and outdoors);
- heat losses due to conduction;
- luminance levels.

4.1 *The “switched on” EF assessment*

The “switched on” EF accounting is based on the determination of monthly heating energy requirements and illumination energy requirements.

Nowadays several software and tools provide the lighting and thermal primary energy amount. Some of the results processed can be assumed within the “switched on” EF accounting.

Afterwards is possible to determine the total consumption of primary energy multiplying the value obtained, referred to square measures, by the number of years of the lifecycle of the building (for instance 80 years).

Thanks to specific factors each energy source (e.g. electricity, natural gas, etc) is converted into equivalent hectare as it is shown in table 2.

5 CASE STUDY AND EXPECTED RESULTS

In order to assess the effectiveness of indicators a case study has been defined. See figure 2. Mid term results have verified the potentiality of the methodological approach developed even if some critical issues need to be properly faced up. In the final report will be focused the corrective actions and the latest out comings.

Concerning the case study the research project has been organized through the steps described as follows:

- formulation of the general list of materials used, both as yard materials and as construction materials, as from the estimate of building products and building systems quantity;
- evaluation of primary energy content for each building material considered (from previous studies /data bases) and their own transportation stage as well;
- definition of conversion factors referred to selected materials;
- definition of conversion factors referred to electrical and thermal consumption and to water consumption;
- calculation of the EF as a product of initial data with specific conversion factors;
- comprehensive assessment of the Building Ecological Footprint;

Table 2. Summary of conversion factors for the assessment of Ecological Footprint

Consumption items	Conversion factors						
	Sequestration area or energy biomass accumulation area	Crop area	Pasture area	Forest area	Built-up area	Fisheries area	Units
Electricity	0.046471	-	-	-	0.000488	-	ha/Gj
Natural gas	0.011017	-	-	-	-	-	ha/Gj
Water	0.000080	-	-	-	-	-	ha/mc
Pellet	0.019517	-	-	-	-	-	ha/mc
Thermal solar	-	-	-	-	-	-	-
PV energy	-	-	-	-	-	-	-

Figure 2. The building assume as case study within the building EF accounting.

6 CONCLUSION

Although the EF accounting method has not been tested on a wide range of case studies and even if not all the life cycle stages of a building have been investigated there are some strength items concerning the research carried out.

The building EF accounting can be assumed as one of the few tools that allow putting into effect the LCA studies within the ecocompatibility assessment of a building. The database developed provides information about the energy and environmental performances otherwise very difficult to get and time consuming in the assessment procedure and in the design stage.

The correlation between the EF accounting and the EU Directive requirements, such as the EU Directive 2002/91 aimed at quantifying the primary energy consumption for thermal and lighting needs, is other important aspect. In particular based on ISO and UNI standards and software simulation tools is possible to get results consistent to indicators selected for Building Ecological Footprint.

Finally the opportunity to measure with a unique value the ecocompatibility of a building in the most parts of its life cycle makes easier the assessment procedures and the design process allowing the comparison among several technological options.

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Towards a quantitative thermography for buildings - indoor measurement ofthermal losses

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ABSTRACT: The current construction trend which calls for minimizing buildings' heat losses by means of thick heat coats leads to the problem of limiting energy consumption for cooling, especially in Mediterranean climates. The control of internal gains and direct radiant energy which enters through windows during the summer season requires rather precise knowledge of the heat exchange dynamics which occur among the walls of rooms. This paper concerns the development of a methodology aimed at the estimation of radiative and convective thermal flux components in room walls. The proposed procedure entails practical, one-side, indoor measurements, which combine dynamic thermography with traditional contact thermal measurements. This provides an effective means for estimating the thermal flux at each of the points depicted by the thermal image.

1 INTRODUCTION

The current construction trend which calls for minimizing buildings' heat losses by means of thick heat coats leads to the problem of limiting energy consumption for cooling, especially in Mediterranean climates. This is usually achieved by controlling the internal gains and direct radiant energy which enters through windows during the summer season, by conveniently dimensioning and positioning shading and heat capacitances in the wall layers, and by developing effective designs of natural ventilation flows. Observing heat exchange dynamics among room walls showed that different parts of the same wall may have different roles in overall heat exchange behavior depending on its morphology, on the external climate conditions, on the ventilation regime and, of course, on its recent thermal history. A rather precise knowledge of heat exchange dynamics among room walls is therefore necessary in order to guide any design procedure aimed at minimizing the effects of large heat coats on the summer cooling energy consumption

Presently, this knowledge level can be acquired either by simulation or by on-site measurements. Whole building analysis practice, combining both nodal network and computational fluid dynamics (CFD) (Clarke 2001) for the evaluation of heat exchanges among room walls, is based on a rather precise knowledge of the layer structure of building envelopes. In the case of old buildings, this knowledge is often not available. Moreover, even when technical drawings and building plans of new buildings are available, the frequent adaptations carried out by constructors to solve unforeseen construction issues, often cause variations of the building's thermal behavior.

On-site measurements of heat exchange among room walls can therefore support and complement modeling and analysis. There exists a long tradition of research concerning the measurement of the surface heat transfer coefficient (the *h* factor) of building envelopes. It is mostly based on fluid dynamics results developed mainly in the field of aerodynamics (Astarita & al. 2000), using a laboratory recreation of the steady state conditions of heat transfer between the surface under study and a moving fluid. Outside applications of these approaches to the building envelopes are described in (Taki & Loveday 1996). A heated panel is raised at different heights in different buildings so that to derive a set of regression curves between convective coefficient and the wind speed for various environmental conditions. (Alamdari & Hammond 1983) developed an expression of the convective heat transfer h_c for the laminar and turbulent regimes as a function of the average temperature difference between the wall surface and the ambient fluid that can be applied to guide the on-site estimation of the h_c coefficient.

This paper concerns the development of a methodology aimed at the estimation of the radiative and convective thermal flux components occurring during the heat exchange among the walls of a room. The proposed procedure combines traditional one side indoor temperature and flux measurements with dynamic thermography. It uses contact measured temperature and flux data to estimate the radiative and convective coefficients on one point of the target wall. It then applies the estimated heat transfer coefficients to approximate the heat flux to every point of the thermo-image that has the same outermost layer and air flow conditions. The procedure thus allows a good estimation of the real heat exchange dynamics occurring among the different parts of the walls of a room by providing the knowledge level needed to control the internal gains and the direct radiant energy.

Section 2 of this article briefly introduces the physical aspects of heat transfer estimation, the analytical formulation of the heat exchange problem as a kind of parameter estimation, and some validating experiments. Section 3 discusses the extension of the proposed methodology to thermography. Finally, section 4 briefly illustrates a noteworthy application of this procedure to the analysis of the thermal behavior of walls.

2 THE ESTIMATION OF CONVECTIVE AND RADIATIVE COEFFICENTS

Ignoring heat transfer by enthalpy, the indoor thermal exchange between room walls is regulated by the convective and radiative dynamics which involve only the outermost layer of the wall. In this section, we will point out the equations governing these mechanisms. Following (Underwood &Yik 2004), a general linear equation for convective and radiative heat exchange can be formulated as follows:

$$q^* = h_c\left(T_{\sup} - T_{amb}\right) + h_{r1}\left(T_{\sup} - T_{\sup 1}\right) + \ldots + h_{rn}\left(T_{\sup} - T_{\sup n}\right) \tag{1}$$

where q^*= exchanged total flux [W/m^2]; T_{sup}= wall surface temperature [K]; T_{amb}= air temperature [K]; $T_{sup1,\ldots}T_{sup,n}$= surrounding surfaces temperature [K]; h_c = heat convective transfer coefficient [W/m^{2}K]; $h_{r1,\ldots}$ h_{rn}= heat radiative transfer coefficient [W/m^{2}K].

In equation (1) the non linearities are restricted to the convective and radiative heat exchange coefficients, $h_c(T)$and $h_c(T)$ respectively, which are dependent on the temperature.

(Alamdari & Hammond 1983) provides a general equation of the $h_c(T)$ coefficient for the linear flows regimes (figure 1), that can be parameterized as it follows:

$$h_c = \beta_c\left(T_{\sup} - T_{amb}\right)^{0,33} \tag{2}$$

where β_c is the coefficient that must be determined through the estimation process; T_{sup} is the wall surface temperature [K]; T_{amb} is the air temperature [K].

The radiative exchange coefficient with the surrounding wall i can be formulated according to (Underwood & Yik 2004) as it follows:

$$h_{r,i} = \beta_i\,\sigma_0\left[\frac{\left(T_{\sup,1} + T_{\sup,i}\right)}{2}\right]^3 \tag{3}$$

where σ_0 is the Stefan-Boltzmann constant [W/m^{2}K^4]; β_i is the coefficient that must be determined through the estimation process, $[0 \le \beta_i \le 1]$.

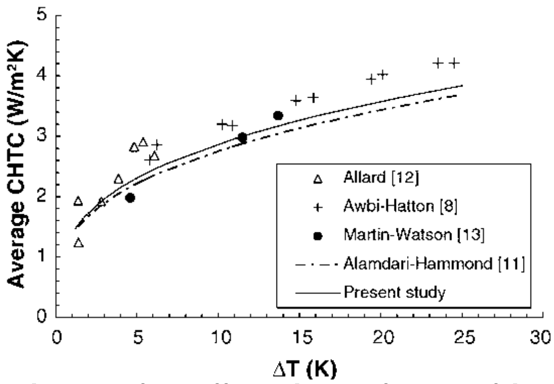


Figure 1. Average convective heat transfer coefficient h_c as a function of the average temperature difference between the wall surface and the ambient fluid ΔT, from (Fohanno & Polidori 2006)

Actually β_i represents the view factor between the wall under analysis and the *i-th* surrounding wall. Therefore for many room walls morphologies a good initial estimation of β_i can be derived from standard tables (Moran & al. 2003).

From the computational point of view equations (1),(2) and (3) represent an effective mean for the estimation of the $h_c(T)$and $h_r(T)$ coefficients, starting from on site temperature and flux measurements and using a non-linear regression algorithms.

The Levenberg-Marquard algorithm (LMA) (Nocedal & Wright 1999) represents a good starting point. It provides a numerical solution to the problem of minimizing a function, generally nonlinear, over a space of parameters of the function. A possible application of the LMA is therefore the least squares curve fitting problem. The application of LMA to the estimation of the heat exchange coefficients is straightforward: given a set of measured flux and temperatures pairs, (q, ΔT_i), optimize the parameters β_i of the model curve $f(\Delta T_i,\beta_i)$ so that the sum of the squares of the deviations becomes minimal.

$$S(\beta)=\sum_{i=1}^{m}\left[q-f\left(\Delta T_{i,}\beta_i\right)\right]^2\rightarrow \min \qquad (4)$$

Like other numeric minimization algorithms, the LMA is an iterative procedure. To start a minimization, the user has to provide an initial guess for the parameter vector, $\boldsymbol{\beta}$. In many cases, an uninformed standard guess like $\boldsymbol{\beta}^T$=(1,1,...,1) will work fine; in other cases, the algorithm converges only if the initial guess is already somewhat close to the final solution.

Unfortunately, the straightforward application of the LMA does not guarantee for results that always have a physical consistency. For example, the unconstrained application of LMA may result in negative coefficients which are unacceptable. Therefore some constraints must be applied to the iterative solution process. In this research, we discovered that the following constraints are suitable to guarantee consistent results in many applications:

$h_{c(\Delta T=0)}\approx 1.4$ *(from Almdari and Hammond)*

$\beta_j>0$ *(positive coefficients)*

$0\le\left(\beta_2,.....\beta_n\right)\le 1$ (*range of view factors*)

$Fv_{mn}=Fv_{nm}$ (*reciprocity relation between view factors*)

The measurement schema is depicted in figure 2. A Matlab software was developed and an experimental campaign was carried out to prove the effectiveness of the methodology. Figure 3(a) shows the measured and estimated fluxes at the wall surface, and the convective and radiative components in one typical take. The mean error is 0.3 W/m^2, the max error is 0.7 W/m^2. Figure 3(b) shows the estimated $h_c(T)$ and $h_{ri}(T)$ and the radiative components related to each surrounding wall.

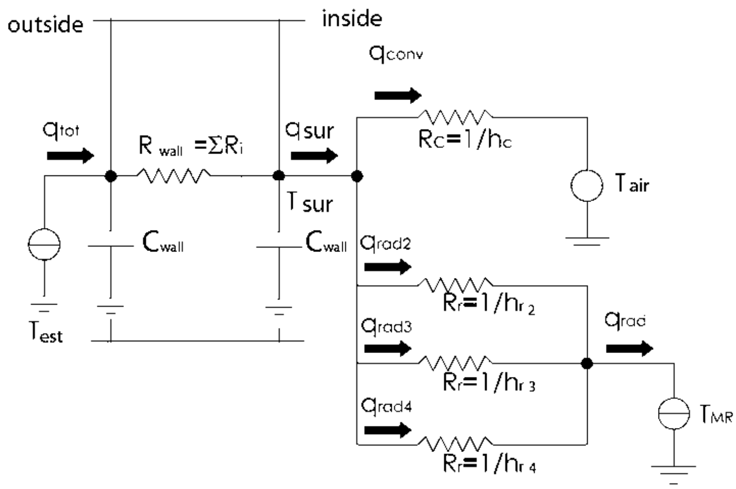
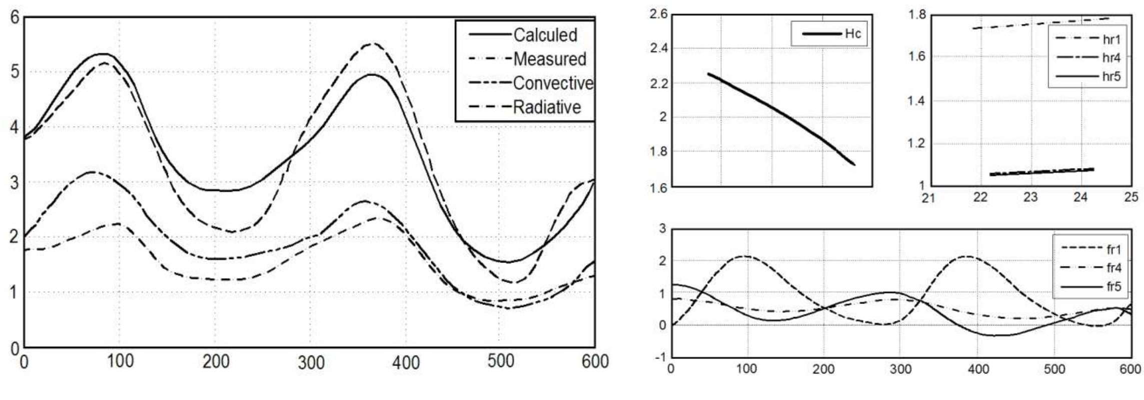


Figure 2. Resistive-capacitive measurement schema for indoor heat exchange, where q is the wall surface flux, T_{sur} is the wall surface temperature, T_{sur_i} is the surrounding wall surface temperatures, T_{amb} is the room air temperature.



(a) *(b)*

Figure 3. (a) Measured and estimated fluxes at the wall surface, and the convective and radiative components. (b) Estimated $h_c(T)$ and $h_{ri}(T)$ and the radiative components related to each surrounding wall.

In order to validate the results, we checked whether the estimated values were within the ranges published in the literature and, more important, whether simultaneous but uncorrelated estimations on facing walls led to consistent results. In particular, we checked whether the estimated radiant components of two facing walls converging to a 90° corner were equal in module but opposite in phase. Results are shown in figure 4.

The sensitivity of the estimation procedure to the changes in the thermal regime is demonstrated in figure 5 which shows how an impulse of natural ventilation affects only the convective component, while the radiative one remains almost unaffected because of the thermal inertia.

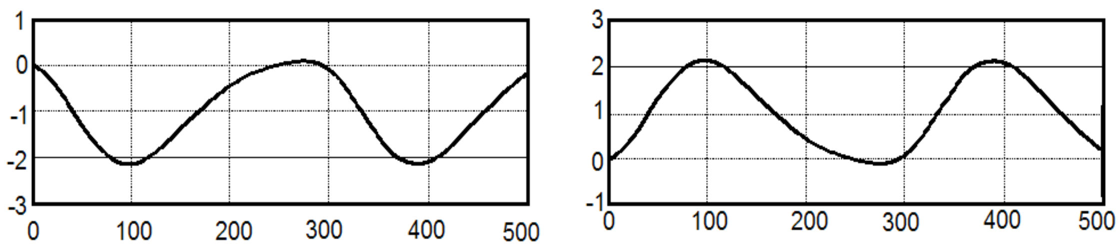


Figure 4. Estimated radiative fluxes for two 90° facing walls. The fluxes are almost equal in module and opposite in phase accordingly to the theoretical results.

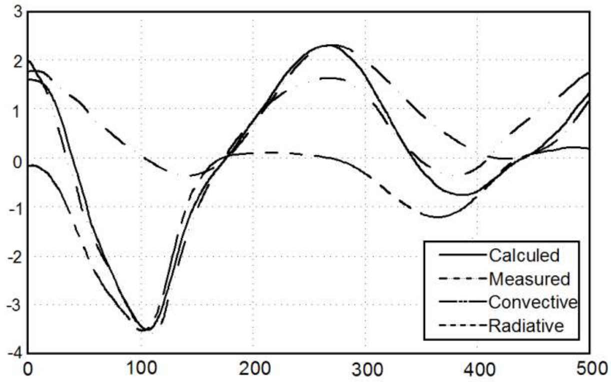


Figure 5. The rapid increase of the convective component due to natural ventilation of the room. It noteworthy that the walls thermal inertias keep the radiative component almost unaffected.

3 EXTENSION TO DYNAMIC THERMOGRAPHY

The extension of the flux estimation techniques discussed in the previous section to dynamic thermography in indoor environments is straightforward. The relative low radiative noise level of indoor environments allows for simple noise suppression techniques. More specifically using, for example, a time sequence of thermographic images recorded at interval of 5 minutes including a contact measurement point (e.g. a thermoresistance) in the view field, the systematic error and the high frequency noise can be eliminated by mean squared error minimization and low pass time filtering respectively. Spatial filtering (Ranieri & Pagliarini 2002) can be used to further improve the image quality. Figure 6 shows a typical result.

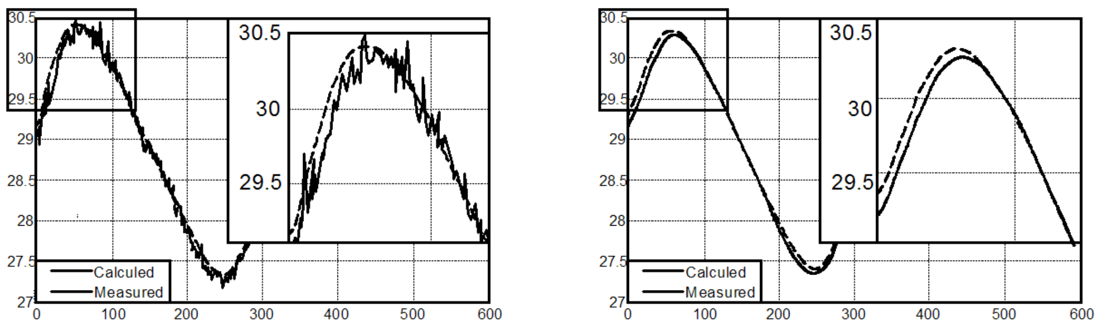


Figure 6. Calibration of a thermal image through curve fitting and time filtering. The picture shows the variation of the temperature with time measured by the thermoresistance (smooth curve) and by the thermocamera (noisy curve) before (left) and after (right) time filtering. Curves were previously aligned by mean squared error minimization.

Once the thermographic image has been calibrated, each pixel of the thermal image can act as a temperature probe for local flux estimation allowing, in principle, for the reconstruction of the whole thermal flux image. The limits of this procedure reside in the limits of applicability of the estimated heat exchange coefficients in points that are relatively distant from the estimation point, and/or in points where the change of the wall morphology causes significant variations of the air flow regime.

In the experimental campaign we investigated the aspect concerning typical thermal bridges occurring at room corners. Figure 7 shows the extent of the homogeneous part of the wall and the limits encountered in the application of the heat exchange coefficients. In this case, the heat exchange coefficients estimated in the central point of the homogeneous region can be extended to the whole region with an error increase of 2-3%. The thermal bridge regions require a new estimation of the heat exchange coefficients, since the application of the coefficients estimated in the homogeneous part results in an unacceptable error increase of 10-15%.

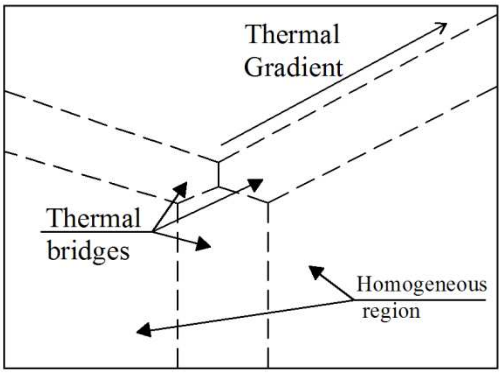


Figure 7. Buondaries setup for the investigation of the limits of the estimation procedure

4 IDOOR MEASUREMENTS OF HEAT EXCHANGE

One of the noteworthy aspects offered by this procedure is the possibility of analyzing the convective and radiative thermal regimes separately - on different parts of the room walls. Figure 8 shows the different behavior of the thermal bridge at the room corner with respect to the homogeneous area of the wall. The thermal bridge exchanged about 186.5 KJ/m^2 for the duration of the experiment while the homogeneous region of the wall exchanged 175.9 KJ/m^2, which is approximately the same amount per unit of area. Things change if we analyze the time period when there is a prevalent convective heat exchange (from frame 0 to frame 200). Here the thermal bridge exchanged about 89.51 KJ/m^2 while the homogeneous region of the wall exchanged 50.9 KJ/m^2, that is approximately a little more than one half of the amount per unit of area. This shows how, for a prevalent convective heat exchange regime (i.e. natural ventilation), the corner thermal bridge was much more efficient than the homogeneous wall. In absence of natural ventilation both the thermal bridge and the homogeneous region behaved roughly in the same manner.

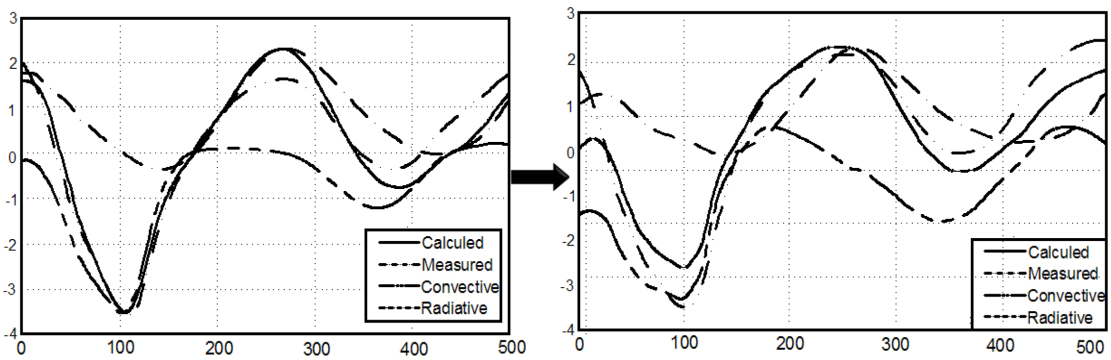


Figure 8. Different behaviors of homogeneous regions and thermal bridges for heat exchange regimes prevalently convective.

4 CONCLUSIONS

In this paper, we discussed the development of a methodology aimed at the estimation of the radiative and convective thermal flux components in room walls, combining one side contact measurements with dynamic thermography. We illustrated the analytical aspects of the estimation procedure and its application to indoor heat flux analysis. The limits of applicability of the procedure were illustrated as well. We demonstrated how, within these limits, the procedure allows for the analysis of the convective and radiative thermal regimes in different parts of the room walls. Forthcoming developments will include further measurement campaigns to detail the applicability limits to a better extent and the extension of the methodology to outdoor environments.

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Methodology for assessing changes to participants' perceptions, awareness and behaviours around sustainable living, in response to proactive sustainable technology interventions in social housing

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ABSTRACT: In this paper the researchers discuss the development and validation of a methodology developed as part of a wider sustainable housing project, whose overall rationale was to find sustainable and affordable retrofit solutions to support CO2 emission reduction in existing social housing stock in the UK.
The concept was based on the idea that through the installation of individual household building management systems, participants could be empowered to take ownership of their own climate change impacts by monitoring their own usage, and thus giving them the potential to make a positive difference by finding ways of reducing their CO2 emissions.
As a significant part of this project, it was necessary to establish perceptions and awareness 'sustainable living' and current behaviours of amongst social housing participants, as well as develop a methodology to investigate changes in participants' perceptions, awareness and behaviours as a result of using the building management system. In addition motivators, barriers and appropriateness of such retrofit technologies to promote sustainable living were to be evaluated.
An interview schedule was developed that allowed researchers to capture participants' implicit and explicit knowledge of climate change and the wider environmental agenda and rank the magnitude of these in relation to each other issues facing society at this time. In addition an exploration of participants' behaviours was undertaken, in order to calculate their ecological footprint by measuring their carbon footprint; food footprint; housing footprint; and goods and services footprint. These measures were calculated at key intervention points during the lifespan of the project to measure changes in participants' perceptions, awareness and behaviours. Semi-structured interviews were also undertaken to elicit motivators and barriers to positive change at different stages in the project. Despite the project's focus on CO2 emission reduction, calculating the participants' ecological footprints allowed the researchers to establish whether positive change in the principal domain, namely their carbon footprint, had a knock on effect in the other domains and thus lowered the participants' footprint overall.

1 INTRODUCTION

In this paper the researchers discuss the development and validation of a methodology developed as part of a wider sustainable housing project, whose overall rationale was to find sustainable and affordable retrofit solutions to support CO_2 emission reduction in existing social housing stock in the UK. The concept was based on the idea that through the installation of individual household building management systems, participants could be empowered to take ownership of their own climate change impacts by monitoring their own usage, and thus giving them the potential to make a positive difference by finding ways of reducing their CO_2 emissions.

In the UK the proportion of energy used by the domestic sector rose from 24-27% in the 1970's to 28-31% in 2001 (Utley & Shorrock, 2008). Over this period there was also an increase in domestic energy consumption of 36%. This is largely due to growth in the number of households, as opposed to a significant increase in energy use; energy use per household has only increased by 5% (Utley and Shorrock, 2008). According to the Office of National Statistics at the Department of Trade and Industry, energy use for space heating has risen by 24%, for water heating by 15%, and for lighting and appliances by 157% since 1970. In contrast, energy use for cooking has fallen by 16%. Space and water heating accounts for 85% of domestic energy consumption and the number of centrally heated homes has risen from 34% in 1971 to 90% in 2001 (Department of Trade and Industry, 2009). Increased insulation and energy efficiency measures have created a saving of 51% in domestic energy consumption from 1970 to 2006 relative to energy consumption without them (Utley and Shorrock, 2008). These behavioural patterns have implications for tackling climate change.

Indeed perceptions of climate change in the UK vary greatly. In a public attitude survey 28% of people interviewed stated that ‘we will have to change our lifestyles to reduce energy consumption’, whereas 27% of respondents stated that ‘global warming is a problem but the UK won’t do anything about it’. Indeed 27% stated that ‘researchers will develop new technologies to solve the problem’; which means that a significant proportion of the population do not feel they have a responsibility to change their environmental behaviour (Curry *et al.*, 2005).

A central argument in the climate change debate is the understanding that transition requires changes to human action and behaviours (Moloney *et al.,* 2009) and according Costanzo *et al*. (1986) behavioural change is seen as the only goal worth pursuing; however this viewpoint has been contest in recent years (Fein *et al.,* 2008).

1.1 *Environmentally responsible behaviour (ERB)*

There have been a number of initiatives undertaken to create environmentally responsible behaviour (ERB), many of which have incorporated theories of: persuasion; attitude change; an individual’s decision making process; understanding the correspondence between attitudes and behaviours; addressing issues of durability; and the scope of behavioural interventions (e.g. (Costanzo *et al.,*1986; Harland *et al.,* 2004). However there is no consensus on the most effective strategies for influencing individuals to develop ERB and additionally motivators and barriers have to be considered when aiming to create ERB (Maloney *et al.,* 2009).

Initiatives are based on three common assumptions that: providing relevant information will lead to ERB; if a person understands their personal contribution to climate change they will respond with ERB; and individual behaviour change is superior to that of the collective (Fien *et al*., 2008). Whilst these assumptions may be valid, when isolated they do not achieve the required aims ((Costanzo *et al.,*1986).

In addition recent research has demonstrated that convenience and cost influence likeliness and willingness to act. This must be considered alongside any altruistic position an individual may take. Any initiative must find a balance between moral responsibility and a desire for economic gain (Kaplan, 2000; Winefield, 2005). Furthermore avoiding economic loss has more influence over household behaviour than securing gain; even of the same quantity. Initiatives should therefore inform the individual of their current losses and before mentioning possible gain (Costanzo *et al.,* 1986).

Media is an effective tool for informing and creating awareness but interpersonal sources have greater influence on an individuals’ decision to act with ERB. Research shows that social diffusion has greater influence over household energy use than other sources of information (Costanzo *et al.*, 1986) and therefore a supportive social environment is effective in creating durable change. In a study by Weenig and Midden (1991) advice from friends or family had a noticeable influence on the adoption of energy conserving technologies. In addition engaging participants in effective and participatory problem solving gives an opportunity for individuals to develop their own solutions to ERB and initiatives which incorporate devices to feedback about performance to the participant increase the sense of both individual and collective value (Bandura, 1977). Feedback alongside social support is more likely to accomplish durable ERB (Harland *et al.,* 2004) due to humanity’s innate desire to be a part of something rather than feeling ineffectual and helpless (Kaplan and Kaplan, 1989).

1.2 *Technological interventions*

Initiatives which focus on empowering participants to take ownership of and reduce their impacts on climate change, must consider both how technology can be used to reduce carbon emissions and the extent to which user behaviour must respond to technology to create durable change (Costanzo *et al.*,1986). The technological component of this research involves the installation of a residential energy monitoring and feedback system that allows participants to monitor their home energy usage, with the intention of encouraging them to reduce consumption. The system will monitor the participants' consumption of gas (space heating, cooking, hot water), and electricity (lighting, washing machines, and other appliances). To support this information real weather data, participants' routine activities and utility price will be collated.

In addition there are a number of levels of 'interventions' in different homes:

1. Energy monitoring system;
2. Energy monitoring system + AAA rated appliances; and
3. Energy monitoring system + AAA rated appliances + renewable energy source.

The intention of this approach is to undertake a cost benefit analysis, identifying energy saving 'quick wins'; in other words, how great a reduction in carbon emissions can be made by each level of intervention.

Although the focus is currently on energy saving as a result of technological interventions, the monitoring system is intended to engage the participants in a more proactive manner. Individuals/families frequently lack the knowledge and motivation to run their homes at optimum efficiency. This means that positive changes to an individual's carbon and wider ecological footprint are not always realised. By providing the participants with daily feedback via the monitoring system, they can make a direct link between their behaviours and the consumption of energy. It is the intention of this research to demonstrate that a behaviour change approach, in conjunction with carbon reducing technology measures, is a constructive way forward.

2 APPROACH

On the whole, as demonstrated by the literature, people's awareness of their contribution to carbon emissions as well as to other environmental issues is limited (Curry *et al.*, 2005). To address this gap in understanding of people's perception and awareness of sustainability a qualitative interview-driven approach was favoured over a questionnaire survey (Willig, 2001).

The interviews took the form of a semi-structured format rather than open format (Smith and Eatough, 2008) as this allowed the researchers to direct the interviews in such a ways as to cover all areas relevant to the topic in the allotted time of 30-45 minutes which was considered most appropriate for retaining the individual/families interest and attention (Breakwell, 1990).

Interactive tools including flash cards, ranking and ratings scales were adopted in order to engage all family members in the process, especially when asked to discuss their understanding of difficult concepts. Flash cards were used to trigger thoughts and awareness of issues, ranking was used to illicit importance's attached to issues, whilst rating scales were employed to identify consumption patterns as well as behaviours so that the researchers could, following the interviews, calculate the individual/families carbon and wider ecological footprint in order to get a base level reading.

The interviews were split into three sections:

- Scene setting: Perceptions and awareness were captured by getting the families to rank firstly, key issues facing society today in order to see how highly they prioritise sustainability issues such as climate change, the energy crisis and overpopulation, in relation to other current affair such as obesity and the credit crunch. Following on from this, they are given a list of topics which all negatively impact to some extent or another on the environment, and again asked to rank these according to how important they are perceived to be. In both these instances flash cards were adopted. Finally in this section the participants were asked to say what sprung to mind when different terms used in the media to refer to environmental impacts were stated for example, biodiversity, one planet living and food miles (Slovic *et al.*, 1991).

- Behavioural measures and frequencies: By asking participants about their day to day lives including their shopping (consumption) habits including food and white goods, transport usage, recycling practices and home energy and water use. Using the data, the researchers were then able to calculate the following ecological footprint domains: carbon footprint; food footprint; housing footprint; and goods and services footprint of each of the participants using the calculator provided online by Redefining Progress (2009).
- Feedback: This part of the interview allowed the researchers to get feedback from the participants about the process of taking part in the interview. In addition participants were given the opportunity to discuss any issues relating to the interview process and the topics covered. However it was insured that the researchers did not unduly influence the participants' awareness, perceptions and behaviours, which could skew the results of future sessions.

In this instance it was determined that three interview stages be adopted in order to establish the base line and then consequently investigate any step change behaviours after 12 and then 24 months. At these later stages the discussion will also include open ended questions to elicit participants' reflections on the being involved in this process, including response to the different technological interventions. Motivators and barriers to behaviour change in the different domains will also be explored.

In the pilot study three families living in two storey terraced houses were interviewed. Each family had the same demographic profile and income. Additionally the houses shared the same construction, namely traditional brick built in the 1950's with insulated cavity walls, timber suspended floors and flat concrete roofs. They also had the same principal energy source of gas condensing boilers installed in the last 3-5 years. Their size is classified as 3 Bedroom, 4 Person houses - between 80 and 90sq m.

3 RESULTS

The pilot study results are presented below according to the interview sections.

3.1 *Scene setting*

When asked where the participants found out about news, current affairs and topical issues, the most common response was the internet and TV. Participants only listened to new on the radio when travelling by car. None of the participants interviewed purchased a newspaper regularly. When asked to rank in order of importance their perception of the key issues facing society today, they perceived climate change to be the most important. The other issues ranked 2nd and 3rd included: species extinction, diseases, overpopulation and the energy crisis.

When ranking issues relating specifically to the environment, the top ranking issue identified was global warming, followed by thinning of the ozone layer, in each instance. Pollution and Greenhouse Gas Emissions were ranked as third or fourth.

When participants were asked to were asked to say what sprung to mind when different terms used in the media to refer to environmental impacts were given to them, they found the task difficult. They found it easier to verbalise concepts such as 'alterative energy' and 'renewables' than 'sustainable development, 'biodiversity' and 'one planet living'. When giving a response to some of the other concepts such as 'food miles', ecological footprint' and 'zero carbon' they demonstrated a limited understanding, often focusing in on one area rather than demonstrating an understanding of the bigger picture.

3.2 *Behavioural measures and frequencies*

In the first instance transport use was explored. This included vehicle ownership and distances journeyed using different methods of transport including walking, cycling, private and public transport. This information was necessary in order to calculate their carbon footprint. When discussing home energy use, participants were provided with a list of common applicants found in the home. They were asked how many of each they owned as well as whether they knew the energy rating for each appliance. Examples include kitchen and bathroom appliances, entertainment systems and home office equipment. In addition they were asked which was most important when choosing to buy a new appliance out of cost, energy rating, aesthetics and brand. This enabled the researchers to understand the importance of energy saving as a component of the participants' decision making. Following on from this, participants were asked whether they used any energy saving devices (examples were provided) and/or their behaviours exhibited energy saving characteristics. This was done in order to establish the level of involvement in energy saving attitudes in the home. When considering food, participants' diets, eating habitats, self sufficiency and shopping routines were all discussed in order to calculate their food footprints. When considering housing, water use and recycling including composting were examined. It was not necessary to discuss energy use in the home as this was covered in depth earlier in the interview. It was necessary to highlight water and recycling at this stage in order to calculate their overall housing footprint. In addition goods and services consumption was discussed. This included choices relating to cleaning products, this time establishing the importance of cost and brand relative to ecological/non toxic factors in their decision making. Also discussed were consumption patterns looking at needs versus wants. Waste and recycling practices were also discussed in detail in order to calculate their goods and services footprint.

Finally, to understand their decision making processes, sources of influence were ranked in order of importance from the following: media, 'bread winner', extended family, friends, children, partner, community groups and other. The ecological footprint values for the participants were calculated and an example of the results can be found in Figure 1. The results ranged from 2.94 Earths (46.17 global hectares) to 3.08 Earths (48.45 global hectares). The average UK person's ecological footprint is calculated as 48.10 global hectares, the equivalent of three Earths (Redefining Progress, 2009).

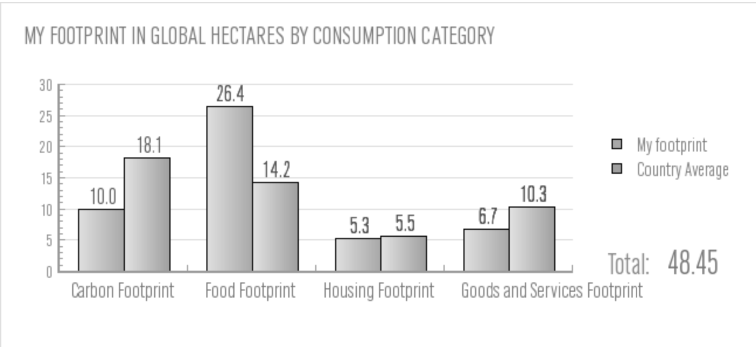

Figure 1. Ecological Footprint results for household A.

The carbon footprint values for the participants ranged from 10.0 global hectares to 11.2 global hectares. The average UK carbon footprint is significantly higher at 18.10 global hectares (Redefining Progress, 2009). Indeed the housing footprint and goods and services footprint for the participants also follow this trend. However their food footprint in each instance is significantly higher (25.2 global hectares) than the national average, which is 14.2 global hectares (see example in Figure 2). This is because all participants fell into the category 'Top of the food chain' in other words they eat meat, seafood, or dairy at almost every meal. Also all participants shop in large supermarkets as opposed to growing any foods themselves and/or using local produces and famers markets/local cooperatives etc.

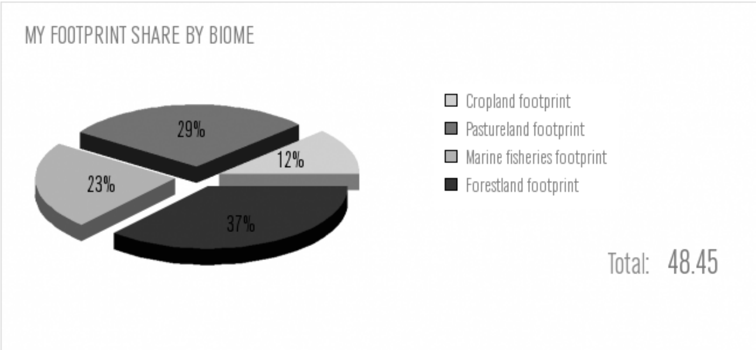

Figure 2. Food Footprint results for household A.

3.3 *Feedback*

At the end of each interview participants were given the opportunity to discuss how they felt about the interview, the questions being asked and the approach taken. In each case the participants expressed apprehension at the beginning of the session. Especially when asked to identify key issues as presented in the media. Otherwise no concerns were highlighted and they said that felt the process was neither intrusive nor offensive. Television programmes that had made them angry were mentioned, e.g. the melting of polar caps and loss of habitat for polar bears and that this had made them think more about living sustainably.

4 DISCUSSION AND WAY FORWARD

The three stage interview approach presented in this paper yielded some interesting observations to take forward into the next stage of the project; highlighting the difference between awareness and understanding, identifying gaps in participants' knowledge as one of the possible barriers to behavioural change and as a direct result supports knowledge creation and transfer through identification and association of all the facets of sustainability.

When considering perceptions and awareness of climate change, participants were aware of climate change issues, however they found it difficult to articulate, lacking understanding and clarity. Human nature requires a sequence of digesting information if it is to have an impact on behaviour; it must be perceived and evaluated favourably, understood and remembered. (Costanzo *et al.*,1986). Even after this process information alone is unlikely to create lasting change (Maloney *et al.*, 2009). Costanzo *et al.* (1986) found that even though 85% of respondents regarded the energy crisis as serious there was no clear relationship between energy related attitudes and conservation behaviour.

It has been suggested that if people understand their impact on climate change ERB will automatically follow (Fein *et al.*, 2008). However a number of studies have demonstrated that 'knowledge' can in fact create a mixed responses including disinterest, disempowerment, scepticism and even fear (Finger, 1993). The methodology presented in this paper supports identification of motivators and barriers to ERB as well as exploring how and why individual's respond differently to the same information. Furthermore, by investigating how receiving feedback on their contribution to carbon emissions (as a result of their home energy consumption) has a knock on effect on other areas of their lives by generating wider awareness. In effect how these individuals/households as informed users have made changes, if any, to other areas in their lives such as food, travel and general consumption behaviours. Despite the project's obvious focus on carbon reduction, by calculating the families' ecological footprints using the domains outlined above, the researchers will be able to establish whether the feedback in one domain, namely carbon footprinting, has had a knock on effect, i.e. educational/attitudinal/behavioural on the other domains and thus lowered the families' ecological footprints.

It has been documented that previous initiatives fail as a result of not providing information to support individuals' understanding and awareness of the key issues (Costanzo *et al.*,1986). Indeed an understanding key sustainability issues varies significantly from person to person; is frequently inadequate; and in some instances, it is the information provided by that particular initiative that is the only information an individual will have. Costanzo *et al.* (1986) found that approximately one half to three quarters of their participants claimed understanding yet lacked accurate knowledge. Alongside lack of knowledge there are many unfounded assumptions linked to ERB which must be dispersed if progress is to be made, e.g. the solely moral objective is a common misconception and has portrayed a message that to achieve ERB one will have a reduced quality of life (Kaplan, 2000). Although the importance of conveying information has been highlighted, information alone can not only be ineffective, it can have a negative impact on the individual, causing uncertainty and confusion about how to act in an environmentally responsible manner (Harrison *et al.,* 1996). It often creates the belief that, 'the actions of one person could achieve little in the face of massive intractable global problems' (Harrison *et al.*, 1996, pp. 217). Research shows ERB is less likely from those who feel helpless which is why it is not only important but it is the pivotal issue in the context of ERB (Donn, 1999; Kaplan, 2000). Indeed Kaplan (2000, pp. 499) goes as far as to state that "any psychological approach to ERB that does not directly address the helplessness issue may have limited practical value". This methodology helps the participants see that by making small changes to their behaviours they can have an impact that if undertaken by others, can have a significant impact.

The advantage of the approach developed and outlined above is that it gives the opportunity for the participants to explore their awareness and understanding of issues, challenge their assumptions and build on their knowledge constructively in a way that is not confronting, but controlled by them. As a result this approach does not need to be facilitated by an outsider but has the potential to be developed as a self-lead tool which can tackle behaviours relating not just to energy use and carbon reduction but the wider sustainability challenge.

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Indoor Performance and Sustainability

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ABSTRACT: Perfection (Performance Indicators for Health, Comfort and Safety of the Indoor Environment, 2009-11) is a European Coordination Action under EC's 7th Framework Programme. It aims to help enabling the application of new building design and technologies that improve the impact of the indoor built environment on health and comfort, feeling of safety and positive stimulation integrated within a sustainable built environment.

Perfection project consists of the following components

- the inventory of current standards, regulations, technologies, and ongoing and recent research activities and policies related to the optimal indoor environment
- an analysis of current indicators for health and comfort, safety and accessibility, positive stimulation, adaptability and usability positioned within a generic framework to assess their impacts to sustainability
- experiences from pilot cases exploiting the key indoor performance indicators in different building types.

This paper presents the findings from applicable design technologies and potential Key Indoor Performance Indicators (KIPIs) representing health and comfort, accessibility safety and positive stimulation, usability and adaptability in relation with their impacts to sustainable buildings.

1 INTRODUCTION TO PERFECTION PROJECT

The aim of the Perfection Coordination Action is to help enable the application of new building design and technologies that improve the impact of the indoor built environment on health, comfort, feeling of safety and positive stimulation within the following framework

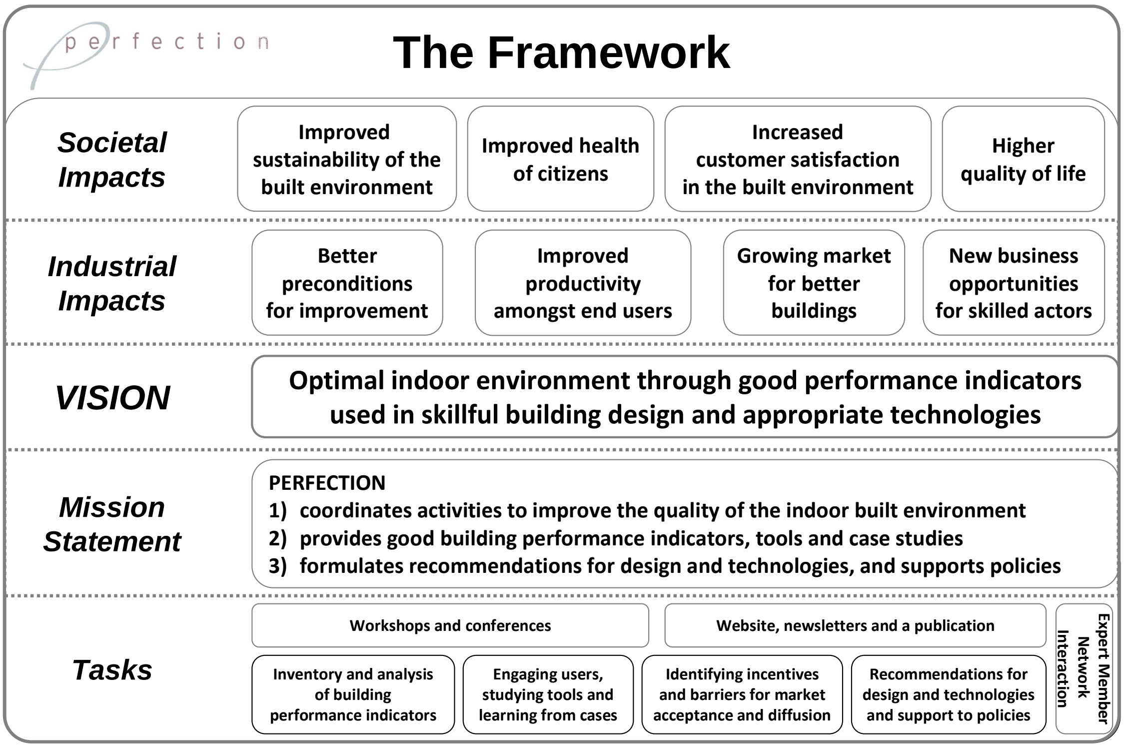

Figure 1. The Perfection vision and expected impacts.

Perfection will deliver

- a repository of good indoor performance indicators for health, comfort and safety
- a repository of state of the art environmental technologies that appear to have the potential for an important impact on the indoor performance and sustainability of the built domain
- an interoperable framework for performance indicators qualifying the indoor environment, allowing the successful life cycle management of sustainable buildings and stimulating the exploitation of appropriate technologies
- a decision support tool for different user groups applicable to different building types
- findings from selected pilot cases of the use of the indicators framework and the relevant indoor performance indicators
- recommendations on policies and the future research agenda: a roadmap including incentives and barriers for the application of building design and technologies to improve the quality of indoor environments
- knowledge and good practices on performance indicators for health, comfort and safety in the indoor environment.
- a wide dissemination of findings through an extensive expert network and the organisation of a series of events.

This paper presents its first results on sustainable building technologies, health and comfort indicators, accessibility, safety and positive stimulation indicators, usability, adaptability and sustainability impacts.

2 REVIEW OF SUSTAINABLE BUILDING TECHNOLOGIES

Technological development in recent years has brought a lot of tools and knowledge enhancing sustainability of the built environment.

The most discussed today are clean energy sources and energy saving measures such as combined head and power generating units, low energy and passive cooling systems, heat recovery, multifunction ventilation systems, high-tech insulations etc. Parallel to this sustainability "mainstream" there is a lot of other remarkable related technologies improving comfort and efficiency of the buildings.

New technologies enable advanced monitoring and controllability of healthy indoor environment. Compact sets of wireless sensor networks can be used to data collection and more efficient real-time building operation management. The information flows can be used to increase safety of the building. Monitoring camera systems equipped with face recognition can help with security provision (on the other hand the feeling of safety and privacy could suffer).

Individually controlled micro-environment of workplaces increases productivity and give the occupants positive stimulations. The comfort of indoor environment is increased by intelligent light-gathering and new energy efficient lighting systems.

Specific kind of technology is software - tools for building simulation and design, life cycle performance monitoring, analysis and efficient facility management.

Current issue is utilization of BIMs (Building Information Models) in design process as well as operation phase and looking for multidisciplinary suitable common standard thereof, which will ease integrated design process.

As buildings become more sophisticated, in some ways they can become less robust, more dependent on specialized technologies and vulnerable to privacy violation or cyber attacks. Hand in hand with accuracy of design and production, complexity of building technologies and sophisticated control systems comes need of highly skilled professionals in programming, information technologies and sensors engineering who will provide a new knowledge for more comfortable and sustainable buildings operation.

One of the Perfection goals is to provide a roadmap including incentives and barriers for the application of building design and technologies to improve the quality of indoor environments.

3 REVIEW OF HEALTH AND COMFORT INDICATORS

Performance indicators for health and comfort, which have been documented in standards, regulations, guidelines, research activities and policies used in design and construction of the built environment have been reviewed. It is the objective of the project to provide an overview and a complete list of performance indicators for health and comfort, which can be applicable in a performance indicator framework for the assessment of building performance. Focusing on the development of such a framework, the performance indicators have been grouped into five core indicators: acoustic comfort, visual comfort, indoor air quality, quality of drinking water, and thermal comfort. Each core indicator is described by several performance indicators. Within the project, a performance is defined as a property of a product, building component or building, which closely reflects or characterizes its performance (state or progress towards an objective) in relation to the performance requirement that has been set (Loomans et al. 2005). The indicator should be a quantitative, qualitative or descriptive parameter that can be readily assessed.

3.1 *Acoustic comfort*

The acoustic comfort in a building is determined by the acoustic performance of the rooms in the building (intra-acoustics) and the acoustics between the different rooms in the building (inter-acoustics). The overall objective of the performance indicators regarding the acoustic comfort in a room is to provide acoustic conditions in a building that facilitate clear communication of speech between the users of the building.

The literature on the following topics has been reviewed: indoor ambient noise levels airborne, sound insulation between spaces, airborne sound insulation between corridors or stairwells and other spaces, impact sound insulation of floors reverberation, speech intelligibility. Based on the study, the acoustic comfort is characterized by four performance indicators: background noise, reverberation time, speech intelligibility, and structural vibrations. Each performance indicator is described by one or several parameters. For example the background noise is described by airborne sound insulation of the separating construction, the airborne sound insulation between the different spaces in a building, and the impact sound transmitted into spaces via the floor.

Moreover, it has been observed that a separate assessment of each single performance indicator may be difficult. The performance indicators are directly connected with each other. For example, the speech intelligibility of a space is directly connected with, and is often considered to be a function of, the background noise and the reverberation time (Järnstrom et al. 2009).

3.2 *Visual comfort*

Generally, the function of lighting in a building can be subdivided in three domains: Health and safety, visual performance, and aesthetics (Howarth 2005). First of all, the lighting of an area should be adequate to ensure that people can live safely, and it should not in itself be a health hazard. Assessment of the visual environment can provide information as whether or not these criteria are met.

Second, the visual performance defines whether the lighting solution in a room is suitable for the performed task(s). Compliance to the standards is critical for the performance of the visual task and thus fulfilling the required activities.

Third, aesthetics defines the positive effects of the lighting in a room upon human well-being, both psychologically and biologically. The lighting contributes to the users' well-being, has activating effects, and adapts to the desired luminance levels.

The visual comfort has been characterized by seven performance indicators: illuminance, discomfort glare, disability glare and reflections, uniformity and contrast, flicker, color aspects: color rendering, color temperature, daylight. Each performance indicator is dependent of the specific indicators or parameters. Moreover, guidelines and target values for each indicator or parameter are defined by the standards and regulations for lighting design, depending on the lighting task(s) performed in the space.

3.3 *Indoor air quality*

The indoor air quality in a building is determined by chemical components which are present in the indoor environment. The task of reducing levels of exposure to indoor air pollutants is a complex one. It begins with an analysis to determine which chemicals are present in the air, at what levels, and whether likely levels of exposure are hazardous to human health and the environment. The most recent guidelines for indoor air quality in Europe (WHO 2000) have been published by the World Health Organization in 2000. Furthermore, intensive studies, such as (Schuh 2000), have been performed focusing on performance indicators for indoor air quality. In this project, five classes of indoor air pollutants (performance indicators) have been categorized: organic pollutants, inorganic pollutants, classical pollutants, indoor air pollutants, and bioaerosols. The performance indicators include one or several indoor air pollutants. Focusing on each indoor air pollutant, an exposure evaluation as well as a health risk evaluation has been carried out, and guidelines have been reviewed.

Incorporation of the list of performance indicators in a framework may result in a long and complex list of indicators/parameters, which may not be very practical and useful for building design and building management. It is recommended to use a relatively short and simple list of performance indicators to ensure that these indicators are applicable. For example, a list of performance indicators presented in Table 1 (Schuh 2000) could be applied. The measurements required to implement these indicators are simple to conduct and it is relatively inexpensive to obtain or rent the equipment. Appropriate guidelines are available for all but one of the indicators. Odour intensity indicator is used to monitor the reoccurrence of IAQ problems, identify potential sources, and follow infiltration paths.

Table 1. Performance indicators for indoor air quality (Schuh 2000)

Performance Indicator	**Indicator/Parameter**	**Guideline**
Effective Temperature	Temperature and relative humidity	ASHRAE 55-2004R ISO 7730-2005
Effective Ventilation	Carbon Dioxide	600 ppm
Combustion Infiltration	Carbon Monoxide	10 ppm
Odour intensity	Intensity and Character	-
Particulate matter	Total mass of particles > 2.5µm	40 µm/m^3

3.4 *Quality of drinking water*

The quality of drinking water in a building is mainly determined by maintenance protocols, regular cleaning, temperature management and maintenance of a disinfectant residual, which are within the responsibility of the drinking water supplier. However, responsibility for many actions essential to the control of drinking-water quality in buildings is outside the responsibility of the drinking-water supplier. The literature review showed that ingress of microbial contamination, proliferation and dispersal of bacteria growing on water contact surfaces (especially legionella) and addition of chemical substances from piping, jointing and plumbing materials are the principal hazards that may accrue in the drinking-water systems of (large) buildings.

The prevention and control of legionella in in-building water systems showed to be most critical with respect to the quality of drinking water. The research showed that the main performance indicator is the availability of a water safety plan, focusing on the prevention of legionella in the in-building water systems.

3.5 *Thermal comfort*

The thermal comfort in a building is determined by the influence of the indoor environmental parameters on human's thermal sensation. Thermal comfort assessment includes a part of unambiguously defined performance indicators (PI) based on the notion of objectively quantifiable performance measures. The set of indicators is founded on existing knowledge in biophysics and physiology. One of the most widely used indices in moderate thermal environments, the PMV index (predicted mean vote), predicts the mean value of the overall thermal sensation of a large group of persons as a function of activity (metabolic rate), clothing insulation, and the four environmental parameters: air temperature, mean radiant temperature, air velocity, and air humidity (ISO 7730-2005, Fanger 1970).

Alternatively, other methods for the assessment of moderate thermal environments could be used, such as the new effective temperature (ET) and the standard effective temperature (SET) (Nishi et al. 1977). These indices are based on a relatively simple model of the human body. Moreover, more advanced models are currently available that allow for the transient prediction of very detailed thermoregulatory parameters and, for some of the models, subjective responses to a wide range of environmental conditions (Nicol 2001, Dear 2009).

In this project, Performance Indicators for the thermal comfort in a building are presented based on the models which are currently available. The thermal comfort is characterized by five performance indicators: operative temperature, Percentage of Dissatisfied (PPD), draught, vertical air temperature differences, radiant asymmetry. Each performance indicator is dependent of the specific indicators or parameters.

3.6 *Implementation in a Performance Indicator framework*

The study showed that the level of detail on which the information for the assessment of a building is available, is the main issue that influences the complexity of the indicator framework. Often, a specific indicator can be assessed on a global level, based on a qualitative and more subjective evaluation of the performance indicators, or a more detailed level, based on a quantitative and objective evaluation. While questionnaires and checklists showed to be suitable assessment methods for the first approach, detailed measurement of the performance indicators and corresponding parameters are recommended for a second more thorough approach. Focusing on the development of an indicator framework it is recommended to apply such a distinction (global vs. detailed) within the Perfection project. Moreover, the framework could be applied in different phases of the life cycle of a building, such as the design process, the construction, and the in-use phase. In each phase, different assessment methods can be applied for the evaluation of the (core) performance indicators.

4 REVIEW OF ACCESSIBILITY, SAFETY AND POSITIVE STIMULATION INDICATORS

Accessibility, safety and positive stimulation have an impact on the sustainability of a building influencing strongly in the social aspect of the built environment. Accessible buildings provide the opportunity to every user to use it with the same low-level of effort. However, accessibility is not the only aspect to be considered when designing sustainable buildings. In order to stimulate the user to participate to social life or to improve his general positive feeling of the built environment (user experience), it is important to consider positive stimulation. This concept guides the users to do or to feel something. For example, if a designer creates large public space with mailbox in a residential building, it will invite people to meet each other in this semi-public space. Positive stimulation is an abstract concept which enhances the user experience. Safety aspects must be considered in the approach of the sustainable design because they are a basic requirement for human life in the indoor environment.

4.1 *Accessibility indicators*

A definition of an accessible building is one that is capable of being accessed and used by each kind of user (disabled people, pram, older people, children, etc.). An accessible environment is one in which a user (e.g. a disabled people) can enter and make use of independently or with help from a partner or assistant, including being able to escape in the event of fire or other emergency.

The indicator measures the accessibility of services of an indoor environment. With the help of this indicator, it will be possible to say if yes or no a service provided by the building is reachable and usable by a user. This kind of indicator could be a check list, a coefficient giving the quality of the access, etc. This indicator is qualitative (but the assessment is objective).

The accessibility of the building needs to consider the following

- the approach to the building, including car parking, other transport stop off points and access routes
- the entrance to the building, including the steps, ramps and entrance doors (typically the principal entrance)
- movement inside the building, including lobbies, corridors, surfaces, internal doors and vertical circulation
- facilities, particularly including access to sanitary accommodation, but any function of the building could be considered.

Accessibility relates with communication within the building, including the use of any communication equipment, cognitive assistance and other devices. An example of such an indicator is the design needs linked to the entrance of a building considering ramps or steps, prior to the entrance door. That is a complex matter and subject to specific requirements that are given in a detailed review of indicators. Perfection project makes a review of these indicators.

4.2 *Safety indicators*

The safety indicators express the ability of the indoor environment to provide safe and resistant space for the users and occupants of the building.

The fundamental of safety is of course the structural stability under normal exploitation charges but the intent of Perfection is also to collect indicators related to feeling of safety, including some security aspects. In this way, the safety aspect is extended to the following topics

- stability against loadings considering exceptional loadings because of earthquake, explosion and heavy wind when relevant

- resistance against weather exposure considering lightning or heavy rains and flood
- fire safety
- glazing related safety
- risks of falling
- electrical/electromagnetical safety
- security-privacy
- cyber security
- resistance to attack.

If we consider the risk of falling, the slippery resistance coefficient of the floor is a partial indicator and it must be combined with other indicator in order to evaluate the risk of falling (e.g. no unexpected difference of levels, properly shaped stairs, etc.).

4.3 *Positive stimulation indicators*

These indicators express how the indoor environment stimulates its users and occupants to do something (better participate to the social life, to feel better, to improve productivity, etc.).

The aspects of positive stimulation include

- social aspects
- senses stimulation aspects (seeing, hearing, smelling, …)
- economic aspect (higher productivity, ...)

Some examples of positive stimulation used are

- the consideration of a stress reducing design of the indoor environment
- fragrance stimulation of workers
- inclusive architectural design
- use of different colours at different times to stimulate productivity
- use of video game console in age care homes to stimulate the elderly to make physical exercises etc.

The Perfection project will provide a collection of examples which will be used to define positive stimulation indicators.

5 NOTES ON USABILITY, ADAPTABILITY AND SUSTAINABILITY IMPACTS

Perfection project will also outline additional indoor performance indicators relating with e.g. adaptability and usability. The impact of Perfection Key Indoor Performance Indicators, KIPIs, to sustainability, covering social, environmental and economic dimensions, will be mapped. This Perfection framework will serve as a basis for the development of a web-based tool to be used in case studies to manage the indoor performance of buildings.

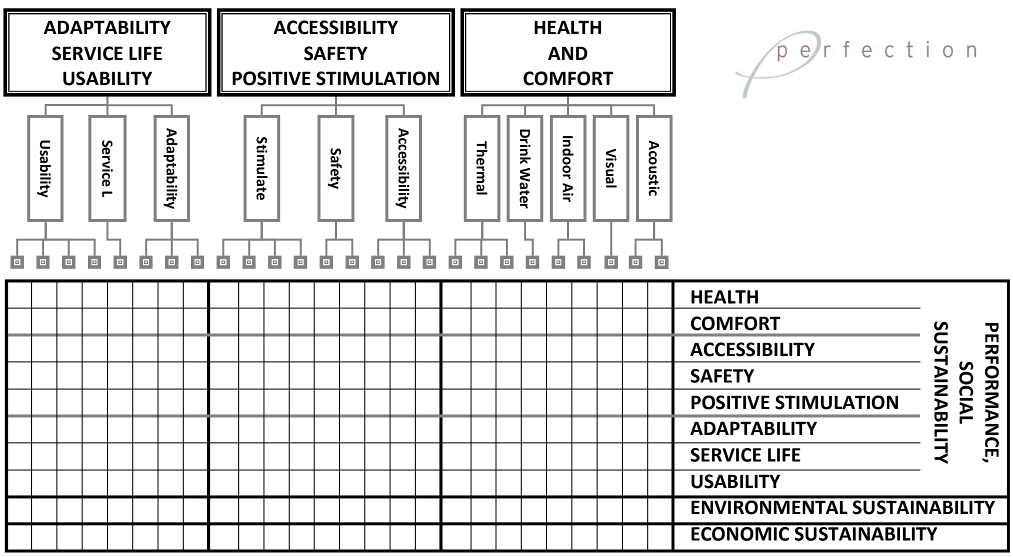

Figure 2. A schematic view on the draft generic framework

6 CONCLUSIONS

Perfection project (2009-2011) will deliver a generic framework for performance indicators qualifying the indoor environment, allowing the successful life cycle management of sustainable, healthy, comfortable, safe and accessible buildings and stimulating the exploitation of appropriate technologies. The framework will be integrated in a web-based tool and used in a series of case studies. The tool will be available for producers, designers and users to evaluate products, technologies and buildings with regard to the indoor environment. By creating a database of showcase products, technologies and buildings the project will stimulate good indoor environmental practices around Europe.

In order to communicate with the user community, the Perfection consortium is creating a forum for interaction, a web-based evaluation and promotional module and a specific project website (http://www.ca-perfection.eu). A couple of events are also organised in order to inform you about the progress of the project, and to discuss some of the results and research work.

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The "energy cost" as performance parameter. A Decision Making Support System for retrofit actions.

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ABSTRACT: In the general context of the impact evaluation of the building sector on the mechanisms of environmental systems in the local scale – and in a global point of view, the energy parameter represents a fundamental factor for the inquiry and constitutes a necessary indicator to give a quantitative evaluation to the environmental compatibility of a building product and/or technical system.
In this research, the studies are focalized on the building envelope systems, taking in consideration at the same time:
– climatic and microclimatic characteristics of the intervention context (Southern Italy);
– thermophysical behaviour of the used building materials and components;
– quantity of energy used in the production of materials and components.
The purpose of the study is the definition of a Decisions Making Support System for the interventions on existing building.

1. INTRODUCTION

1.1 *Definition of inquiry context*

Since, in Italy, the 34% of the building interventions, currently, are directed to the existing building stock, the field of inquiry is the public residential buildings stock that requires interventions of energy retrofit, to restore the performances to the levels expected by the energy saving regulations in force.

The objectives of the present research derive from the necessity to define a methodology of intervention in this ambit and to associate it to systems that, since the production phase, have an energy behaviour in line with the necessity to guarantee interventions with low environmental impact.

The proposed model allows to take in consideration the energy performance of an existing building organism by means of a series of parameters and indicators, in tight relationship with the context of intervention. From the results of the evaluation spring the possible strategies of intervention and the relevant operative actions.

1.2 *Aim of the study*

The final goal of the proposed research is the definition of a Decisions Making Support Tool for the actions of energy retrofit on existing public buildings in Mediterranean climate.

The choice to elaborate this type of system derived from the necessity of interventions, in particular on existing building stock, that are able to take in consideration the principal features of the context and of the object of intervention.

Such approach allows, from a hand, to limit the risks of a performance under-dimensioning due to a not correct interventions; and, on the other hand, to avoid a performance over-dimensioning due to the necessity to optimize use of the resources.

For these reasons, results of large importance the knowledge of the object of intervention and of the surround conditions -that can influence, both positively and negatively, the behaviour the of building object and on which the building object can have to its time a certain influence.

The Decision Making Support System has the aim to put in connection, across a structured series of operating steps, the phase of knowledge of building object of intervention, the features of the wider context in which it is localized and the strategies to carry out with the purpose to improve the energy performances.

In addition, the choice of the technical solution to adopt in the actions on existing building, takes in consideration the parameter of energy cost in production phase. The existing building stock, in fact, already embodies a certain quantity of energy, defined as “latent energy”. Such energy store should not undergo excessive increase in consequence of over-dimensioned actions for energy requalification.

2 THE DECISION MAKING SUPPORT SYSTEM

2.1 *General information*

The Decision Making Support System is articulated through different levels of successive deepening that drive the operator, specifically the designer, in the knowledge, the evaluation and the action on existing public buildings.

2.2 *The Knowledge: Module M1*

The knowledge actions are developed by the collection of a series of information, with successive specification degrees. Such phase is supported by the use of a filing system, with simple compilation, that allows to collect data with different deepening levels.

The Knowledge Module M1 is constituted by two sub-modules:

- M.1a: relevant to the general information on the object and on the local context of intervention;
- M.1b: relevant to more specific information subdivided in four levels of study that are:
  1. the level of the environmental context;
  2. the settlement level;
  3. the level of building organism;
  4. the level of building envelope.

2.3 *The Evaluation: Module M2*

The phase of evaluation allows to express a judgment on the conditions of existing building, in function, not only of technical and technological parameters relative to the building organism, but in function of a set of parameters and indicators that are relative to the wider context of insertion of the object of the study and that can influence its behaviour from the point of view of the energy performance. In this phase extremely different variables, that are factors with environmental origin and factors with technical and technological origin, are compared and put in relationship.

For this purpose were individualized four problems of inquiry:

A) external thermal loads;
B) dispersion through building envelope;
C) shading;
D) indoor/outdoor air flows.

The structure of the proposed evaluation system is articulated following a methodological pattern, similar to that used at first for the GBCTool (the International Green Building Challenge sustainable rating method) and subsequently re-elaborated for the compiling of ITACA Protocol (an adaptation of GBCTool elaborated by Federal Organization of the Italian Regions and Provinces).

Unlike such evaluation tools, that aim to a wider dissemination and utilization independently from the context of use, the proposed tool does reference to parameters and indicators tightly connected to the local context (for example values of solar irradiance and radiation measured at the latitude 38°).

The logic that subtends the construction of the model does not exclude, however, the possibility to adapt it to other latitudes, only replacing some reference values.

For each individualized Problem were defined some “Influence Categories” that, in their turn, are described by “Subcategories” or “Influence Parameters”, for which were determined assessable indicators in function of reference values (benchmarks).

The benchmarks derived from values set and/or individualized by the regulations in force, or in absence of these, from previous experiences sprung by the analysis of other evaluation systems of the environmental performance of building interventions or by statistical data.

X	**PROBLEM**		
	X_1	CATEGORY OF INFLUENCE 1	
		$X_{1.1}$	Sub-category of influence 1
		$X_{1.2}$	Sub-category of influence 2
		$X_{1.n}$	Sub-category of influence n
	X_2	CATEGORY OF INFLUENCE 2	
		$X_{2.1}$	Sub-category of influence 1
		$X_{2.2}$	Sub-category of influence 2
		$X_{2.n}$	Sub-category of influence n
	X_n	CATEGORY OF INFLUENCE n	
		$X_{n.1}$	Sub-category of influence 1
		$X_{n.2}$	Sub-category of influence 2
		$X_{n.n}$	Sub-category of influence n

A	**EXTERNAL THERMAL LOADS**		
	A_1	SOLAR GAINS	
		$A_{1.1}$	Exposure to the sun
		$A_{1.2}$	Irradiation
		$A_{1.n}$	….
	A_2	SURFACE MATERIALS	
		$A_{2.1}$	Albedo
		$A_{2.2}$	Coefficient of emissivity
		$A_{2.n}$	…
	A_n	….	
		$X_{n.1}$	Sub-category of influence 1
		$X_{n.2}$	Sub-category of influence 2
		$X_{n.n}$	Sub-category of influence n

Figure 1. Framework of the proposed method and exemplification of the Problem A “External Thermal Loads”

The definition of the indicators is necessary to allow the evaluation. In fact, for each benchmark relevant to each indicator, was assigned - always considering GBTool articulation as basis -, a score included between 1 and 4 and so defined:

- Negative: not respect of minimum value foreseen for example by regulations or current practice. Score -1.
- Admissible: respect of the value set by regulations in force, or in absence of these, with the current practice. Score 0.
- More than admissible: it represents a slight performance improvement as regards the regulations in force or the current practice. Score 1.
- Positive: it represents a moderate performance improvement as regards the regulations in force or the current practice. Score 2.
- More than positive it represents a meaningful performance improvement as regards the regulations in force or the current practice. Score 3.
- Best practice: it represents the best current practice. Score 4.

2.3.1. The weighing

The proposed Decision-Making Support Tool provides a system of weighting that involves all of the considered levels. To each Problem was assigned a percentage of importance, and in function of the fact that the actions are carried out in Mediterranean climatic context, greater weight is been given to the aspects joined and influencing the external thermal loads and thermal insulation.

Each Influence Category has an its own weight and a weight relevant to the Problem, and each Influence Parameter has a weight relevant to the Influence Category and another weight relevant to the Problem of reference. Everything with the intent to obtain an aggregated score and to include the relevant level of influence between the considered variables.

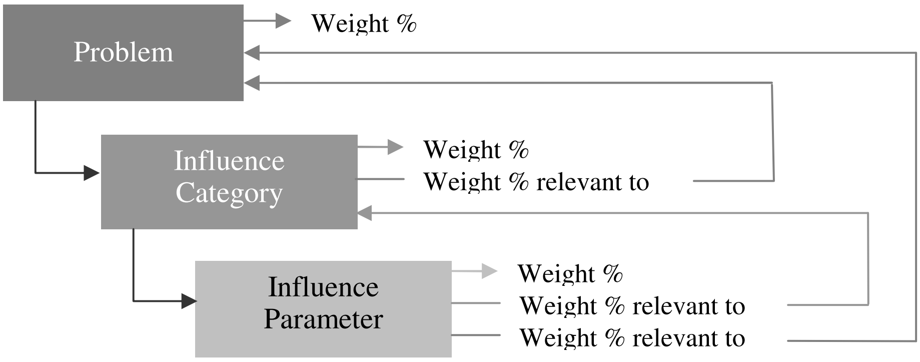


Fig. 2 – Framework of weighing system

The Figure 3 allows to individualize the weights assigned to each investigated level relative to Problem A.

			Weights assigned to Problems	**Weights assigned to Influence Categories**	**Weights assigned to Influence Parameters**	**Weights assigned to Influence Parameters in relation to the Problems**
Problems to survey:		**EXTERNAL THERMAL LOADS**	**30.0%**			
Category of influence:	**A1**	**Solar gains**		30.0%		
Parameters:						
	A.1.1	Exposure to the sun			10.0%	**0.9%**
	A.1.2	Maximum summer solar irradiance incident on opaque surfaces			10.0%	**0.9%**
	A.1.3	Maximum summer solar irradiance transmitted across light glass			10.0%	**0.9%**
	A.1.4	Exposure and mean monthly solar daily irradiance on vertical and horizontal surfaces.			20.0%	**1.8%**
	A.1.5	Exposure of façade			20.0%	**1.8%**
	A.1.6	Solar Factor g of envelope glazed parts			15.0%	**1.4%**
	A.1.7	Transmission of glazed elements			15.0%	**1.4%**
Category of influence:	**A2**	**Surface Materials**		25.0%		
Parameters:						
	A.2.1	Solar reflectance (albedo) of circumjacent surfaces			50.0%	**3.8%**
	A.2.2	Color of envelope/external surfaces materials			25.0%	**1.9%**
	A.2.3	Albedo of Vegetation			25.0%	**1.9%**
Category of influence:	**A3**	**Devices for exploitation of energy gains**		10.0%		
Parameters:						
	A.3.1	Surface, Exposure, Typology of devices for energy gain uptake			100.0%	**3.0%**
Category of influence:	**A4**	**Thermal inertia**		35.0%		
Parameters:						
	A.4.1	Envelope typology			20.0%	**2.1%**
	A.4.2	Coefficient of thermal wave damping			40.0%	**4.2%**
	A.4.3	Coefficient of thermal wave phase displacement			40.0%	**4.2%**

Figure 3. Weights assigned to investigated level (example of Problem A “External Thermal Loads”)

2.3.2. The methodology of calculation adopted

The procedures of calculation are made by means of sum and product to keep account of the percentages in weight of each considered variable. Specifically, the calculation follows this course:

1. the score assigned to each indicator multiplied for the weight assigned to the relevant Influence Parameter gives as result the weighed value of the Influence Parameter.

$$(\text{Indicator Score})_i \times (\text{Influence parameter weight in percentage } \%)_i = \\ = (\text{Value of Influence Parameter})_i$$

2. The sum of the weighted values of each Influence Parameter multiplied for the weight attributed to the relevant Influence Category gives as result the weighted value of influence Category.

$$\sum_i^{1=n} (\text{Values of Influence Parameters})_n \times (\text{Influence Category weight in percentage } \%)_i = \\ = (\text{Value of Influence Category})_i$$

3. The sum of the weighted values of each Influence Category multiplied for the weight attributed to the Problem to which this does reference gives as result the weighted value of the same Problem.

$$\sum_i^{1=n} (\text{Values of Influence Categories})_n \times (\text{Problem weight in percentage } \%)_i = \\ = (\text{Value of Problem})_i$$

To make easier the calculation, in the ambit of this research, were arranged some spreadsheets for the automatic elaboration of the final results and of the relevant graphic representation.

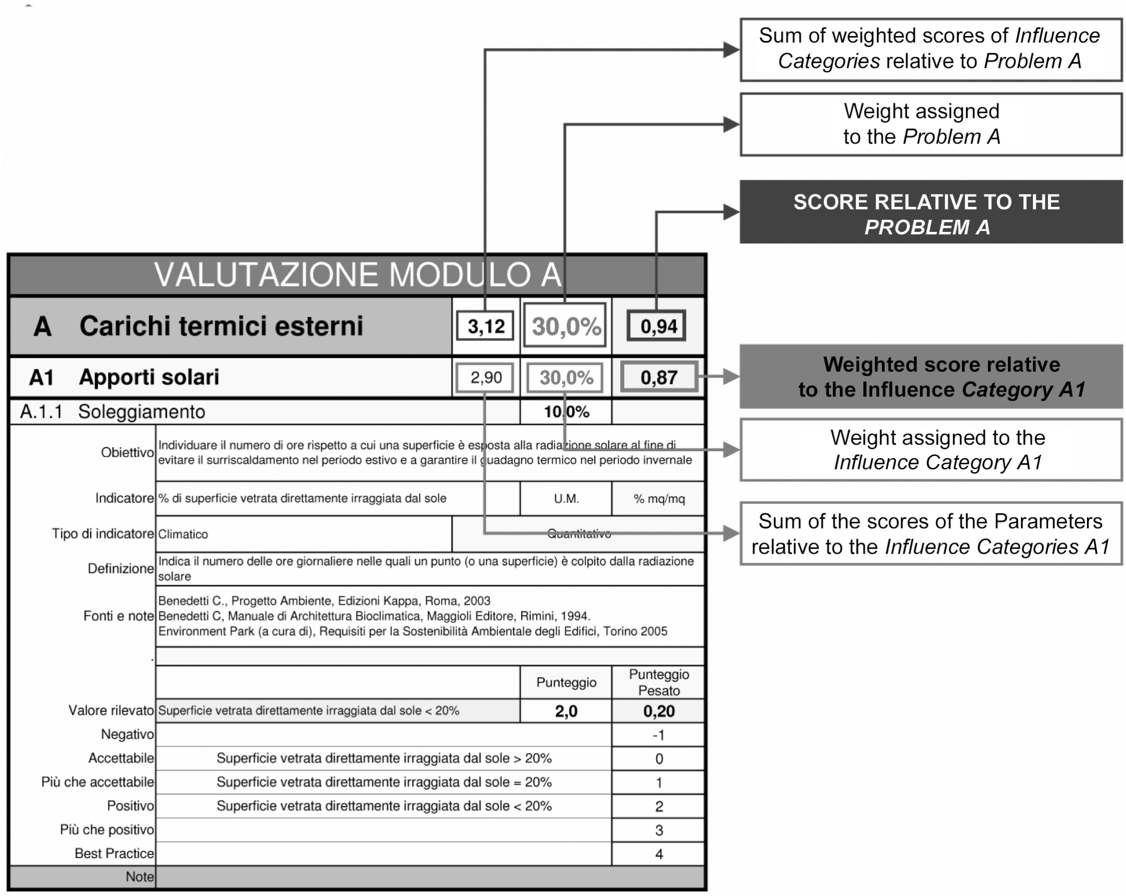


Figure 4. Framework of the evaluation (example relative to the Problem A “External Thermal Loads”).

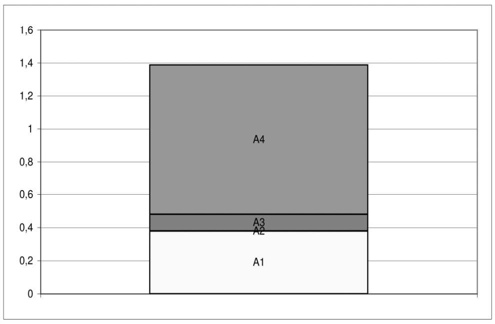
2.3.3 The results presentation

As previous indicated, the calculation sheets elaborated to facilitate evaluation and weighting operations, allow also an immediate display of the results by means of histograms.

It was chosen to visualize the results in two moments and by means of two different graphic representations.

The first one, contained in the sheet named "Partial Results", allows to visualize the evaluations of each Influence Category in the context of the relevant Problem. This allows to individualize immediately how the evaluations of the Influence Categories contribute to the definition of the evaluation of the relevant Problem.

Results relative to the Categories



Partial result for Category

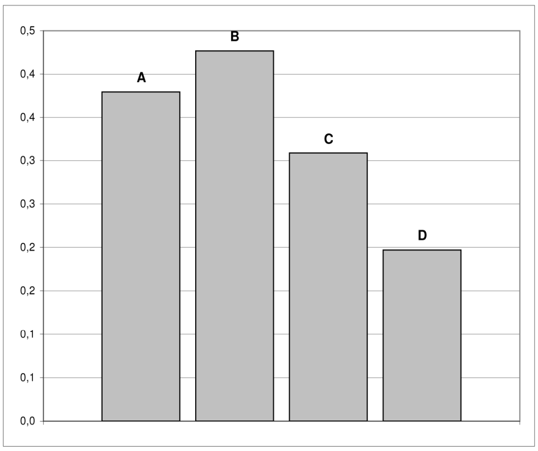
A	**External Thermal Loads**			
A1	Solar Gains	0,85	30%	**0,38**
A2	Surface Materials	0,00	25%	**0,00**
A3	Devices for the exploitation of energy gains	1,00	10%	**0,10**
A4	Thermal Inertia	2,60	35%	**0,91**
Total weighed scores of the Categories of the Problem A				**1,39**

Figure 5. Presentation of the partial results (example relative to the Problem A "External Thermal Loads").

The second graphic representation, contained in the calculation sheet named "Overall Results", supplies the aggregate weighted values relevant to each Problem, agreeing to visualize an immediate comparison between the four Problems investigated.

Results relative to the Problems

Results relative to the Problems



Description of some characteristics of the inquiry object

SUMMARY OF THE EVALUATION		Weigh	Weighed Scores
A	External Thermal Loads	30%	**0,4**
B	Dispersion through building envelope	30%	**0,4**
C	Shading	20%	**0,3**
D	Indoor/outdoor air flows	20%	**0,2**
Total of Weighed Scores			**1,3**

Figure 6. Presentation of the overall results.

2.4 *The Action: Module M3*

In accordance with the results of the evaluation it is possible to define the most fitting strategies of intervention in relation with the characters of the building organism and of the local conditions.

Objective of the whole proposal is to consider other parameters in the determination of the possible interventions of retrofit energy, going beyond the tendencies that follow the minimal standards set by the regulations in force. These last, in Italy, in fact, consider only the aspects joined to the enhancement of the U-values of envelope elements, underestimating the possibilities offer also from other types of approaches.

For what concerns the Action Module M3, were individualized four macro-categories for the control and the management of the energy flows in terms of heat earnings and dispersions passing through the envelope:

1. strategies for thermal insulation, St. 1;
2. strategies for the reduction of the thermal load, St. 2;
3. strategies for the temporal phase-displacement of thermal load, St. 3;
4. strategies for the control of the outdoor air flows, St. 4.

For each proposed strategy are individualized some actions of intervention and the possible technical solutions to adopt. These are assessed in function of the "energy used in production phase" parameter.

2.4.1 *Definition of the ranks for the determination of possible actions*

The purpose of the evaluation is to reduce the field of the possible solutions for the actions of retrofit and to individualize the most appropriate solution with respect to the surveyed conditions.

For this reason, for each Problem were individualized the maximum, minimum and medium values achievable by Evaluation Module M2, to which the possible strategies are associated through the matrix presented in the Figure 8.

	EVALUATION RANGE A (EA)		
PROBLEMS A	Low	Medium	High
	$-0.24 \leq EA < 0$	$0 \leq EA < 0.51$	$0.51 \leq EA \leq 0.94$
	excessive thermal loads	admissible thermal loads	optimal condition

Figure 7. Evaluation Range of the Problem A "External Thermal Loads".

		Pr. A 30%			Pr. B 30%			Pr. C 20%			Pr. D 20%		
		Valutazione			Valutazione			Valutazione			Valutazione		
		Alta	Media	Bassa	Alta	Media	Bassa	Alta	Media	Bassa	Alta	Media	Bassa
Pr. A 30%	Valutazione Alta				St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4
	Media				St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4
	Bassa				St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4
Pr. B 30%	Valutazione Alta	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4				St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4
	Media	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4				St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4
	Bassa	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4				St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4
Pr. C 20%	Valutazione Alta	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4				St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4
	Media	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4				St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4
	Bassa	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4				St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4
Pr. D 20%	Valutazione Alta	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4			
	Media	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4			
	Bassa	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4	St.1 St.2 St.3 St.4			

Figure 8. Matrix of the combination of the possible strategies of intervention, in function of the evaluation relative to the inquired Problems.

2.5 *Evaluation of action: Module 4*

The actions that characterize the strategies and the relevant technical solutions are evaluated in function of the "energy cost parameter". Naturally the evaluation is carried out considering equal technical performance offered by the possible technological options.

Since normative references and standard connected to the "energy cost parameter" are currently lacking, it was done reference to ranges and scores deriving from other evaluation systems.

Of the indicators used to describe the parameter “Energy cost in production phase” were considered:

- The energy consumption for production (information derived from EPD - Environmental Product Declaration);
- The presence of the environmental product and/or process certifications.
- The energy consumption for transportation (connected with the distance from the point of production and the point of utilization).

3 CONCLUSIONS

3.1 *Final considerations and open problems*

The present research provides a contribution toward the identification of integrated strategies of requalification, built on the local characters specification, for a more efficient and more effective policy of intervention.

Therefore, the proposed tool allows to define design criteria, in the viewpoint of the concept of the individuality of requalification action, that doesn’t allow rigid standardizations, but suggests approaches connected with the conformation of the building organism and with the context in which this is localized.

The choice to consider, as discriminant factor for strategies of intervention, only the energy parameter could mislead the inexperienced and with low technical and technological culture user. It’s necessary to underline the experimental character of proposed tool, emphasizing the possibility to implement and to improve it with the insertion of other parameters (for example durability and manutenability of technical solutions).

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Contributo para o Módulo de Turismo da Metodologia SBTool^{PT}

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RESUMO: O presente trabalho tem como principal objectivo contribuir para o desenvolvimento do módulo de turismo da ferramenta de avaliação da sustentabilidade de edifícios SBTool^{PT}. O presente contributo pretende dar uma resposta a mudança de paradigma no sentido do desenvolvimento sustentável no sector do turismo, através da apresentação de uma nova abordagem para uma metodologia de avaliação da sustentabilidade dos edifícios de turismo. Essa nova abordagem assenta na avaliação do seu desempenho deste tipo de edifícios ao nível das três dimensões do desenvolvimento sustentável. Para além de se focar na fase de construção destes edifícios, a metodologia pretende igualmente avaliar a boa gestão do edifício na sua fase de utilização, uma vez que a última representa os maiores impactes do ciclo de vida dos edifícios. A metodologia apresentada, encontra-se direccionada para as várias tipologias de empreendimentos turísticos existentes, quer sejam novos, existentes ou renovados.

1 INTRODUÇÃO

A construção sustentável é da maior actualidade, tendo-se verificado uma crescente importância desta temática na última década, apesar de ser um assunto de relativo interesse há bastante tempo. Para além de assistirmos há décadas a uma crise social e ambiental, hoje assistimos, a nível mundial, a uma crise económica que veio de certa forma consciencializar as populações para uma viragem nas prioridades a definir nas suas sociedades. O comodismo e a falta de preocupação das populações dos países desenvolvidos a nível mundial, que estiveram na origem desta crise tridimensional (social, ambiental e económica) parecem agora desvanecer com o aparecimento de novas iniciativas que visam mudanças de atitudes por parte das populações.

O sector do turismo, até aos anos de 1925-30, foi um sector com uma importância geográfica e económica limitada, uma vez que representava um luxo apenas ao alcance da aristocracia e burguesia. Posteriormente, os progressos sociais permitiram o acesso a este sector por parte da classe media, surgindo assim a chamada democratização do turismo, isto é, o turismo de massa, característica da civilização contemporânea. O turismo tornou-se assim num importante instrumento de crescimento económico e social, que fomenta a inserção social, oportunidades de emprego, novos investimentos e receitas, pelo que tem que ser um sector bem gerido e planeado, de modo a não promover impactos negativos no ambiente, na sociedade e na economia. Todavia, durante décadas este sector, que actualmente constitui uma das maiores indústrias mundiais, só se preocupou pelos aspectos económicos da sua actividade sem ter em conta as consequências negativas que podia causar no ambiente e na sociedade. Assim, foi surgindo alguma consciencialização para um turismo sustentável, que para além da vertente da construção sustentável, abrange a sensibilização e educação para sustentabilidade de todos os seus intervenientes, uma vez que a sustentabilidade não é somente inerente à construção de um estabelecimento mas sim a todo o seu ciclo de vida: concepção, construção, utilização, reabilitação e demolição ou desmantelamento do edifício.

A implementação da sustentabilidade no turismo obriga ao envolvimento e participação de cada segmento, instituição e entidade que constitui o contexto deste sector, isto é, é necessária a participação não só dos intervenientes na construção dos edifícios de turismo, mas também dos próprios utilizadores (turista e funcionários). Todos são responsáveis e devem ser educados em relação a essas obrigações e responsabilidades no sentido de contribuir para um turismo social e ambientalmente responsável.

Neste trabalho apresenta-se uma metodologia de avaliação da sustentabilidade de edifícios de turismo. A metodologia aqui desenvolvida teve por base a Metodologia de Avaliação Relativa da Sustentabilidade para Edifícios de Habitação – MARS-H (Mateus, 2009). Este novo módulo, direccionado a edifícios de turismo, é intitulado de Metodologia de Avaliação Relativa da Sustentabilidade de Edifícios de Turismo (MARS-T).

Esta metodologia permite a avaliação da sustentabilidade de um edifício de turismo na fase de projecto e concepção, assim como na sua fase de utilização. A presente abordagem pode ainda ser utilizada no apoio ao projecto de um novo edifício de turismo sustentável ou de uma operação de reabilitação em que se pretenda aumentar a sustentabilidade do edifício reabilitado.

Em suma, com a apresentação da metodologia MARS-T pretende-se, por um lado, promover e premiar a adopção de soluções alternativas às soluções construtivas e processos de construção convencionais, de modo a que os edifícios de turismo se tornem compatíveis com os objectivos do Desenvolvimento Sustentável e, por outro, promover e premiar a adopção de medidas sustentáveis de gestão durante a fase de utilização.

2 OBJECTIVOS DO TRABALHO DESENVOLVIDO

Este trabalho de investigação teve como objectivo o desenvolvimento de uma proposta para uma metodologia genérica destinada à avaliação da sustentabilidade de edifícios de turismo (existentes, novos ou renovados) nos contextos ambiental, sociocultural e económico de Portugal.

Resumidamente, os objectivos específicos traçados inicialmente para o desenvolvimento deste trabalho foram (Machado, 2010):

i) Estudar e perceber os objectivos da construção e do desenvolvimento sustentável no sector do turismo;
ii) Estudar as boas práticas de sustentabilidade que têm sido aplicadas a edifícios de turismo;
iii) Pesquisar, estudar e analisar diversas metodologias existentes no domínio da avaliação da construção sustentável e processos de certificação ambientais ou de sustentabilidade direccionados ao turismo, tendo em atenção as suas semelhanças, limitações e diferenças;
iv) Com base nas conclusões retiradas dos pontos anteriores, desenvolver um módulo direccionado a edifícios de turismo baseado na metodologia de avaliação da sustentabilidade MARS-H, adaptado ao contexto nacional, sociocultural e económico, deste sector;
v) E finalmente, aplicar a metodologia desenvolvida a um caso de estudo, permitindo verificar a sua viabilidade e adequação ao contexto dos edifícios de turismo nacionais.

3 A CONTRIBUIÇÃO DAS METODOLOGIAS DE AVALIAÇÃO PARA A CONSTRUÇÃO SUSTENTÁVEL

Actualmente, encontram-se desenvolvidos e em fase de desenvolvimento uma série de ferramentas e sistemas para a avaliação da sustentabilidade do edificado. No entanto, esta avaliação é muito complexa e nenhuma destas ferramentas ou destes sistemas desenvolvidos é amplamente aceite. Esta situação deve-se fundamentalmente à subjectividade do conceito "construção sustentável", que se deve fundamentalmente às diferenças políticas, tecnológicas, culturais, sociais e económicas existentes, não só, entre os países, mas também, dentro de cada país, nas suas diversas regiões. A melhor abordagem passa então pela avaliação da sustentabilidade através da comparação do desempenho do edifício em avaliação com o desempenho de um edifício correspondente à prática corrente (solução de referência) num determinado país ou região.

A maior parte das metodologias de avaliação da sustentabilidade baseiam-se na análise de indicadores que cobrem os diversos tópicos da sustentabilidade que são considerados relevantes. Um indicador é geralmente um valor derivado da combinação de diversos parâmetros. Um parâmetro é uma propriedade mensurável ou observável, que fornece informação acerca de um fenómeno, ambiente ou área (Mateus et al, 2004). A utilização de indicadores e de parâmetros da sustentabilidade é baseada em definições, regras, métodos, classificações e na atribuição de pesos, pelo que o carácter pessoal destas acções acaba por introduzir uma certa subjectividade no resultado da avaliação.

Hoje em dia, praticamente todos os pais europeus, assim como os Estados Unidos, o Canadá, a Austrália, o Japão, entre outros, possuem um ou mais sistemas de avaliação e de classificação do desempenho ambiental de edifícios. O contexto da criação de cada uma destas metodologias varia, assim como o âmbito da sua aplicação.

De modo a traçar um quadro abrangente dos sistemas existentes de avaliação ambiental de edifícios, referem-se o sistema de BREEAM (Building Research Establishment Environmental Assessment Method), o precursor dos restantes sistemas, o LEED (Leadership in Energy & Environmental Design do USGB), actualmente o método com maior potencial de crescimento devido ao grande investimento aplicado na sua difusão e aperfeiçoamento, o NABERS (National Australian Buildings Environmental Rating System), que resulta da assimilação dos aspectos positivos dos sistemas BREEAM e LEED, o BEPAC (Building Environmental Performance Assessment Criteria), o CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), o HQE (Association pour la Haute Qualité Environnementale) e o instrumento de avaliação internacional SBTool (Sustainable Building Tool). Estes sistemas ponderam de forma diferente os diversos tópicos considerados na quantificação da sustentabilidade global, apresentando a Figura 1 as diferenças existentes a este nível entre o LEED, o BREEAM, o CASBEE e o GBTool.

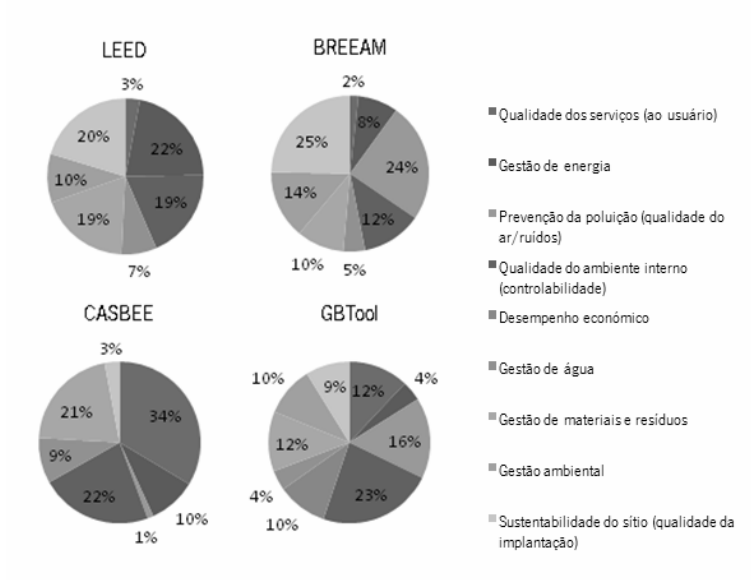

Figura 1: Comparação entre as distribuições das ponderações de diferentes sistemas de avaliação da sustentabilidade (Brito et al,, 2008)

Efectuando a analise entre alguns destes métodos de avaliação verifica-se que eles são relativamente diferentes, apesar de assentarem numa base comum. Estas diferenças devem-se ao facto de os níveis de pressão sobre determinados aspectos ambientais variarem consoante o país em questão, tanto no bloco dos países desenvolvidos ou de países em desenvolvimento ou de economias em transição. Outro aspecto são as práticas construtivas e de projecto diferentes e influenciadas, em parte, por questões climáticas. De grande influência também pode-se destacar também a receptividade dos mercados à introdução dos métodos de avaliação.

Como já foi referido anteriormente, assistimos hoje a um constante crescimento no sector do turismo, prevendo-se que este sector aumente para o dobro do seu tamanho ao longo da próxima década, pelo que a preocupação pela sustentabilidade deste sector tem vindo também a aumentar. Assim, nestes últimos anos tem-se assistido ao aparecimento de um grande número de programas de certificação nesta área que permitem ilustrar o desempenho ambiental ou a sustentabilidade global deste tipo de edifícios. Contudo, é de salientar que todas as certificações referentes ao turismo se encontram, em grande parte, relacionadas com a fase de utilização dos edifícios, não permitindo uma avaliação que abranja a totalidade do ciclo de vida do edifício.

A certificação do sector do turismo quanto à sustentabilidade surge, não só pela crescente preocupação com a conservação e gestão de recursos, mas também devido ao aparecimento de turistas que seleccionam o seu destino de férias com base em critérios ambientais e sociais. Deste modo, as exigências dos mercados e dos consumidores engendra a necessidade de gerir e desenvolver métodos de apreciação da qualidade, ambiente e segurança, numa perspectiva de sustentabilidade do produto turístico. O objectivo da certificação ambiental de destinos turísticos passa por adequar ambientalmente a actividade turística, de uma forma economicamente viável e socialmente justa. A certificação confere longevidade ao destino turístico, garantindo que a sua preservação e a qualidade dos seus atractivos sejam mantidas, promovendo a sustentabilidade da actividade através de um aumento da competitividade de destinos turísticos ambientalmente adequados. A certificação revela-se assim num importante instrumento de política ambiental, auxiliando o consumidor na escolha de produtos e serviços menos nocivos ao meio ambiente, e servindo de instrumento de marketing para as empresas que diferenciam os seus produtos no mercado (Lopes, 2008).

Uma análise efectuada às ferramentas aqui referenciadas, sejam elas direccionadas à construção do edifício ou à sua fase de utilização, demonstra facilmente o carácter subjectivo na definição da sustentabilidade, que varia muito consoante o país de origem ou até mesmo a região ou local onde possa ser aplicada. Outro aspecto muito importante de referir, é o facto da maioria destas metodologias serem muito “fechadas”, não existindo nenhuma divulgação pública dos seus métodos de avaliação, pelo que não é possível comprovar o seu rigor. Muitas delas também têm por base uma avaliação mais qualitativa, não existindo um processo de cálculo definido, o que as torna muito subjectivas. O desenvolvimento da MARS-T teve como principal objectivo ultrapassar estas barreiras, ao tentar criar uma metodologia baseada num processo de cálculo bem definido, que permite uma análise mais quantitativa e consequentemente mais objectiva da sustentabilidade de um edifício de turismo.

4 ESTRUTURA E PROCESSO DE AVALIAÇÃO DA METODOLOGIA MARS-T

Na elaboração da Metodologia de Avaliação Relativa da Sustentabilidade de Edifícios de Turismo (MARS-T) procurou-se efectuar a conjugação da avaliação de parâmetros mais inerentes à construção do edifício de turismo com a avaliação de parâmetros direccionados especificamente à fase de utilização deste tipo de edifícios. Esta associação permite assim promover e premiar aspectos relativos à fase de construção, que influenciam também o bom desempenho do edifício na sua fase de utilização, mas também promover e premiar uma gestão sustentável do estabelecimento na sua fase de utilização.

A metodologia MARS-T foi desenvolvida com o sentido de permitir uma avaliação do comportamento de um edifício durante a fase de concepção, isto é, tendo por base o comportamento previsto para a totalidade do ciclo de vida do edifício, sendo aconselhável que a avaliação seja realizada nas fases mais preliminares de um projecto de construção ou de reabilitação. Deste modo, consegue-se, desde o início da concepção, estimar a sustentabilidade do edifício e introduzir medidas que permitam melhorar o seu desempenho. Apesar da metodologia MARS-T estar orientada para a fase de projecto, depois da construção pode-se realizar uma avaliação do edifício que tenha por base a monitorização do seu comportamento real.

Os resultados obtidos na avaliação de um edifício durante as fases mais preliminares de projecto são dados importantes no suporte das tomadas de decisão, pois desta forma as equipas de projecto tem acesso, desde o início, ao desempenho esperado para o edifício a construir, podendo dessa forma avaliar o impacto de certas soluções alternativas. De maneira a facilitar este processo foi desenvolvido um Guia da Avaliação que permite justificar a importância de cada indicador e respectivo(s) parâmetro(s) e simultaneamente facilitar a interpretação dos resultados obtidos. Adicionalmente, a apresentação dos diversos critérios necessários à avaliação dos diferentes parâmetros torna os resultados mais objectivos, diminui os erros associados à avaliação e atenua a variabilidade de resultados, quando um mesmo edifício é avaliado por diferentes avaliadores (Lopes, 2008).

4.1 *Indicadores, parâmetros e categorias*

A metodologia MARS-T é constituída por uma série de 28 indicadores e respectivos parâmetros, agregados em 9 categorias, que permitem avaliar o desempenho de um edifício ao nível das três dimensões do desenvolvimento sustentável. A Tabela 1 apresenta os indicadores e categorias de sustentabilidade da metodologia MARS-T.
A principal função dos indicadores é a caracterização e quantificação de critérios que permitem seleccionar a melhor solução para um projecto de construção. Uma categoria resulta da combinação de vários indicadores (Bragança e tal, 2008)

Tabela 1: Categorias e Parâmetros da Metodologia MARS-T

Dimensões da Sustentabilidade		
Ambiental	Social	Económica
C1 - Alterações climáticas e qualidades do ar exterior: P1 - Valor agregado dos impactes ambientais dos materiais de construção por m^2 de área útil de pavimento por ano. **C2 - Biodiversidade e uso do solo:** P2 - Percentagem utilizada do índice de utilização líquido disponível; P3 - Índice de impermeabilização; P4 - Percentagem da área de intervenção previamente contaminada ou edificada; P5 - Percentagem de áreas verdes ocupadas por plantas autóctones; P6 - Percentagem de área em planta com reflectância igual ou superior a 60%. **C3 - Energia:** P7 - Consumo de energia primária não renovável na fase de utilização; P8 - Medidas disponíveis que visam a redução dos consumos de energia primária não renovável; P9 - Quantidade de energia que é produzida no edifício através de fontes renováveis. **C4 - Materiais e Resíduos Sólidos:** P10 - Percentagem em custo de materiais reutilizados; P11 - Percentagem em peso de conteúdo reciclado do edifício; P12 - Percentagem em custo de produtos de base orgânica que são certificados; P13 - Percentagem em massa de materiais substitutos do cimento no betão; P14 - Potencial do edifício para a promoção da separação de resíduos sólidos*; P15 - Potencial de gestão dos resíduos sólidos. **C5 - Água:** P16 - Volume anual de água consumida nos sanitários por hóspedes; P17 Percentagem de redução do consumo de água potável.	**C6 - Conforto e Saúde dos utilizadores:** P18 - Potencial de ventilação dos espaços interiores; P19 - Percentagem em peso de materiais de acabamento com baixo conteúdo de COV; P20 - Percentagem em peso da utilização de produtos com rótulo ecológico*; P21 - Nível médio da qualidade do ar interior*; P22 - Nível de conforto térmico anual médio anual; P23 - Média do Factor de Luz de Dia Médio; P24 - Nível médio do isolamento acústico. **C7 - Acessibilidade:** P25 - Índice de acessibilidade a transportes públicos; P26 - Índice de amenidades interiores*; **C8 - Formação dos funcionários e sensibilização dos hóspedes:** P27 - Medidas implementadas com vista a uma gestão sustentável do edifício de turismo*.	**C9 - Custos:** P28 - Valor actual dos custos de utilização por m2 de área útil.

* Parâmetros que só podem ser avaliados durante a fase de utilização

4.2 *Processo de avaliação*

Na sua globalidade, o processo de avaliação da sustentabilidade de um edifício pela MARS-T, engloba três fases distintas:

i) Quantificação do desempenho ao nível de cada indicador;
ii) Quantificação do desempenho ao nível das categorias, dimensões do desenvolvimento sustentável (Ambiental, Social e Económica) e quantificação do Nível de Sustentabilidade (NS), isto é, a agregação dos resultados;
iii) Preenchimento do Certificado de Sustentabilidade.

Dos 28 parâmetros apresentados na Tabela 1, 23 aplicam-se à fase de concepção de um novo edifício de turismo ou à fase de concepção de uma operação de reabilitação e/ou ampliação de um edifício de turismo existente, e os restantes 5 à fase de utilização de um edifício de turismo.

4.2.1 *Quantificação do desempenho ao nível de cada indicador*

Os métodos a utilizar na quantificação de cada um dos 28 parâmetros da metodologia MARS-T encontram-se apresentados no "Guia de Avaliação da MARS-T" e incluem: resultados de estudos anteriores, opinião de especialistas, processamento de bases de dados e ferramentas de simulação. A avaliação do desempenho do edifício em avaliação faz-se através da comparação do desempenho do edifício (ao nível de cada parâmetro), com os valores correspondentes aos edifícios de referência (*benchmarks*). Para efectuar esta comparação é necessário recorrer à normalização dos parâmetros. A normalização visa fixar um valor adimensional que exprime o desempenho do edifício em avaliação relativamente aos desempenhos de referência.

Ao longo de toda a metodologia, a normalização dos parâmetros é realizada através da equação Diaz-Balteiro (Equação 1). Esta equação é válida simultaneamente para os parâmetros do tipo "quanto maior é melhor" e "quanto maior é pior", e corrige os efeitos de escala na agregação de indicadores.

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \qquad (1)$$

Nesta equação, P_i representa o valor resultantes da quantificação, P_{*i} o *benchmark* para a prática convencional e P^*_i o *benchmark* para melhor prática. Quando um parâmetro normalizado assume o valor de 0, significa que corresponde ao nível de prática convencional e quando é igual a 1 significa que corresponde ao nível de melhor prática. O valor do desempenho de um parâmetro pode tomar um valor superior ao da melhor prática ou inferior à prática convencional. No entanto, de forma a se evitarem distorções na posterior agregação destes parâmetros, os valores normalizados nunca podem ser inferiores a -0,2 e superiores a 1,2.

Nesta metodologia, os *benchmarks* para as práticas convencionais correspondem aos valores mínimos aceitáveis, abaixo dos quais não se pode considerar um edifício sustentável, e encontra-se baseado nos níveis mínimo prescritos nos regulamentos e normas de construção ou prática corrente da construção de edifícios de turismo em Portugal. Por sua vez, os bench*m*arks para as melhores práticas correspondem aos valores de trabalho produzido por projectistas e/ou promotores e/ou estabelecimentos em funcionamento que já apresentam alguma reputação no domínio da construção e gestão sustentável ou ao nível de politicas e normas existentes. Durante a determinação dos *benchmarks* houve sempre a preocupação do uso de referências de Portugal, contudo, na ausência destas referências utilizaram-se por vezes, dados de outros países.

Para que os resultados da normalização sejam apresentados numa escala mais perceptível, o seu valor é convertido numa escala qualitativa. A conversão é realizada

A classificação ao longo dos 28 parâmetros da metodologia, através destes valores adimensionais, encontra-se representada na Tabela 2 e encontra-se associada a uma escala qualitativa de modo a facilitar a compreensão dos resultados obtidos.

Tabela 2. Equivalências utilizadas na conversão do valor normalizado de cada parâmetro numa escala de avaliação qualitativa

Escala qualitativa	Valor normalizado
A^+	$\overline{P} > 1{,}00$
A	$0{,}70 < \overline{P} \leq 1{,}00$
B	$0{,}40 < \overline{P} \leq 0{,}70$
C	$0{,}10 < \overline{P} \leq 0{,}40$
D	$0{,}00 \leq \overline{P} \leq 0{,}10$
E	$\overline{P} < 0{,}00$

4.2.2 *Quantificação do desempenho ao nível de categorias, dimensões e quantificação do Nível de Sustentabilidade - NS*

De modo a se poder efectuar a comparação de diferentes soluções de projecto e/ou utilização a nível de cada categoria em avaliação e não apenas em termos globais, o nível de desempenho global NS (Nível de Sustentabilidade), deve estar acompanhado pelo comportamento ao nível das dimensões do desenvolvimento sustentável e ao nível de cada categoria. A comunicação dos resultados através de um único valor é inadequada devido à possível compensação entre indicadores na agregação.

A agregação dos resultados, obtidos ao nível de cada um dos parâmetros avaliados, nas categorias e das dimensões da sustentabilidade é efectuada através da Equação 2.

$$I_j = \sum_{i=1}^{n} w_i \cdot \overline{P_i} \tag{2}$$

Nesta equação, I_j representa o valor do macro indicador j e resulta da ponderação de cada indicador, categoria ou dimensão; P_i o valor normalizado de cada indicador, categoria ou dimensão e w_i o peso respectivo a cada indicador, categoria ou dimensão. A soma dos pesos utilizados na obtenção de cada um dos três níveis de macro indicadores é sempre igual 1.

Através da análise da Equação 2 é possível verificar que o peso que se atribui a cada parâmetro condiciona significativamente os resultados obtidos. Não existem dúvidas que alguns parâmetros são mais importantes para a sustentabilidade. Contudo, não existe actualmente nenhum consenso quanto à definição do peso relativo de cada um, uma vez que um sistema de pesos depende em grande parte do contexto e das prioridades locais, mas também das diferentes opiniões dos diversos intervenientes no ciclo de vida dos edifícios (valorização subjectiva). A análise de vários sistemas de pesos, relativos a diferentes ferramentas de avaliação da sustentabilidade de edifícios, permite constatar a inexistência de consenso quanto à metodologia a adoptar na sua definição.

O módulo de avaliação de edifícios de turismo baseia-se no mesmo sistema de pesos desenvolvido para o módulo dos edifícios de habitação . Este sistema de pesos resulta do trabalho de investigação desenvolvido nos últimos anos pelo Laboratório de Física e Tecnologias das Construções da Universidade do Minho (LFTC-UM). No desenvolvimento deste sistema de pesos teve-se em consideração, entre outros (Mateus, 2009):

i) O sistema de pesos de outras metodologias: foram analisadas as principais metodologias de avaliação da sustentabilidade de edifícios de modo a identificar os indicadores que são normalmente considerados mais importantes;
ii) O actual estado de conhecimento no que respeita à importância de cada categoria de impacte ambiental na quantificação do desempenho ambiental: foram analisadas várias metodologias de avaliação do desempenho ambiental de ciclo de vida (LCA) e a opinião de vários especialistas na matéria;
iii) A opinião de diversos intervenientes no ciclo de vida dos edifícios: o sistema de pesos desenvolvido, para além de considerar a opinião de especialistas do meio da investigação, considera a opinião de um grupo de intervenientes constituído por projectistas, consultores de sustentabilidade, uma empresa de construção e um conjunto de utilizadores de edifícios.

A comunicação do resultado da sustentabilidade do edifício em avaliação é efectuada através da emissão de um rótulo de sustentabilidade. Este rótulo permite a comunicação da sustentabilidade através de uma escala graduada que possibilita a interpretação e compreensão dos resultados a nível do desempenho global do edifício, assim como a nível das três dimensões da sustentabilidade e das nove categorias que constituem esta ferramenta de avaliação. Esta escolha está relacionada com o facto da comunicação da sustentabilidade usando apenas um índice/valor ser muitas vezes insuficiente. Esta situação deve-se, não só, à possível compensação entre indicadores nos processos de agregação, como também devido ao facto de certos decisores pretenderem medir, interpretar e comparar o desempenho do edifício ao nível de uma determinada categoria de sustentabilidade (Bragança et al, 2008).

Nesta metodologia, a categorização dos níveis de desempenho é realizada através de uma escala constituída por 6 níveis, que vão de E (menos sustentável) a A+ (mais sustentável) e onde D corresponde à prática convencional e A à melhor prática. A Figura 2 apresenta resumidamente a estrutura e as etapas do processo de avaliação da metodologia MARS-T.

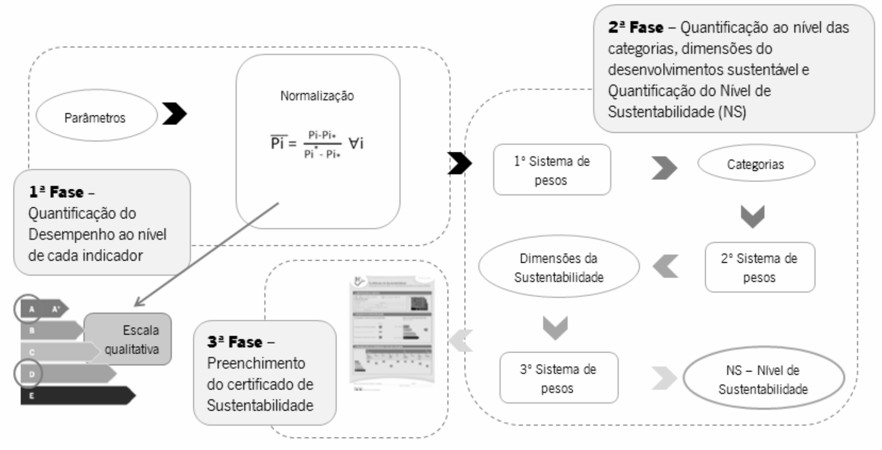

Figura 2. Processo de avaliação da metodologia MARS-T

5 CONCLUSÕES

O desenvolvimento da MARS-T teve como principal objectivo ultrapassar as barreiras de carácter subjectivo existentes actualmente no apoia a concepção e avaliação da sustentabilidade de edifícios de turismos. Para o efeito, a metodologia apresentada encontra-se baseada num processo de cálculo bem definido, que permite uma análise mais quantitativa e consequentemente mais objectiva da sustentabilidade de um edifício de turismo. Adicionalmente o processo de avaliação encontra-se baseado num Guia de Avaliação. A sua estrutura transparente e objectiva permite que se chegue rapidamente a conclusões de modo a saber onde se deve ou pode actuar no sentido de se melhorar o desempenho obtido na avaliação de um edifício de turismo. Este tipo de ferramentas permite a sistematização e uma abordagem holística a um conceito multidisciplinar e complexo como o da construção sustentável, pelo que a sua aplicação na fase de projecto de um edifício novo ou operação de reabilitação é essencial para prossecução dos objectivos do desenvolvimento sustentável nos edifícios de turismo. Com as soluções apresentadas, a metodologia de avaliação da sustentabilidade desenvolvida e os resultados obtidos pretende-se contribuir para a promoção do surgimento de edifícios de turismo mais sustentáveis, não podendo deixar de relembrar que o desenvolvimento sustentável atende às necessidades presentes, mas sobretudo, salvaguarda a satisfação das necessidades das gerações futuras.

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Sustainability Assessment of an Affordable Residential Building Using the SBTool^{PT} Approach

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ABSTRACT: This paper will present the sustainability assessment of an affordable residential building block using the SBTool^{PT} – H approach. This building block resulted from a cooperative housing project that fulfils some of the priorities of high-performance and low environmental impact buildings and is internationally recognised as a good example of a sustainable project. The aim of this study is to verify the usefulness of the SBTool^{PT} approach in promoting sustainable buildings that have lower life-cycle costs when compared to conventional ones.

1 INTRODUCTION

1.1 *The developments in the sustainability building approach*

Due to the increasing awareness about the consequence of the contemporary model of development in the climate change and to the growing international movement toward high-performance/sustainable buildings, more and more the current paradigm of building is changing. This is changing both the nature of the built environment as well the actual way of designing and constructing a facility. This new approach is different from the actual practice by the selection of project teams members based on their eco-efficient and sustainable building expertise; increased collaboration among the project team members and other stakeholders; more focus on global building performance that on building systems; the heavy emphasis placed on environmental protection during the whole life-cycle of a building; careful consideration of worker health and occupant health and comfort through all phases; scrutiny of all decision for their resource and life-cycle implications; the added requirement of building commissioning; and the emphasis placed on reducing construction and demolition waste (Kibert, 2005).

Although there are several definitions for a sustainable building, generally speaking, it uses resources like energy, water, land, materials in a much more efficient way than conventional buildings. These buildings are also designed and used in order to produce healthier and more productive living, work and living environments, from the use of natural light and improved indoor environmental quality (Syphers et al, 2003). Therefore, sustainable building aims the proper balance between the three dimensions of the sustainable development: Environment, Society and Economy.

1.2 *The importance of the sustainable residential building affordable to all*

In Portugal, most of the impacts of the built environment in the sustainable development are related to the residential sector (Mateus, 2009). At the environmental level this sector is directly and indirectly related to the consumption of a great amount of natural resources (energy, water, mineral, wood, etc.) and to the production of a significant quantity of residues. For example, although Portugal has a mild climate, residential sector accounts for about 17% of the total national energy consumption (DGGE, 2005). Additionally, it uses a considerable amount of water resources, about 132 l/inhabitant/day of potable water, being a significant part of this capitation used in toilets (INAG, 2005). At the socioeconomic level and compared to other sectors, buildings is the most important sector, not only because about 10% of the global economy is related with its construction and operation, but also because it significantly influences the quality of life and heath of its inhabitants: in the developed countries, people are inside buildings in about 80% to 90% of the period of their life (Roodman and Lessen, 1995). Nevertheless, some studies in Portugal showed that most buildings are not sustainable in terms of operating and maintenance costs and do not provide a comfortable and healthy indoor environment for their occupants (Mateus, 2009). For example, the reality shows that 23% of the Portuguese residential buildings need to be repaired and their owners do not have the necessary income for the necessary investment (INE, 2001).

The abovementioned reality shows that the case for creating sustainable affordable housing is substantial. Compared to the conventional practice, the sustainable affordable houses concept is related to the creation of healthy homes with low operation costs, at a minimum level of environmental impacts. Another significant difference is that in affordable housing developers are motivated to consider durability and maintenance costs when selecting materials while for-profit developers only consider this issue if residents are willing to pay for upgrades from less expensive options (Syphers et al, 2003).

One of the most important barriers for the wider adoption of this concept is that many stakeholders do not recognize the benefits of the sustainable construction and the do not understand the potential higher capital cost implications. For instance, the adoption of solar collectors, photovoltaics, grey water recycling devices will lead necessarily to higher capital costs, but also to lower operation costs and therefore to costumer's satisfaction. Despite this, when planned and designed well, projects can achieve at least a basic level of sustainability with little to no additional cost (Kibert, 2005).

In the next sections, this paper will present an affordable residential building that was built in Portugal and its sustainability will be assessed using the building sustainability assessment tool $SBTool^{PT}$ – H.

2 PRESENTATION OF THE CASE STUDY

The case-study is a multifamily cooperative housing building block that is the Portuguese pilot - project of the European Program "SHE: Sustainable Housing in Europe" (http://www.she.coop).

The Portuguese pilot project was the second phase of the Ponte da Pedra housing state that was built in the municipality of Matosinhos, Northern Portugal (Figure 1). It is a multifamily social housing project, which promoter is NORBICETA - União de Cooperativas de Habitação, U.C.R.L. This project has two building blocks, a footprint of 3105m2, a total gross area of 14.852m^2 and 101 dwellings. It was co-sponsored by the project SHE and by the National Housing Institute (INH) and had the support of the FENACHE (national federation of social housing cooperatives), FEUP (Faculty of Engineering of the University of Porto) and UM (University of Minho). This project aimed to demonstrate the real feasibility of sustainable housing in Portugal and it succeed since it proved the practical feasibility of building a residential building with lower environmental impacts, higher comfort and lower life-cycle costs, when compared to a conventional one.

During the design phase, the project team adopted a series of priorities in order to create a sustainable affordable building block. The most important priorities were:

i) To use pre-developed land: this housing state was built in an area that was occupied by decayed industrial buildings (Figures 1 and 2). By contributing to the regeneration of the land and to the improvement of around urban area, this project had a positive local impact. On the other hand, due to the fact of not using new land it will contribute for the maintenance of local biodiversity;

ii) Energy efficiency: the primary energy consumption is about 25% of the local's conventional practice; it uses efficient lighting in public spaces; and solar collectors for hot water (Figure 3);

iii) Water efficiency: building is equipped with a rainwater harvesting system that guarantees at about 100% of the water supply for green areas and toilets (Figure 4); and it is equipped with low water flow devices (Figures 5 and 6).

iv) Improvement of the indoor air quality: all window frames are equipped with ventilation grids (Figure 7).

v) Management of household waste: all kitchens are equipped with containers for each of the four types of household solid waste (Figure 8); the outside containers are located nearby the building's entrance.

Figure 1. General exterior view of the building blocks.

Figure 2. Aspect of the local before the intervention.

Figure 3. Hot water solar collectors (thermodynamic system).

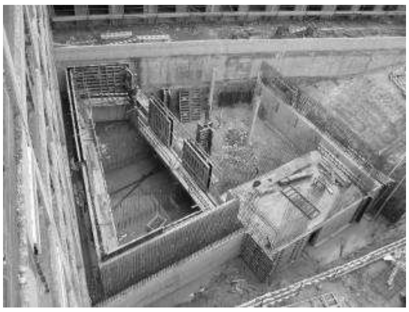

Figure 4. Rainwater tank (construction phase).

Figure 5. Low flow showers.

Figure 6. Double flush toilets (6/3 l).

Figure 7. Ventilation grids on window frames.

Figure 8. Containers for solid waste separation.

vi) Controlled costs: compared to the first phase of the Ponte da Pedra housing state (that have the same type of architecture but uses the conventional building technologies) the construction cost was about 9% higher. The promoter assumed part of this higher capital cost and the dwellings were sold at a price 5% higher than the first phase. According to the promoter, the turn-off of this higher capital cost will about 5 to 6 years. Nevertheless, dwellings were sold at an average price that was 20% bellow the local's average market practice.

3 USED BUILDING SUSTAINABILITY ASSESSMENT METHODOLOGY

Building sustainability assessment involves various relations between built, natural and social systems. Therefore it comprises hundreds of parameters, most of them interrelated and partly contradictory. To cope with this complexity and to support the sustainable building design, it is necessary to implement a real methodological work. The main objective of a systematic approach is to define sustainable building concept through tangible goals in order that, as a result of the sustainable design process, it is possible to achieve the most appropriate balance between the different sustainability dimensions (Mateus et al, 2008).

The study presented in this paper uses the SBTool^{PT} methodology (Sustainable Building Tool adapted to Portugal). The SBTool is a building sustainability assessment method that result from the collaborative work of several countries, since 1996 and it was promoted by the International Initiative for a Sustainable Built Environment (iiSBE). This international involvement supported its distinction among the others methodologies, since SBTool was designed to allow users to reflect different priorities and to adapt it to the regional's environmental, socio-cultural, economy and technological contexts.

The Portuguese version of SBTool - SBTool^{PT} - was developed by the Portuguese chapter of iiSBE, with the support of University of Minho and the company Ecochoice. In this methodology all the three dimensions of the sustainable development are considered and the final rate of a building depends on the comparison of its performance with two benchmarks: conventional practice and best practice. This methodology has a specific module for each type of building and in this paper the module to assess residential buildings (SBTool^{PT} – H) was used.

The physical boundary of this methodology includes the building, its foundations and the external works in the building site. Issues as the urban impact in the surroundings, the construction of communication, energy and transport networks are excluded. Regarding the time boundary, it includes the whole life cycle, from cradle to grave.

Table 1 lists the categories (global indicators) and indicators that are used in the methodology to access residential buildings. It has a total of nine sustainability categories (summarizes the building performance at the level of some key-sustainability aspects) and 25 sustainability indicators within the three sustainability dimensions.

The methodology is supported by an evaluation guide and its framework includes (Figure 8):

i) Quantification of performance of the building at the level of each indicator presented in a evaluation guide;
ii) Normalization and aggregation of parameters;
iii) Sustainable score calculation and global assessment.

In order to facilitate the interpretation of the results of this study the main steps of the SBTool^{PT} approach will be presented in the next sections.

3.1 *Quantification of parameters*

The evaluation guide presents the methodologies that should be used by the assessor in order to quantify the performance of the building at level of each sustainability indicator.

Table 1. List of categories and sustainability indicators of the SBTool^{PT} methodology.

Dimension	Categories	Sustainability indicators
Environ-ment	C1 – Climate change and outdoor air quality	P1 – Construction materials' embodied environmental impact
	C2 – Land use and biodi-versity	P2 - Urban density P3 – Water permeability of the development P4 - Use of pre-developed land P5 – Use of local flora P6 – Heat-island effect
	C3 – Energy efficiency	P7 – Primary energy P8 – In-situ energy production from renewables
	C4 – Materials and waste management	P9 – Materials and products reused P10 – Use of materials with recycled contend P11 – Use of certified organic materials P12 – Use of cement substitutes in concrete P13 – Waste management during operation
	C5 – Water efficiency	P14 – Fresh water consumption P15 – Reuse of grey and rainwater
Society	C6 – Occupant's health and comfort	P16 – Natural ventilation efficiency P17 – Toxicity of finishing P18 – Thermal comfort P19 – Lighting comfort P20 – Acoustic comfort
	C7 – Accessibilities	P21 – Accessibility to public transportations P22 – Accessibility to urban amenities
	C8 – Awareness and edu-cation for sustainability	P23 – Education of occupants
Economy	C9 – Life-cycle costs	P24 – Capital cost P25 – Operation cost

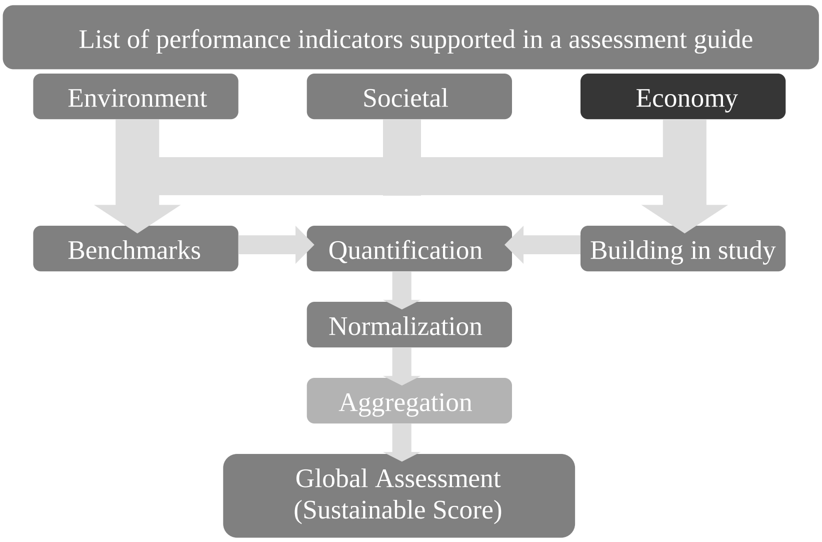

Figure 8. Framework of the SBTool^{PT} methodology.

At the level of the environmental parameters, SBTool^{PT} uses the same environmental categories that are declared in the Environmental Product Declarations. At the moment, there are limitations with this approach due to the small number of available EPD. Therefore the authors of the methodology decided to develop a Life-cycle Assessment (LCA) database that covers many of the building technologies conventionally used in buildings (Bragança et al, 2008b). Nevertheless, since the LCA did not cover all building technologies used in the assessed building, in this study was necessary to use one external LCA tool (SimaPro).

At the level of the societal performance, the evaluation guide presents the analytical methods that should be used to quantify the parameters.

The economical performance is based in the market value of the dwellings and in their operation costs (costs related to water and energy consumption).

3.2 *Normalization and aggregation of parameters*

The objective of the normalization is to avoid the scale effects in the aggregation of parameters inside each indicator and to solve the problem that some parameters are of the type “higher is better” and others “lower is better”. Normalization uses the Diaz-Balteiro et al. (2004) equation (Equation 1).

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \tag{1}$$

In this equation, P_i is the value of i^{th} parameter. P^*_i and P_{*i} are the best and worst value of the i^{th} sustainable parameter. The best value of a parameter represents the best practice and the worst value represents the standard practice or the minimum legal requirement.

Normalization in addition to turning dimensionless the value of the parameters considered in the assessment, converts the values between best and conventional practices into a scale bounded between 0 (worst value) and 1 (best value). This equation is valid for both situations: “higher is better” and “lower is better”.

In order to facilitate the interpretation of results, the normalized values of each parameter are converted in a graded scale, as presented in Table 4.

Table 2: Conversion of the quantitative normalized parameters into a qualitative graded scale.

Grade	Values
A+ (Above best practice)	$\overline{P_i} > 1{,}00$
A	$0{,}70 < \overline{P_i} \leq 1{,}00$
B	$0{,}40 < \overline{P_i} \leq 0{,}70$
C	$0{,}10 < \overline{P_i} \leq 0{,}40$
D (Conventional practice)	$0{,}00 < \overline{P_i} \leq 0{,}10$
E (Bellow conventional)	$\overline{P_i} \leq 0{,}00$

The aggregation consists on a weighted average of the indicators into categories and the categories into dimensions in order to obtain three single indicators. These three values are obtained using the equation (2) and the final result gives the performance of the building at the level of each sustainability dimension.

$$I_j = \sum_{i=1}^{n} w_i . \overline{P_i} \tag{2}$$

The indicator I_j is the result of the weighting average of all the normalized parameters $\overline{P_i}$. w_i is the weight of the i^{th} parameter. The sum of all weights must be equal to 1.

In the definition of the environmental indicators’ weights the methodology uses the US Environmental Protection Agency’s Science Advisory Board study (TRACI) and the societal weights are base on studies that were carried out in the Portuguese population (Bragança et al, 2008a).

3.3 *Global assessment*

The last step of the methodology is to calculate the sustainable score (SS). The SS is a single index that represents the global sustainability performance of the building, and it is evaluated using the equation (3).

$$SS = w_E x I_E + W_S x I_S + W_C x I_C \tag{3}$$

Where, *SS* is the sustainability score, I_i is the performance at the level of the dimension *i* and w_j is the weight of the dimension j^{th}.

Table 3 presents the weight of each sustainable solution in the assessment of the global performance.

Table 3: Weight of each sustainability dimension on the methodology SBTool^{PT} – H.

Dimension	Weight (%)
Environmental	40
Societal	30
Economy	30

Normally, the majority of the stakeholders would like to see a single, graded scale measure representing the overall building score. Such score should be easily for building occupants to understand and interpret but also one which clients, designers and other stakeholders can work with. However, due to the possible compensation between categories, in the SBTool^{PT} approach the global performance of a building is not communicated using only the overall score. The performance of a building is measured against each category, sustainable dimension and global score (sustainable score) and is ranked on a scale from A+ to E

4 RESULTS

4.1 *Performance at the level of each sustainability category and dimension*

Table 4 presents the values obtained in the assessment of the performance at the level of each sustainability category and dimension. Analysing the results it is possible to verify that all priorities adopted by the project team (described above) were recognised by the SBTool^{PT} methodology and therefore almost all categories (except one) have a performance grade above the conventional practice. The analysed building is only worst than the conventional practice in the category C1 “Climate change and outdoor air quality”. This situation results from the fact that the building uses solid clay bricks on the exterior cladding (one material with greater embodied environmental impacts than the conventionally used materials). In compensation, building is above the best practice’s benchmarks at the level of three categories: C5 “Water efficiency”, C8 “Awareness and education for sustainability”, C9 “Life-cycle costs”. The good performance at the level of the water efficiency is mainly influenced by the implementation of the rainwater harvesting system; the good performance on category C8 is because all dwelling have a complete user manual that guides the inhabitants for the sustainable management of it; and the good economy performance is quite dependable on the lower market price of the dwellings (20% lower than average local’s market practice).

Table 4: Results obtained from the SBTool^{PT} – H for each sustainability category and dimension.

Dimension	Category	Performance (normalized value)	Performance (qualitative value)	Weight (%)	Dimension Performance (I_A)
Environmental	C1	-0,20	E	13	B
	C2	0,56	B	20	
	C3	0,72	A	32	
	C4	0,10	D	29	
	C5	1,03	A+	6	
Societal	C6	0,60	B	60	B
	C7	0,74	A	30	
	C8	1,13	A+	10	
Economy	C9	1,20	A+	100	A+

4.2 *Global assessment*

Table 5 resumes the obtained results at the level of each dimension of the sustainable development and the global performance (Sustainable Score). According to the results this building has an A grade, which means that it is considered the best practice in the Portuguese context.

Table 5: Results obtained from the SBTool^{PT} – H for the global assessment.

Dimension	Performance (normalized value)	Performance (qualitative value)	Weight (%)	Sustainable Score (SS)
Environmental	0,41	B	40	A
Societal	0,69	B	30	
Economy	1,20	A+	30	

5 CONCLUSIONS

Sustainable design, construction and use of buildings are based on the evaluation of the environmental pressure (related to the environmental impacts), social aspects (related to the users comfort and other social benefits) and economic aspects (related to the life-cycle costs). The sustainable design searches for higher compatibility between the artificial and the natural environments without compromising the functional requirements of the buildings and the associated costs.

The actual environmental, societal and economy context shows that he case for creating sustainable affordable housing is substantial. The presented case-study showed that even with little increase on capital costs (9%) it is possible to design a building with a good level of sustainability, even in cooperative housing (dwellings' price was 20% lower than the local conventional prices). Being this pilot-project nationally and internationally recognized has a good sustainability practice it is possible to conclude that the SBTool – H is well adapted to the Portuguese's environmental, societal and economy contexts.

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Survey on the main defects in ancient buildings constructed mainly with natural raw materials

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ABSTRACT: Many of the existing buildings constructed mostly with natural raw materials, in European sites, are frequently lacking proper maintenance and, therefore, a high degree of degradation is verified in these buildings compromising their integrity and reducing their lifetime probability. Often in the rehabilitation or reconstruction of old buildings the solution adopted is the partial or integral demolition and substitution of several building components. The aims of this study are to describe the most common constructive solutions in Portuguese buildings constructed with raw natural materials, to specify the principal problems that affect each building component, and to present possible solutions to correct each defect. This study is focused on the principal elements that compose the building structures in Portugal, including load-bearing walls, wooden floor and roof structures. The corrective solutions presented and studied privileges the adoption of materials and techniques similar and most compatible with the original ones.

1 INTRODUCTION

In Portugal, the main traditional construction techniques that make use of earth are rammed earth, adobe and half-timbered. These techniques fell into disuse upon the appearance of reinforced concrete and ceramic bricks (Carvalho et al, 2008).

An expressive amount of the existing Portuguese buildings reveals a certain lack of maintenance or conservation and the main reason for this fact is inherent to cost reasons. It is almost symptomatic to observe pathologies even in recent buildings. The cause of these premature pathologies may be building error, design error, inappropriate building conception, inappropriate or deficient building materials, among others. On the other hand, the degradation tends to increase with the age of the construction and it may be considered as a natural degradation related to natural pathologies.

The presence of undesirable water during a long period of time frequently deteriorates the materials properties which decreases the stiffness of the structural elements and may result in partial or total collapses of the constructions.

A regular maintenance or conservation work is required to avoid undesirable unexpected building construction deterioration. The occurrence of a pathology may lead to others and, in the limit, may results in a progressive structural collapse (Pinto et al, 2002).

In this context an early 19th century Portuguese watermill building is used as a study case to show how a roof leaking may lead to a progressive building collapse.

A brief description of the building is done followed by an identification/characterization of the building materials. In particular, an experimental study of the structural mortar was done in the Microscopic Electronic Unit of the Trás-os-Montes e Alto Douro University (UTAD) in which the chemical elementary composition was studied by scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) and the mineralogical elementary composition was studied by X-ray tests. The experimental identification of wood specimen was done at the Laboratory of the Forest Department of UTAD.

The chronological partial roof structural failure sequence is presented and described in which a pathology cause/effect link is also done. Meanwhile, the analysis of this failure sequence may give evidence for achieving better robust timber structural roof solutions and also reinforcement repairing structures proposals for traditional Portuguese buildings.

The building used as a study case may be seen a real experimental model of a traditional Portuguese building which are in general sustainable.

2 BUILDING UNDER STUDY

2.1 *Historical and geographic context*

In this research work, the building adopted as a study case is an early 19th century watermill which its main function was to provide the neighborhood and the surrounding villages of flour. Its activity ended by the mid 70`s with the boom of the supermarket networks which started to offer pre-packed cereals and flour. The death of the owner plus the above described situation were the main reasons why the watermill building has been without any use and maintenance from that time. The Fig. 1 shows the watermill building in 2000 in which it is evident that a partial roof collapse has occurred (Fig. 1, detail I).

The building is located in Portugal continental central region, on the coast, in the district of Coimbra, in the municipality of Figueira da Foz, in the village of Carritos (Fig. 2).

Figure 1. Watermill building's condition in 2000

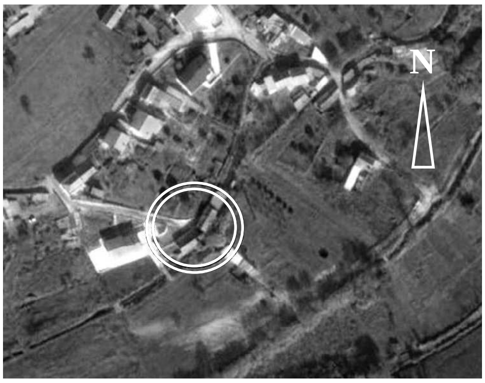


Figure 2. Location (http://maps.google.pt/)

2.2 *Architectural and construction conditions*

An expressive amount of the existing Portuguese buildings reveals a certain lack of maintenance or conservation and the main reason for this fact is inherent to the related cost. It is almost symptomatic to observe pathologies even in recent buildings. The course of these premature pathologies may be building error, designs error, impropriated buildings conception, impropriated or deficient building material, among others. Of course that the degradation tends to increase with the age of the construction and it may be considered as a natural degradation.

A regular maintenance or conservation work is required to avoid unexpected building deterioration (Faria et al, 2008). The occurrence of a pathology may led to others and, in the limit, may result in a progressive structural collapse.

The presence of undesirable water during a long period of time frequently deteriorates the material proprieties which decreases the stiffness of the structural elements and may result in partial or total collapses of the construction.

The watermill building was thought of only working purposes which may explain the very simple but efficient architectural solution adopted (Fig. 3 and 4).

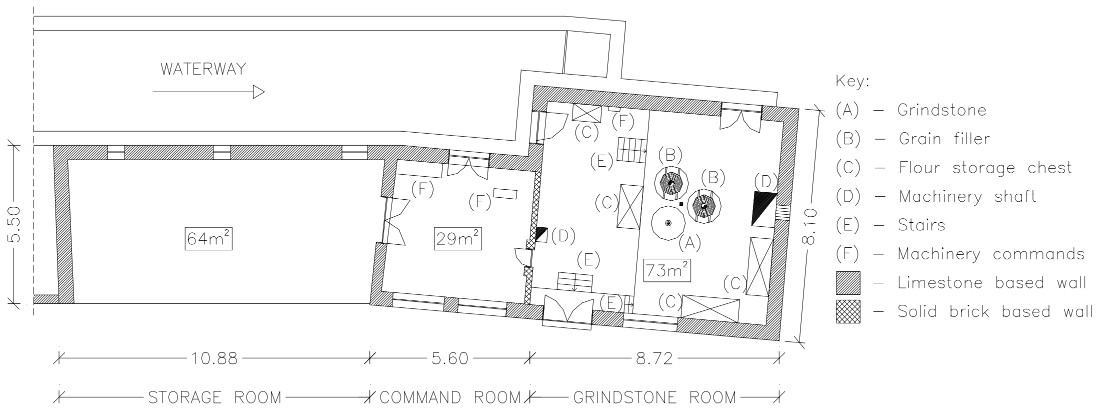


Figure 3. Ground floor Plant, 2009 (m)

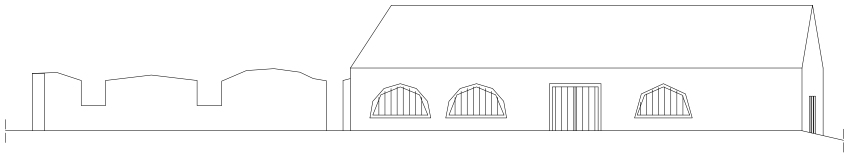


Figure 4. Frontal view, 2009

The building has basically three rooms located in the ground floor. These rooms are the grindstone room, the machine command room and the storage room, Fig. 3. The grindstone room has a 73 m^2 area in which exist the grindstone, two grain filers and massive wooden chests to retain the flour. The machine command room has a 29 m^2 area where the turbine's switching levers are located. Finally, the storage room has a 64 m^2 area and its purpose was for storing the grains and flour. Thus, the building has a total area of 166 m^2.

3 IDENTIFICATION AND CHARACTERIZATION OF THE BUILDING MATERIALS

The used building materials are limestone, structural mortar, timber, solid and hollow ceramic bricks, finishing plaster and ceramic tiles.

Since this region is sparse in stones, the structural stone masonries walls (exterior and interior) had been built up using irregular and small sized limestone pieces (Fig. 5, detail I) agglutinated by a structural mortar (Fig. 5, detail II). The average thickness of these walls is 0.40 m.

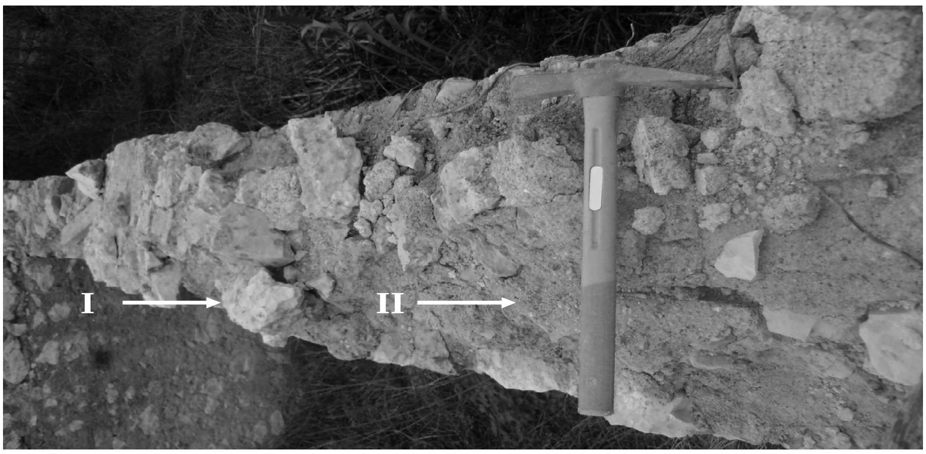


Figure 5. Detail of the structural stone masonries walls

Timber was highly used in this building. The floor, the purling, the beams of the roof structure and over the openings (windows and doors) and the ground pavement are timber. Since the building is next to a watercourse we suspect that its foundation system includes also timber piles to reach good capacity resistance soil. However, this last fact needs to be further confirmed through an excavation.

It is also possible to find ceramic hollow bricks punctually on the top of the timber boards located on the windows. At the same time, there is an interior partition wall that was built using solid ceramic bricks. The mortar attached to these bricks seem to be different of the used in the structural walls and may indicate that this wall is earlier than the others and may be related to any renovation work.

A finishing plaster material was used in most of the walls excluding the ones of the storage room. The exterior covering of the roof is ceramic tiles.

In order to identify the type of mortar, the type of finishing plaster and the specimen of timber, experimental tests were done.

The identification/characterization of the chemical and mineralogical elementary compositions of the mortar and the finishing plaster materials was done by scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) and X-ray tests which were performed in the Microscopic Electronic Unity of the UTAD. Similar tests have been already done in the framework of other research projects (Pinto et al, 2009), (Silva et al, 2009) to characterize the available and used materials for the local traditional constructions.

Four mortar material samples (sample 1, 2, 3 and 4) were collected and tested. It was also tested a lime sample and a hydraulic lime sample since they are the more common binding material used in these traditional buildings.

The preparation of the mortar material samples required a triturating process because only the thinner portion is used.

The chemical elementary composition results obtained by the SEM/EDS test are presented in Table 1. The mineralogical elementary composition results of the X-ray test shown in Table 2.

Table 1. Chemical elementary composition results of the SEM/EDS (%).

Chemical element	Sample 1	Sample 2	Sample 3	Sample 4	Lime	Hydraulic lime
Oxygen (O)	52.01	51.44	52.07	49.06	56.06	39.85
Sodium (Na)	--- --	-----	-----	0.90	-----	-----
Magnesium (Mg)	-----	-----	-----	0.68	2.01	0.50
Aluminium (Al)	6.37	6.11	8.74	6.68	3.40	0.38
Silicon (Si)	13.84	9.45	17.48	15.01	7.42	-----
Chorine (Cl)	-----	-----	-----	0.58	-----	-----
Potassium (K)	1.90	1.09	3.45	1.65	0.99	-----
Calcium (Ca)	24.92	31.17	17.36	22.51	28.01	59.26
Iron (Fe)	0.96	0.74	0.90	2.94	1.4	-----

Table 2. Mineralogical elementary composition results of the X-ray test

Sample 1	Mineralogical composition
Sample 1	Quartz, Calcite, Muscovite
Sample 2	Calcite, Kaolinite, Quartz
Sample 3	Calcite, Quartz
Sample 4	Calcite, Quartz, Plaster
Lime	Calcite,Calcium Oxide
Hydraulic lime	Calcite, Quartz, Plaster

Mortar material samples 1, 2 and 3 have very similar elementary composition in particular in terms of chemical (Table 1).

On the other hand, the mortar material sample 4 seems to be slightly different of the others (5^{th} column, Table 1 and 5^{th} line, Table 2) and shows a lot of mineralogical elementary composition similarities with the hydraulic lime (Table 2).

At the same time, this sample was gotten from the above described interior partition wall which is earlier than the others.

Based on these results and the above analyses we may consider that the mortar material samples 1, 2 and 3 are a mixture of local earth and lime and the mortar material sample 4 is a mixture of a local earth and hydraulic lime.

All the samples have an expressive amount of Ca. Taking into account that it is a limestone geological region, the earth must be also limestone based. Thus, further experimental work is required using local earth samples in order to confirm if samples 1, 2 and 3 are earth based mortars.

The experimental identification and characterization process of the six timber samples was done at the Laboratory of the Forest Department of UTAD. Two timber samples of the timber structural roof were experimentally identified as being *Pinus pinea* specimens. One timber sample of the ground floor pavement was experimentally identified as being *Pinus pinaster* specimen. These are both local trees specimens.

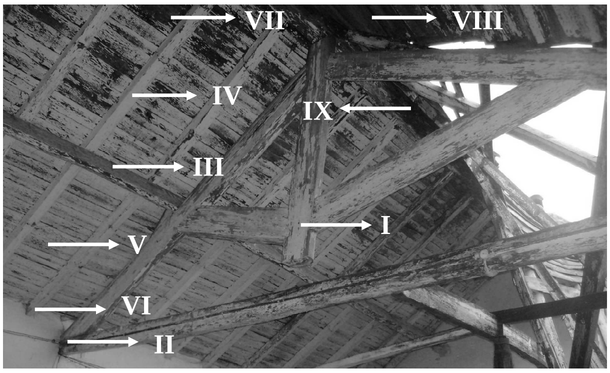
Based on the above building material description it is possible to realize that most of the used materials are natural and local and, the building itself is associated to building techniques that require small amount of energy consumption and releases an unexpressive amount of noxious gases to atmosphere (Murta et al, 2009). Consequently, we have a remarkable example of a sustainable building solution.

It is important to study the composition of the existing mortar and to identify the wood specimen used for future renovation and conservation works for this building, in particular, and for traditional Portuguese buildings in general. We are also particularly interested of verifying if the mortar is an earth based material.

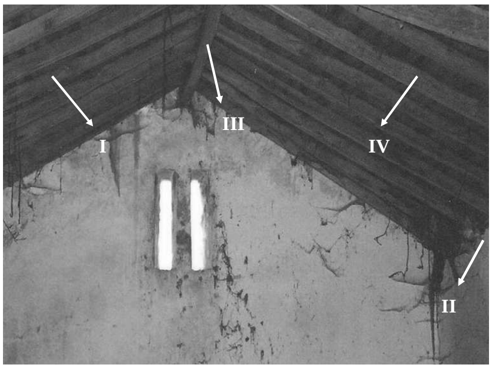
4 STRUCTURAL SOLUTION

According to Fig. 3 there are two types of walls. There are several limestone based masonries walls and one solid ceramic brick based wall. The function of the last one is partition. In contrast, the main ones have a structural function since they support the roof system.

The roof timber structural solution comprises two types. In the grind stone and the command rooms (Fig. 6-a) it was adopted trusses (Fig. 6-a, detail I) directly supported on the limestone based masonries walls (Fig. 6-a, detail II), these trusses support beams (Fig. 6-a, detail III) which are supporting the purling (Fig. 6-a, detail IV). On the purling there are timber boards (Fig. 6-a, detail V) supporting the ceramic tiles.



a. Trussed type roof structural solution



b. Beamed type roof structural solution

Figure 6. Roof structural systems

The other type of roof timber structural solution was only applied in the storage room, Fig. 6-b, which includes timber beams (Fig 6-b. detail I) which were structures supported on the limestone based masonry walls (Fig. 6-b, detail II) and a central timber beam (Fig. 6-b, detail III). On these timber beams there were timber boards (Fig.6-b, detail IV) supporting the ceramic tiles.

These are remarkable traditional timber structures built under skills based on experience.

5 FAILURES AND PATOLOGIES

5.1 *Roof structural failures*

The roof timber structure has been facing partial collapses throughout the last 9 years. The first partial collapse occurred in 2000, in which part of the roof of the storage room was lost (Fig. 8-a, detail I). It is important to underline that the main structural timber elements which are trusses did not get damaged.

The second structural failure of the roof occurred in 2007 resulting in the completely loss of the roof of the storage room (Fig. 8-b, detail I) and part of the frontal limestone based masonry wall (Fig. 8-b, detail II).

The third roof structural failure occurred this year in the roof of the grindstone room (Fig. 8-c, detail I) in which its roof was partially lost. In this case, the purling (Fig 6-a, detail IV) collapsed in the zone of their support (the limestone based masonry wall (Fig. 6-a, detail VI) generating a load redistribution which resulted on the collapse of the beam (Fig. 6-a, detail III). This load redistribution was possible because the roof structural solution works as a structural system (CEN, 1998).

a. 1st Collapse (2000) b. 2nd Collapse (2007) c. 3rd Collapse (2009)
Figure 8. Roof's partial collapses

5.2 *Pathologies*

This section is focused on the pathologies associated to the above described failures. Figure 8-a in its detail II shows a local permanent deformation of the roof system of the grindstone room in its connection to the frontal wall. Some ceramic tiles were also missing there.

Meanwhile, Figure 8-a illustrates the roof's condition of the grindstone room before the above described third roof's structural collapse occurred in 2009 (Fig. 8-c). Some purling and timbers boards showed an advance stage of deterioration in the contact zone with the structural wall. Through Figure 6-a, detail I, it is also possible to notice that these timber elements had a darker shade than the similar ones located outside of the damaged zone which indicated a leaking problem. By doing a similar analysis, Figure 6-a, details VII, VIII and IX indicated that there were some cracked ceramic tiles or the ceramic tiles/timber board direct contact solution was not the appropriated one because may increase an undesirable water moister in the timber structural elements.

An expressive vertical crack located in the junction of two limestone based masonry wall of the storage room (Fig. 9, detail I) was formed just before the occurrence of the second roof's structural collapse occurred in 2007. The thickness of this vertical crack decreases from the top to the bottom.

Figure 9. Vertical crack, 2007

6 MAIN CONCLUSIONS

The architecture solution, the structure solution, the building material's identification/ characterization, the sequence of structural failures and the main pathologies identification/ characterization related to an early Portuguese 19^{th} century watermill were described and detailed.

This building may be considered as a real scale experimental model which may contribute to the rehabilitation and conservation fields of traditional Portuguese buildings.

Based on the fact that the experimental material study concluded that the building used as a study case is environmental friendly and may also be used as a sustainable building model. The structural limestone based masonry walls adopted solution has the particularity of using small size limestone pieces connected by an earth based structural mortar which is also a sustainable and economic solution.

The reported structural failure sequence has been caused basically by roof leaking problems which has been deteriorating the timber structural elements of the roof of the watermill building. Then, a regular maintenance is required in order to avoid building failures. This fact is much more relevant in traditional buildings.

The trussed timber roof structural solution had shown a better structural behavior than the beamed timber roof structural solution because it avoids total collapse and, consequently, it is more robust. These facts may be easily extrapolated to the repairing of the Portuguese traditional buildings which are in general environmental friendly.

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Performance measurement and improvement of non residential buildings: carbon dioxide accounting and energy saving

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ABSTRACT: The paper deals with the themes of sustainability with the aim to set up a general framework for the assessment and the improvement of selected environmental performances of large non residential building (e.g. commercial, exhibition, ...) taking into account:

- strategies for energy saving in heating and air conditioning,
- definition of accounting criteria for carbon dioxide emissions
- definition of life cycle costing procedures with the inclusion of environmental costs.

The paper presents different approaches that could be combined in order to create supports for evaluations and for decisions in the field of environmental performances of buildings. The aim is to give to owners and/or to others operators (designers, energy managers, ...) tools (methods, procedures, …) to monitor the building performances, to evaluate the results of alternative strategies and to assume decisions on possible improvement actions.

1 INTRODUCTION

1.1 *Energy consumption and carbon dioxide emissions in non residential buildings*

The sector of large non residential buildings represents an important part of the construction industry: in Italy in year 2007 (considering only the industrial, the commercial and the hospitality buildings) more than 7000 new building has received the building permit for an amount of more than 90 millions cubic meters (source ISTAT “Statistiche sui permessi di costruire”, July 2009). The average volume is significantly larger in urban areas with more than 100.000 inhabitants (more than 33.000 cubic meters per each building) so the impact for the environment of these new buildings is even higher than it is in small towns.

Moreover, it is important to underline the fact that at present an important volume of non residential buildings constructed in the sixties and in the seventies is still in use. They are buildings characterized by more and more inefficient energy behaviors, often with exterior façades and roofs not or insufficiently insulated, with large surfaces of light curtain walls highly dissipating in winter and unprotected from solar radiation in summer, with obsolete equipments, generally deficient both in solar gain systems and in any kind of attention for energy saving solutions. Inside this scenario we must consider too the fact that the demand for comfort inside non residential buildings both in winter and particularly in summer has been largely growing in the last years, also in relation both with innovations in working practices and with climate conditions rapidly changing and hardly predictable; the final effect is the constant growing of energy consumption for different activities in non residential sector.

Table 1 Energy consumption (electrical) in non residential sector. (GWh) Source TERNA

	1998	1999	2000	2001	2002	2003	2004	2005
Total	37.088	39.243	41.361	43.654	46.284	49.905	52.011	55.644

These data must be considered in relation with the fact that, inside the general scenario of activities, civil sector represents an important energy user, demanding (table 2) all the types of energy and, therefore, contributing in a significant measure to the carbon dioxide emissions.

Table 2. Final consumptions in Italy for sector and for type of energy in 2007 (unit Mtep = millions of oil tons). Source: Data MiSE (synthetic balance sheet 2007) elaborated by ENEA

	Consumptions (Mtep)	Oil (%)	Gas (%)	Carbon (%)	Electricity (%)
Transportations	44.65	97%	1%		2%
Industry	41.02	19%	40%	12%	29%
Residential and Non Residential	43.41	11%	55%	4%	30%
Total	144.10	48%	29%	5%	18%

All these aspects carry to highlight some pressing problems:

- operations in non residential buildings produce high costs both on economic and on environment;
- there is an important interest for renewal and retrofit activities regarding non residential buildings;
- both in new buildings and in energy rehabilitation interventions it is possible to notice the general lack of strategies able to consider simultaneously many aspects, such as: improvement of energy performances both in winter and in summer; implementation of technical solutions adapted to the specific ways of using buildings; reduction of impacts both on costs in use and on environment resources considering the life cycle of materials and components adopted; the influence of different and alternative project choices on CO2 emissions, etc.
- frequently, choices adopted to improve energy behavior of buildings seem to be fragmented, able to consider only particular aspects, ignoring synergic and indirect effects; concurrently mainly methodologies and tools developed to evaluate and simulate the effects of choices tend to isolate particular aspects and performances.

Nowadays it is important to orient a sector of sustainability and energy saving researches in the direction of tools characterized by:

- a synthetic vision of the interactions of the different influences of various aspects (environment, energy, money, etc.) and on numerous dimensions of space and of time;
- the fact to be supports for the strategic decisions, in the phase in which many alternatives must be evaluated and confronted in relation with different parameters and with various policies.

The researches presented in the following paragraphs represent three different approaches that could be combined in order to create supports for operators of non residential buildings (designers, energy managers, public and private real estate owners, etc.) in order to evaluate and confront from different points of view the results of alternative strategies and to assume decisions on possible improvement actions.

2 ENERGY ASSESSMENT AND IMPROVEMENT OF EXISTING BUILDINGS

2.1 *Aim of the research*

The research aims to develop a methodology to evaluate the energy behavior of existing buildings and to give some guidelines in the choice of the strategies for energy efficiency improvement by simulating combined solutions in different seasons. What is suggested is an analysis method able to guide the designer in the evaluation of different alternatives to improve the energy behavior focusing on office buildings, a particular typology which presents some critical aspects including high values of energy consumption, high values of embodied energy, fast phenomena of functional/spatial/technological obsolescence, particular periods of occupation.

This methodology has been tested on a “case study” located in Milan, a typical office building of 1960, with a common construction type and with a little isolated envelope. The project for energy efficiency improvement follows four main categories of strategies: the reduction of the envelope thermal transmittance (both opaque and transparent elements), the reduction of solar factor, the application of solar shading systems and the implementation of ventilation (free cooling). The choice of the strategy has to consider both the situation in winter and summer: in fact, for example, strategies that reduce the energy demand in winter could increase energy demand in summer.

2.2 *Simulation method*

There are two basic mathematical models to assess the energy requirements of buildings: the first one is based on the stationary method, which calculates the thermal balance on a long period of time (typically a month or a season) neglecting the heat stored and released from the walls and which takes into account dynamic effects through an empirically determined factor of loss or gain. The second model is based on a dynamic method, and it calculates the thermal balance on a relatively short period (typically one hour) and, unlike the first model, it takes into account the heat stored and released from the mass construction.

The comparison of the two models shows that the two methods work in a different way and so they return different results (Figure 1).

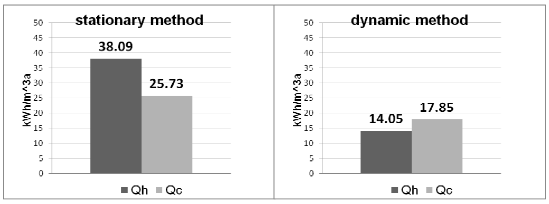

Figure 1. Winter and summer energy demand (Qh and Qc) of a sample cell of the office building calculated by stationary and dynamic simulation method.

EnergyPlus, developed by the United States Department of Energy (DOE), is the software used to simulate the building in dynamic conditions; it is based on a very specific description of the construction by the user, regarding envelope characteristics (geometry, display, thermo physical characteristics), parameters of use of the building (number of occupants, operation hours of power plants, design temperature) and climate data.

One of the problems in using dynamic simulation software concerns the construction phase of the model in order to start the simulation, that should define a very detailed description of the building to make the results closer to reality. The approach tested in this research aims to simplify the process of constructing the model to avoid spending a large amount of resources on the implementation of the building model. It has been chosen the more representative portion of the building, a "sample cell", placed in strategic locations within the building.

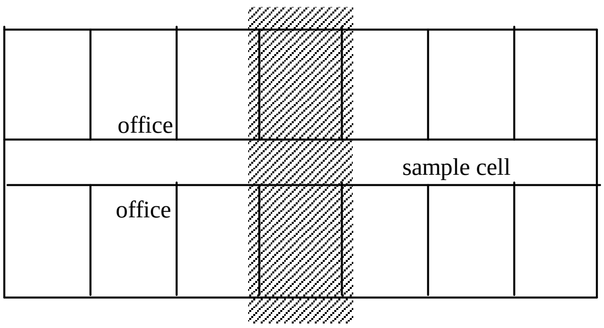

Figure 2. Schematic plant of the “sample cell”.

2.3 *Results of synergic effects of combined solutions*

Interventions that simulate the cell to increase the energy performance are illustrated in the Table 3.

Table 3. Simulated solutions.

Interventions
Internal/External insulation
Ventilated façade
More performing windows
Application of horizontal/vertical shading “brise soleil” in summer/winter
Spring/summer night ventilation (free cooling)
Overhang
Roof insulation

Before to simulate the effects of combined solutions, individual interventions have been simulated using the software EnergyPlus. The Figure 3 and Table 4 show the most significant results.

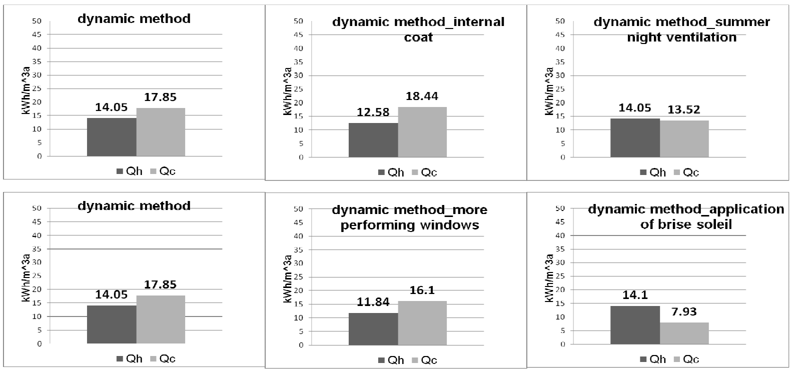

Figure 3. Individual interventions: comparison between the energy demand in winter (Qh) and summer (Qc) of the sample cell, sample cell with internal insulation, sample cell with a summer night ventilation, sample cell with more performing windows, and sample cell with shading “brise soleil” in summer.

Table 4. Energy savings.

Intervention	Energy savings			
Internal insulation	10.5%	in winter	3.31%	in summer
Summer night ventilation	0%	in winter	24.3%	in summer
More performing windows	15.7%	in winter	9.8%	in summer
Application of brise soleil in summer	0.36%	in winter	55.6%	in summer

After that, combined solutions have been simulated looking for improvements for both heating and cooling demand. The most effective solution has tried to find a balance between the reduction of the energy need in winter and in summer; the interventions that have been simulated in this best solution are: roof insulation, internal insulation, application of brise soleil, replacement of windows.

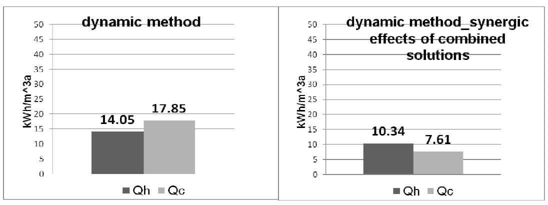

Figure 4. Comparison between the energy demand in winter (Qh) and summer (Qc) of the sample cell with or without solutions of energy retrofit

The results of the best simulation show that it could be possible to achieve an energy saving of 26% in winter and 57% in summer. It is important to consider the synergic effect of the interventions to achieve more significant energy savings in all seasons.

2.4 *Methodology*

In the Table 5 the main steps of the method have been summarized. This procedure is mainly indicated to office buildings, because of their particular spatial distribution that allows for the identification of sample cells.

Table 5. Main steps of the method

Step	Description
1.	Data acquisition
2.	Sampling
3.	Dynamic simulation of the sample cell
4.	Study of strategies for upgrading energy
5.	Dynamic simulation of solutions on the sample cell
6.	Comparison of simulation results

2.5 *Work in progress*

Following the presented research, two different experimental researches are now developing.

The first one analyzes an existing exhibition pavilion. In this case it has not been necessary to consider sample cells to simulate solutions because it is an open space. Moreover, simulating the whole building, it is possible to compare the results in term of energy consumptions with the real total consumption of the building, so the model used to simulate different solutions is closer to reality. This type of building is very different from office buildings, especially for its periods of occupation: indeed there are periods of concentrated occupation during events and periods (between two events) in which there are no people.

The second study that is starting aims to quantify the environmental impacts of an intervention of energy retrofit by the application of LCA "Life Cycle Assessment" methods and tools and the LCGCA "Life Cycle Green Cost Assessment", that is presented hereafter.

3 LIFE CYCLE GREEN COST ASSESSMENT OF A HEATING AND COOLING GEOTHERMAL PLANT IN A LARGE NON RESIDENTIAL BUILDING

3.1 *The reason for a Life Cycle Cost Assessment including environmental issues*

In the last years, the interest for the life cycle cost assessment (LCCA) of building projects has grown up due to different reasons:

- the continuous increase of energy cost for heating and air conditioning;
- the increase in costs for other utilities (e.g. electricity, water supply, ...);
- the clear perception that operating costs, over the life cycle of the building, are much higher than construction costs;
- the requirements from laws and regulations that ask to the architects and the designers to design building taking into account the whole life cost and not only the construction cost. For instance, the Italian law on public contracts (Decree 559/94) explicitly requires the architects to "design buildings with the objective to obtain the better ratio between the expected performances and the whole lifecycle cost (including construction, operation and maintenance".

LCCA is basically a method (Fuller S., Petersen S., 1995) for the economic evaluation of projects (especially alternative projects) taking into account all the costs arising from the acquisition, the ownership, the operation, the maintenance, the decommissioning and the demolition of a building or a part of it. For practical reason, the structure of LCCA costs can be described as follows:

- initial costs (e.g. feasibility studies, financing, design, permits, land acquisition, construction, handover, ...);
- operation costs (e.g. administration [taxes, insurances, ...], operational costs [energy, utilities, safety, ...], maintenance costs [maintenance, inspection, cleaning, ...]);
- final costs (e.g. decommissioning, demolition, disposal, resale value (to be subtracted if present), ...).

In the last decade, different researchers started to experiment the application, to the main structure of LCCA, of additional economic factors that have been identified in relationship with the environmental issues associated to the building construction and operation; the LCGCA "Life Cycle Green Cost Assessment" has been introduced (Lijing G., 2008) as a new method of evaluation of buildings during their lifecycle with the objective to integrate two different approaches:

- a purely economical evaluation developed with the method of Life Cycle Cost Analysis;
- a purely environmental evaluation developed with the method of Life Cycle Assessment as defined by international standards ISO of 14000 series (especially ISO 14040, ISO 14041, ISO 14042).

The reasons for this integration derive from the consciousness that environmental issues (Koeppel S., et al., 2007) are becoming important also from an economic point of view: in this perspective the definition of fiscal policies, e.g. the so called "carbon tax", or the possibility to manage economically the environmental externalities can be considered as references to modify and improve the traditional LCCA method and evaluation techniques).

3.2 *An experimental analysis of a geothermal plant*

Starting from an existing model for LCGCA (Lijing G., 2008), a model has been set up with the objective to evaluate the LCGCA of a HVAC plant, located in a large non residential building in north Italy; assuming that LCCA/LCGCA are basically methods to compare each other different alternatives, the experimentation has been developed to compare two alternative plant design:

- an innovative HVAC system with heat pumps connected to a large geothermal installation assuring winter heating and summer cooling;
- a traditional HVAC system with gas boiler for winter heating and air condensed chillers for summer cooling.

A specific LCGCA model has been prepared for this case study adding to the usual components of LCCA (traditionally called "input costs") the following items:

- Event related costs: in this category two main costs have been considered: C_{down} = total cost of lost or deferred production due to downtime of the plant; C_{risk} = total cost due to unexpected and dangerous events (e.g. explosion, soil or water pollution, ...)
- Environment related costs/benefits: in this category the amount of carbon dioxide emissions has been accounted with reference to different life stages: CO_{2mat}: tonnes of CO_2 equivalent to the energy incorporated in the materials used for the fabrication of the plants equipments; CO_{2cstr}: tonnes of CO_2 equivalent to the energy incorporated in the construction process of the plants; CO_{2oper}: tonnes of CO_2 emissions over the operation stage of the plants; CO_{2dis}: tonnes of CO_2 equivalent to the energy incorporated in the disposal process of the plants. With the aim of evaluating the alternative between the traditional HVAC plant and the innovative geothermal plant, the accounting of CO_2 emissions has been considered not as a cost but as a benefit: the hypothesis is that the use of the geothermal plant can reduce the carbon dioxide emissions and, therefore, the CO_2 savings could be evaluated as CER (certified emissions reductions) that could theoretically be traded at a defined value reducing the whole life cost of the alternative technical solution.
- Corporate image related costs/benefits: this cost component has the objective to account for the benefit or costs that the company (that operates the building in which the plant must be installed) may receive from the installation and use of an "environmental friendly" technology. This cost component, however difficult to be correctly estimated (Aaker D.A., 1991), could be significant in case of buildings used for activities directly offered to consumers (e.g. hospitality, retail buildings and shopping malls, restaurants, ...).

The analysis has been developed assuming a service life of the building of 20 years also if these assumption is particularly punishing for the geothermal plant that has an initial cost very high of the exchanger with the ground (the exchange section of the plant to be realized with vertical probes with an average height of about 230 feet); the choice has been made by analyzing the service life of similar buildings before their complete refurbishment. In order to manage this particular situation, considering that that the exchange section has not theoretically defined limits to its service life, three hypothesis have been made:

- re-use of the geothermal plant at the refurbishment of the building after 20 years;
- disposal of the entire building with its plant;
- resale of the geothermal exchange section to other buildings that are in proximity.

The estimation of the initial cost of the two alternative plants has been made including all the technical and administrative costs (lump sum – turn key); the geothermal plans has been quoted by contractors (by means of requests for proposal) in a range varying between 1200 and 1500 k€. The operational annual costs – including administrative cost, utilities, energy, maintenance – has been estimated at 59 k€/year for the geothermal plant and at 145 k€/year for the traditional plant based on comparison with existing similar building and plants.

The environmental cost has been calculated as the addition of two parts: one part estimated assuming the possibility to sell the CER (that is now not allowed by the European Emissions Trading Scheme that can be accessed only by few subjects concerned with specific emission processes as electricity production, cement plants, ...); the other parts estimated in according to the Italian law that promotes energy saving with the trading of the so called “white certificates” or TEE “Energy Efficiency Title” (1 TEE is assigned for the certificated energy saving of 1 tonn of oil). Assuming the value of the CER at 20 € per ton of CO_2 (at the time of the analysis that has been performed in early 2009) and the value of 1 TEE at 100 €, a benefit of about 9500 €/year has been estimated for the geothermal plant compared to the traditional plant.

As a result of these analysis, the two alternatives have been compared and the geothermal plant, with an initial investment cost four times higher that the traditional one, has resulted to be more convenient over the life cycle of twenty years with a performance in cost saving (respect to the traditional plant) varying from 19,5 % (case of disposal of the geothermal exchanger) to 30 % savings (in case of re-use of the geothermal exchanger for a new building).

4 ACCOUNTING CRITERIA FOR CARBON DIOXIDE EMISSIONS IN BUILDING MANAGEMENT

4.1 *The general framework*

The last research presented in the paper deals with the setting of a model for the accounting of CO_2 emissions in building operation and management considering all the possible sources of greenhouse gases. The objective was to define a tool to compare the effective contribution of buildings, and their related activities, to CO_2 emissions that are, so far, mainly associated to the energy use in buildings without considering other activities that are sometimes of the same importance.

To this aim, a general model for CO_2 accounting in building has been defined starting from the criteria stated by ISO 14064 standards with the identification of all the possible sources and sinks of GHG in buildings; the model has also been compared to the accounting criteria of GHG defined by the European Emission Trading Scheme EETS.

4.2 *The model and the experimentation*

Starting from the identification of GHG sources in building, the accounting method has been defined and different “accounting areas” have been identified:

- Direct emissions due to the combustion of fossil fuel for heating and domestic hot water;
- Indirect emissions due to the use of: electricity (for air conditioning and cooling, for lighting, for auxiliary systems as lifts, pumps,…), steam or district heating from combined generation plants;
- Emissions due to the production of MSW Municipal Solid Waste;
- Emissions due to production of domestic wastewater;

- Compensation (absorption) due to the presence of carbon sink (as green areas pertinent to the building).

For each accounting area, different tools to calculate the GHG quantities have been identified and analyzed in order to merge in a single method tools that are defined from different scientific disciplines. The method has then been tested on a large land settlement (2 millions sqm of area, 500000 sqm of gross floor surface, major parts of heating provided by a district heating combined heat and power plant) mainly in order to evaluate the relative importance, respect to the direct emissions, of indirect emissions and of the emission due to wastewater and solid waste; the reason for this analysis is also related to the fact that the application of the EETS accounting method to a building should not include the indirect emissions and, therefore, the objective was also to evaluate the possible mistakes in assessing GHG emission from buildings without considering indirect emissions.

The results of the assessment of the land settlement shows the importance of indirect emissions, mainly for electricity consumption, and of emissions due to solid wastes (table 6)

Table 6. Carbon dioxide emissions (tons)

Source	Emissions	percentage on whole emissions
electricity	21587	78%
solid waste	3798	14%
wastewater	216	1%
heating	2136	8%

5 CONCLUSIONS

The three research areas that have been synthetically summarized in this paper, show the importance of an organic approach to the environmental assessment of non residential building that are associated to specific processes that may generate large quantities of GHG emissions. The importance of this assessment is related to the fact that building sector can contribute significantly to carbon dioxide emissions reduction due to: the significant quantity of energy used by existing buildings; the generation of solid waste and wastewater associated to building use that impact on GHG emissions; the bad performance, concerning energy saving, of the large amount of buildings built between 50’s and 80’s that could be significantly improved with low effort.

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RAPPORTO ENERGIA E AMBIENTE 2008: ANALISI E SCENARI, ENEA, Roma, 2009

Behaviour of green facades in Mediterranean continental climate

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ABSTRACT: In evaluating the potential of the green vertical systems as passive systems for energy savings in buildings we must consider some important aspects. First, the type of green vertical system, as there are significant differences among systems. The construction system, the types of plants, the maintenance, the operation, vary among systems. Second, the parameters that influence their behaviour must be considered. Basically, the interception of solar radiation by the effect of the shadow produced by the vegetation, the thermal insulation provided by vegetation and substrate, the evaporative cooling that occurs by evapotranspiration from the plants and the substrate, and through the variation of the effect of the wind on the building. Finally, it is important to consider that for the efficient operation of these systems it is essential to know the behaviour of the different species in local weather conditions. According to these considerations, a long-term work has been raised in order to obtain data on the behaviour of green facades in buildings as a passive system for energy savings in dry Mediterranean continental climate. This work presents the results of a year monitoring a double-skin green facade (also called green curtain), made with modular trellis and wisteria sinensis in the village of Golmés, near to Lleida city (Catalonia, Spain).The first results confirm the great ability to provide shade from the green curtain and that the air in the intermediate space is changed, creating a microclimate where environmental conditions are; higher temperature and lower relative humidity in winter (leafless period), and lower temperature and higher humidity in summer (period with leaves).

1 INTRODUCTION

The use of green vertical systems, well designed and managed, can be a useful tool for thermal regulation of buildings with interesting energy savings (Köhler 2008). But in evaluating the potential of these systems as passive systems for energy savings in buildings the following aspects must be considered.

First the type of green vertical system, as there are significant differences between systems. The construction system, the type of plants, the maintenance, the operation, vary among systems (Table 1), and these will affect their behaviour as passive energy saving systems (Pérez et al 2010).

Second, the parameters that influence their behaviour must be considered (Table 2). Basically, there are four fundamental mechanisms that characterise green vertical systems as a passive system for energy savings: the interception of solar radiation by the effect of the shadow produced by the vegetation (Papadakis et al 2001, Stec et al 2004, Miller et al 2005, Hoyano 1988), the thermal insulation provided by vegetation and substrate (Papadakis et al 2001, Hoyano 1988), the evaporative cooling that occurs by evapotranspiration from the plants and the substrate (Papadakis et al 2001, Miller et al 2005, Schmidt 2006), and finally, through the variation of the effect of the wind on the building (Dinsdale et al 2006, Ochoa 1999).

Table 1. Classification of green vertical systems of buildings.

	Extensive systems		Intensive systems
Green facades	Traditional Green Facades		
	Double-skin green facade or green curtain	Modular trellis	
		Wired	
		Mesh	
			Perimeter flowerpots
Living walls			Panels
			Geotextile felt

Table 2. Parameters that influence in the behaviour of the green vertical systems as passive energy-saving systems.

Interception of solar radiation. Shadow	Thermal insulation and storage	Evaporative cooling	Variation of the effect of the wind
Density of the foliage (number of layers)	Density of the foliage (number of layers) Changes in the air in the intermediate space Barrier effect of wind *Substrate: thickness, bulk density and moisture content.**	Type of plant Exhibition Climate (dry / wet) Wind speed *Substrate moisture**	Density of the foliage (number of layers) Orientation of the facade Direction and wind speed

Finally, it is important to consider that for the efficient operation of these systems it is essential to know the behaviour of the different species in local weather conditions, because the end result may differ greatly from one climate area to another, spoiling the expectations of energy savings that had been planned according to theoretical calculations for a given system.

Given the extreme climatic conditions in the area of Lleida (continental part of the region of Catalonia, Spain), it is even more necessary to have more knowledge about the development of these species in local weather conditions. Lleida has a climate classified as dry Mediterranean continental, characterized by its great seasonal variations. It has low rainfall and it has a thermometric regime with large differences between a long winterand a very hot summer.. This is a very similar climate to that of the area of Madrid.

According to these considerations, a long-term work has been raised in order to obtain data on the behaviour of green facades in buildings as a passive system for energy savings in dry Mediterranean continental climate. The experimentation started refers specifically to double-skin green facade or green curtain. This typology has been chosen because of its easiness to assemble and disassemble, its easiness to integrate it into the building, and because it requires minimum posterior maintenance.

2 OBJECTIVE

The main objective of this experiment was to study and monitor during one year a double-skin green facade or green curtain, with modular trellis and Glycine (*Wisteria sinensis*), in Mediterranean continental climate.

3 METHODOLOGY

In May 2007 the rehabilitation of a former building in Gomés (Lleida, Spain) as social activities local was finished. A double skin green facade with a structure of steel and *deployè* sheet steel, in the northwest, southwest and southeast facades was included in the project (Figure 2). Different parameters to evaluate this green facade were measured from September 2008 to August 2009.

The species planted on all three fronts is *Wisteria sinensis*, a deciduous climbing plant which is characterized by its rapid growth and great development, well adapted to the conditions of the dry Mediterranean continental climate.

The collection of data was done weekly. Different points of the intermediate space between the structure and the facade, and also the exterior, were measured (Figure 3). This distribution compared the behaviour of the green facade in different orientations with the exterior environment values.

Figure 2. Theatre *Lo Casal* de Golmés green facade, 2008.

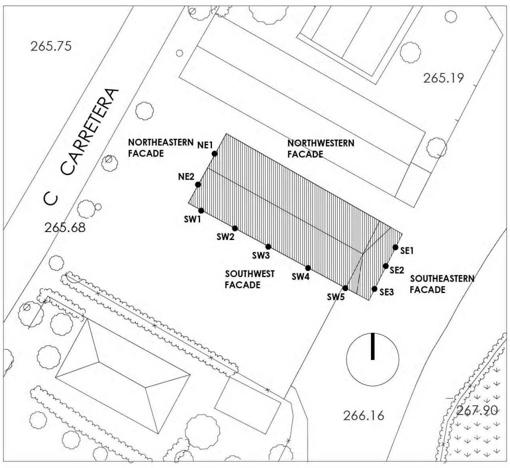

Figure 3. Location of measurement points in Golmés.

The parameters that were monitored were intermediate and exterior illuminance (Lux), with a TESTO 545 light meter, intermediate and exterior environmental temperature (°C) and intermediate and exterior environmental relative humidity (%), with a TESTO 625 digital thermo – hygrometer, surface temperature of the built facade (°C), with a TESTO 845 infrared thermometer, and finally, the wind speed outside (estimate based on the Beaufort scale). These measures were always taken at about 14:00 hours.

4 RESULTS AND DISCUSSION

4.1 *Illuminance*

Figure 4 presents the evolution of the monthly average illuminance (lux) measured in the intermediate space between the green curtain and the wall of the building for the three orientations (SE facade, NW facade and SW facade), the outside monthly average illuminance (Outside), and finally we have also included the evolution of monthly average value for all vegetated facade, which takes into account the three orientations (All facades). These values measure the ability to produce shade of the green facade.
A different dynamic was found in the three orientations, being the south east orientation, as measures are taken at noon, the best representative of the shadow effect of the vegetation.

The difference between the intermediate space illuminance and the outside illuminance was about 10,000 to 30,000 lux in the months without leaves. That difference could be attributed to the shade produced by the steel structure, the trunks and the branches. At the time that the foliage began to grow, this difference began to increase, reaching peaks in July and August, when the leaves were fully developed, presenting differences in illuminance higher than 80,000 lux.

Figure 5 shows the light transmission factor of the green curtain, calculated as the ratio between the illuminance in the intermediate space and the illuminance outside, for different orientations and for the total facade. This value varies from 0 to 1, indicating the amount of light radiation that passes through the green screen.
Whereas the measures were taken at noon, the south façade is where the measurements are more representative of the vegetated screen ability for to intercept radiation. These values varied from 0.04 in July to 0.37 in April, season with the foliage developed, and from 0.38 to 0.88 in the period without leaves. These values are comparable to the best values of the shadow factor that can be obtained by using artificial barriers for the south orientation which we can see in Table 3 (Spanish Building Code 2006).

The increase of illuminance in the months of May and June on the south east facade is due to the position of the sun at the time when the measures were taken, because the sunlight came through the top of green facade.

4.2 *Building wall surface temperature*

Figure 6 presents the temperature of the wall surface of the building in the intermediate space (with shadow), for the three orientations, and in a sunny area in the south-west facade. Although not all data is available, the surface temperature in an area without shade was on average approximately 5.55 ºC higher than in areas partially covered by vegetation. This difference was higher in August and September, reaching maximum values of 15.18 ºC on the south west side in September.

4.3 *Environmental temperature*

Figure 7 shows the monthly average environment temperature data. Here, no significant differences were found. In general, during the period without leaves the values of the temperature in the intermediate space were higher than the temperature outside, while in the period with leaves the inside temperature was lower than the outside.
Comparing the different orientations, this effect is especially evident in the south west facade. In July, in the intermediate space of the south west orientation, a temperature 1.36 ºC lower than the temperature outside was achieved. On the other hand, the effect is emphasized in winter, with maximum of 3.8 °C higher in the intermediate space than the outside temperature.

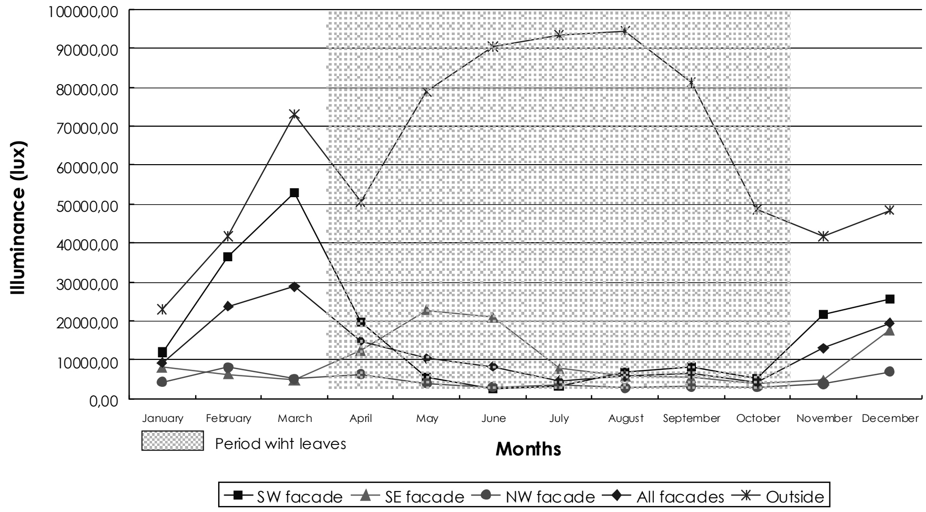

Figure 4. Iluminance measured at the Golmés green facade, in 2009.

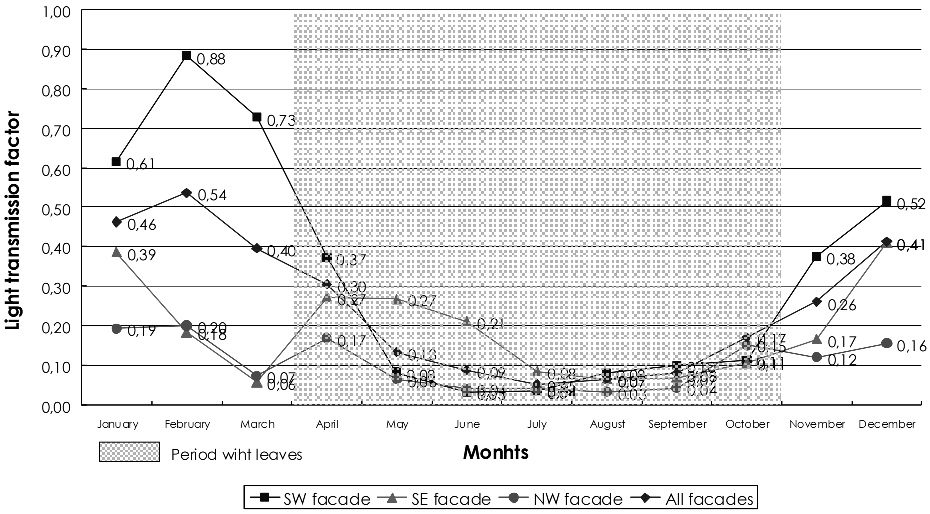

Figure 5. Calculated light transmission factor for the Golmés green facade, in 2009.

Table 3. Shadow Factor for artificial barriers in south orientation

Artificial barrier	shadow factor
Cantilever	0.16 – 0.82
Setback	0.17 – 0.82
Opaque awnings	0.02 – 0.43
Translucent awnings	0.22 – 0.63
Horizontal slats	0.26 – 0.49
Vertical slats	0.32 – 0.44

4.4 *Environmental relative humidity*

Figure 8 shows the evolution of the monthly average relative humidity of the environment. In general, for all orientations, it was observed that during the period with leaves the relative humidity of the intermediate space was higher than the outside. This difference increased with the growth of the foliage, being this effect very evident in the south west facade, which was around 7% higher in July. In the period without leaves, the relative humidity in the intermediate space was lower in all directions, being also the south west facade the one where the effect was most evident, in December, with maximum differences of approximately 8%.

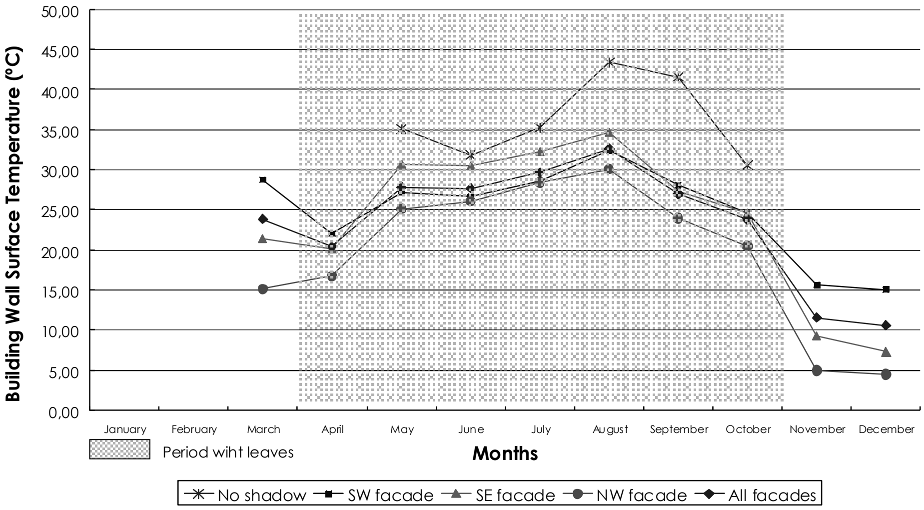

Figure 6. Building wall surface temperature measured at the Golmés green facade, in 2009.

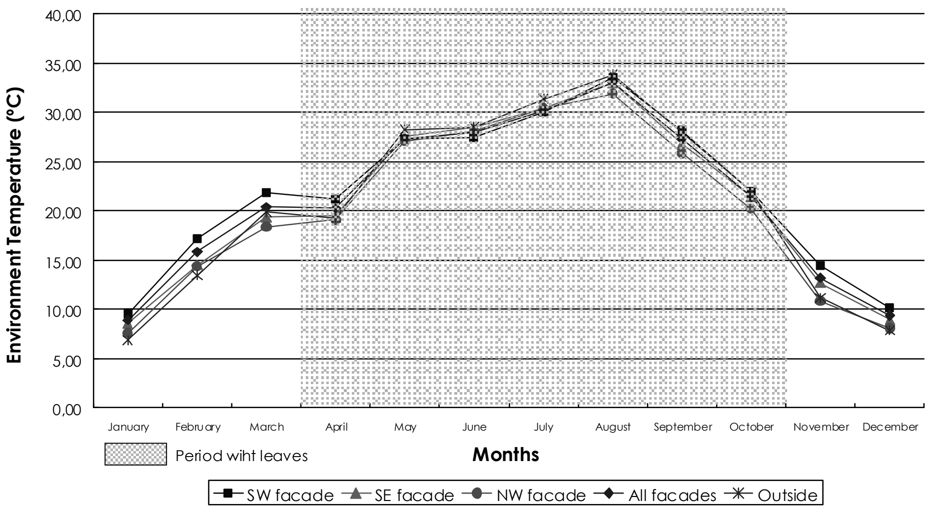

Figure 7. Environment temperature measured at the Golmés green facade, in 2009.

4.5 *Wind effect*

Figure 9 shows the variation of wind speed estimated according to the Beaufort scale. This information, although it was estimated, is of great interest in order to interpret the data of temperature and relative humidity. The persistence of a weak to moderate wind means that the values of outdoor temperature and humidity are lower than those achieved with calm wind. In summer, with the foliage developed, the shadow effect reduces the temperature in the intermediate space (Figure 7), but the wind effect makes the difference between outside and intermediate space temperatures to be lower. The relative humidity (Figure 8) is higher in the intermediate space in summer, and is higher outside in winter. In months with strong wind, for example in March, April and May, these differences are reduced.

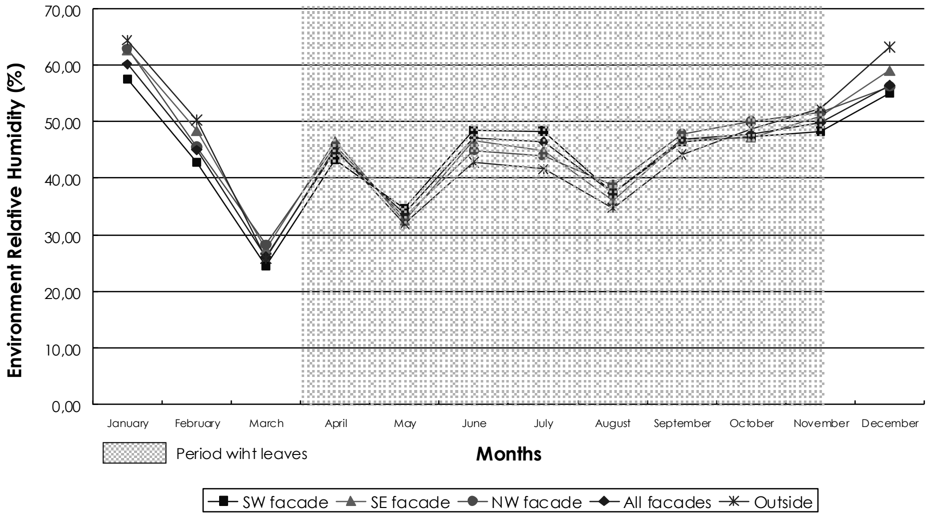

Figure 8. Environment relative humidity measured at the Golmés green facade, in 2009.

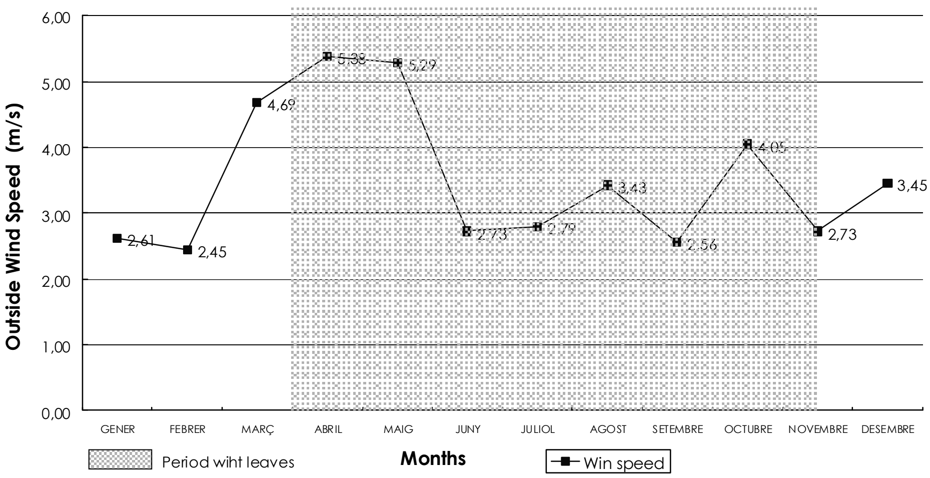

Figure 9. Outside wind speed at the Golmés green facade estimated according to the Beaufort scale, in 2009.

5 CONCLUSIONS

In the use of green vertical systems as passive systems for energy savings in buildings, one must consider the type of system, the parameters that influence their behaviour, and finally it is essential to know the behaviour of the different species in local weather conditions.
Studying and monitoring a double-skin green facade or green curtain, using modular trellis and Glycine, in Mediterranean continental climate, it was found that:

- The difference between the intermediate space illuminance and the outside illuminance was about 10,000 to 30,000 lux in the months without leaves, difference that can be attributed to the shade produced by the steel structure, the trunks and the branches. At the time that the foliage began to grow, this difference began to increase, reaching peaks in July and August, when the leaves were fully developed, with differences of more than 80,000 lux.
- For the south west orientation the values of the light transmission factor were from 0.04 in July to 0.37 in April, with the foliage developed, and were between 0.38 and

0.88 in the period without leaves. These values are comparable too to the best values of shadow factor that can be obtained by using artificial barriers for the south orientation.

- The building wall surface temperature in an area without shade was on average approximately 5.5 ºC higher than in areas partially covered by vegetation. This difference was higher in August and September, reaching maximum values of 15.2 ºC on the south west side in September.
- The illuminance and light transmission factor values, as well as the differences in the building wall surface temperatures, confirm the great capacity of the green screen to intercept the radiation.
- During the period without leaves, the values of the temperature in the intermediate space were higher than the outside temperature, while in the period with leaves the inside temperature was slightly lower than the outside. In the south west orientation, the intermediate space reached 3.8 ºC higher temperatures in winter, and 1.4 ºC lower in summer.
- It is observed that during the period with leaves, the relative humidity of the intermediate space was higher than the outside (7% higher in July) and lower in the period without leaves (8% lower in December).
- The air in the intermediate space changed, creating a microclimate where environmental conditions are higher temperature and lower relative humidity in winter (leafless period), and lower temperature and higher humidity in summer (period with leaves). This fact verifies that the green facade acts as wind barrier and shows the effect of evapotranspiration of plants.
- The wind can change this tendency by reducing the differences between the values of the intermediate space and the outside.
- The results do not allow to withdraw conclusions about the insulation effect of a green facade.

6 ACKNOWLEDGEMENTS

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Conception of Sustainable Construction in civil engineering projects. Dimensions and Indicators of Sustainability

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ABSTRACT: Sustainable construction must be real not only at building scale but also at infrastructure scale. Thus, it is a first approach to the sustainability of infrastructure projects in Spain by implementing a series of techniques (interviews, surveys and brainstorming) by the standards of project management. It has been identified those elements that different parties involved in an infrastructure project seen as key elements that must be evaluated to consider a project as sustainable. It is a first step in selecting indicators and dimensions of sustainability in the field of civil engineering in Spain, where they have noted the different views existing about sustainability according to the professional area of each actor. It is shown a first selection of sustainability indicators identified through this collection of information

1 INTRODUCTION

The term "sustainability" came into use in the 50s when it was observed that in fisheries and timber production were obtained less than those usually obtained, and was described as "sustainable yield" that it drew resources at a lower speed that the rate of regeneration (Torrijos, 2007). Gradually, this concept has been flooding all existing fields.

Until a few years ago, society has been characterized by rapid growth and development in industrialized countries, technocentric consciousness, belief that resources are unlimited, population growth and all of this coupled with impacts that are not appreciate directly (long term impacts). This makes that the effects of our development model gets them for future generations. The truth is that resources are limited, nature has limits production of materials, services and waste absorption, there are enormous social and economic differences between developed and third world, like within the same society, ecc. (Millennium Ecosystem Assessment, 2005). This means that in recent decades has begun to raise a new model of social and economic development: sustainable development.

Evolution of sustainable development term has gained importance to even be considered the most important challenge of the new century, but: do we understand all the same for sustainability or sustainable development?

There are different trends in meaning the sustainability varying the rigidity discussed by various authors (Bell and Morse, 2008; Dresner, 2008) and basically reflect two different ways of understanding sustainability, what is usually called weak sustainability vs strong sustainability. The former are defenders of the current way of conducting human activities but seeking a better balance with the planet's capacity. The latter argue that there must be a profound change of mentality, development model and, therefore, change in human activities. Among the latter, you might include supporters of the new concept emerged called "degrowth" with its theoretical foundation in the Club of Rome by the Report Meadows in 1972 and, especially, in Nicholas Georgescu-Roegen in 1971. These are precursors of the idea that we need a brake on growth to help the world meeting needs of humans and environment and balance the scales tilted excessively toward the side of economic development. The following table (table 1) displayed in summarized the evolution of sustainable development concept since its inception in 1968. Even with different visions of sustainability, what can be concluded of these new concepts and theories is, of course, that the current model of doing things is not consistent with surrounding environment: environment, social economy and society, and must therefore change the way we do things, also in the construction sector. In 1994 starts the awareness in construction sector seeking the sustainability in the field (Kibert, 1994) with the first congress of sustainable construction in the world. The biggest problem in this sector is the wide variety of actors and parties that are involved in varying degrees during the life cycle of a civil engineering project (Button, 2002). It is for this reason that it presents a first study to know the sensitivity of existing knowledge about sustainability and sustainable engineering in the professional and real life.

Table 1. Evolution of sustainable development term

Year	Subject	Developments
1968	Creation of Club of Rome	Stable growt of mankind *"The limits to growth"* published in 1972
1972	Earth Summit in Stockholm	Posible Climate Change New concept of development
1987	Brundtland Report	Sustainable development concept
1992	Earth Summit in Rio de Janeiro	UNFCCC (189 countries ratify) Agenda 21
1997	Earth Summit in New York (Rio + 5)	Need to make concrete progress Establish national strategies for sustainable development
2000	Millenium Summit of the United Nations, New York	Millenium development goals (MDG)
2002	Earth Summit in Johannesburg (Rio + 10)	Sustainable Development Summit 3 pillars: economic, social and environmental
2005	Enters Kyoto Protocol	> 50 % of sending countries signed the protocol
2007	Rio + 15 Conference in Rio de Janeiro	Final document in Bali (Indonesia)

2 OBJETIVES AND SCOPE

As shown in the brief introduction, sustainability concept is a term now well developed. What concerns us as engineers is to know how sustainability can be implemented in infrastructure projects, because it is not enough to know about the three pillars of sustainable development: respect for the environment, social integration and social economy. It has been carried out an identification of all stakeholders of an infrastructure project related directly or indirectly throughout the project life cycle. Subsequently it has set a target to perform an identification of sustainability indicators through a series of surveys, interviews and brainstorming with all stakeholders. The objetive is to achieve a compilation of information and data about dimensions and sustainability indicators that different actors think are necessary be measured for the sustainable evaluation. To do this, no pre-determined indicators have been suggested in order not to condition our own concept of sustainability, and being different actors involved in a project who opine about sustainability concept. Indicators model was selected because it is the most used model to assess sustainability, as the International Organisation for Standardization suggests for building sector (ISO 21929-1, 2006).

Thus, proposals of indicators for sustainable assessment in infrastructure projects of those stakeholders involved in a project will be shown as a first step towards a first sustainability model for infrastructure projects in Spain. The ultimate objective is to identify those indicators that should be considered, according to different actors, to make possible the study of sustainability of an infrastructure project and enable comparison with other proposals such as those of Dasgupta and Tam (2005) and Ugwu et al (2006).

3 SELECTING STAKEHOLDERS AND COLLECTING DATA

Following the methodology of *Who Counts?* (Colfer et al, 1999) it was performed to identify those involved in an infrastructure project life cycle using the criteria of dependence, work areas, activities and legal rights. Thus, it is shown schematically actors involved in a generic infrastructure project at various stages in the life cycle (Figure 1).

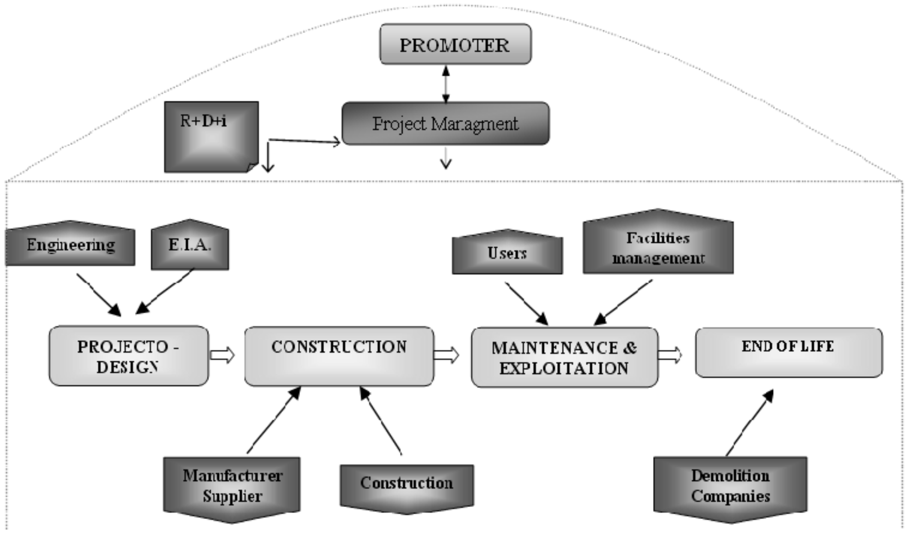

Figure 1. Life cycle of an infrastructure project and stakeholders

Then we proceeded to collect the information using three existing techniques following a project management standard of the Project Management Institute (2004): surveys, interviews and brainstorming.

The survey is one way for achieving gather information from experts and stakeholders in a project with a given profile. This technique allows the use of remote media such as e-mail or regular mail, which overcomes some of the logistical constraints of brainstorming or interviews, while maintaining some scope for the exchange of ideas (APM 2004). Thus, there were sent a total of 200 surveys to the various agents involved in the project. According to Lapietra (2006) return rate is usually around 30% in this type of surveys. Finally it has been possible to analyze a total of 79 surveys distributed among the different actors involved (39.5% return). They are given the option to assess the different dimensions considered by the various tools of sustainability assessment of construction projects. These questions were semi-open with scoring options from 0 to 6 in order of importance each respondent considered. Zero means no relationship between the dimension and the achievement of a sustainable infrastructure project and a score of six means the establishment of this dimension as a fundamental part of a sustainable project. It was also requested for indicators that it should assess or measure the sustainability of an infrastructure project using open questions, so that the respondent would suggest those variables considered critical to achieve sustainability. So the survey was based on proposals by the respondent and not an assessment of indicators proposed by researchers. Sampling was not probabilistic because what interests us it was actors who supply us more information (those involved in an infrastructure project). Moreover, it should be noted that, in the case of a questionnaire "it is read the question" so it is standardized and is drawn equally to all, thereby reducing the bias of interpretation by the interviewer. As we are in identification phase, we are not looking for a statistical analysis. We consider only the process by receiving completed surveys until the information was becoming repetitive. In fact, the data redundancy (repetition of the indicators without providing new) provides greater validity to the information being gathered (Alaminos and Castejon, 2006).

The score given by different stakeholders to the 13 dimensions suggested to achieve sustainable construction in an infrastructure project are those listed in the following table 2. They are significant data in the way that shows how dependent are fields of work of each actor in giving more importance to different areas. For example, ecologists gives more importance to aspects as biodiversity, atmosphere, energy, water than other sectors in general, same as users give more importance to security, social economy or integration to the society.

Table 2. Dimension scores following the responses of different stakeholders

Actors / Dimensions	Designer	Constructor	Environment expert / ecologist	Manufacturer / Supplier	R+D+i	Users	Promoters	Maintenance / Deconstruction
Water	4.95	5.55	5.62	5.67	6	5.34	5.71	5.75
Biodiversity	4.47	4.42	5.33	4.67	4	4.9	4.71	3.75
Atmosphere	4.33	4.36	5.88	4.83	4	4.82	4.57	3.8
Energy	4.14	4.37	5.55	4.67	5.3	4.75	5.57	4.75
Innovation	4	3.63	3.25	4.5	4.5	3.9	3.83	4
Culture	3.94	3.22	3.56	3.5	2.5	4.6	3.57	2.25
Soil	4.71	4.37	4.44	3.83	3.5	5.22	4.57	5.5
Landscape	3.3	3.67	5.5	4.5	4.5	4.4	5	5.5
Social economy	4.35	5	4.75	4.8	5.1	5.9	5	4
Resources	5.1	5.8	5.67	5	5.8	5	5.5	5.4
Wastes	3.52	5.5	5.2	5	5.3	5	5	5
Health and safety	3.23	5.2	4.9	5.2	5	4.9	5	5
Society	3.1	5	5.5	5	4.7	5.3	4.5	4.6

Sustainability indicators suggested by different respondents, it is interesting that many have been repeated in part by the association between them and sustainable construction concept such as waste management, greenhouse gases emissions or water management and protection that are of vital importance in the Spanish reality. Table 3 lists the proposed indicators and reflected the number of times it has been proposed in the different surveys. In total, they have suggested a total of 49 sustainability indicators that respondents considered essential.

Table 3. Indicators proposed by respondents

Indicators	Times proposed	Indicators	Times proposed
Water management	32	Recoverability of original environment	4
CO_2 Emissions	25	Number of protected species	4
Biodiversidad afection	20	Soil loss	4
Water quality	19	Energy efficiency	4
Disease to rivers / discharges	18	Ecological soil value	4
Contaminant gaseous emissions	16	Education courses for society & users	4
Waste management	16	Cooperation between administrations	3
Use of local materials	16	Public information of the project	3
Energy consumption in life cycle	14	Recicling of materials	3
Landscape	13	Renewable energy use	3
Employment generation	10	Barrier effect	2
Ensuring availability of water resources	10	Saving water	2
Protection and respect of cultural and historic heritage	10	Afection to society	2
Use of local vegetation	8	Cumulative impacts with other projects	2
Aquifer protection	8	Number of accidents in work	2
Environmental awareness	7	Number of illness	2
Public transport	6	Number of accidents in use	2
Liquid waste control	5	Health in work	2
Air quality	5	Saving energy	2
Environmental hazards of materials	4	Control of noise	2
Reusing materials	4	Green zones	2
Earthmoving balanced	4	Encourage traditional and cultural values	2
Environmental audits	4	New techniques and technologies / Innovation	2
Using woods with green certificates	4	Environmental formation of workers	1
Durability	4		

The second technique used is interview. This technique involves conducting interviews with experts and stakeholders and, in this case, it will serve to identify sustainability indicators. The use of this technique is a major source of data collection for the identification of opportunities (PMI, 2004). Interview has many of the advantages of brainstorming technique that will be discussed later and requires a similar semi-structured approach, where the interviewer assumes the role of facilitator. The disadvantages are, of course, the interviewer's time consuming and that the emergence of ideas is more limited than in a group of experts. However, some people are more comfortable expressing herself openly in a *one to one* situation (APM, 2004). This will make those more introverted people to express their ideas more easily. One of the key criteria in the interviews is to be present only the interviewer and interviewee, where it can be done a normalization of the interaction between them (Alaminos and Castejon, 2006, 69). In applying this technique, the facilitator or interviewer was the same person, so the error of different interpretations when questioning is eliminated. In these interviews, it has contacted the following organizations: members of World Council of Civil Engineers (WCCE), members of College of Civil Engineers in Spain (CICCP), Observatory of Sustainability in Spain (OSE), Observatory for Sustainable Aviation (OAS), Association of Promoters and Constructors of Spain (APCE), Ecologists in Action based in Madrid, Association of Building Materials (ASEMACO), user associations like the Association of Spanish Highway (AEC) and Spanish Federation of Friends of the Railroad, professors and researchers from the Universidad Politécnica de Madrid (UPM). In these interviews (about 30 in total) have come to identify the following indicators proposed by the various respondents (table 4) reaching a total of 22 indicators. In the case of dimensions, all respondents were more or less related to sustainable development concept, so there were a virtual unanimity in the selection of the dimensions of sustainability in infrastructure projects: environment, economy, society and territory.

Table 4. Indicators proposed by interviewee

Indicators	Times proposed	Indicators	Times proposed
Energy consumption	22	Optimization of resources	10
CO_2 emissions	20	Public information / Afection to neighbors	9
Vial security (citizens and users)	18	Accoustic comfort	9
Barrier effect of infrastructure projects	16	Jobs (money invested/workplace)	8
Health and security	15	Increase in CO_2 indirect emissions	7
Maximum recycling rate	12	Necessity of work? / Is there a better alternative?	5
Public participation	12	Basic accesibility	5
Contaminant emissions (PP – NO_2) / Air quality	12	Impacts to groundwater flow / groundwater hidrology	4
Depletion of non renewable energies – Use of renewable	11	Call effect of new infrastructures / evaporation effect of deconstruction	3
Hazards (fires, floods, droughts)	10	Environmental criteria in rehabilitations	2
Quality of life	10	Water-soil interaction	1

Finally, last technique used in this study was the brainstorming. The goal of brainstorming is a complete list of indicators or variables of sustainability in an infrastructure project by a dynamic group. It must be done with a multidisciplinary group of experts that should not belong to the research team. The brainstorming technique was applied to generate ideas quickly about dimensions and sustainability indicators under the leadership of a facilitator who is responsible of supervising and leading experts in their search of ideas. Although widely used in projects, brainstorming sessions have some limitations as to be favorable to the extroverted people. Facilitator was based on three sustainable breakdown structures (SBS) to guide the brainstorming. These were based on the breakdown of: life cycle, pillars of sustainable development and generic systems in which can be divided a civil engineering project. Profiles selected for brainstomring were: design engineer, construction engineer, maintenance engineer, expert in environmental impact assessment and sustainability, developer/promoter, administration, manufacturer and supplier of materials, professor-researcher and users. A total of nine people were subdivided into two groups. Initially it was explained the context of work and then it began with brainstorming within each group separately following the breaking structures comented. Before the end, the group is joined again to show the ideas, indicators and dimensions that emerged in each group. Consensus on sustainability pillars (environment, economy and society) as the fundamental dimensions resulted in a complete quorum. Sustainability indicators that were considered essential for assessing sustainability of an infrastructure project, came up to a total of 22 indicators such as "happiness" or "ethic" that emerged as concepts that should be present in all sustainable project. Table 5 shows these indicators proposed in brainstorming session.

Table 5. Indicators proposed in brainstorming

Indicators	Indicators
Water contamination	Civil engagement
Energy consumption (renewable / non renewable)	Happiness of citizens and users
CO_2 emissions	Cost / Benefit
Landskape afection	Life cycle cost
Afection to protected species	Water consumption
Biodiversity loss	Accesibility / Adaptation to human biodiversity
Area of land affected by the project	Social integration
Materials consumption	Ethic
Compensation resources	Social cost (opportunities for future generations)
Transport (number of accidents)	Local economy
Risk management	Flexibility of the project

4 DISCUSSION AND CONCLUSIONS

It has been treated by this first initial study, the need to make more manageable the sustainability or sustainable construction concept in infrastructure projects. It was considered essential initial awareness that different construction actors have about sustainable construction. It has also sought to identify dimensions and sustainability indicators by stakeholders considered basic for the sustainable assessment. So it has tried wherever possible to collect all this information without prior contamination of the background of the researchers. This was done using Project Management Institute standard (2004) using techniques of identifying opportunities through surveys, interviews and brainstorming sessions. These three techniques complement each other perfectly because of their defects and weaknesses are supplemented with the strengths of others. Thus, in brainstorming session unimaginable indicators can be obtained through the dynamics of spontaneous generation of ideas by a multidisciplinary group. Problems are, as already noted, that introverted people are pushed into the background and probably do not provide information to the study. This error is mitigated through personal interviews and surveys. The biggest weakness in surveys is the unknown status of the respondent and the importance given to each question. On the other hand, interviews allow the exchange of information beyond the questions in a questionnaire. With the experience achieved in interviews, the information was much bigger in this last case than in the others, because of the interest of the interviewed giving further information, documentation and viewpoints beyond the objetive of the interview. As a negative aspect is has been the large amount of time needed for the development of all interviews. With the weaknesses, threats, strengths and opportunities of each technique it can be achieved a triangulation to identify all sustainability indicators which are considered by the various stakeholders as key indicators.

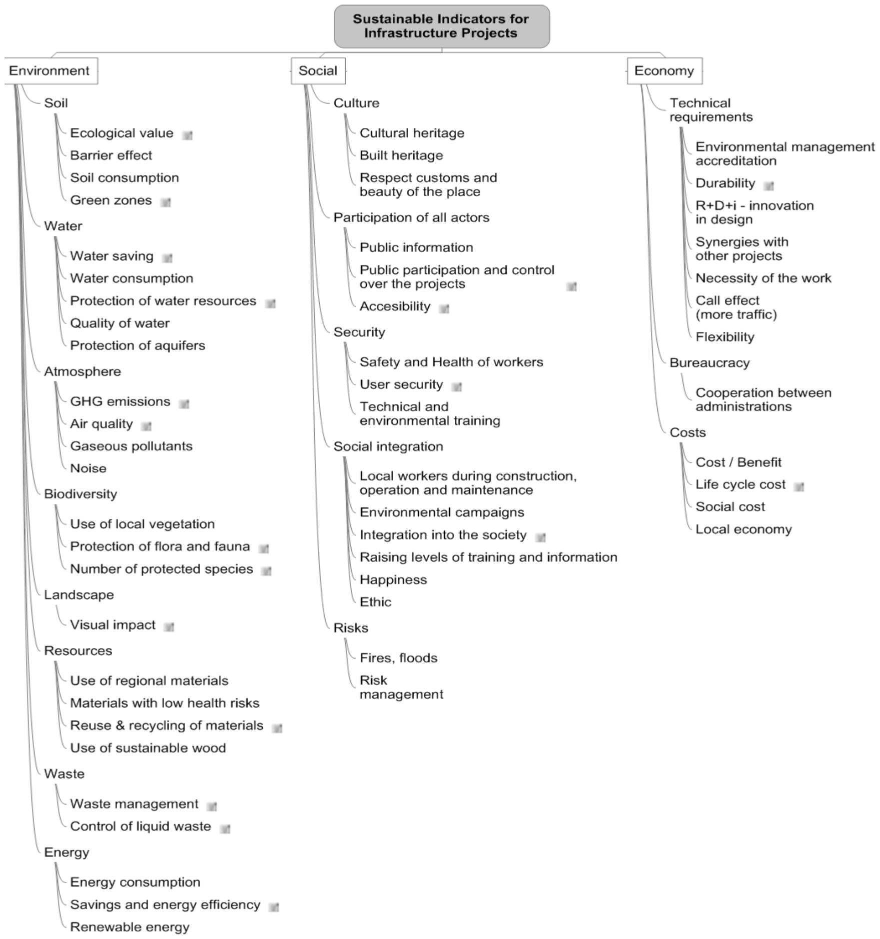

Figure 2. Sustainable indicators identified by interviews, surveys and brainstorming

Sustainability indicators identified by the information-gathering techniques are reflected in the general scheme (figure 2). As shown, it has produced a great number of indicators selected by different actors and, as others have noted, the number of them in any assessment of sustainability must be reduced (Button, 2002; Alarcon, 2005). In addition, the number of indicators obtained related to environment area is far superior to those obtained for social and economic areas, as others have pointed out about the various existing models of sustainable assessment (GTIS, 2004; Saparauskas, 2007). This means that the image of sustainability is still covered mostly by environmental criteria. Obviusly, although these criteria are essential for achieving a sustainable construction, one should not underestimate the importance of social and economic areas to achieve a sustainable balance in infrastructure projects. To make a proper balance between social, economy and environmental areas in this case, it will be necessary to analyze and prioritize sustainability indicators to obtain few key indicators for infrastructure projects and make it manageable and evaluable. This future sustainable assessment based on these key indicators can be a great value added to infrastructure projects decision-making process when deciding between various alternatives, as at present in building sector much more developed.

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Computer simulation applied to urban analysis for the rehabilitation of sections of the Federal District - Brazil.

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ABSTRACT: This paper is about the sustainable environmental performance analysis assisted by computer simulations of the Brazilian Federal District urban expansion. As a practical case study, was chosen, a satellite city Gama. At first, an environmental diagnosis of the area, the second phase of the analysis was the tridimensional microclimatic simulations done by the ENVI-met free software. In this phase, 03 different urban sceneries are presented: The Present Scenery, The Future Scenery 1 and The Future Scenery 2. These sceneries represent the in- creasing growth of the usage and occupation of the soil, and the verticalization of the area. With the simulations it is concluded that both future sceneries result into climatically uncomfortable sceneries. From the final diagnosis, policies for a bioclimatic urban design were casted with the intention of generating a smaller environmental impact in the area and suggesting sustainable alternatives to weaken the negative impact caused by the changing of the usage and occupation of the soil in the area. Keywords: computer simulation, urban sectors, environmental performance.

1 INTRODUÇÃO

1.1 *Espaços Urbanos*

O desempenho ambiental das cidades depende tanto do clima pré-existente quanto de modificações climáticas introduzidas pela urbanização, principalmente na velocidade e direção dos ventos, na qualidade do ar, radiação solar e umidade relativa. Essas condicionantes são afetadas principalmente pelo volume de massa construído, pela forma das edificações, poluição atmosférica, alterações das superfícies que aumentam o calor (reflexão e absorção), impermeabilização do solo e escassez de vegetação e água.

Vê-se que o processo de urbanização tende a criar microclimas peculiares. Estes, por sua vez, apresentam condições de habitabilidade e sustentabilidade nem sempre satisfatórias ampliando a necessidade de intervenções urbanas bioclimáticas que podem reverter ou minimizar estas conseqüências.

Dessa forma, percebe-se que muitos dos problemas causados pelo processo de urbanização estão intimamente relacionados ao microclima, o que tem feito crescer o número de pesquisas sobre o desempenho climático dos espaços urbanos. Isto é justificável, uma vez que as variáveis do clima urbano afetam não somente os espaços abertos, mas atuam de forma clara nos espaços construídos, repercutindo diretamente no conforto dos usuários.

Como objeto de estudo, foi escolhido Setor Industrial do Gama, em virtude das propostas do SEDUMA – Secretaria de Estado de Desenvolvimento Urbano e Meio Ambiente para alteração do gabarito deste setor, visando a preparar o setor para receber a demanda de população que apresenta grande taxa de crescimento. Além disso, são previstas alterações no sistema viário da área que repercutem em forte impacto no entorno da Região Administrativa do Gama, localizado na região sul do DF.

2 CARACTERIZAÇÃO CLIMÁTICA DO DISTRITO FEDERAL

2.1 *Distrito Federal do Brasil*

O Distrito Federal do Brasil está situado aproximadamente a 16º de latitude sul (entre os paralelos 15º30' e 16º03', acima dos 1000 metros de altitude (1.070m), com uma temperatura média de 21,1ºC, se enquadrando dentro dos limites da região tropical. (FERREIRA, 1965, p.12).

O clima do DF pertence às categorias CWA e CWB de Köpper, que correspondem aos climas mesotérmicos úmidos de verão quente e de verão fresco. Pode ser classificado como Tropical de Altitude e é marcado por dois períodos distintos ou duas estações do ano bem definidas: Período quente-úmido – verão chuvoso, de outubro a abril, com uma temperatura média de 22ºC. E o período frio-seco – inverno seco, de maio a setembro, com temperaturas mais baixas no seu

início, a partir de fins de maio a agosto, com cerca de 19ºC média.

É comum a sensação de desconforto decorrente da temperatura elevada durante o dia e que diminui abaixo dos limites de conforto à noite. Devido à localização na área central do país e à sua altitude, essas amplitudes diárias de temperatura são consideráveis, especialmente no período seco sendo de aproximadamente 14ºC. Na estação chuvosa as amplitudes diárias de temperatura são aproximadamente 10ºC. A forte incidência de radiação solar ofusca as estações intermediárias, assim, a primavera e o outono mal são notados na região.

Com relação à insolação, os valores ficam em torno de 2.600 horas mensais sendo a média no verão (chuvoso) de 160 horas mensais e no inverno (período seco) de 290 horas mensais. Mais precisamente na região oriental de Goiás, da qual o Distrito Federal faz parte, mais de 70% do total de chuvas acontece de novembro a março. O inverno é extremamente seco, as chuvas são raras e em pelo menos um mês não há registro de nenhum dia de chuva.

A umidade relativa do ar média anual é de 67%. De abril a setembro a umidade relativa do ar sofre uma diminuição considerável, alcançando níveis inferiores a 25%. O mês mais seco é o mês de agosto, com 56% de umidade relativa média. A umidade relativa mínima absoluta registrada é de 8% no mês de setembro. Assim, ventos moderados e constantes sopram de leste (freqüência média anual), sendo que são mais constantes nas direções leste e sudeste no inverno e noroeste no verão, como mostra a Figura 1. Para este estudo são levados em consideração dos elementos do clima: ventos dominantes, temperatura do ar e umidade relativa do ar.

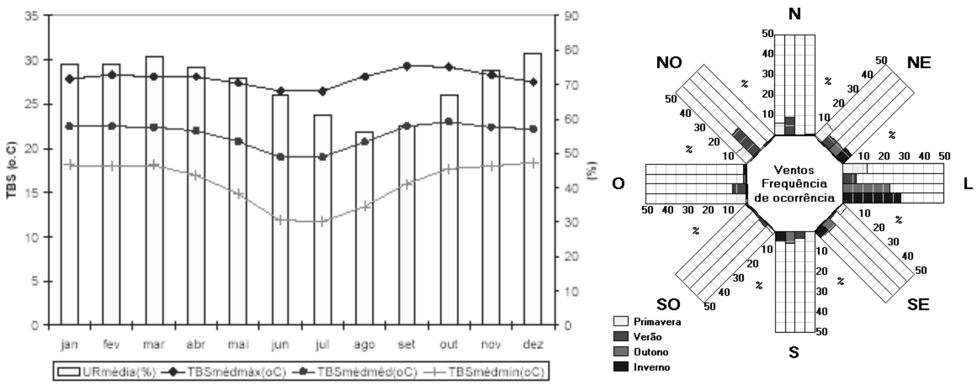


Figura 1: Dados Climáticos do Distrito Federal – Temperatura do ar e Velocidade dos Ventos.

3 OBJETO DE ESTUDO E CARACTERIZAÇÃO DOS CENÁRIOS

3.1 *Área de Estudo*

A área do estudo compreende o trecho leste da Região Administrativa II Gama, situada a sudeste do Distrito Federal. A área compreende as quadras QI 1 a QI 7 e Praça 1 da Região Administrativa do Gama, com 132,89 ha. (Figura 2)

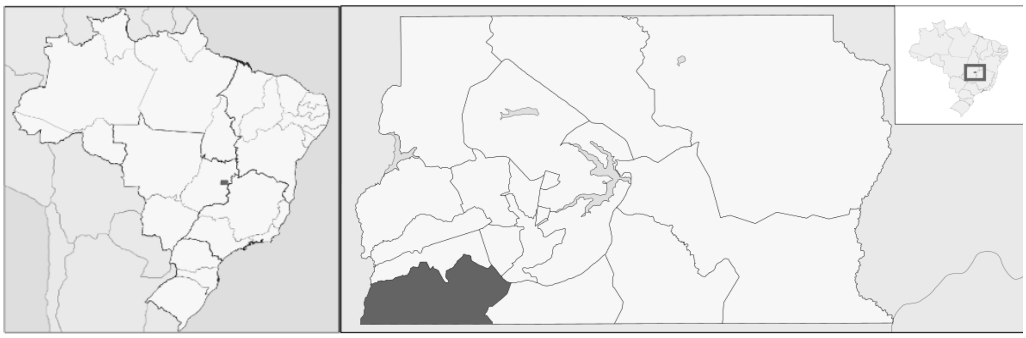


Figura 2: Localização do Distrito Federal – Demarcação da Região Administrativa – Gama – Objeto de Estudo.

Esta primeira etapa do estudo bioclimático avalia as alterações morfológicas do cenário 0 (situação atual) para o cenário 1, onde é proposto a implantação das edificações com projetos previamente aprovados na Administração Gama.

A análise tem como foco principal os conseqüentes impactos na ventilação, umidade relativa e temperatura, especialmente no microclima, e é utilizada como ferramenta de simulação o software ENVI-met, onde são apresentadas as simulações do desempenho ambiental realizada para os dois cenários.

Cenário 0: situação atual de morfologia urbana da área de estudo, considerando todas as edificações existentes e as 24 edificações aprovadas em primeira instância na Administração Regional, que estão em processo de implantação ou em fase final de construção. (Figura 3).

Cenário 1: Considera a situação atual e a implantação de 12 edificações, cujos projetos atualmente estão protocolados na Administração e ainda não construídos. (Figura 4).

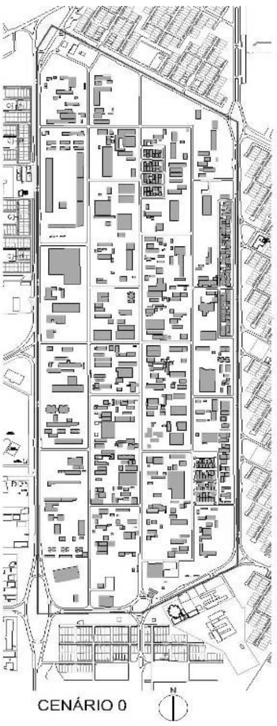


Figura 3: Croquis das edificações do Cenário 0

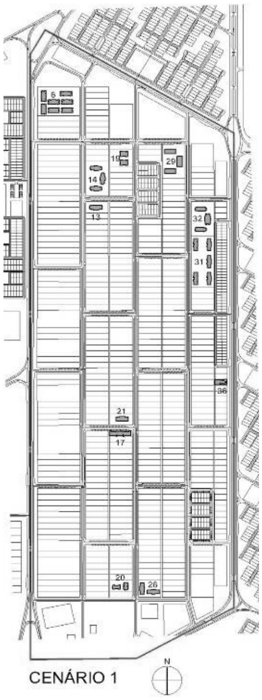


Figura 4: Croquis das novas edificações implantadas no

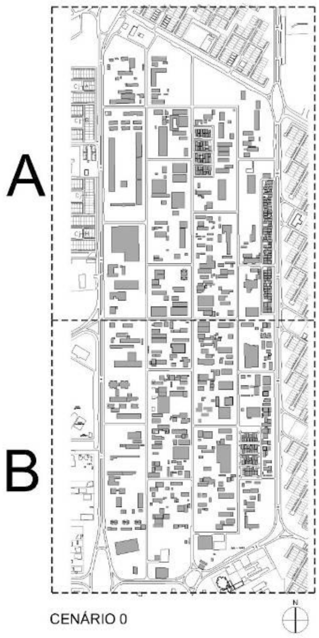


Figura 5 – Divisão da Área de Estudo em duas partes para simulação: A e B

4 DESEMPENHO AMBIENTAL

Para a análise do desempenho ambiental dos cenários 0 e 1 do Setor Industrial do Gama, são definidos alguns passos para a simulação computacional.

4.1 *Simulação de Desempenho Ambiental (Software ENVI-met)*

A segunda etapa deste estudo se dedicou às simulações computacionais realizadas por meio do programa ENVI-met. Bruse (2008) cita que este programa é baseado em diversos projetos de investigação científica e está, portanto, sob constante desenvolvimento. Sua proposta baseia-se no prognóstico das leis fundamentais da dinâmica de fluidos e da termodinâmica. O modelo inclui a simulação de: enchente ao redor e entre edifícios troca de processos de calor e vapor na superfície do solo e nas paredes turbulência troca de vegetação e parâmetros de vegetação; bioclimatologia; dispersão de partículas.

A aplicação do ENVI-met se dá nas áreas da climatologia urbana, arquitetura, design de prédios ou planejamento ambiental, entre outras correlatas. ENVI-met vem junto com um software adicional (Leonardo) que abarca editores e ferramentas de visualização gráfica para a modelagem dos resultados.

Para a finalidade deste trabalho, serão realizadas simulações com diferenciados ordenamentos, quantidades e tipos de vegetação nos pontos estudados, como também com diversos materiais de revestimento de solo, em diferentes proporções e índices de permeabilidade. Para isso, será seguida a metodologia de Duarte et. al (2008), em que usa simulações paramétricas explorando as diferentes formas de distribuição verde no espaço e seu impacto em diferentes configurações urbanas, a fim de verificar as reduções da temperatura e o aumento da umidade do ar, como também a de Silveira (2005) que estuda o desempenho da ventilação no espaço livre.

As simulações serão apresentadas por horário do dia, comparando-se as áreas entre si e focando os principais impactos com a inserção de novas construções.

O mês de setembro é escolhido para as simulações, tendo em vista que é esse mês que será dedicado a se realizar a coleta de dados in loco, por representar a época quente e seca, e, logo, mais significativa como uma situação desconforto para a cidade de Brasília e entorno.

Os horários em que são gerados os mapas de simulação são às 9 h, 15 h e uma extração de da- dos adicional de 12h. Para isso, seguiu-se o preestabelecido pela OMM – Organização Mundial de Metereologia.

De modo a possibilitar um melhor desempenho nas simulações e maior precisão nos resultados, a área de estudo (Setor Industrial do Gama) foi dividida em duas partes: A e B (Figura 5). No entanto, para a interpretação dos resultados, esta análise considerou as subáreas A e B como uma grande área unificada, sendo apresentados e discutidos os resultados das simulações para os horários significativos para o microclima do setor.

Para este artigo serão apresentados os resultados gráficos para a fração A.

4.2 *Entrada de dados no programa*

O programa ENVI-met apresenta uma interface bastante simplificada. Na tela principal do programa, é apresentada a área de inserção dos dados, e, na lateral esquerda, ficam os elementos básico que configuram a área a ser simulada, como vegetação, tipo de solo e gabarito das edificações.

Antes da simulação, cria-se um arquivo com configurações básicas para a cidade de Brasília. Para os dados não obtidos da estação climatológica de referencia da cidade, são utilizados da- dos oficiais disponibilizados nos aeroportos do mundo; utilizam-se, como referência, dados do aeroporto de Brasília – DF.

A seguir, é representada, para cada área, a transformação dos dados reais, partindo de imagem de satélite tirada no primeiro semestre do ano, para dados digitais, convertidos, inicialmente, em pixel no programa AutoCAD, em seguida, convertidos em arquivos Bitmap para a inserção na interface do programa ENVI-met. Torna-se importante salientar que cada área representada é de 1.400.000 m² (2000 m x 700 m), e, para melhor desempenho da simulação, são convertidas em duas tramas de 210 pixel x 140 pixel, logo, são construídas grades com dimensão de 5 m x 5 m.

Como etapa seguinte, é passada a representação das áreas, de arquivo AutoCAD (extensão DWG) para arquivo de imagem (extensão BMP) para, a partir deste, dar entrada no arquivo principal do programa, denominado area1.in. Neste arquivo, toda a caracterização da área é inserida, pixel a pixel, conforme detalhamento esquemático (Figura 6).

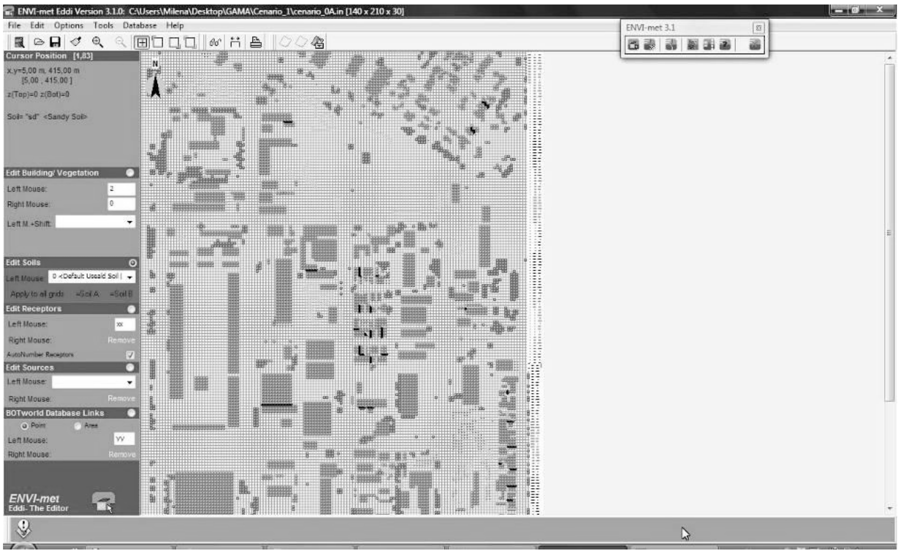


Figura 6 – Área A no ENVI-met

5 RESULTADOS DA SIMULAÇÃO COMPUTACIONAL APLICADA À ANÁLISE URBANA

Serão apresentados gráficos de resultados da simulação no ENVI-met, para o horário 15h, com os parâmetros de temperatura, umidade relativa e ventos na área de estudo.Os dados foram sistematizados em quadros sínteses e posteriormente analisados.

Através das simulações no ENVI-met, confirmadas pela avaliação sensorial, percebe-se que o Setor Industrial do Gama, na situação atual, possui uma baixa qualidade ambiental, pois não possui elementos e configuração morfológica que promovam conforto ambiental nos espaços urbanos.

São observadas, numa primeira análise, alguns pontos mais críticos: degradação espacial das edificações e vias, áreas verdes deterioradas, arborização insuficiente e ausente na área interna do setor, impermeabilização do solo (vias e calçadas), ausência de espaços de convívio, inexistência de mobilidade para os pedestres, poucos espaços gregários e com baixa qualidade ambiental (praças), sensação de insegurança pela ausência de pessoas, e ruído proveniente de pequenas fábricas e industrias que existem no setor.

As propriedades físicas dos materiais constituintes da massa edificada, da vegetação e das superfícies, pavimentadas ou não, dentro da estrutura urbana influem diretamente na quantidade de energia térmica acumulada e irradiada para a sua atmosfera e são expressas, principalmente, pelo albedo, absorção e emissividade. Dessa forma, contribuem para aumentar as temperaturas em um determinado espaço alterando inclusive o microclima.

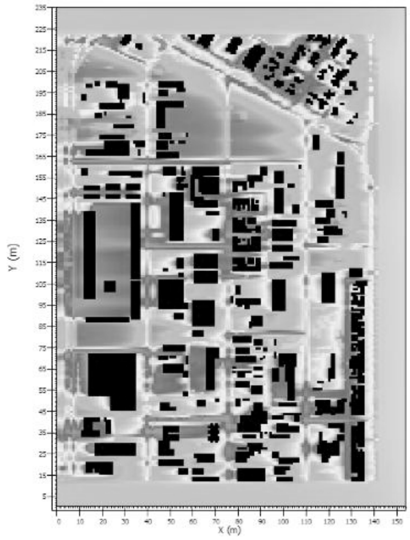
É nítida a predominância de espaços revestidos por materiais impermeáveis (vias asfaltadas e calçadas cimentadas e de concreto), albedos baixo e médio, baixa refletividade térmica e alta emissividade, configurando, assim, um prejuízo para o conforto higrotérmico. A impermeabilidade do solo é responsável:

- *pelo rápido escoamento das águas pluviais* que, uma vez não permanecendo no solo, não contribui para uma melhoria dos índices de umidade relativa do ar;
- *pela elevação das temperaturas* devido à absorção de calor pelas vastas áreas asfaltadas, pavimentadas e edificadas.

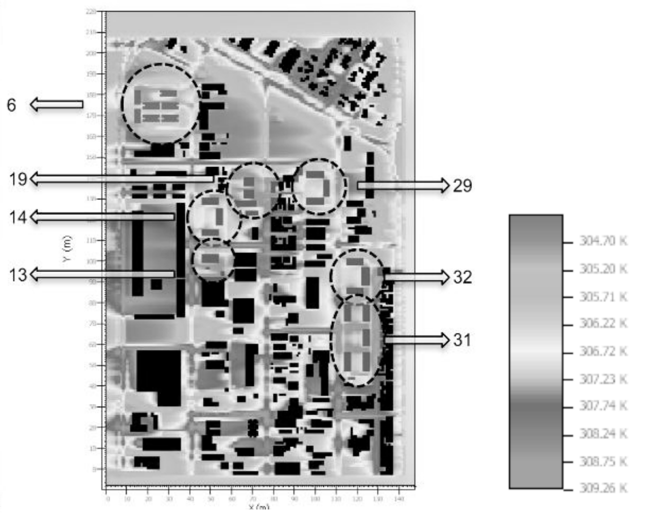
As áreas permeáveis são isoladas e degradadas, configurando vazios urbanos, com o solo sem revestimento ou terra nua. Esses são os locais de maior umidade, pela presença da terra, mas são esteticamente e espacialmente inibidores da presença dos usuários.
A arborização e forração vegetal são insuficientes, localizadas na periferia do Setor Industrial do Gama, principalmente nos canteiros centrais das avenidas de contorno, no campo de futebol e no parque infantil. Existe grande potencial de revitalização das áreas verdes, para melhoria do conforto ambiental do setor, além de possibilidade de maior qualidade nos espaços públicos de convivência, assim como nos lotes residenciais, desonerando-se assim o Poder Público da exclusividade de promover uma sustentabilidade ambiental.
É importante promover a arborização, alternando o surgimento de lugares de permanência e convívio, ou ainda de passagem e fruição dinâmica, como calçadões que ora se alargam ora se estreitam, melhorando o micro-clima.
Para alteração de uso do setor, de industrial para residencial é essencial uma requalificação espacial dos espaços públicos, pois as necessidades de qualidade ambiental são diferenciadas. Atualmente a área está deteriorada, não adequada para a mobilidade de pedestres e não permitindo aos usuários espaços adequados para a vida cotidiana. Não existem equipamentos e mobiliários urbanos, que convidem e sugiram à permanência e ao convívio, qualificando os espaços de cotidiano, importante na escala residencial.
É importante ressaltar que, para uma intervenção num espaço público ser bem sucedida, deve haver uma combinação de fatores que assegurem sua vitalidade permanente; buscar uma qualidade de implantação com lugares explicitamente convidativos e agradáveis, com uma correta execução e, principalmente implementar instrumentos fatídicos para uma manutenção exímia e constante, incorporando a comunidade local, o que auxilia a permanência das intervenções e a redução dos custos.
São utilizadas as dimensões Romero (2000) que analisa o espaço público urbano, considerando-o como uma unidade resultante de elementos ambientais climáticos, históricos, culturais e tecnológicas. Esses elementos ambientais são os ordenadores do espaço, agindo como estímulos dimensionais, em que, forma, pele e interior compõem as três grandes categorias de condicionantes de análise ambiental.

5.1 *Resultados das Simulações: 15 horas*

Temperatura do ar

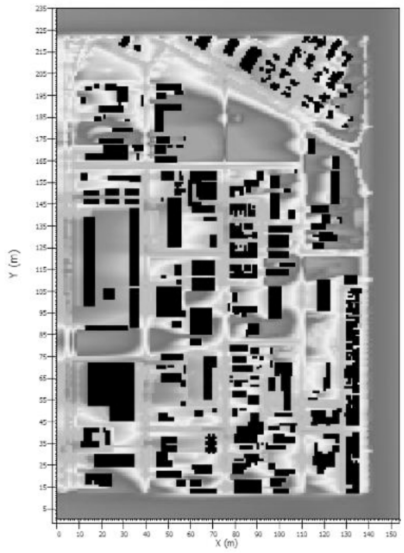


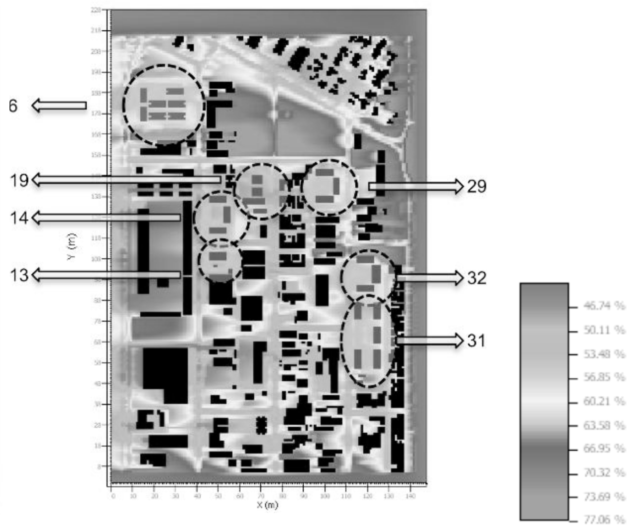
Temperatura do Ar - Cenário 0A



Temperatura do Ar - Cenário 1A

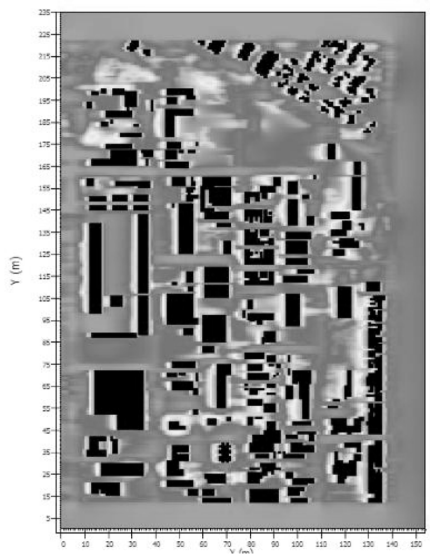
Velocidade dos ventos

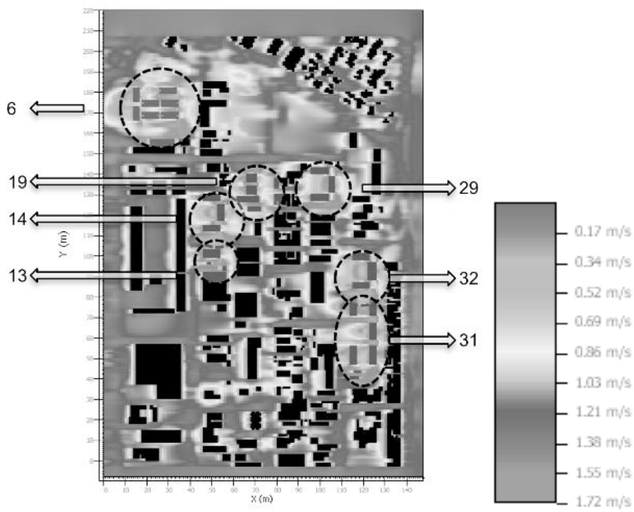




Temperatura do Ar - Cenário 0A Temperatura do Ar - Cenário 1A

Umidade Relativa do Ar





Umidade Relativa do Ar - Cenário 0A Umidade Relativa do Ar - Cenário 1A

5.2 *Conclusões*

Estudos como este são importantes como ferramenta comparativa e como indicativo de alternativas concretas de reabilitação de áreas urbanas. As simulações realizadas nos cenários fictícios quantificam que, caso haja mudança de gabarito em todo o setor, isso garantirá a falta de qualidade ambiental no Setor Industrial do Gama.

Foram registrados nas 15h, que representa um horário de bastante desconforto, valores máximos de temperatura do ar encontrados, nesta área de até 37,21˚C. Neste mesmo horário, foi verificado que nas quadras centrais, onde se concentra o grande volume edificado, os valores de temperatura do ar são os mais extremos, o que combinado com valores de menor umidade rela- tiva do ar (44,22%) culminam em um cenário desconfortável ambientalmente.

Table 2. Quadro Síntese das Variações e Amplitudes Máximas (15h) Parâmetro

	Variação	Amplitude
Temperatura do ar (ºC)	31,65 a 37,21 °C	5,56 C.
Umidade Relativa do Ar (%)	44,22 a 77,10%	32,88%.
Velocidade dos Ventos (m/s)	0,16 a 1,66 m/s.	1,5m/s.

Ainda em relação a umidade relativa do ar (%), pode-se perceber que as vias representam lugares bastante áridos, e são facilmente percebidos no resultado das simulações como cânions urbanos secos, corroborados pelo fato de canalizarem os ventos que chegam ao local.
Os volumes edificados nas quadras periféricas promovem efeitos desagradáveis para o desempenho do vento no local, ora formando canalizadores de ventos secos (vias sem arborização ou outros elementos ambientais capazes de umidificar os ventos), ora formando regiões de sombras de vento (região de calmaria, onde a brisa não pode ser sentida).
Com a inserção das 12 edificações (ou conjuntos) neste atual cenário, o impacto ambiental significativo é verificado na escala da quadra (numa primeira análise), o que fica diluído na escala do setor. São visíveis as alterações ambientais (temperatura do ar, umidade relativa do ar e velocidade dos ventos) na escala próxima as edificações (entorno imediato) e os impactos gerados para o espaço público, diagnosticados pontualmente em relação a cada horário (conforme mostraram as tabela de resultados).
De forma geral, os valores de temperatura do ar (˚C) tiveram aumento, e, em contrapartida, os valores de velocidade dos ventos (m/s) tiveram impacto com efeitos negativos de calmarias e canalizações, a umidade do ar teve redução em conseqüência do aumento da massa edificada e impermeabilização do solo.
Constata-se ainda que com o aumento do gabarito, (atualmente as edificações possuem em média altura de 2 pavimentos) a movimentação dos ventos será alterada, surgindo mais locais de sombra de ventos, assim como canalização, o que reforça a diminuição da umidade. Tais efeitos devem ser minuciosamente analisados, principalmente numa suposta implementação de mais edificações com grandes alturas no setor.
Vê-se que o Setor já se encontra bastante degradado ambientalmente e a reabilitação de toda a área com ou sem a implementação do cenário 1 faz-se extremamente necessária para qualidade de vida dos atuais e futuros habitantes. Dessa forma, mostra-se que a simulação computacional pode tornar-se forte aliada para subsidiar reformas e reabilitação de grandes setores urbanos, incorporando princípios sustentáveis para a escala do pedestre, conferido qualidade para o espaço público.

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Building's external walls in Life-Cycle Assessment (LCA) research studies

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ABSTRACT: The evaluation of the environmental impacts of buildings should consider the source of the construction materials, the resources used in the execution, the maintenance operations, the expected service life, and the replacement and/or demolition operations of each of the building assemblies. The Life-Cycle Assessment (LCA) integrated approach allows for the collection of the data concerning all these phases of the building's life-cycle and the evaluation of the corresponding environmental impacts.

The envelope is one of the main parts of the buildings and the external walls directly influence the thermal and environmental performance of the building envelope. This paper presents a detailed review of LCA results of more than ten years of international research studies on the environmental impact of a building's external walls, including the summary of the main results. The recommendations to improve the reliability and widen the scope and usefulness of these research studies are also presented.

1 INTRODUCTION

The evaluation of the environmental impacts of buildings should be made from a life-cycle point of view. This implies the consideration, for each building assembly, of the source of the construction materials, of the resources used in their execution, of the maintenance operations, of their expected service life, and of the replacement or demolition operations. The life-cycle assessment (LCA) integrated approach is one of the most used ways to achieve this goal. This methodology could be applied via a "cradle to grave" approach (including the extraction and processing of raw materials, the transport and distribution, the use, maintenance and final disposal) or "cradle to cradle" approach (also including the reuse and/or recycling) (Ortiz et al. 2009) based on ISO 14040:2006 and ISO 14044:2006 international standards (ISO 14040:2006(E) 2006, ISO 14044:2006(E) 2006). The application of the LCA evaluation method must be followed by the creation of extensive and reliable Life Cycle Inventory (LCI) data on the processes, namely concerning the construction materials. This effort is already being done in Europe (ELCD - European Life Cycle Database (Commission 2009)) and North America (US LCI Database - http://www.lcacenter.org/ database.html).

The envelope is one of the main parts of the buildings. One of its parts, the external walls, directly influence the thermal and environmental performance of the building envelope through their considerable weight in the envelope's initial embodied energy, life cycle energy consumption, life cycle cost and the users comfort. They could represent up to 15 % of the overall environmental impacts of a building over a 60-year life cycle (Bingel et al. 2006). The environmental impacts of each external wall solution result directly from the attributes of the materials used, such as its initial embodied energy and thermal properties, and from the way the solution is designed and built.

This paper presents a detailed review of LCA results of more than ten years of international research studies on the environmental impact of a building's external walls. The studies included in this paper differ in various parameters, namely their scope, objectives, level of simplification, completeness and transparency. Nevertheless, the results of each study contribute to identify the most environmentally friendly solutions for external walls of buildings.

2 SCOPE AND METHODOLOGY

The most important studies concerning the comparative evaluation of the environmental impacts of external walls of buildings were searched for in the main scientific databases (Science Direct, CIB and ASCE using keywords such as wall, LCA, brick, PhD, Thesis, building, etc. and combinations thereof). This compilation of studies includes scientific papers, thesis and technical reports from Europe (60 %), North and South America (19 %), Asia (13 %) and Oceania (8 %). The majority of these studies were done after 1999. This reveals the increasing concern about the environmental impact of buildings and building materials in the XXI century.

Only a third of the studies compare functionally equivalent products while half of them do not even refer the thermal performance of the external wall solutions being evaluated and their results cannot be compared in equal terms. Therefore, and because the former are representative of different regions of the world, the latter are just cited but not fully described nor analyzed in this paper. Nevertheless, the studies that compare external walls that are not functionally equivalent but regard the operation energy are also considered in this paper.

3 BUILDING'S EXTERNAL WALLS IN LIFE-CYCLE ASSESSMENT (LCA) RESEARCH STUDIES

All 38 studies found include the production of the construction materials and just a third includes the end-of-life of the building assembly (Fig. 1). The majority (63%) evaluate the embodied energy of each external wall and 39% clearly refer to the use of an Environmental Impact Assessment Method (mostly *EcoIndicator 99*) and a LCA software, but just one of them explicitly mentions that it followed the methodology described in LCA international standards.

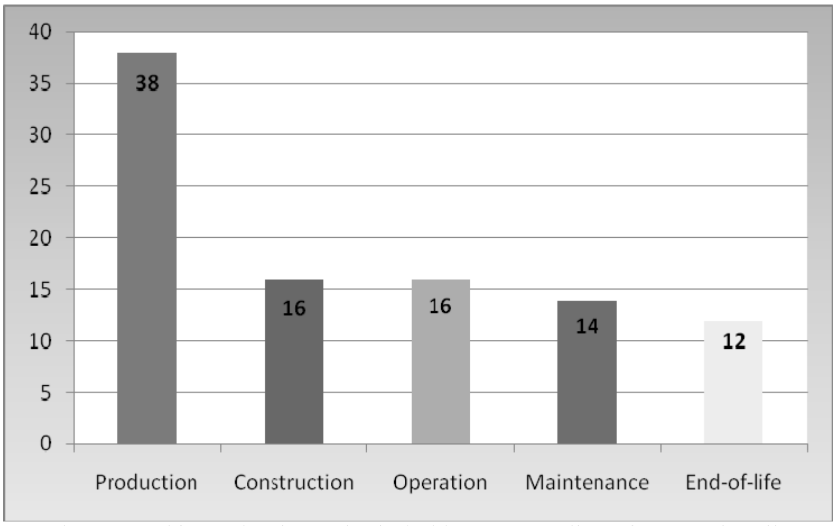

Figure 1. Life-cycle phases included in LCA studies of external walls

Table 1 presents an overview of the studies that compare functionally equivalent external walls or refer to the thermal performance of the solutions evaluated. The life-cycles considered for external walls differ greatly between studies. The list included in this paper is considered in-complete as the majority of LCA studies is made for the specific use of decision-makers and is not accessible as scientific literature (Werner & Richter 2007).

Table 1. Comparative LCA of building´s external walls: equivalent functional (P - partial), wall structure Life-Cycle (LC; in years) and databases used

			Databases		
Studies	**Functional Equivalent**	**Wall structure LC**	**Software**	**National data**	**Prior works**
(Pinto 2008)	P	50	SimaPro	X	
(Mateus 2004)	P				X
(Hassan 2004)	X	120			X
(Monticelli 2007)	X		X		
(Lemaire 2006)	P	100			X
(Kellenberger 2008)	X	50	EcoInvent		
(Athena 2009)	P	60	Athena		
(Thormark 2006)	X	50		X	
(Allacker & De Troyer 2005)	X	75	X	X	
(Huberman & Pearlmutter 2008)	X	50		X	
(Gu et al. 2007, Gu et al. 2008)	X		X	X	
(Utama & Gheewala 2009)		40		X	
(Pierquet et al. 1998)	P	30			X

Within the 38 studies, less than half include the environmental impacts of the operation phase of the building, namely the energy use in HVAC systems calculated by a simulation tool for each external wall solution within a building. These are shortly described in section "3.2 Studies concerning LCA of entire buildings" while the other ones are described below.

3.1 *Comparative LCA studies of different solutions and materials for external walls*

This subsection includes the studies that compare the thermal, environmental and even economic performance of complete external wall solutions or evaluate the impacts of the production phase of blocks of different materials that are normally included in these solutions. The nine that compare functionally equivalent products are described next.

A study of solutions for external walls with different coverings and insulation materials was made in a PhD Thesis in Portugal (Pinto 2008). It included the LCA of the walls based on "cradle to grave" LCA of individual construction materials using the methodology described in ISO 14040(ISO 14040:2006(E) 2006). In the same country, a master Thesis included the comparative analysis of six external wall solutions based only on the Primary Energy Consumption (PEC, same as embodied energy) already calculated by other researchers (Mateus 2004). Both works mainly regarded traditional masonry solutions.

In Sweden, a value-focused thinking to support the environmental selection of external wall solutions was developed (Hassan 2004). This model was based on LCA results and environmental categories of prior works and tried to get concrete, fired clay and wood solutions with similar thermal transmittance. The weight of each environmental category was author-defined.

The LCA evaluation of four low-weight solutions (also with similar thermal transmittance) for external walls of buildings was concluded in Italy (Monticelli 2007). At first, this work only considered the production and the end-of-life of the construction materials. In a second part the operation energy of each solution was also included.

In France, a PhD Thesis developed a multi-criterion decision-aid tool that compares building products according to their environmental and health characteristics (Lemaire 2006). This tool was applied in the evaluation of three external wall solutions with identical functional performance. The environmental and health impact categories considered in this study were the same of those included in the European Product Declarations.

The LCA from cradle to grave of two external wall solutions were included in a study that tried to define which materials and processes could or could not be neglected in this kind of work (Kellenberger & Althaus 2009). Therefore, the results only include the impacts for each impact category and wall assembly by life-cycle phase.

A calculator of thermal resistance and environmental impact of external walls was developed in New Zealand (Kellenberger 2008). The LCA of these low-weight wood solutions excluded the construction and demolition of the building and the operation energy.

The Athena Sustainable Materials Institute in Canada provides a free informatics tool, the *EcoCalculator* (Athena 2009). This tool makes the simplified LCA from cradle to grave of construction assemblies according to North American data.

The Green Guide to Specification of the Building Research Establishment (BRE) is already in its fourth edition (Anderson et al. 2002). This Guide is a database of environmental profiles of building assemblies with functional equivalence and comprises six building types (e. g. housing, commercial, education and health). The LCA of each solution followed the BRE Environmental Profiles Methodology and is expressed in an Ecopoint index (between A+ and E).

Some research works compare the environmental impact of external wall solutions with different thermal transmittance (König et al. 2007, Mak et al. 2008). Other studies do not even refer to the thermal performance of the solutions evaluated (Junnila 2003, Vandevyvere & Neuckermans 2004, Nielsen 2008, Lindeijer et al. 2002, Chani et al. 2003, Wang et al. 2003). There are also studies concerning the evaluation of the environmental impacts of the production of blocks and masonry units of different materials (Badino et al. 2004) (Koroneos & Dompros 2007, Kus et al. 2008, Zhang et al. 2007, Carvalho & Sposto 2008, Silva et al. 2008). These types of studies normally consider the energy and emissions of the production of one metric ton of product avoiding any conclusions about its use in external walls.

3.2 *Studies concerning LCA of entire buildings*

This section includes six studies that compare the thermal, environmental and even economic performance of complete external walls solutions within a building.

The best external wall solution was studied for a thermally efficient building in Sweden (Thormark 2006). The operation energy was calculated via a dynamic calculation method.

In Belgium, a decision support tool based in the environmental cost and quality of construction assemblies was developed (Allacker & De Troyer 2005). This work included the LCA from cradle to grave of two external wall solutions within a three-floor building, including the energy consumption during use phase.

A study dedicated to the buildings of the Negev Desert in Israel calculated their Life Cycle Energy Analysis (LCEA), including the cumulated and operation energy and pay-back time of five functionally equivalent external wall solutions (Huberman & Pearlmutter 2008).

In China, five façade solutions for an office building were compared through the energy consumption, the life cycle environmental load, the life cycle cost, the green payback time and the general payback time (Gu et al. 2007, Gu et al. 2008).

A study concerning the materials of the external walls (two alternatives) and other assemblies, and the operation energy was recently concluded in Indonesia (Utama & Gheewala 2009).

In the USA, a research study included the calculation of the embodied energy and thermal performance of twelve external wall solutions within a building in a cold climate region (Pierquet et al. 1998).

A work already cited (Pinto 2008) includes the LCA of two solutions with different and undefined thermal transmittance: a glass curtain wall and a traditional wall of fired clay hollow bricks with external insulation covering. Other studies do not clarify the characteristics of the external wall solutions evaluated (Itard 2009, Nemry et al. 2008) (Zold & Szalay 2008, Rivela & Bedoya 2007, Massone 2007, Anastaselos et al. 2009, Utama & Gheewala 2006, Arena & de Rosa 2003, Horne et al. 2006, Frenette et al. 2007).

3.3 *Results*

In Tables 2 and 3 the main results of the studies described in 3.1 and 3.2 are summarized. The relative deviations from the mean, the minimum or the maximum for each product and impact category are evaluated according to the classes described in Tables 2 and 3 and the method used in similar studies (Werner & Richter 2007).

3.4 *Interpretation*

The main purpose of the present work was to identify the most environmentally friendly solutions for external walls of buildings based on the results of the studies collected. However, this purpose was not easy to attain because of the following causes:

- Not all the studies clearly refer to the corresponding scope, assessment method and methodological assumptions;
- The evaluation method differed between studies and just a few of them apply the LCA methodology to compare alternatives;
- The completeness of each study is different because the life-cycle stages included are not the same: some studies just compare the initial embodied energy and/or the environmental impacts of the production of the construction materials, other also evaluate the operation energy, and just a few make a LCA approach "from cradle to grave" of all the solutions;
- The solutions evaluated in each study depend on the current constructive methods applied in the corresponding country or continent;
- Some studies compare the thermal, environmental and even economic performance of complete external wall solutions (but not always describing all the elements of the wall and the corresponding width) alone or within a building, while others just evaluate the impacts of the production phase of blocks of different materials that are normally included in these solutions;
- Most of the studies do not compare functionally equivalent products and this hinders the comparison of their environmental impacts in equal terms.

These problems create limitations to the interpretation of the results of the studies. However, careful and detailed readings of all the studies collected allow some partial and global conclusions that maintain the aim and justify the significance of this work.

In each study, the environmental impacts of each alternative are compared to the better or to the worst solution in order to conclude which is the best product or solution for external walls. Even though the solutions evaluated in each study depend on the current constructive methods applied in the corresponding country or continent, all the partial conclusions (most of them illustrated in Tables 2 and 3) were weighed and some global conclusions were made, following the method already used in similar studies (Werner & Richter 2007). First, some conclusions about the environmental impacts of wall coverings are presented:

- The replacement of a cement mortar by aluminum panels (100% recycled) in the façade could increase the CO_2 emissions and the embodied energy just 10% but the use of aluminum of first fusion may augment the environmental indexes (CO_2 emissions, embodied energy and Ecopoint UK) (Pinto 2008) up to 70%;
- Bevel-backed weatherboards may have a worse environmental profile than fibrocement weatherboards because of the lower durability and higher land use (Kellenberger 2008).

There are also some conclusions about the wall insulations:

- An aluminum sandwich panel with PUR (Polyurethane foam) insulation could have a high environmental impact due to the metallic ion emissions to the water and the high energy consumption of the PUR synthesis (Monticelli 2007);
- The replacement of the EPS (Expanded polystyrene foam) insulation for cellulose fiber solution would allow for the saving of more than 30% of the wall's embodied energy and 14% of raw material consumption (Thormark 2006); this material could also have a higher cumulated energy demand than MW (Mineral Wool) (Kellenberger 2008).

Concerning the common alternatives for external wall solutions, the main conclusions are:

- A brick veneer with insulation in the air gap instead of a single wall of fired clay hollow bricks with the same insulation solution could increase the environmental indexes (CO_2 emissions, embodied energy and Ecopoint UK) as much as 20% (Pinto 2008);

Tables 2 and 3. Relative impacts of external walls solutions. Evaluation: ++: very positive (< 50% of average impact); +: positive (50% to 90% of average impact); 0: average (90% to 110% of average impact); -: negative (110% to 150% of average impact); - -: very negative (> 150% of average impact). Abbreviations: ETICS: External Thermal Insulation Composite Systems; XPS: Extruded polystyrene foam; U-value: Thermal transmittance; CED: cumulated energy demand; GWP: global warming potential; AP: acidification potential; POP: photochemical ozone formation potential; HT: human toxicity potential; EI: Environmental impacts

Table 2

Study	Wall structure	Insulation/Covering	U-value ($W/m^2.K$)	Energy: Embodied	CED	GWP	AP	POP	HT	Wastes: Solid	Reactive	Hazardous	Emissions: Air	Water	Soil	Resources consumption	Water consumption
(Hassan 2004)	Lightweight timber	Glass wool	0.2	0		0							0	--	0		
	Low weight concrete blocks and clay brick	MW	0.2	--		--							--	0	--		
	Reinforced concrete	EPS	0.2	--		--							--	--	--		
(Lemaire 2006)	Clay brick	/Gypsum plasterboards	0.39		--	--	--	--		--	--	--	--	--			-
	AAC blocks	/Gypsum plasterboards	0.39		0	0	0	0		0	0	0	0	0			0
	Concrete blocks	Undefined/Gypsum plasterboards	0.42		+	+	--	--		--	--	--	--	++			-
(Athena 2009)	Low-weight steel frame	Glass wool/ETICS and gypsum plasterboards	U1			++							++	++		++	
	Glass curtain wall	Undefined	1,7.U1			--							--	++		-	
	Reinforced concrete	XPS/Clay tiles and gypsum plasterboards	U1			-							--	++		--	
	Concrete blocks	XPS/Precast concrete tiles and gypsum plasterboards	U1			-							0	++		0	
	Insulated concrete forms	EPS/PVC tiles and gypsum plasterboards	U1			-							-	++		--	
	Lightweight timber	Glass fibre/ETICS and gypsum plasterboards	1,2.U1			++							+	++		++	
	Fibrocement sandwich panel	EPS/Timber claddings and gypsum plasterboards	U1			++							+	++		++	

Table 3

Study	Wall structure	Insulation/Covering	U-value ($W/m^2.K$)	Energy: Embodied	Operational	CED	EI(total)	GWP
(Pinto 2008)	Fired clay hollow bricks	/Cement mortar	1,3	+			+	+
	Fired clay hollow bricks	/Cement mortar and gypsum plaster	1,3	0			0	0
	Fired clay hollow bricks	/Gypsum plaster	1,3	-			-	-
	Fired clay hollow bricks	XPS/Cement mortar and gypsum plaster	0,42	0			0	0
	Fired clay hollow bricks	XPS/Aluminium panels (100% recycled) and gypsum plaster	0,42	-			0	-
	Fired clay hollow bricks	XPS/Aluminium of first fusion panels and gypsum plaster	0,42	--			--	--
	Fired clay hollow bricks - single wall	XPS/Cement mortar and gypsum plaster	0,29	0			0	0
	Fired clay hollow bricks – double wall	XPS/Cement mortar and gypsum plaster	0,28	-			-	-
	Fired clay hollow bricks – double wall	XPS/Cement mortar and gypsum plaster	0,39	0			0	0
	Fired clay hollow bricks – double wall	MW/Cement mortar and gypsum plaster	0,38	0			0	0
(Monticelli 2007)	Timber sandwich panel	PUR and EPS/Clay brick	0,109	0			+	
	Timber sandwich panel	PUR and EPS/Fibrocement weatherboards	0,109	0			0	
	AAC blocks and aluminium sandwich panel	PUR/Clay brick	0,109	0			-	
	Glass wool sandwich panel	PUR and glass wool/Gypsum plasterboards and metallic panels	0,109	+			0	
(Kellenberger 2008)	Lightweight timber	XPS/Bevel-backed weatherboard	0,64			--	--	-
	Lightweight timber	MW/Fibrocement weatherboards	0,64			0	0	0
(Huberman & Pearlmutter 2008)	Reinforced concrete	XPS/Stone veneer	0,51	0	0			
	Concrete blocks	XPS/Stone veneer	0,51	+	-			
	AAC blocks	XPS/Stone veneer	0,51	+	-			
	Stabilized soil blocks	XPS/Stone veneer	0,51	+	0			
	Fly ash blocks	XPS/Stone veneer	0,51	+	-			

- A clay brick solution may be better than others (based in concrete or wood) in terms of emissions to the water, but worse in energy consumption, recyclability, global warming potential and emissions to the air and soil (Hassan 2004); this solution could have lower environmental performance than AAC (Autoclaved Aerated Concrete) or normal concrete block solutions in the following environmental categories: climatic change, atmospheric acidification, production of inert waste, emissions to the air, and energy consumption (Lemaire 2006);
- A concrete wall structure could have worse environmental performance than clay brick and wood in emissions to the water and emissions from construction materials for the interior environment (Hassan 2004), namely because of the high level of fine powder emission in the production of cement (and also of concrete blocks (Monticelli 2007)); this solution may have up to twice the embodied energy of other solutions of blocks (concrete, AAC, stabilized soil and fly-ash) because of the high cement and steel content, but its high heat capacity could allow for savings in the building operation energy (Huberman & Pearlmutter 2008);
- A concrete block solution may have better environmental performance than clay brick or AAC block solutions in climatic change, and water and energy consumption (Lemaire 2006);
- A AAC solution could have better environmental performance than clay brick or normal concrete blocks in atmospheric acidification, inert waste production and emissions to the air, but worse in water consumption (Lemaire 2006); even with greater embodied energy, the greater thermal resistance of the AAC blocks would allow for the use of a lower insulation thickness, and turns it into an environmentally competitive wall solution, but the low heat capacity of the blocks could increase the building operation energy of the solution (Huberman & Pearlmutter 2008);
- A low-weight steel frame wall with MW and ETICS (External Thermal Insulation Composite Systems) insulation and gypsum plasterboards could be preferable to heavy solutions (of clay or concrete) because of its low embodied energy and thermal transmittance (Athena 2009, Mateus 2004).

There are also some achievements concerning non-traditional external wall solutions:

- A glass curtain wall could be the worst solution for a facade when both the production and operation impacts are analyzed (Athena 2009, Pinto 2008, Gu et al. 2007, Gu et al. 2008); nevertheless, this solution could be better than a clay brick and steel frame solution but only when the thermal transmittance is different or undefined and the building use phase is not taken into account (Junnila 2003);
- A lightweight timber wall (based on renewable resources) may have better environmental performance than clay or concrete blocks, structural concrete or steel frame wall (based on non-renewable resources) in consumption of energy, global warming and emissions to the air and soil (Hassan 2004, Pierquet et al. 1998, Allacker & De Troyer 2005);
- Wall structures built with natural materials (e.g. rammed earth, straw bale or cordwood masonry) could have a higher environmental performance by avoiding production and transport impacts (even better than solutions that integrate industrial wastes) and because of their high heat capacity (König et al. 2007, Huberman & Pearlmutter 2008, Pierquet et al. 1998).

The interpretation and use of the results described above must be made carefully. The life-cycles of buildings and their assemblies are complex and long-term processes. The production of construction materials is much simpler to model than the use of the buildings. The latter depends on the user needs, habits and behavior (Werner & Richter 2007). Therefore, all the assumptions influence, more or less, the LCA results. Also the quality and representativeness of the inventory data modify the environmentally preferable solution. This is a huge limitation to the extrapolation of the results of some study to the same (or other) geographic and temporal context without the fully comprehension of the scope, assessment method and methodological assumptions beneath it.

4 CONCLUSION AND PERSPECTIVES

In conclusion, each country has their own common construction materials and solutions for exterior walls, as stated in the works described in this paper. The production technology, energetic mix and most significant environmental impact categories also differ from country to country. Despite these differences, all LCA research studies of external wall solutions must have a definite scope and methodological approach to compare functionally equivalent products. The majority of the studies included in this paper does not follow these principles and prevents any inter-comparison between their results.

For these reasons, it is important to develop LCA studies from cradle to cradle of the traditional external wall solutions of each region with production data of the same regional source and including the maintenance and reuse or recycling phases and the operation energy. This last feature is a powerful tool by allowing the comparison of alternatives without the functional equivalent of thermal performance compulsion and enlarging the amount of solutions that the designer can consider. The LCA analysis could be complemented by a life-cycle cost calculation for each alternative, without forgetting that all these solutions must comply with the regulations and standards minimum requirements (Bingel et al. 2006). The LCA studies should be based on ISO 14040:2006 and ISO 14044:2006 international standards (ISO 14040:2006(E) 2006, ISO 14044:2006(E) 2006) in order to allow for the direct comparison between them and allow the creation of an important source of information for the building's designer who aspires to make progresses in his road to sustainable construction.

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Economic Feasibility Analysis of Sustainable Construction Measures

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ABSTRACT: The economical analysis of a construction project allows the feasibility evaluation on the monetary resources being applied, in terms of initial investment and / or future costs (operation, maintenance, etc.), considering equally technical liable options for construction.
This analysis gives the investor a more realistic and comprehensive approach about the investment he is about to make, and in what this results in terms of building use. The cost-benefit analysis can precisely demonstrate which economical benefits can be reached with what costs.
In this work the Life Cycle Cost – LCC - method (also called LCCA - Life Cycle Cost Analysis) was used to calculate the global cost associated to a construction project, though a specific period of time, comparing it to equivalent alternatives, so that the least global cost alternative could be defined.
The development of this method starts by making a life cycle study identifying every steps in which a project, service or product development is engaged, since its conception to the end of its life cycle, where that project becomes obsolete.
In a life cycle analysis, considering a sustainable point of view, environmental, social and economical aspects must be considered. In the specific LCC analysis only the economical aspects, associated with all evolved costs, are measured. Although the initial investment costs of a construction project can be very significant (construction stage) it's during the use stage that most costs are made, associated with normal use, maintenance, repairing, substation, etc., of the constructed space. This effect is also related to the duration of the use stage, compared to the construction stage. Also, the demolition, landfill and / or recycling costs must be considered as a part of all building costs.
In this work an analysis about the LCC, its objective, functionality, applicability and advantages was made. It was also a goal of this work to test this method applicability to a sustainable construction case study. In this example the LCC method was applied to determine the least global cost of a housing project considering a conventional vs. sustainable alternative project.

1 INTRODUCTION

This work aimed to develop an analysis about the LCC method and how it can be applied in the economical analysis of sustainable construction projects. In this application the LCC was applied to test which least global cost, in a housing project, can be obtained comparing a sustainable and a conventional project alternative.

The LCC is an economical evaluation method where all costs associated to the acquisition, operation, maintenance and final landfill are considered, being all important to investors decision.

Having these considerations in mind the LCC is particularly indicated to analyze different project alternatives, in terms of building conceptions that can match some desirable performance, as comfort needs, security, meeting legal requirements, etc., and that have different initial, maintenance, operation and reparation costs. The LCC can be easily used to evaluate different investments that have bigger initial costs but that can produce less costs through the life cycle, being an appropriate economical methodology to long term projects rather than the simple investment cost evaluation (Fuller et al, 1995).

This methodology gives the investor several data about the investment he is about to make, face to a group of technically liable equivalent options. Although, it's important to refer that economical aspect can just be one of several selection criteria in construction projects, but, when considering equivalent technically liable options, this analysis can give the best choice considering the global cost of each alternative.

The LCC is a very demanding method that implies the evaluation of specific information on the investment and also on the present value cash flows, with the appropriated discount rate of the investment, according to the minimal rate of return presented by the investor.

A construction project's planning, design and construction evolves several decisions, many of them purely economical. Nevertheless some decisions include other aspects: environmental, social, political, esthetic, etc. It´s important to refer that design has a crucial impact in the building future performance, in its operation and maintenance costs and, with that, its global costs. Because of that, LCC must be adopted since the project initial stages, supporting project choices that can be reflected in the use of the building. The detail in which this analysis can be made depends on the needs and goals of the owner, and can be developed to the complete building conception evaluation or in future material or construction techniques selection.

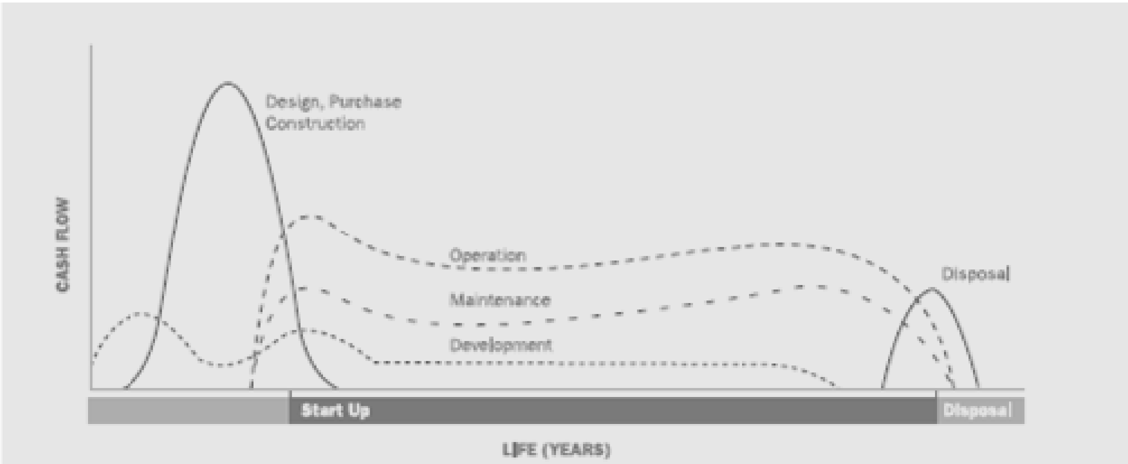

Figure 1 – Cash Flow related to construction projects (Australian National Audit Office, 2001)

It's important to refer that the economical analysis developed by LCC can also be used in another different aspect. Knowing the global cost of several alternatives it's also possible to establish an equivalent comparative base and define the choices to be done with other criteria (environmental, esthetics, etc.).

Any global cost study must be well documented in order to allow an objective evaluation of all steps of the decision making, when selecting the best alternatives, and also to make this information available to future evaluations.

2 LIFE CYCLE COST METODOLOGY

Independently the method to be chosen, the first step to an economical analysis corresponds to the description of the project and its general characteristics. In the specific case of construction projects, this information must focus on the building design as also on the type of occupation, activities and internal comfort needs. The alternatives criteria of evaluation and analysis must be developed according to this information, as also the technical and legal requisites to be considered.

After these, the acquisition, operation, maintenance and final scenario calculation processes must be developed according to all alternatives considered.

There are two cost categories that must be determined, namely:

- Investment Costs, generally associated to the initial moment of analysis in the LCC; and
- Operation Costs, to which all future costs are related.

The first ones are related to acquisition, installation, design, planning, etc. of the solutions being studied. The operation costs include all costs that result of the normal use of the solutions, its maintenance necessary to its corrected functioning, all reparation or substitution costs, and also costs associated to end of life that can be recycling of equipments or final landfill, etc.

Also the residual costs of the solution at the life cycle end must also be presented, if they exist, corresponding to the actual market value of the solution at the end of life cycle.

Both costs must be considered face to its annual value, so that the corresponding cash flow investment diagram can be developed.

After obtaining these costs and the cash flow diagram there's possible to calculate the Global cost of each alternative.

The Global Cost (CG) is given by:

$$CG = \sum_{t=0}^{N} \frac{C_t}{(1+d)^t}$$

Where:

- Ct = Sum of all relevant costs occurring in the t period of time, including the initial investment costs (CF not actualized to year t)
- d = discount rate
- t = time period (period of the LCC analysis)

After the Global Cost methodology analysis it's possible to determine that there are several benefits in its use, particularly in construction projects.

Construction projects generally are projects that present significant investment costs, where it's crucial to develop the adequate economical to the investment to be made.

In practical terms the LCC allows the calculation of the costs that will exist in use stage of buildings, although the inevitable uncertainty when predicting future building consumptions and costs, and, with that, the global cost of several alternatives.

3 CASE STUDY APPLICATION

The project used as a case study corresponds to the Arcos de Santa Iria urbanization that is composed on 45 independent housing, located in the municipality of Óbidos, in Portugal.

All housing considered has three or four bedrooms, existing small variations in both typologies. The project was conceived in 2007 and the construction started in 2008.

Several sustainability measures were studied by the consultancy company ECOCHOICE S. A., according to the owner objectives on the project (ECOCHOICE, 2007). To this economical study only those that were chosen by the owner were considered.

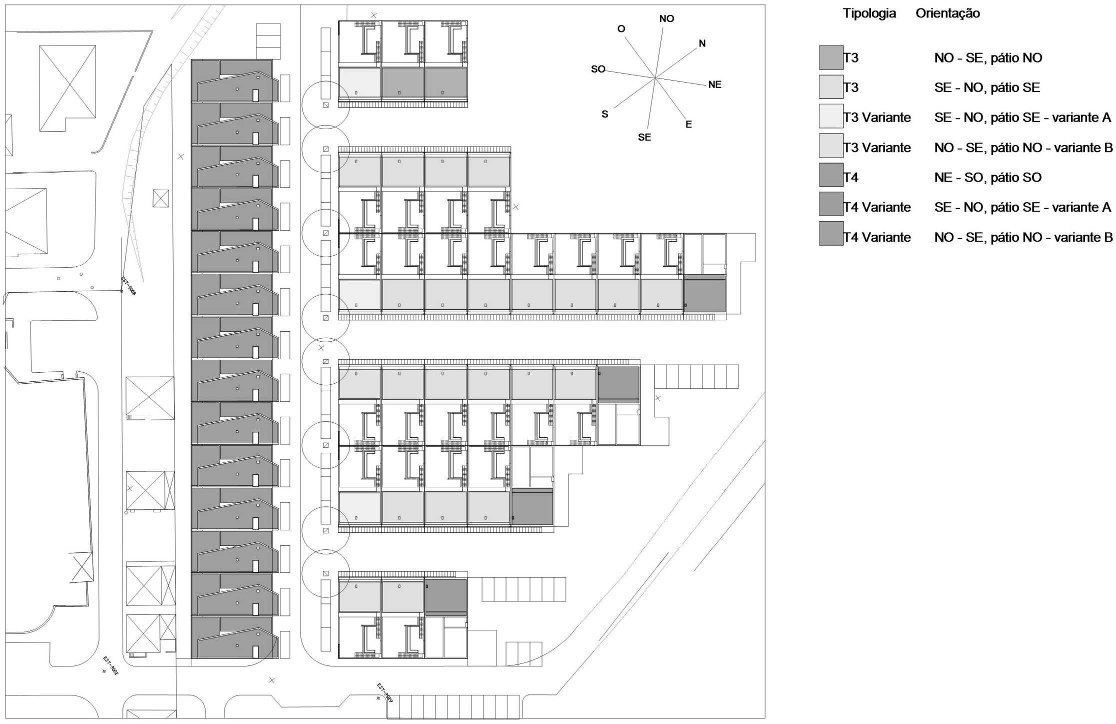

Figure 2 – Urbanization Arcos de Santa Iria – Óbidos, Portugal (ECOCHOICE, 2007)

Those measures were developed to improve the bioclimatic performance of buildings, the energy consumption and efficiency and also to reduce the water consumption. Other measures were also proposed but not included in the project.

To facilitate the LCC process the four bedroom typology was used as the element of analysis, so all costs were calculated according to its dimensions and characteristics.

According to the considered measures the conventional and sustainable scenarios were analyzed.

The main difficulties of the LCC method are related with the fact that some of the benefits and some of the operation and maintenance costs are very difficult to obtain and have large uncertainty. Some benefits are very difficult to translate into economical units, like indoor comfort, soil and biodiversity protection, etc.

To develop the economical analysis a thirty years period was consider, since this is the maximum period of time considered adequate to this method. Although buildings normally are planned to a minimum of fifty years of duration, a thirty years period of housing use can be considered as an acceptable average.

The discount rate used was about 7%, since this was the combination between the national Treasury bill rates with the risk rate of the investment.

To determine other costs calculations the energy tariffs (common to all municipalities) were analyzed and also the local water tariffs (that differ according to the municipality). The following values were found:

- Energy: 0,1143 €/kWh in low voltage electricity;
- Water: 0,74€/m^3 to consumptions between 11 and 30 m^3 for each two months.

In a general way, it's possible to say that, in quantitative aspects, the sustainable measures are directly translated in monetary benefits though the reduction of energy and water, without interfering in the comfort perception by users.

All selected measures are divided into planning and integration areas, namely, in bioclimatic architecture to obtain passive ways to meet legal requirements; energy production systems and also water saving strategies.

3.1 *A Scenario –Conventional Construction*

The first investment option respects to the use of measures and equipments equal to common practice which doesn't represent any improvement to global performance, by comparison to traditional housing in Portugal.

These measures are:

- The thermal insulation will be composed by extruded polystyrene foam (XPS) with 4 cm;
- The slab will be directly constructed on the ground;
- The windows are simple and the frames have no thermal break;
- The electric devices and lamps have no energy efficiency label;
- The taps, showers and flushing tanks will be produced with standard materials and will have regular flows (10 and 15 liters per minute, respectively, and 10 liters per flushing);
- The domestic hot water (DHW) and the heating systems will be met though an electric thermo accumulator.

All these options were define in order to establish the most common construction strategies at that time. Its import to refer that, at the time the project was developed (2007) the energy performance directive, already translated to Portuguese laws, wasn't yet an obligation. Although, since 2008 this have turned to be an requirement to all news buildings, and, since then, the energy certificate to new buildings must be obtain in order to get the house use license.

This means the owner had to consider what measures he would apply to his its project in order to improve the energy performance in a time where these were not considered and where a lack of knowledge and expertise was still missing.

3.2 *B Scenario – Sustainable Construction*

To improve global sustainable performance of building, sustainable construction measures were analyzed and proposed, by changing the previously presented one's, in order to meet sustainable parameters. With these parameters the all house would be capacitated to improve its performance and, with that, to reduce resource consumptions and operation costs, though its life cycle.

The alternative measures considered to improve the bioclimatic performance of the house were:

- Cork insulation, locally produced, with 6 cm (larger than the XPS alternative considered);
- Ventilated Slab, by opposition to the slab-on-ground;
- Double glazing windows with thermal break frames, that have a extremely higher energy efficiency than those considered in the conventional construction;

These solutions will improve the passive performance of the building envelope reducing the energy needs to indoor acclimatization.

To minimize and optimize the remaining energy consumptions, there were proposed alternatives like:

- Electric devices and lamps with A-rated according to European energy label ratting;
- Also to reduce the energy consumption of equipments and electric systems a solar energy system to DHW, supported by the thermo accumulator, was proposed.

This strategies can reduce the direct use of electricity and also, though the solar system, develop local energy production systems, avoiding grid electricity use.

To reduce water consumption in taps and showers flux reduction devices will be considered and, to reduce flushing tanks water volume, double flushing tanks and, simultaneously, lower maximum volumes of discharge. By other hand, for pure environmental reasons, the chosen taps and showers are made of a special ecological material with no lead. This fact makes this investment more expensive than the normal materials that are used but doesn't reflect directly into economic benefits, when evaluating the global cost of the house.

This is one of the aspects that seriously difficult the LCC analysis when more intensive environmental measures and solutions are considered since there economic added value cannot be seen at local level (building, region, etc.) but at the positive impact to biodiversity or resource depletion, for example.

4 RESULTS

According to data presented in the previous chapters each alternative global cost analysis was developed, considering the initial investment costs but also the future costs that each alternative represents.

To do so, the unit average costs and also the initial costs were determined for each measure, to the four bedrooms house. To this house the project's information needed to make the global calculations, after the unit average costs have been determined, are:

- External walls area: 281,11m^2
- Roof area: 140,7 m^2
- Windows area: 24,98 m^2
- Slab area: 110, 49 m^2

Table 1 – A Scenario Investment

Solution	Type	Unit Cost	Units	Total quantity	Total Cost (€)
Insulation	XPS (4cm)	4,5	€/m2	313,81	1412,145
Slab	On ground	20,04	€/m2	110,5	2214,42
Windows	Simple	170,8	€/m3	25	4270
Lamps	Filament	1	€/lamp	24	24
Electric devices	E - rated	2500	€/kitchen	1	2500
DHW and heating	Thermo accumulator	300	€/equipment	1	300
Taps	Conventional	106,9	€/equipment	5	534,5
Showers	Conventional	456	€/equipment	2	912
Flushing tanks	Conventional	300	€/equipment	3	900
Total investment					13.067,065

For the considered solutions, has referred in table 1, the existing costs that are necessary to develop to LCC analysis, where calculated and presented in table 2.

To do this calculations some simplifications had to be made corresponding to users profile. In order to do so, a four element family was considered with a house occupation mainly during the late afternoon and night.

Some other simplifications had to be done, also considering the average consumption of water and electricity per occupant. Although this can bring some uncertainty to this study, this aspects is minimized by the use of the same simplifications in both scenarios.

Table 2 – Costs related to A Scenario – Conventional Construction

Conventional Construction		
Initial Investment	13067,065	€
Energy costs	1728,78	€/year
Water costs	117,22	€/year
Residual value (30 years)	0	€
Maintenance costs	0	€
Substitution costs (lamps)	48	€/year

In the B Scenario – sustainable construction, several changes occur when considering unit average costs, which can be seen in table 3.

Table 3 – B Scenario Investments

Solution	Type	Unit Cost	Units	Total quantity	Total Cost (€)
Insulation	Cork (6cm)	8,25	€/m2	313,81	2588,933
Slab	Ventilated	29,28	€/m2	110,5	3235,44
Windows	Double glazing (thermal beak frames)	248,89	€/m3	25	6222,25
Lamps	CFL	9	€/lamp	24	216
Electric devices	A rated	2500	€/kitchen	1	2500
DHW and heating	Solar energy panels and thermo accumulator	3470,45	€/equipment	1	3470,45
Taps	Ecological + flux reduction device	223	€/equipment	5	1115
Showers	Ecological + flux reduction device	990	€/equipment	2	1980
Flushing tanks	Double flushing (3 and 6 L)	300	€/equipment	3	900
Total investment					22.228,07

Has developed for A scenario, also to the sustainable construction options the life cycle costs were determined, through the same simplifications in terms of the users profile, has described before.

Table 4– Costs related to B Scenario – Sustainable Construction

	Sustainable Construction	
Initial Investment	22 228,07	€
Energy costs	387,93	€/year
Water costs	55,22	€/year
Residual value (30 years)	0	€
Maintenance costs	0	€
Substitution costs (lamps)	216	€/6 in 6 years

Has it can be seen, the initial investment of B Scenario – Sustainable Construction is about 1,7 times superior than the conventional option.

On the other hand the global cost of each alternative, which can be seen in next table, shows that, for the 30 years period of the study, the Global Cost of option A – Conventional Construction is about 1,5 times higher than the Sustainable Construction alternative.

Table 5 – Global Costs for both A and B Scenarios

Scenario	Initial Costs (€)	Global Costs (€)
Scenario A – Conventional Construction	13.067,06	45.454,36
Scenario B – Sustainable Construction	22.228,07	28.240,82

According to this analysis it's possible to see that the option in the implementation of the sustainable measures can be translated into an economy of 17.213,54€ in the thirty years scenario in which this study was made.

5 CONCLUSIONS

The Global Cost of the two alternatives made possible to conclude that the sustainable measures, in the 30 years period of the study, are liable, although they correspond to a larger initial investment cost. In economical terms, at the end of the 30 years, the sustainable measures, made possible an economy of around 17.000 €. This economy is due to the reduction of operation costs, that in the case are energy and water costs.

The main difficulties that this study revealed are related to the difficulty when trying to calculate in financial values the benefits that some of the measures can make. Also some difficulties were felt on predicting some maintenance and operation building costs. These were the reason why the residual cost for all measures and also the maintenance of the solutions, although that is not the most desirable way to make this approximation, were considered being null.

Other difficulties were found when trying to calculate the added value that these measures can bring to the building, by the improvement of indoor comfort and quality, user's satisfaction, etc. Also, there are other parallel effects that these solutions carry on, that are equally difficult to measure, like the reduction of green house gases, by the reduction of fossil fuels energy; effluents reduction, reducing the pressure in local treatment systems, etc.

Has an improvement to this analysis a study on how these parallel impacts can be translated in economical values would be very helpful and help to calculate the real effect of sustainable measures, through the building life cycle.

The sustainability measures considered in the case study represent only a few solutions that can be applied to sustainable construction. Other recommendation for future studies can be the development of projects with a larger complexity, considering, for example, other renewable energy systems, the use of gray and rain water systems, use of sustainable materials, solutions to improve soil and biodiversity protection, more complex bioclimatic solutions (green roofs, trombe wals, natural ventilations strategies, etc.) and also, some innovative solutions not yet developed.

By this study, it's possible to consider the LCC method very useful and objective when evaluating the economical liability of sustainable construction solutions that made possible to reach the initial goals for this study.

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Thermal Performance of Residential Buildings with Large Glazing Areas in Temperate Climate

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ABSTRACT: This work presents the results of an experimental and numerical study of a residential building, in a temperate climate, the particularity of these buildings is the large glazing areas around 65% to 85% of exterior façade. The thermal performance is presented and discussed. The study was developed taking into account the implementation of monitoring during the summer and winter for a housing unit in an intermediate floor with only one façade in contact with the exterior (south façade) without solar protection by the glass (glazing area 80% exterior façade) located in Lisbon, Portugal (Latitude 40 º N); as well as detailed modeling of this unit using EnergyPlus for thermal simulation. The detailed model took into account the characteristics of the housing unit and the conditions under which it was monitored during the summer and winter. To simulate the detailed model under the monitored conditions the climatic data was carefully introduced in the thermal simulation (climate file), the data was obtained from the meteorological stations of the National Laboratory for Energy and Geology (LNEG, Lisbon) for the same periods of the monitoring. From the detailed model different parametric variations were performed (summer and winter). Thus we obtained a set of effects that let you check the parameters of major and minor influence on the thermal performance of housing units with large glazing areas situated in temperate climates. This work intends to provide tools and guidance to building designers with regard to the thermal performance of buildings

1 INTRODUCTION

The main heat exchange in a building usually occurs through the transparent elements (windows, skylights zenith, and other transparent elements). The exchange by conduction and convection in the glazing exhibit the similar behaviour to the opaque elements with the possibility of controlling the exchange of air between the interior and exterior - opening or closing. However, the radiation is the main factor because the portion directly transmitted through the glass into the interior.

The non-opaque envelope (glazing) can be considered a major factor in the control of radiation, ventilation and natural lighting (more dynamic, easier to adapt / adjust to obtain the desired interior conditions). Thus, the non-opaque envelope presents a greater degree of control and flexibility to adapt to climatic variations compared with the opaque envelope. It is the more flexible and interesting element of the building envelope.

In addition, glass and other transparent and translucent materials are considered essential for the successful implementation of most passive solar heating systems (when they have a proper solar orientation).

In Portugal, in the case of habitation, the needs in the winter season are easily satisfied by a correct orientation and scaling of the glass areas, thermal mass, thermal insulation (opaque envelope and thermal insulation of glazing areas at night). However in the summer season, the cooling needs are usually resolved with the proper design of the outer skin, night ventilation cooling, shading the windows and thermal mass inside.

At the same time the interest in glass materials in construction has increased in order to verify progress in the development of production of that material. The evolution of the glass production and progressive independence between skin and supporting structure, promoted the process of dematerialisation of the facades and the dilution between the wall and windows of buildings. A increase of glazing areas on the facades of residential buildings can also be noticed in the Portuguese built stock mainly in the buildings constructed over the past decades (see Figure 1). Thus verifying residential buildings with 65% -85% of façade in glazing.

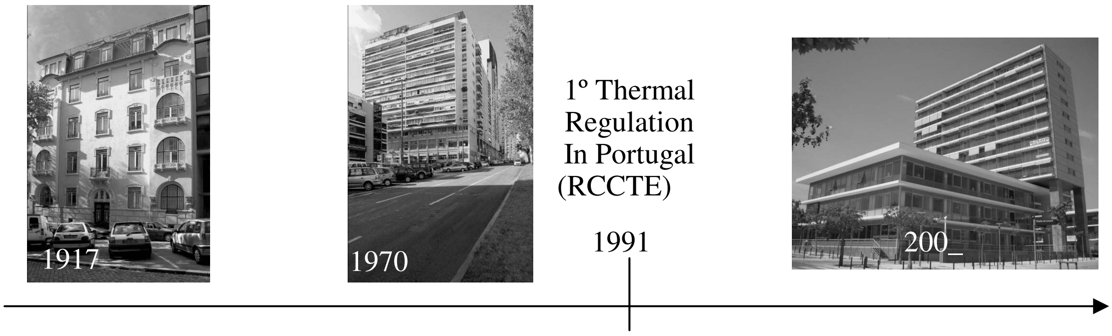

Figure 1. The increase of glazing areas on the facades of residential buildings in last few decades (Lisbon).

So, the thermal behaviour of buildings with large glazing areas will directly depend on a number of factors including: glazing control and protection systems, the thermal inertia within the environments and the degree of building insulation.

2 METHODOLOGY

2.1 *Object of study*

For the study in question was selected a housing unit located in a building chosen among others buildings identified in the Portuguese building stock. These buildings present important features to this study; in particular the glazing areas, because these are buildings with glazing areas over 65% of the main façade.

This housing unit keeps the features already mentioned (about the glazing areas), and these features are related to the construction and architecture practiced in recent years in Portugal.

This housing unit is located an intermediate floor (Lisbon, Latitude 40 º N) with a single façade in contact with the outside (facing to the south) and without any protection device in the glazing areas (80% of the façade is glazed). This housing unit has a balcony (0.85m wide) over the entire glazing, so this balcony provides shading on the glazing under study.

	Facade(s) Exposed Orientation	Housing Unit	Compartment	Location in Building	FF (Form Factor)	Glazing Facade(s) Orientation	Glazing Area/ Facade Area in Corresponding Exposition (%)	Total Glazing Area/ Floor Area (%)	Exterior Shading
South	SSE	H 2	living room	Intermediate	0.16	SSE	85%	34%	horizontal shading
			bedroom		0.34		77%	69%	

Figure 2.Housing unit features.

2.2 *Phases of the Study*

The study was developed in different phases: monitoring during the summer and winter, the construction of the detailed modeling using EnergyPlus for thermal simulation, the simulations of the detailed model under the monitored conditions (summer and winter), the calibration of the detailed model and different parametric variations for the detailed model (summer and winter).

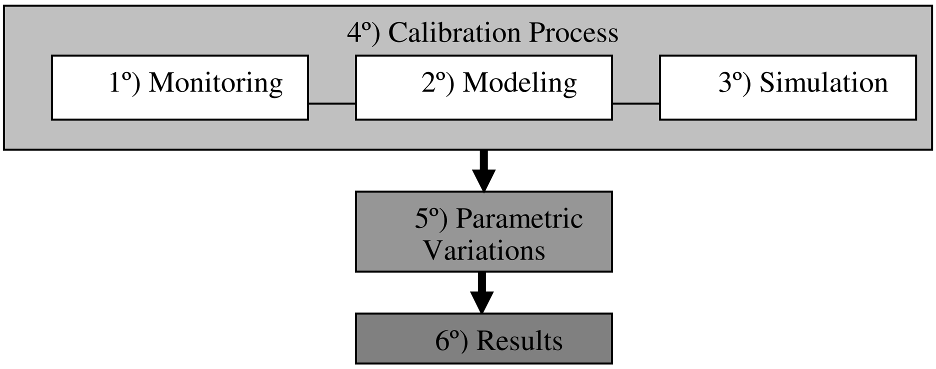

Figure 3. Study phases.

3 ANALYSIS

3.1 *Summer and Winter Monitoring*

Beginning with the selected housing unit, and with the support of the architectural projects, a more detailed assessment was performed. This made possible the site monitoring during both, summer and winter periods of 2007-2008.

Temperature and relative humidity (hygrothermal behaviour - mini datalogers) sensors were installed in the selected housing unit (living room and bedroom). The use and occupancy pattern of housing unit was also recorded during the measurements, as well as the views of residents through a survey targeting the issues of thermal comfort. Thus, we obtained a set of data and other important information for understanding the thermal behaviour of the compartments of the study unit.

While the monitoring were performed the external conditions were obtained from the LNEG Meteorological Station (LNEG-National Laboratory for Energy and Geology, IP) installed in the Solar XXI Building, Lisbon.

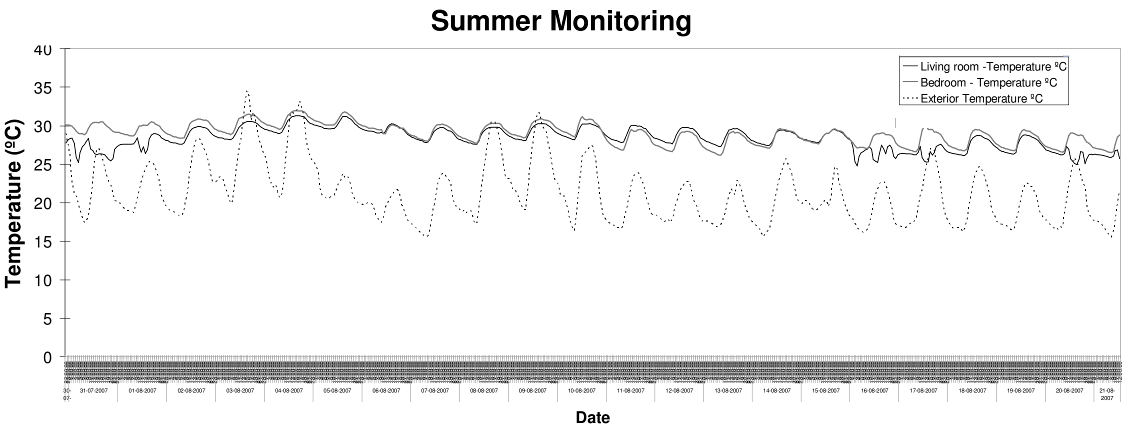

Figure 4. Summer Monitoring..

Summer Monitoring Period - 30 July to 21 August 2007:

Inside the flat were observed the mean temperature for the both compartments. In the living room the mean temperature was 28.5 ºC, and for the bedroom was 29 ºC.

The mean thermal amplitude was 6.5 ºC in the living room and 6 º C in the bedroom.

Temperatures in the living room and bedroom were above 25 °C (temperatures above the comfort level) in 100% of the time. Temperatures in the living room were between 27 ºC and 31 ºC in 80% of the time and the temperatures in the bedroom were between 27 ºC and 31 ºC in 90% of the time. Approximately 84% of the time the outside temperatures were below 25 °C.

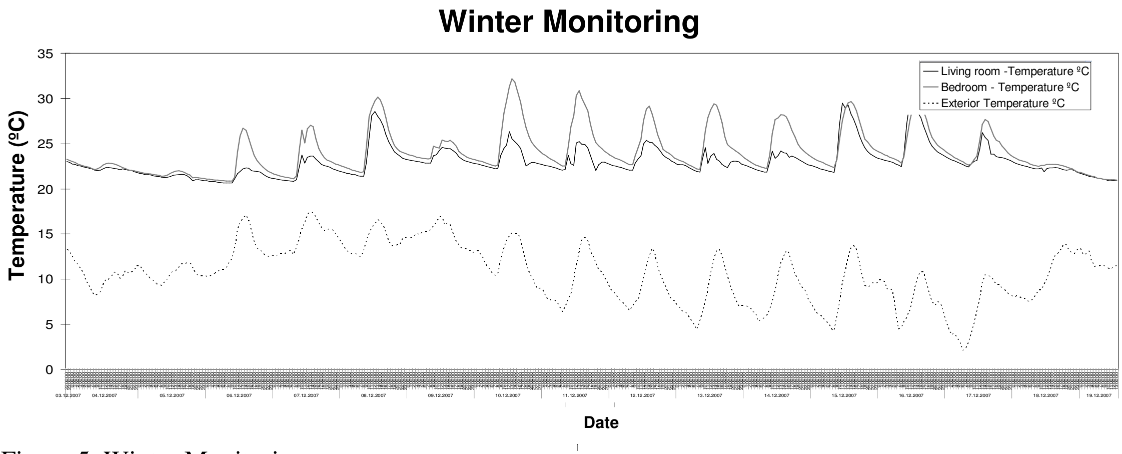

Figure 5. Winter Monitoring..

Winter Monitoring Period - December 30 to 19 December 2007:

Inside the flat the mean temperature for the living room was recorded in 23 ºC and in the bedroom 24 ºC. The mean thermal amplitude was 9 ºC in the living room and 11 ºC in the bedroom. Temperatures in the living room were between 20°C and 25 °C in 90% of the time and 73% of the time in the bedroom. Approximately 4.5% of the time temperatures in the living room were above 27 °C and in 6% of the time temperatures in the bedroom were above 29 ºC. There were no temperatures below 20 ºC in these compartments.

The outside air temperatures were below 15 °C in 85% of the time, and in 37% of the time the temperatures were between 5 ºC and 10 ºC.

3.2 *Summer and Winter Simulation*

Based on information obtained from the housing unit in question, a detailed model was constructed in the thermal simulation software EnergyPlus (E+) The detailed model took into account the features of the housing unit and the conditions under which it was monitored during the summer and winter (geometry, orientation, location, construction solutions, pattern of use and occupation, renewal rates by time, equipment ...). In order for the model to simulate under the monitored conditions special care was taken to introduce into the thermal simulation software the climatic data (climate file) obtained from the meteorological stations of the National Laboratory for Energy and Geology (LNEG, Lisbon) the same periods of monitoring.

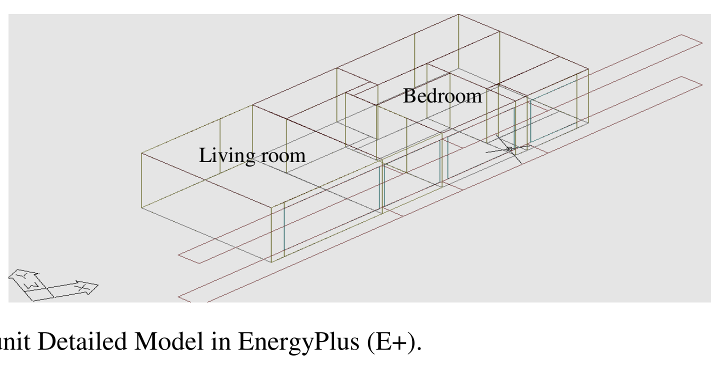

Figure 6.Housing unit Detailed Model in EnergyPlus (E+).

The results obtained from the simulations were compared with the results obtained from the monitoring (Detailed Model calibration), thus allowing to confirm that the detailed model presents results and thermal performance similar to that obtained in the real model.

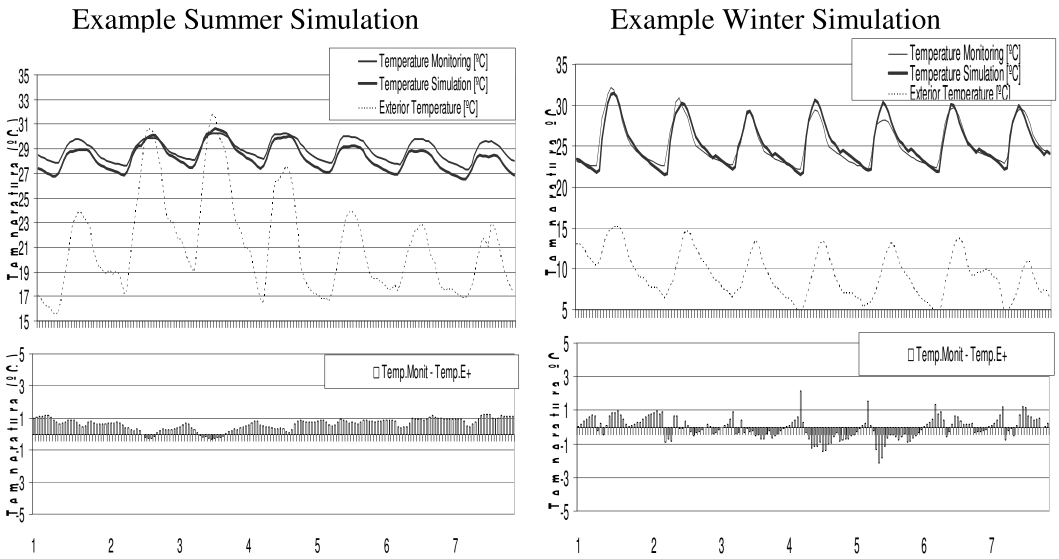

Figure 7. Calibration Detailed Model, monitoring and modeling.

The difference between the temperatures obtained during the monitoring and those obtained through simulations for the environment living room (during the seven days selected to represent the summer season) was on average 0.62 ° C, and for the bedroom was 0.44ºC.

The difference between the temperatures obtained during the monitoring and those obtained through simulations for the environment living room (during the seven days selected to represent the winter season) was approximately 0.32 ° C; and for the bedroom was 0.04ºC.

The manufacturer of the equipment uses a margin of error of + or - 0.5 ºC and that the weather station is not located exactly on the building site studied. Thus, the results in terms of calibration can be considered satisfactory, taking into account the above observations and the mean differences obtained in both seasons (monitoring and simulations), which were no more than + or - 0.62 º C.

3.3 *Parametric Variations - Summer and Winter Simulation*

The Detailed Model (calibrated) was used to perform different parametric variations (summer and winter). Thus, permitting to verify the parameters of major and minor influence on thermal behaviour of the unit in question.

The parametric variations were made in the detailed model as a whole (considering all zones in the model, which represent the different environments existing in the housing unit chosen). However, for this study was adopted an example room to demonstrate the influence of parametric variations performed and the thermal behaviour of the model.

Summer Parametric Variations:

The charts bellow demonstrates the importance of natural ventilation and the presence of sun protection devices near the windows to achieve a better thermal performance in housing units with characteristics similar to that adopted for this study.

The variations in the air change per hour (ACH), showed a great potential to reduce the indoor temperature, up to 3ºC. The changes made relative to the size of the horizontal shading (width) showed the possibility to reduce temperatures by up to 8ºC on average, this possibility with the interior wood shutters were between 1ºC and 3ºC, and with the exterior blinds were between 1.5 ºC and 4.5ºC. The variations on the degree of insulation on the outside elements (in this case the exterior walls, because it is an intermediate floor fraction), as well as on the type of cloth wall (single wall) had little influence on results.

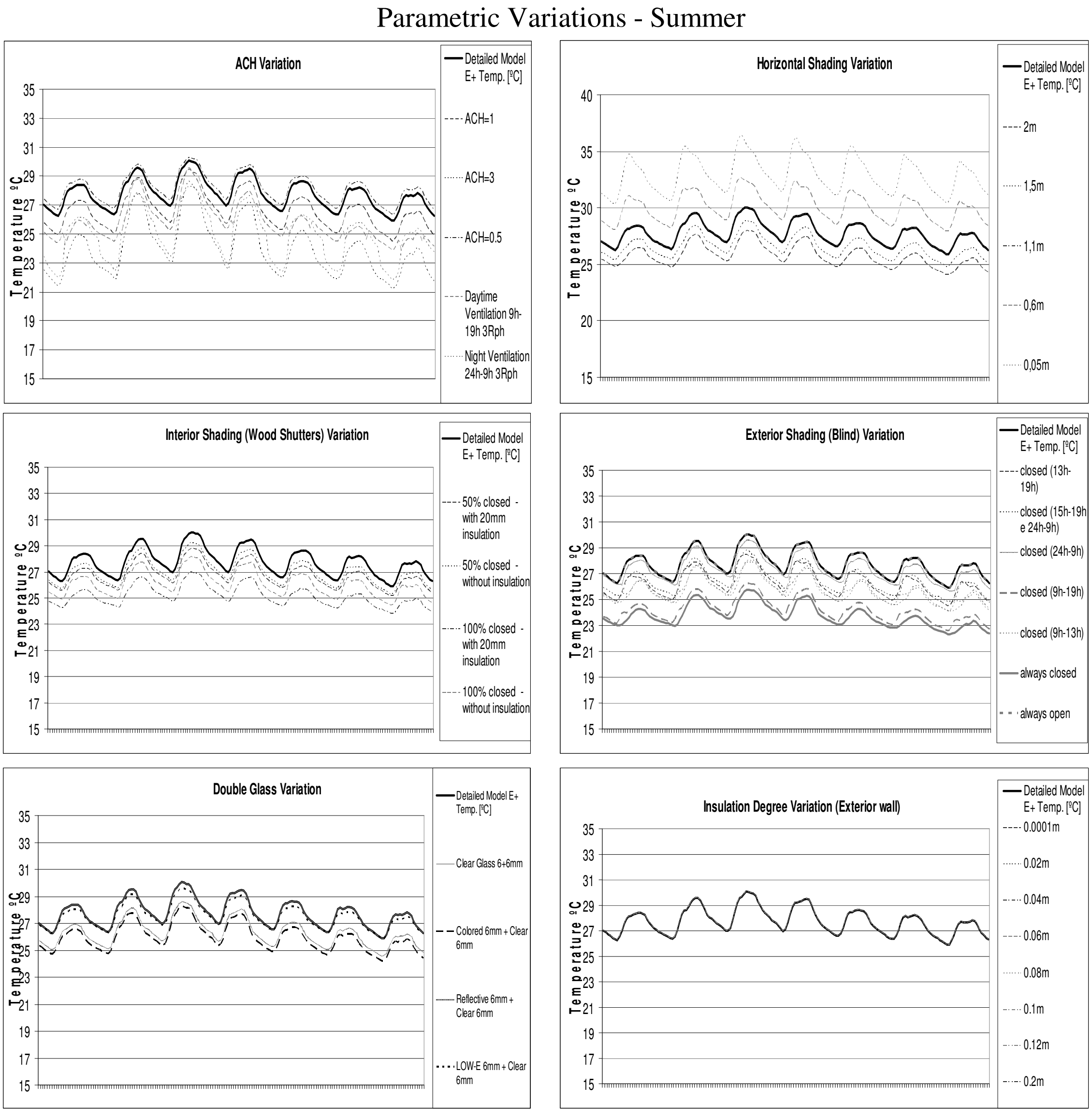

Figure 8. Summer parametric variations (Detailed Model).

Winter Parametric Variations:

Through the charts bellow we can see the infiltration influence, because the difference between the two situations (with 0.5ACH and 1ACH) in terms of temperature, can be of 4.5 º C on average,

The solutions between 0.6 ACH and 1.2 ACH are recommended in DL/80 2006 as winter conditions for all glazing (closed), and the ACH rate varies consonant with the wind exposure and the type of frames.

Regarding the types of protection, the solution that showed the best results for this season was the solution that considers the exterior blind closed between the 24h-9h (Night). The solution with blind closed 24 hours showed temperatures below the reference (Tsimulation) at 10ºC on average.

The best glass type solution for this season was the clear double glass. This solution presented temperatures above the solution with coloured double glass (difference of 4ºC on average).

As with the summer parametric variations, the degree of insulation and the type of cloth wall had little influence on the result.

Parametric Variations - Winter

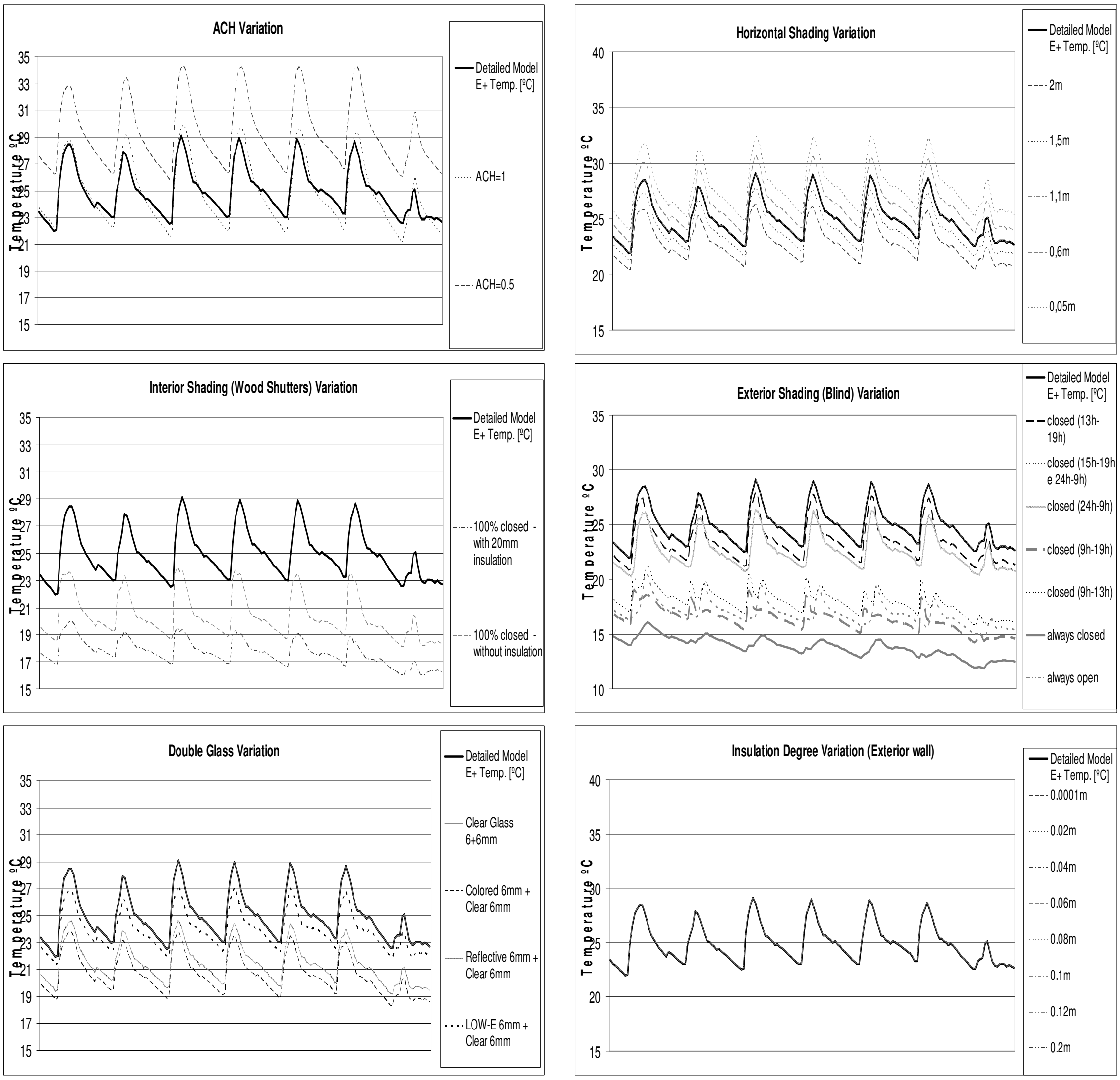

Figure 9. Winter parametric variations (Detailed Model).

4 FINAL REMARKS

This study showed the influence of various parameters on the thermal behaviour of housing units with large glazing areas. It was verified (within the range studied) that the interior temperatures ranged up to 8ºC in summer and 10 ºC in winter depending on the adopted solution.

During the summer, the natural ventilation and the type of protection contributed significantly to a better thermal behaviour of the model in question.

In winter the point of greatest care is the infiltration (reducing infiltration while maintaining levels of indoor air quality) as well as how to use the protection devices by the users (to provide better reception of solar radiation available).

Thus, this study aims to help and alert the professionals to some solutions that can be adopted for buildings with large glazing areas in temperate climates.

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Life Cycle Inventory (LCI) analysis of structural steel members for the environmental impact assessment of steel buildings

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ABSTRACT: Sustainable building can be achieved with the use of specific methodologies and tools that aim at optimizing the design stage of a building project according to the principles of sustainable development. One of the most widely acknowledged and used sustainability evaluation method is Life Cycle Assessment (LCA), which is based on the collection and management of environmental impact data most often drawn from available Life Cycle Inventory (LCI) databases. The present research forms the basis of a newly developed LCI database focusing on steel structures. Hot rolled structural steel members are used as a reference point in order to collect the required data, through contact with one of the leading steel producing companies in Greece and detailed literature research. Data is analyzed and categorized with regard to the stages of the manufacturing process for hot rolled steel sections, from raw material acquisition to the storage of products ready for use (cradle-to-gate) and then transferred to computer software for processing and results interpretation. The outcome is presented in this paper, both as an available tool within the scope of LCA studies regarding steel structures and also as a framework which can be applied within other geographic regions for similar purposes.

1 INTRODUCTION

The evaluation of the sustainability of a building project can be conducted with the help of a number of tools that have been developed over the last few years. One of the most complete and detailed analysis methodologies, based on the concept of the life cycle, is Life Cycle Assessment (LCA). LCA considers the entire life cycle of a product or system, from raw material extraction, through material production and energy requirements, to use and end of life treatment (ISO, 2006). Through such a systematic overview, environmental burdens are identified and possibly avoided. LCA can assist in identifying opportunities to improve the environmental performance of building projects at various points in their life cycle.

In order to conduct an LCA analysis, certain stages have to be executed, ranging from goal/scope definition and Life Cycle Inventory (LCI) to Life Cycle Impact Assessment (LCIA) and results interpretation. During the Life Cycle Inventory stage, a list of raw material requirements and environmental emissions is drawn that forms the basis on which the final impact is calculated. As this is a crucial issue with an immediate effect on the validity of the study, it is necessary to examine the data used in detail (Zygomalas et al, 2009). In most cases, it is not recommended to use already available data as found in existing databases, because of substantial differences in factors such as geographic range, technology level, time period etc. (Bragança et al, 2007). It is therefore necessary to create new, better suited LCI databases according to the particular properties of projects or -as a more tangible starting point- countries.

The current research concerns the development of such a LCI database for Greece, with particular focus on steel structures, a widely acknowledged building technology with significant environmental sustainability potential.

1.1 *Research Methodology*

Since there are two major categories of steel making processes, the first being the blast furnace route with requirements of raw material quantities and the second the electric arc furnace route that produces steel from used scrap, the initial part of the research focuses on allocating the LCI data requirements between the two routes.

According to statistical data, the steel manufacturing companies in Greece produce steel with the electric arc furnace (EAF) route, based on the recycling of iron and steel scrap rather than the extraction of raw materials. For year 2006, the total annual production of steel in Greece was approximately 2.416 thousand metric tones (World Steel Association, 2009), with all of the quantity being produced with the EAF route. Since the EAF route is the only steel manufacturing method used in Greece, it can be assumed that an LCI database based on its detailed examination is representative of the country's steel producing market and can be used for LCA studies within its geographic limits.

In order to obtain the data required for the development of the LCI database, the only structural steel member manufacturing company in Greece was contacted and informed of the research purpose and methodology. The data received in reply covered the majority of the manufacturing process for hot rolled structural steel members in detail. Where necessary, data was added as a result of literature research (Athena Sustainable Materials Institute, 2002). After the completion of the collection and categorization of the data, it was entered into the SimaPro software for management and analysis purposes.

2 LIFE CYCLE INVENTORY OF STRUCTURAL STEEL MEMBERS

2.1 Analysis goal

The goal of the analysis is to create a new Life Cycle Inventory (LCI) database, which will contain the raw material requirements and environmental impact (emissions to air, water and soil) associated with the production of one (1) kg of hot-rolled structural steel members (steel quality Fe360, equivalent to S235JR or RSt 37-2). Based on the results, it will be possible to calculate raw material requirements and environmental emissions for all similar type structural steel members, according to their weight.

2.2 Data collection and organization

The data received from the Greek manufacturing company was examined in detail and organised according to the flow of the manufacturing process for hot-rolled structural steel sections, from scrap assembly to storage of finished products (cradle-to-gate). The main manufacturing stages are presented in Figure 1.

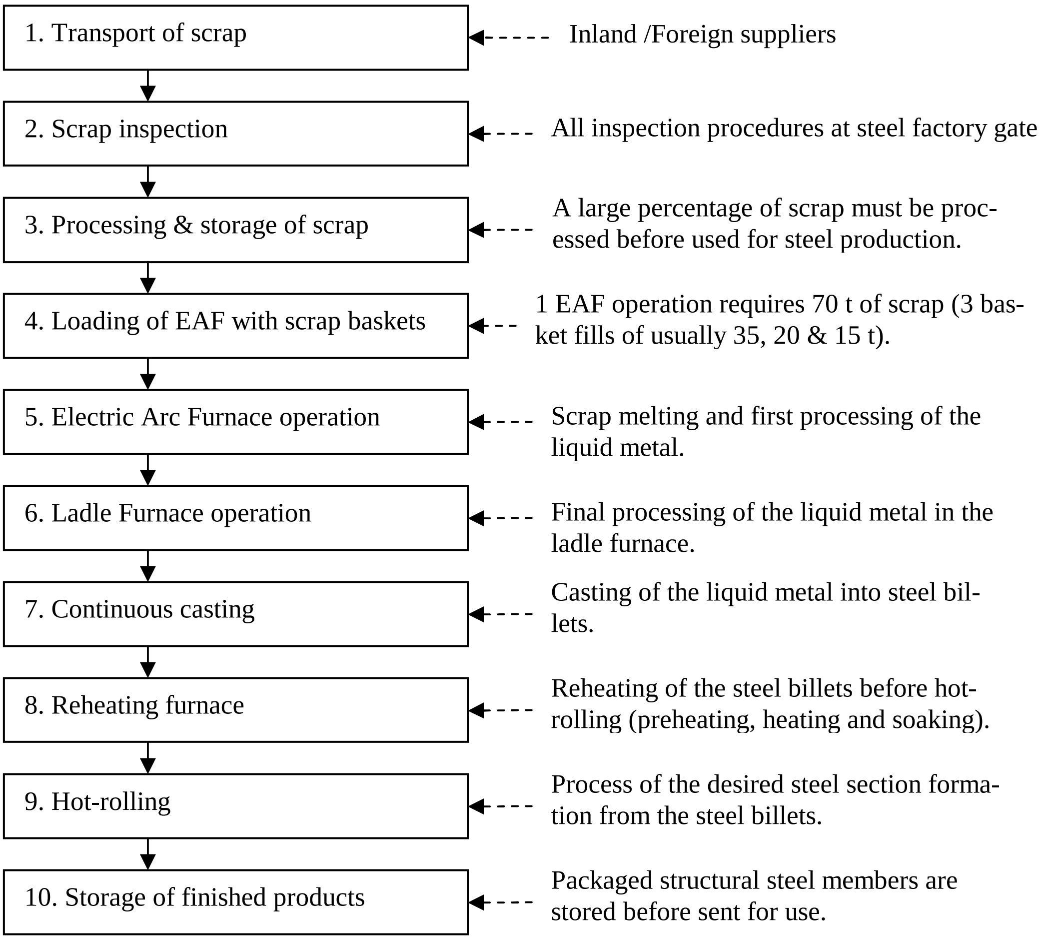

Figure 1. Main manufacturing stages for hot-rolled structural steel sections.

Based on this analysis, each main manufacturing stage is further analysed into processes and sub-processes, so that the environmental inputs and outputs can be documented in detail (Gulyj et al, 1996). As a representative example, the input requirements for the electric arc furnace are presented in Table 1.

Table 1. Required environmental inputs for the electric arc furnace stage.

Manufacturing stage	Process	Required data	Data for Life Cycle Inventory (LCI)	Comments
Operation of electric arc furnace	Scrap melting and first processing of liquid metal.	- Materials added to the furnace. - Power consumption (kWh).	Per billet t: - 380-450 kWh (average=415) - infusion of 0-5 kg magnesium oxide MgO (average=2,5) - 20-30 kg graphite C (average=25) - 25-50 Nm3 oxygen (average =37,5*1,4291=53,6 kg) - 10 MJ natural gas from the urban network. - Coal. - 0-10 kg petroleum coke (average=5) - 30-60 kg quicklime CaO (average=45)	Each operational circle with 70 t of scrap produces: 62,9 (84,8%) t steel, 0,593 t (0,8%) scrap, 3,11 t waste (4,2%) & 7,49 t non-metallic waste (10,1%).

3 ENVIRONMENTAL IMPACT OF HOT-ROLLED STRUCTURAL STEEL MEMBERS

Based on the documentation of the manufacturing processes for hot-rolled structural steel members, corresponding process entries were created within the SimaPro software, thus allowing for the evaluation of the associated environmental impact. Results are calculated on the basis of 1 kg of manufactured product, so that they can be easily compared to similar studies' findings and also used within the scope of similar future studies. In order to assess the environmental impact, the Eco-Indicator method was used (Eco-Indicator 99 (E), Europe EI 99 E/E).

The results obtained contain 766 entries in total, referring to the environmental inputs (raw material requirements) and outputs (emissions to air, water and soil) associated with the manufacture of 1 kg of hot-rolled structural steel section members according to the Greek conditions. Table 2 contains the most important substances according to input and output category, whereas Figure 2 presents the environmental impact of each main manufacturing stage according to the Eco-Indicator impact categories.

Table 2. Life Cycle Inventory (LCI) data for the production of 1 kg of hot-rolled structural steel section member in Greece.

	Substance	Category	Unit	Amount
Inputs:	Coal (brown, in ground)	Raw material	kg	0,9302
	Dolomite ($CaCO_3$, in ground)	Raw material	kg	1,6727 E-04
	Iron (46% in ore, 25% in crude ore, in ground)	Raw material	kg	0,0713
	Manganese (Mn, in ground)	Raw material	kg	5,1938 E-08
	Natural gas (in ground)	Raw material	m^3	0,1010
	Oil (crude, in ground)	Raw material	kg	0,0627
	Steel scrap	Raw material	kg	1,3132
	Water (unspecified natural origin)	Raw material	lt	7,4807
	Zinc (Zn, in ground)	Raw material	kg	2,5301 E-09
Outputs:	Carbon dioxide (CO_2)	Air emission	kg	0,2672
	Carbon dioxide, fossil (CO_2)	Air emission	kg	1,0898
	Carbon monoxide (CO)	Air emission	kg	3,6529 E-03
	Dinitrogen monoxide (N_2O)	Air emission	kg	2,1935 E-05
	Hydrogen Chloride (HCl)	Air emission	kg	2,2360 E-04
	Hydrogen Sulphide (H_2S)	Air emission	kg	5,2839 E-06
	Lead (Pb)	Air emission	kg	4,5187 E-07
	Mercury (Hg)	Air emission	kg	5,3244 E-08
	Methane (CH_4)	Air emission	kg	4,0908 E-04
	Nitrogen oxides (NO_x)	Air emission	kg	1,7179 E-03
	Non-methane volatile organic compounds (NMVOC)	Air emission	kg	6,1780 E-04
	Particulates, < 2.5 um ($PM_{2,5}$)	Air emission	kg	5,4259 E-04
	Particulates, < 10 um, mobile & stationery (PM_{10})	Air emission	kg	4,1696 E-06
	Sulfur dioxide (SO_2)	Air emission	kg	4,0054 E-03
	Sulfur oxides (SO_x)	Air emission	kg	9,8143 E-05
	Zinc (Zn)	Air emission	kg	5,6612 E-07
	Ammonia, as N (N)	Water emission	kg	1,4202 E-07
	Cadmium, ion	Water emission	kg	6,0885 E-07
	Chemical Oxygen Demand (COD)	Water emission	kg	0,0014
	Chromium, ion	Water emission	kg	6,5059 E-07
	Iron	Water emission	kg	4,6990 E-06
	Lead (Pb)	Water emission	kg	3,2072 E-06
	Nickel, ion	Water emission	kg	4,6555 E-05
	Suspended solids	Water emission	kg	2,9094 E-04
	Zinc, ion	Water emission	kg	2,1268 E-05
	Calcium	Soil emission	kg	1,5291 E-05
	Heat, waste	Soil emission	MJ	0,0100
	Iron	Soil emission	kg	1,4020 E-05
	Oils, unspecified	Soil emission	kg	2,4071 E-04
	Steel waste	Waste	kg	0,0620
	Waste, unspecified	Waste	kg	0,1640

As shown in Figure 2, the most environmentally damaging processes are the operation of the electric arc furnace and hot-rolling. The reheating furnace and ladle furnace processes also result in noticeable environmental impacts, while the rest of the processes affect the overall impact at a lower degree. With regard to the environmental impact categories (Figure 3), the categories “fossil fuels” that refers to natural resources and “respiratory-inorganics”-associated with negative effects on human health- are mainly burdened. The manufacturing stages primarily responsible for these negative effects are again identified as the operation of the electric arc furnace and hot-rolling.

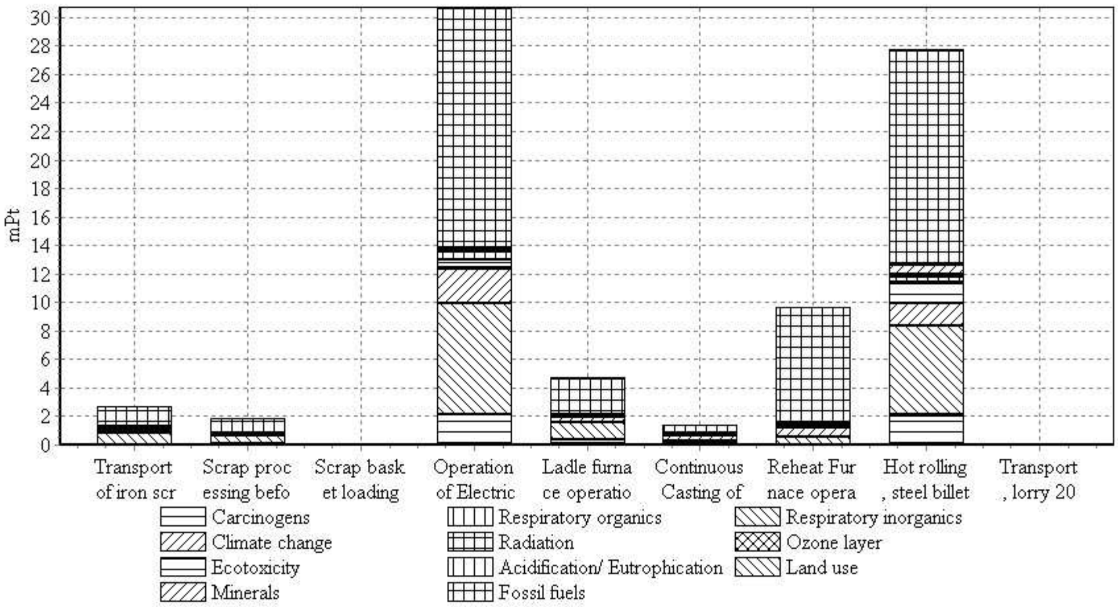

Figure 2. Environmental impact of main manufacturing stages for 1 kg of hot-rolled structural steel section member in Greece.

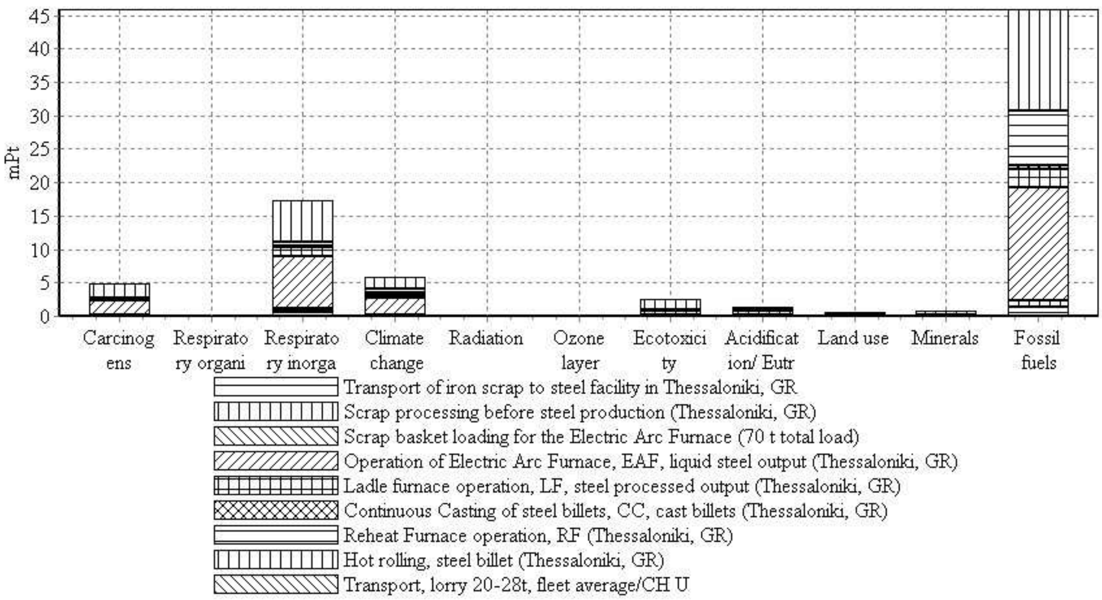

Figure 3. Environmental impact of 1 kg of hot-rolled structural steel section member in Greece according to impact categories.

In order to identify the sources of environmental burden within the boundary of each manufacturing stage, it is also necessary to examine the network of environmental burden flow for the production of 1 kg of hot-rolled structural steel members, presented in Figure 4. For presentation purposes, this diagram does not contain all of the processes, but only the most influential ones. As the thickness of the arrows indicates the environmental loads, it is evident that electricity requirements are responsible for more than half (55,6%) of the total environmental impact.

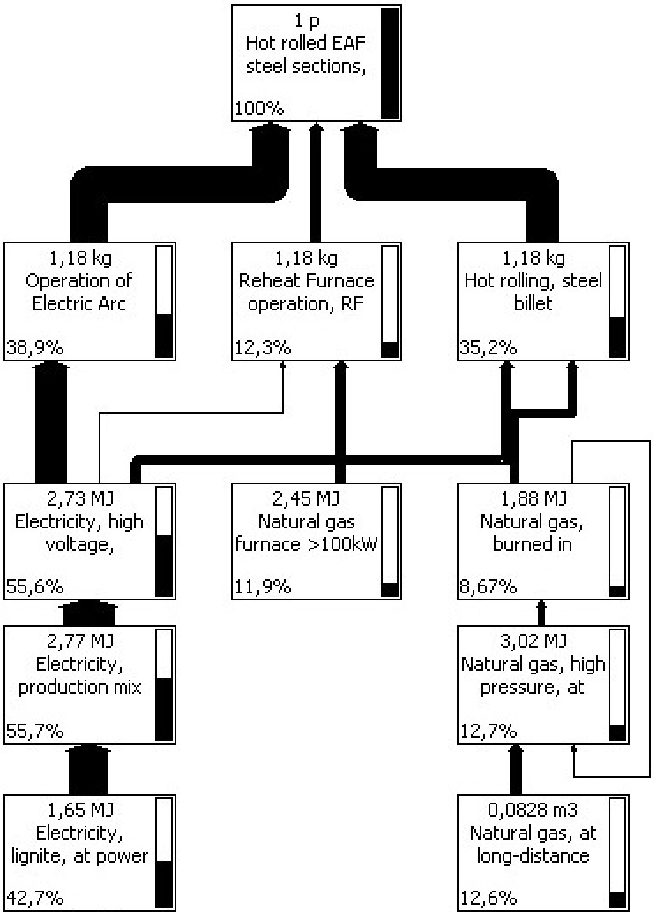

Figure 4. Environmental burden flow for the manufacturing of 1 kg of hot-rolled structural steel section members in Greece.

Further down in the diagram, the lignite burned at the power plant for the production of the electric energy is revealed as the main source of environmental burden. This also explains why the “fossil fuels” impact category is so heavily affected by the operation of the electric arc furnace and the hot-rolling process, both of which require significant amounts of electricity. On the other hand, natural gas is also used as an energy source, yet its environmental impact is quite lower. 4,33 MJ of natural gas energy required in total for the reheating furnace and the hot-rolling process (2,45 MJ for the reheating furnace and 1,88 MJ for hot-rolling) are responsible for 20,6% of the total environmental burden, as opposed to 55,6% corresponding to 2,73 MJ of electric energy required in total. Regardless of source, energy requirements account for 76,2% of the total environmental load, a figure which leaves little room for doubt that in order for hot-rolled structural steel member manufacturers to improve their products’ sustainability, they will have to reconsider their current energy strategies.

Another parameter which was examined was the carbon dioxide emissions to the atmosphere. In this respect, it is both electric energy and also natural gas energy which are responsible for the largest percentage of emissions. It is therefore clear that in order to reduce the total environmental impact, energy requirements -particularly electric energy- will have to be reduced.

4 GLOBAL WARMING POTENTIAL (GWP) ANALYSIS

It is also possible to estimate the amount of equivalent carbon dioxide air emissions, by the calculation of the Global Warming Potential (GWP) index (IPCC, 2007). This methodology is based on specific factors with which every substance emission is multiplied and thus translated into equivalent gr of carbon dioxide, which are finally added to a total. In this manner, a single index becomes an immediate depiction of the environmental impact of a product or system, for a time horizon of 20, 100 or 500 years. For 1 kg of hot-rolled structural steel members, the GWP results are presented in Table 3. For a 100-year time horizon the equivalent carbon dioxide emission was calculated at 1,405 kg CO_2 eq.

Table 3. GWP index for the production of 1 kg of hot-rolled structural steel members, based on the IPCC GWP 2007 methodology.

GWP methodoly	Unit	Total
IPCC GWP 20a (20 έτη)	kg CO_2 eq	1,4838
IPCC GWP 100a (100 έτη)	kg CO_2 eq	1,4054
IPCC GWP 500a (500 έτη)	kg CO_2 eq	1,3732

The contribution of each main manufacturing stage is displayed in Figure 5. As was shown by the Eco-Indicator analysis, the stages which are mainly responsible for the total environmental impact are the electric arc furnace operation, the hot-rolling process and the reheating furnace operation.

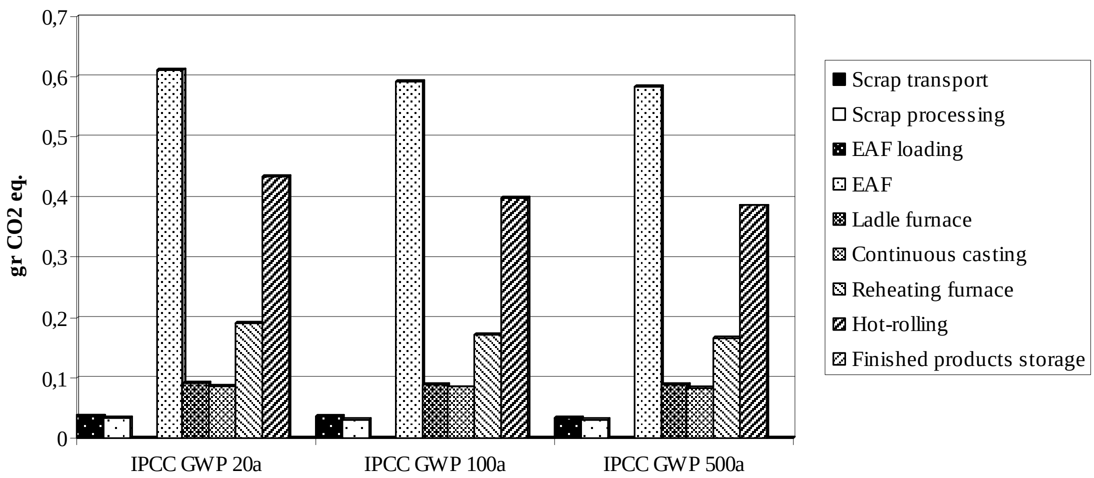

Figure 5. Process contribution to total environmental impact as estimated with the IPCC GWP 2007 methodology.

5 CONCLUSIONS

While the Life Cycle Assessment (LCA) methodology provides a detailed approach to calculating the environmental impact of steel structures, it never ceases to associate its validity with the quality of the Life Cycle Inventory (LCI) data which is used. The research conducted provides a useful initial attempt at the development of a new LCI database for structural steel elements in Greece. The impact of the manufacturing of hot-rolled structural steel members was estimated, based on data provided by a Greek steel manufacturing company and secondary data found in literature and existing LCI databases as well.

It is not possible to claim that any LCI database contains data which represent environmental impacts with total accuracy. However, as is the case with the current newly formed database, they do serve as a reliable estimation which can be used for future decision-making, strategy planning, or in the case of steel structures, optimization of the design processes.

With regard to environmental impact, the main source of burden associated with the manufacturing of hot-rolled structural steel members was found to be the energy requirements. While electric energy accounts for more than half of the total environmental impact, natural gas energy is responsible for almost 60% of the total carbon dioxide emissions to the atmosphere. Energy has been an issue within the scope of sustainable development for quite some time now and as was shown by the research undertaken, it must also be integrated into the manufacturing process for steel members in order to ensure a sustainable manufacturing procedure.

The analysis described can also be used as a framework which can be applied to other geographic regions for the assessment of the environmental impact of hot-rolled structural steel members. The main manufacturing stages will require minor modifications to fit the specific conditions which apply for each country, with the most significant part of data required remaining the energy requirements.

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Chapter 6

Case-studies

Assessment of Solar XXI Building Sustainability by SBTool^{PT} Methodology

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ABSTRACT: In this paper that focus on the building sector, it's presented the evaluation of the sustainable performance of an office building in Lisbon – Solar XXI. This analysis was performed using the SBTool^{PT} methodology, which is a methodology initially developed by (Mateus and Bragança 2006) at Minho's University, for application in residential buildings. This study confirmed not only the high performance of Solar XXI but also the flexibility and adaptability of SBTool^{PT} to different kinds of buildings, locations and cultural concepts.

1. INTROCUCTION:

1.1. *Sustainable construction*

Nowadays, the construction industry is one of the most active and dominant activities in the world, with a strong influence on its economy, society and environment. According to OECD (2003) this industry, in 2003, represented 9,7% of the GNP (gross national product) in Europe.

In Pinheiro (2006) is mentioned that the construction sector is responsible for 7% of the employment in the world, which may increase up to 23% in developing countries. In what concerns to environment, the construction industry contributes actively to its degradation through the dilapidation of natural resources, since it consumes 3000 Mt/year of raw materials, in the world (Torgal and Jalali 2007), 55% of the wood extractions for non-fuel purposes and 40% of stone, gravel and sand (Roodman and Lenssen 1995). It is also responsible for 40% of the primary energy annually consumed in the world as stated by Energy Efficiency in Buildings (2009) and responsible for 180 million tons per year of the waste produced in Europe (OECD 2003).

The main purpose of the construction sector is to provide buildings that are able to satisfy the owners' functional needs, given their budget and the design aspects. Combining these aspects and the actual way of life, the living conditions in the world will became unbearable.

Therefore, an improvement on the way of thinking and acting, especially in the construction sector, is essentially to achieve the sustainability.

Mateus and Bragança (2006) and Pinheiro (2006) cited Charles Kibert to apply the sustainable concept to the construction industry, "*Sustainable construction is the responsible development and management of a healthy built environment, based on the efficient use of the resources and on the ecological principles*". This concept integrates the eco-efficiency principles with the economic and social constrains, merging therefore the three dimensions: environment, society and economy.

The principles have to be applied during the entire life cycle of the building, such as: (a) minimizing the water consumption; (b) re-use resources when possible; (c) recycle materials; (d) protect the natural resources and their function in every activity related to them; (e) avoid the products and sub-products with high level of toxicity.

2. BUILDING CHARACTERIZATION

This study focus on the Solar XXI, which is an office building in Portugal headquarters to the Renewable Energy Department of LNEG, in Lisbon. This building, constructed between 2004 and 2005, intends to be an example of energy efficiency and self supporting energy, as it integrates the solar passive concepts of the bioclimatic design with the active ones, looking forward to reduce its own need of heating and cooling (Gonçalves and Cabrito 2006).

The building has about 1500 square meters along its three floors, one of them lying underground in the South façade. The main occupied spaces, such as office rooms, are located on the south part of the building while the less occupied ones, as meeting rooms and laboratories, are in the north side.

The central part has a skylight that harnesses natural lighting for the three floors, as there are transparent elements between the central corridor and adjacent rooms (CEETA and Keep Cool). Moreover, it is possible to transfer heat from the southern to the northern side of the building due to the existing openings in the internal doors, by natural convection. Planned to maximize the solar gains during winter and minimize them during summer, Solar XXI has an entire façade turned south, which has a high area of double glazing with external movable venetian blinds.

The envelope of the building is external insulated with 5cm thick of EPS (expanded polystyrene) in a single masonry wall and has 10 cm insulation on the roof (5cm of EPS + 5cm XPS (extruded polystyrene)) (Gonçalves et al. 2008). These measures contribute to reduce the heat gains through opaque façades, helps on the heat storage in the mass of the building and its releasing during the night to indoor spaces. In addition, the building has a solar thermal system, located on the rooftop, consisting in eight collectors which fill up 15 square meters of reception area. Their efficiency is about 70% and they have a loose of 3.4 W/m2·K. In cooler days, this system assists the auxiliary heating system (boiler and radiators). The solar thermal system is also used in sanitary hot water preparation. In order to construct a building without air conditioning, Solar XXI has as main strategies for air cooling the prevention of solar gains, the night ventilation and a buried earth tubes. These last ones consist in a set of 32 concrete buried pipes at 4.6m depth, with 30cm of diameter each, allowing the air to flow from the inlet outside the building – 15m from the South façade – to the inside. The atmosphere air is cooled to the underground's temperature (≈ 16ºC) entering in the basement of the building and going up to the next floors. There are two incomings of fresh air in each south room which can be controlled individually by the inhabitants. The north rooms are less problematic in what regards the solar heat gains, and the cooling is obtained through natural ventilation.

At last, but not least, it is integrated in the building two Photovoltaic (PV) Systems, one in the South façade and the other on the car parking, to produce energy for own consumption. On the South envelope the PVs are located vertically reaching an area of 96 square meters (12 kWp) and providing around 12 MWh per year (Gonçalves et al. 2008). It's important to refer that due to the way that these PVs are installed it is possible to recover some heat produced by them in order to be used on the building's heating process. The PV system on the car parking has 6kWp and covers an area of 95 square meters. The two systems together correspond to approximately 76% of the electric energy required by the building's.

3. METHODOLOGY

Due to the significant changes needed to mitigate the environmental impact of building sector, progress has been made to amplify the building's sustainability. Diverse countries tried to develop several assessment tools to evaluate the sustainability performance of the constructions. They vary to a great extent as different phases of a building life cycle, different application scales (global, national, local, etc.) or even different issues taken into account (Haapio and Viitaniemi 2008). Erlandsson and Borg (2003) refer that the majority of tools is developed based on a bottom up principle; this means, the sum of individual performances of the buildings' compounds is equal to the global performance of the building. However, Allecker and DeTroyer (2006) said it is not right to consider the building as the sum of its compounds, because of the design influence on the global impacts. Therefore, it is possible to classify several methodologies by types although there are different opinions in how to do it. Mateus and Bragança (2006) support the division made by the *ATHENA Institute* (Trusty 2000), dividing the methodologies into three categories: (1) whole building design or decision support tools, such as ATHENA^{TM}, BEAT 2000; (2) product comparison tools and information sources, as BEES and TEAM^{TM}; (3) whole building assessment frameworks or systems, as LEED, BREEAM and SBTool. The third group integrates systems and tools that recognize the sustainable construction, during the whole phases of building's life cycle. Therefore within this group a better integration of the three sustainability dimensions is achieved. Although there are different methodologies in this group, all of them analyze the following categories:

- Site selection and planning;
- Energy consumption and its sources;
- Environmental load (water, residues, exterior air quality);
- Inside air quality;
- Functionality (noise, comfort, lighting).

This paper focuses on the study using SBTool (Sustainable Building Tool) which can be found in this last group of methodologies. The development of this tool involved the joint effort of several countries, since 1996 and it was promoted by the International Initiative for a Sustainable Built Environment (iiSBE) (Pinheiro 2006). This international involvement supported its distinction among the others methodologies, since SBTool was designed to allow users to reflect different priorities, technologies and building and cultural traditions in the same methodology. Therefore, SBTool has a global structure; it is adjustable to each country or region providing approximate assessments of a broad of potential environmental performance parameters, all of them related to the performance of benchmarks that are relevant to the region and building type of occupancy.

The Portuguese version of SBTool was developed by the University of Minho in Portugal. This methodology approaches the three dimensions of the sustainable concept: environment, society and economy. In SBToolPT the evaluation is accomplished relatively to the most applied solution in a certain place. The framework of this methodology follows the five steps listed below as stated by Bragança et al. (2007):

- Definition of system boundaries;
- Definition of parameters;
- Quantification of parameters;
- Normalization and aggregation of parameters;
- Sustainable score calculation and evaluation.

3.1. *Definition of system boundaries*

Although, the SBTool^{PT} was at first developed to assess residential buildings, in this study it is applied to office buildings. The object of the evaluation is the building, its foundations and external works in the building site (Bragança et al. 2007). Issues as the urban impact in the surroundings, the construction of communication, energy and transport networks are excluded. Regarding the temporal boundary, it should be the whole life cycle (*from cradle to grave*) for new buildings. For the ones that are already constructed the temporal boundary stars from the moment of the intervention to the final disposal. It is also necessary to define the daily hours of occupation and the occupation density.

3.2. *Definition of parameters*

Being holistic, the methodology cannot assess all the parameters involved on the constructive solution. Thus, there is the need to select the parameters to include in the assessment, setting up their quantity and type. Parameters that are able to raise complexity and subjectivity to the evaluation should be excluded.

The environmental parameters choice was based on the work carried out by the CEN/TC 350 WG1. The environmental performance was assessed by the quantification of the potential effects connected to the materials and technologies used during the building's construction. Although SBToolPT has initially included fifteen parameters distributed in five categories, this assessment evaluated fourteen parameters in the following five categories:

- C1 – Climate change and outdoor air quality (ex.: overall index of environmental impact categories of the building's life cycle);
- C2 – Biodiversity and land use (ex.: percentage of plan area with reflectance equal or greater than 60%);
- C3 – Energy (ex.: consumption of non-renewable primary energy during the occupation phase and quantity of renewable energy produced in the building);
- C4 – Materials and solid waste (ex.: percentage of building's recycled content and building's potential to promote waste separation);
- C5 – Water (ex.: annual consumption per capita, and potential to re-use wastewater).

In the social performance analysis there were only included parameters related to heath and comfort of the inhabitants, distributed in two categories:

- C6 – Comfort and Health of occupants (ex.: thermal and visual comfort, natural ventilation potential and toxicity of the finishing materials);
- C7 – Accessibility (ex.: access to public transports and amenities.

The acoustic comfort was not included because the acoustic project was not available and there was no time to perform resulting tests.

Lastly, the economic performance includes all the costs related to the whole building's life-cycle, however the presented case study only included the occupation costs, because the information need to evaluate the initial cost was not available;

- C9 – Life cycle cost (occupation cost per square meter).

3.3. *Quantification of parameters*

After selecting the parameters it's necessary to proceed with their quantification, which allows the comparison between the solution under study and the benchmarking solutions. As there are several parameters under study and each one has its own way of quantification, it is impossible to describe all of the procedures executed during the assessment. The environmental parameters quantification followed the bibliography Berge (2001), where it is possible to find data about potential sources of buildings' environmental impact. For the quantification of the social parameters, there were used several normalized methodologies available regarding also the national law, in some cases. The last group of parameters, the economic ones, was quantified using the LCCA (life cycle cost analysis) procedures.

3.4. *Normalization and aggregation of parameters*

The normalization aims the extinction of scale effects in the aggregation phase and was achieved applying the Díaz-Balteiro and Romero (2004) equation:

$$\overline{P_i} = \frac{P_i - P_{i*}}{P_i^* - P_{i*}} \quad \forall i \qquad (1)$$

Where Pi is the value of the ith parameter, Pi* is the best value of the ith parameter and Pi* is the standard value for the same sustainable parameters.

This procedure make the parameters values dimensionless, within a scale 0 (worst value) to 1 (best value), facilitating the aggregation and the comparison with benchmarks.

The aggregation consists on a weighted merge of the parameters into categories and the categories into dimensions in order to obtain three single indicators. These three values are obtained using the equation (2) which final result gives the dimension performance.

$$I_j = \sum_{i=1}^{n} w_i \times \overline{P_i} \qquad (2)$$

Where Ij is the weighted average of all normalized parameters $\overline{P_i}$ from the indicator j, wi is the weight of the parameter ith.

This weighting average process may not be consensus and can suffer changes depending on specific situations. The weights used on the environmental performance have international acceptance due to the United States Environmental Protection Agency (EPA) studies, which give the relative importance of each parameter according to its harmful effect on the environment (Bragança et al. 2007). The evaluation of social parameters is easy however there are some discussions, caused by disagreement on the influence of each parameter on the final result. As so, to avoid this subjectivity, it is left out of the assessment all parameters that are not directly related to health and comfort of the building's occupants.

3.5. *Sustainable score determination and evaluation*

The assessment ends with the quantification of the sustainable score (SS). The SS is a single index that represents the global sustainability performance of the building, and it is achieved by using the equation (3).

$$SS = w_{G1} \cdot I_A + w_{G2} \cdot I_S + w_{G3} \cdot I_E \quad (3)$$

Where SS is the sustainability score, Ii is the indicator of the dimension i and wj is the weight of the indicator jth.

The evaluation of the SS is still not consensual, since it is obtain through the use of weighting factors. In this study the environmental dimension had a high importance while social and economic dimensions shared the same weighting value, Table 1.

Table 1. Weight of each sustainable dimension in the SS.

Dimension	Weight (%)
Environment	40
Social	30
Economic	30

The assessment only finishes after the qualitatively classification (Table 2) of the SS and the emission of a sustainable certificate.

Table 2. Levels and conditions to the assessment of the three sustainable dimensions and its indicators.

Level	Condition	Level	Condition
A^{+}	$\overline{P_i} > 1.00$	D	$0.30 < \overline{P_i} \leq 0.50$
A	$0.90 < \overline{P_i} \leq 1.00$	E	$0.10 < \overline{P_i} \leq 0.30$
B	$0.70 < \overline{P_i} \leq 0.90$	F	$0.00 < \overline{P_i} \leq 0.10$
C	$0.50 < \overline{P_i} \leq 0.70$	G	$\overline{P_i} < 0,00$

Where $\overline{P_i}$ represents the parameter i^{th} or the SS.

In spite of the need to determinate in which level fits the SS, this global index should not be presented alone, since the values' aggregation may hide some significant differences between the indicators values. There for it is important to display also the intermediate indicators.

4. RESULTS

In order to facilitate the understanding, this section follows the framework of the SBTool^{PT} methodology.

4.1. *Definition of system boundaries*

As the assessed building is an office building it was necessary to follow the Portuguese law for this type of building – *Regulamento dos Sistemas Energéticos e Climatização de Edifícios (RSECE, 2006)*. According to *RSECE*, Solar XXI is similar to an office building with 14 hours of use per day and it's closed during the weekend. The occupation density was established in 30 square meters per occupant (approx. 50 occupants). From the whole life-cycle of the building there were only assessed the phases of construction and occupancy.

4.2. *Performance evaluation*

4.2.1.Environmental performance

Table 3 resumes the results of the categories assessed on the environmental dimension (D1). Each category has its own parameters performances.

Table 3. Resume of environmental parameters evaluation.

Category	Parameter	P. value	P. value (Normalized)	P. Weighing Factor (%)	P. Weighted Value	P. Performance
C1	P1	-.-	1.3	100	1.3	A+
C2	P3	49.03 %	0.35	8.06	0.03	D
	P4	100 %	1.11	9.68	0.11	A+
	P5	51.73 %	0.84	38.71	0.33	B
	P6	80.27 %	0.23	43.55	0.10	E
C3	P7	31 kgep/m^2.year	1.0	50.0	0.5	A
	P8	6406.04 kgep/year	0.26	50.0	0.13	C
C4	P9	2.03 %	0.14	25.0	0.03	E
	P10	262 ton	0.6	25.0	0.25	E
	P11	23.16 %	4.63	28	1.30	A+
	P12	0.0 %	0.0	18.0	0.0	G
	P13	40 %	0.75	40.0	0.30	B
C5	P14	9.13 m^3/occupant	0.99	64	0.637	A
	P15	0.0 %	0	36	0.0	G

The C1 accounted only the construction phase. So, there were evaluated all the materials and construction solutions used on Solar XXI and their areas, for all the construction elements (walls, floor, etc.) in the following categories: Global warming potential (GWP); Ozone depletion potential (ODP); Acidification potential (AP); Photochemical ozone creation potential (POCP); Eutrophication potential (EP) and Fossil fuel depletion potential (FFDP).

The C2 was accomplished with the evaluation of four parameters: Land waterproofing index (P3); Percentage of used land previously contaminated or built (P4); Percentage of green areas reserved to native plants (P5); Percentage of plan area with reflectance equal or greater than 60% (P6). Each one had a different method of quantification due to their specifications. The third category, C3, evaluated the consumption of non-renewable primary energy during the occupation phase (P7) and quantity of renewable energy produced in the building (P8). Unlike it was expected, this assessment did not confirm the building's energy efficiency. It was expected a class A+ performance given the characteristics of Solar XXI and its known evidences of energy efficiency. The result was a class C performance, probably due to some undisclosed information at the moment. The evaluation of the C4 accounted five parameters: Cost percentage of re-used materials (P9); Weight percentage of building's recycled content (P10); Cost percentage of certificated organic based products (P11); Mass percentage of substitute materials of cement in concrete (P12); Building's potential to promote waste separation (P13). The water category, C5, showed that Solar XXI has a great potential in re-using wastewater as it has no facilities installed to execute this issue (P15). The final result also proved a small amount of water consumption (P14).

4.2.2.Social performance

Table 4 lists the results obtained in the social performance (D2) quantification.

Table 4. Resume of social parameters evaluation.

Category	Parameter	P. value	P. Value (Normalized)	P. Weighing Factor (%)	P.Weighted Value	P. Performance
C6	P16	80 credits	1.67	12.35	0.21	A^+
	P17	99.63 %	1.11	17.28	0.19	A^+
	P18	-. -	0.99	39.51	0.39	A^+
	P19	-. -	2.92	30.86	0.90	A^+
C7	P21	6.0	0.33	55.0	0.18	D
	P22	55	2.7	45.0	1.2	A^+

The C6 as it was said before did not evaluate the acoustic comfort. All the other parameters assessed a class A+ performance, as expected; the ventilation potential (P16), the weighted percentage of finishing materials with low amount of VOC (volatile organic compounds) (P17), the annual average of thermal comfort (P18) and the average of daylight factor (P19). The P18 was not evaluated with the initial proposed values because there wasn´t enough information available, however it was assessed using the values presented on the Gonçalves et al. (2008) paper. The C7 assessment was carried out by the calculation of two parameters: the accessibility to public transports (P21) and to amenities (P22). Despite the good result of P22, the access to public transports obtained an unexpected result to a city as Lisbon. The C8 category – education to sustainability – was not included since the values needed were not available to this office building.

4.2.3.Economic performance

Table 5 shows the results from the unique parameter evaluated on the economic performance (D3), which obtain a good result, class A performance.

Table 5. Resume of economical parameter evaluation.

Category	Parameter	P. value	P. value (normalized)	P. Weighing Factor (%)	P. Weighted Value	P. Performance
C9	P25	20.35 €/m^2.year	0.99	100	0.99	A

4.3. *Sustainability Score Determination*

The table 6 resumes the aggregation process, and shows its final results. Each dimension obtained a very good result: D1 – class A; D2 – class A^+ and D3 – class A. The aggregation of this three values, gave the SS value, which showed that Solar XXI has a class A^+ Sustainable Performance. Moreover, with this result it was possible to emit a Sustainability Certificate to Solar XXI, by the SBTool^{PT} methodology.

Table 6. Category aggregation and SS determination.

Dimension		C. performance	C. Weighing Factor (%)	C. Weighted value	D. performance	SS
D1	C1	1.33	12.0	0.16	0.94 ⇒ A	
	C2	0.56	0.19	0.11		
	C3	0.63	0.39	0.25		
	C4	1.69	0.22	0.37		
	C5	0.64	0.08	0.05		1.15 ⇒ A+
D2	C6	1.69	0.69	1.16	1.59 ⇒ A^+	
	C7	1.38	0.31	0.43		
D3	C9	0.99	100	0.99	0.99 ⇒ A	

5. CONCLUSIONS

Globally, the necessity to think forward on sustainable construction is essential to improve the world and the life of its habitants.

Sustainable design, construction, operation, disposal and refurnishing of buildings should be base on the environmental pressure, social impact and life-cycle costs, otherwise, the rupture of natural resources, comfort and economic systems will be unavoidable.

This paper presents the evaluation of the sustainable performance of the office building - Solar XXI, using the SBToolPT methodology. Although SBToolPT has been specifically developed to residential buildings, in this study it was applied to an office building, testing and proving its flexibility and capability of adapting itself to the particular features of the studied building.

During this evaluation there was a need to readjust some of the parameters and, in certain cases, some were completely excluded. However, the final result was positive, as it was verified that beyond being energetically efficient, the Solar XXI represents a good example in how to achieve the sustainability in the construction sector.

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An Ergological Approach to Building Maintenance

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ABSTRACT: This research project, currently in progress, proposes to investigate building maintenance of steel buildings employing an ergological approach and using evaluations obtained through performance inspections of existing constructions. A case study examining steel buildings of the Engineering Faculty of UFOP (Universidade Federal de Ouro Preto) is used; the study is of an exploratory and interpretative nature, using data obtained through interviews and on-site inspections. The authors believe that this article can make a contribution by using concepts proposed by Ergology as the theoretical methodology for the investigation.

1 INTRODUCTION

1.1 *The building production chain in Brazil.*

Starting in the last decade, several new buildings erected in the principal urban centres of Brazil experimented with the use of semi-finished or industrialized materials in combination with innovative constructive technologies in their management and production processes. These buildings were a response to the process of modernization within the civil construction industry, yet they frequently became examples of a practice where attempts to technologically innovate were combined with a culture of planning, creating and producing the constructed space that was still artisanal in nature. In other words, existing knowledge was not updated, the business vision was frequently distorted, there was little investment in the training of the labour force, and more effective systems for the codification and standardization of materials, services, as well as the products produced by the industry were lacking.

A building is a complex composition of inter-related components that are dependent on the activity of various types of agents. In these newly-constructed urban buildings, serious pathologies, as well as the premature breakdown of the constructional components make an early appearance, compromising the performance of these buildings.

1.2 *Buildings in use and maintenance practices.*

In Brazil, concepts such as performance, service life, adequacy of operation and building maintenance are new, and their applicability to the civil construction production chain is still incipient, even though it has been noted in the market that these are economic activities with great growth potential.

It must be borne in mind that, until recently as far the building industry was concerned, the production of building space was both economically and culturally restricted and, frequently, still is, to a linear process of construct → enter into use. In short the industry was directly focused on a continual renovation of stock. Thus, it is natural to see within this context how maintenance would be reduced to an activity centered on the correction of faults and only taking place when these occur.

Thus, for the great majority of users of urban buildings in Brazil, the maintenance function is still seen primarily as a corrective process and conducted in a preventative manner for certain elements of the building system more related to the health and safety of its users. Such services are contracted out to maintenance management groups, by means of service providers, who function in an isolated manner, without documenting the services performed, without coordination or pre-established planning, or based merely on an annual expense budget (Resende 2004).

In the majority of cases, there is resistance to adopting new concepts in maintenance, given that better performance in building maintenance would imply a greater allocation of resources. A social-cultural difficulty arises, which favors an erroneous understanding that frequently pushes these essential maintenance activities to the side, where they can be postponed (Antonioli 2006).

Gomide (2007) has observed that a building is the "child of many parents", resulting in many conflicts. This author believes it to be an opportune moment to revise positions and methodologies, especially when one considers the new construction and managerial technologies employed in Brazilian civil construction, as well as the new performance regulations and other relevant certification now required in this sector.

Thus, he is in agreement with Wood (2005), when he emphasizes that the maintenance and enhancement of the built environment, together with the quality of life and the well-being of the final user merits serious attention. In this sense, according to him, research in this area, previously considered to be of little importance, is increasingly valued, as is the need to adopt new approaches or study perspectives that point to new directions for the future.

2 RELEVANCE OF THE INVESTIGATION

2.1 *Maintenance as activity.*

In this on-going research project, maintenance is considered to be a "set of actions which enable one to maintain or re-establish an asset in a specific state, or, further, assure an established service", " (Mirshawka 1991; apud Bezerra 2000). Therefore it can be stated that, under productive logic, this function requires the completion of actions that are of a technical/executional, operational and managerial nature, so as to insure that the evolution of the service life of this asset is in line with the expectations anticipated at its conception.

Building maintenance, seen thus, presents itself as a broad research theme that covers a wide diversity of perspectives that, in turn, implies the treatment of a large number of variables.

Treated as a technical function, building maintenance analyses various constructive systems and subsystems and their interfaces, the technical-financial aspects of the deterioration and performance of these systems, their components and, in short, the building performance as a whole, as well as analyzing operational models and their applicability. On the other hand, it is an activity that equally consists of the analysis of the activities of the various agents that could interfere with the durability, performance and optimization of the building lifecycle.

In the last few decades, various academic works have focused on the investigation of maintenance activities. The majority of these emphasize codifying and controlling these activities based on rigorous analysis of operational and technological practices.

Such research takes on a particular relevance, and is translated into attempts to adopt, in line with the realities of businesses and public institutions, an instrumental-technical logic which seeks to become universal; in other words, a logic that is capable of transcending regional and/or local contingencies, and placed within a rationalism that is conceived as a systematic method for quantifying the human experience (Canguilhem 2001).

In another perspective, in observing the intersection with various disciplines that this investigation implies, it may be stated, therefore, that the treatment of the maintenance function, in a more explicit or indirect manner, goes beyond the mere formulation of applicable techniques. It refers in essence not only to the notion of activity, but also to the management of this activity; in other words, it proceeds from the necessity of understanding it as a human endeavor.

2.2 *Justification*

The basic proposal of this research is to establish directives for the maintenance of buildings that incorporate systems and /or industrialized components, in particular, steel structures in their construction process. In light of such considerations, in presenting the theme of building maintenance as applied technology, and affirming that it is intrinsically linked to the notion of human activity or work, the principal premise of this article is that there is the fundamental need to contextualize it.

In this sense, it is necessary that its treatment starts with a situated perspective, where it is possible to make a relational analysis between the actions of maintenance, the physical performance of the buildings conceived as innovative constructed systems, and its use and operation, in short, made according to the specifics of the organizational culture.

To achieve this, a slice of the universe to be investigated is made: the research proposes to evaluate building maintenance activities in the steel structured buildings of the Engineering Faculty of the Federal University of Ouro Preto, located on its main campus, that of the Morro do Cruzeiro.

It is believed that this proposal, using a particular perspective, is relevant. Granted, in the literature on management, with an established strong functionalist tradition, a social dimension is recognized as a variable with potential to affect organizational success (Silva & Vergara 2003). Nonetheless, by gathering and recording data and publishing the results, this research will contribute to the application of new methodological approaches of investigation of the theme, as well as increase new contributions to existing studies, in rediscovering little explored dimensions, and increase the vision of the strategies, processes or technologies.

3 METHODOLOGY

3.1 *The theoretical-methodological basis.*

Given the singularity of its approach, this research project is structured as a case study, in which an understanding of the phenomenon is emphasized, and not its measurement. It is thus characterized by the use of qualitative data that is both exploratory and interpretative, and not by the search for clear and definitive conclusions (Yin 1984). Parallel to this, while the perspective is particular, it is necessary to attempt that this investigation must be inserted into a wider picture of academic discussion, providing the framework for the proposed questions related to the theme (Mazzotti & Gewandsznajder 2000).

Sousa Santos (1988) characterizes the present as ambiguous and complex, a period difficult to understand and investigate. It is “a period of transition”, where, on one hand, an assumed dissemination of a hegemonic thinking and universal practices simultaneously coexists with a social fragmentation into different types of communities existing in regional and local spheres.

Thus, this author proposes a new approach where understanding can be treated as a whole. This totality, while indivisible, also includes that which is singular, and, therefore, must be treated as themes adopted by different communities and of an interpretative character that is “… concrete as the local life projects”. Therefore he believes that, if there is need of fragmentation, it should be along the lines of themes and not disciplines, because in increasing the object of the study, knowledge is also increased. This, conceived as a process, takes shape as a search for new and varied interfaces: in other words, it is intrinsically characterized by differentiation.

However, Sousa Santos (1988) believes that, in thinking of the present as a moment of transition, scientific practice should be characterized by prudence. He defines this as “assumed and controlled insecurity”, since, given the uncertainties of contemporary life, he believes that effectively visualizing concrete investigative projects using this new perspective is difficult to achieve. For Sousa Santos, scientific investigation is divided and fragmented, because of the nature of our societies; in other words, the path can be known, but not exactly where it is going.

Thus, it is agreed here with Santos (2002) when he states that, in the last analysis, actions define objects, giving them meaning, and, therefore, the materiality and the event must be treated together; As well it is agreed with Martins (1998), who completes this idea when he warns that the researcher trying to capture social life as reality must bear in mind that the fact is something inseparable from the conception which he or she holds of it. In other words, the investigation is always impregnated with a particular world vision, defined by his or her social commitment and historical perspectives.

It is in this sense that Ergology has been chosen as the theoretical-methodological basis for this research, because this area of knowledge, in analyzing a given work activity, believes in the human potential to understand and transform this singular situation that the individual is experiencing. This recreates a pertinent new means in itself and in the situation, allowing for a synergic dialogue between different scientific disciplines and knowledge acquired in practice (Athayde & Brita 2007).

3.2 *The bases of the ergological perspective*

According to Schwartz (2007 a), the ergological perspective, when dealing with work, looks at human activity as a whole. Therefore work is viewed differently from those concepts of action theories that are based on general principals that assign value to “human capital”, to performance which promotes the “cult of performance” and to the “physical and psychological over-investment”. Thus, in looking at work within the general context of human activity, this author recognizes that any work situation contains within itself the potential for transformation, for change, because the notion of activity carries within itself the idea of “creating in another form”, thus making it impossible to enclose it within a single model of analysis.

Being a singular perspective, the ergological approach also requires a vision that is simultaneously focused and broad, a “micro-macro pulsar” (microscopic and macroscopic levels of social life). This is because Ergology believes that in any work activity choices are made, norms and prescriptions are interpreted, and (re)configured in a particular manner as a result of the meeting and debate of values concerning social life (Schwartz 2007 a, Durrive 2007).

In Ergology there is a distinction between the concepts of action and activity. The first can be identified, attributed to a decision, submitted to reason, while the second, like Life, has no predefined limit. On the contrary, human activity links everything that the scientific disciplines have represented separately: “the body and the spirit; the individual and the collective; the act and the values; the private and the professional, the imposed and the desired …” (Durrive 2007).

Schwartz (2007b) characterizes human activity as having three essential aspects. The first refers to transgression: no area of knowledge can monopolize the concept of activity because this touches on the conscious and the unconscious, the verbal and the non-verbal, the biological and the cultural, and the mechanical and the values. The second aspect refers to mediation: where the activity imposes a relativization upon all these fields of knowledge, between the micro and the macro levels, between the local and the global. The last involves a contradiction in potential, because activity is always a place-moment of debate; results are always ambiguous, being divided between norms deeply-rooted in the spheres of the social life and the tendencies to new norms resingularized by human beings in their daily life, in short, the basis of human historicity.

With this in mind, Cunha (2005) concludes that, when investigating human activity from the point of view of this singular totality, impregnated with meanings, values, motives and beliefs of a recovered subject, the ergological approach seeks to reunite the psychological, social and cultural dimensions that have been fragmented by scientific rationalism.

3.3 *The methodology adopted*

The methodology uses this ergological approach bearing in mind that, on the one hand, minimal criteria must be adopted for defining methodological procedures for qualitative research (Haguette 1992); on the other hand, there must be flexibility and the possibility of rearranging the investigation.

Thus the methodological process, in progress, is configured by establishing three essential steps and their respective requirements as follows:

A. Contextualizing the area of investigation, consisting of the description and analysis of the organization and the social groups linked to it that refer directly or indirectly to the research theme. This is obtained through the collection and analysis of primary data referring to the norms and /or procedures for the current maintenance system adopted by the institution and as well analyzing qualitative data collected through semi-structured interviews with the staff members who perform the various maintenance activities in the buildings being investigated.
B. Buildings Inspection is carried out by means of the following: identification, collection and analysis of the primary data on the existing technical documentation; determination of the current physical state of the buildings through exploratory visits for mapping and photographing occurrences resulting from poor use and operation and /or immediately identifiable construction pathologies; collection and analysis of qualitative data relative to the use and operation of buildings, by conducting semi-structured interviews with the user population in order to identify and understand the level of knowledge and expectations on the issues under investigation.
C. Analysis of the results obtained, and relating them to issues such as innovative constructive materials, the socio-cultural environment and new concepts, and strategies and techniques for maintenance. These can be used to draw up directives that will contribute to the design and implementation of a building maintenance system for the purposes of renewing the physical performance and optimizing the useful life of buildings that use industrialized construction components, with particular emphasis on steel structures.

4 RESULTS

The results presented in this article refer to several of the analyses already made of the qualitative data obtained through interviews with the maintenance staff working in the teaching units under investigation.

4.1 *The socio-cultural context*

UFOP, founded in 1969, presently offers 24 undergraduate programmes, 26 specializations, 2 professional masters programmes, 11 academic masters programmes and 5 doctoral programmes distributed across 3 campuses: that of the Morro do Cruzeiro, the first and principal campus of the university, situated on the outskirts of the historical centre of Ouro Preto, another in the neighbouring city of Mariana and a third in Monlevade, a mining region known as the Vale do Aço, or the Steel Valley. Aside from these three campuses, as part of the property of UFOP, there are various buildings of historical value in the central region of the City of Ouro Preto, such as the School of Mining on the Tiradentes Plaza, the School of Pharmacy, the Principal's offices, student lodgings, among others.

4.2 *From results already obtained*

When interviewing one engineer of the maintenance staff, it was soon determined that there is an almost complete lack of formalized norms or protocols for the current maintenance system adopted; the prescriptions for this function are only available in the form of an organizational chart, provided by him.

In analyzing this maintenance organizational chart, it can be seen that this sector is directly linked to the Infrastructure Department situated on the Morro do Cruzeiro Campus in Ouro Preto. Only one of the activities related to maintenance, a sub-contracted service responsible for cleaning and conservation of the buildings and public spaces is linked to and, thus, managed by the Administration Department, there being no direct interrelation with the maintenance sector.

A first observation that can be made refers to the great hierachization of the functions, as well as the diversity of the employees, be it by the type of link with the institution, be it by the degree of responsibility and education, as may be seen from the organizational chart presented in Figure 1. This large hierarchy, encompassing the various visions and interpretations favored by the diversity of the maintenance staff, shows the difficulty in obtaining facts that would reveal the system and the organization of maintenance adopted by the institution.

The investigation was confronted by two difficulties: scanty existing standards and the peculiarity in how this activity functions, making it difficult to make a direct and systematic observation of the work. Therefore conducting interviews with the various agents who make up the maintenance sector became a basic instrument for understanding how this activity is organized, what are the relationships between these agents and their work, and how these are defined and redefined in this process

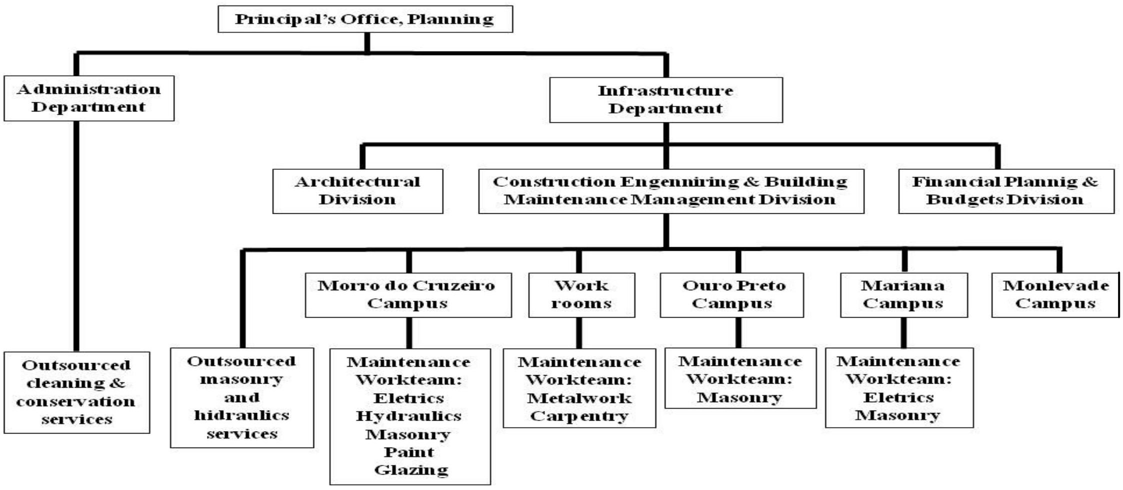

Figure 1 – Partial organizational chart of UFOP´s University Administration. Fonts: UFOP 2007

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Thus, in order to "construct" the work situation through systemizing the experiences of the employees who participate in it, semi-structured interviews were conducted with 23 staff members in various positions of the university administration, as well as members of the technical group employed in maintenance activities.

When analyzing the qualitative data obtained through the interviews, were found statements that the functioning of this sector was precarious, and that, according to many of participants interviewed, the reduction of the maintenance team and the staff members´ lack of adequate qualifications had equally contributed to this situation. Maintenance is a sector of the infrastructure that has not grown or been organized concomitant to the physical expansion undergone by UFOP, principally in the last ten years, with a three-fold increase in installed capacity.

Added to the functional responsibilities shown on the organizational chart there are two additional functions in the administrative area of each teaching unit which deal with maintenance. The guidelines for these are contained in the general regulations of the University as a functional assignment. One of these is the Unit Director who is responsible for obtaining, by means of a formal request, the maintenance services of the teaching unit; and the other is the position of Building Administrator, who is responsible for monitoring the cleaning services within the building, making routine inspections of the installations and those maintenance services that have been requested and already executed, as well as notifying the Director of all requests, both those that he has verified and those solicited by teachers and building staff.

Noticed in the interviews is the tendency of University Administration to substitute personnel with sub-contracted staff, evidence of which may already be seen at the lower levels of the functional hierarchy of this sector, principally in the team of workmen.

It can be stated, as well, that the majority of personnel who comprise the technical and administrative staff in the maintenance sector work under an intense load of requests and have to operate in a confusing series of activities, dependent on the actions of others. These range from the innumerable requests made by the teaching units, to cases where superiors overstep operational targets or people or units employ persuasion and who, in not following the chronological order of service for the processing of the request and evaluation of its seriousness, do not respect the existing service structure. In fact the impossibility for adequate performance, or better, a conflicted relationship has been established.

One of the principal concepts proposed by Ergology is that work always involves use: the use of the individual by himself or herself, and, simultaneously, the use of the individual by others. Thus, work becomes "problematic and fragile" configuring itself as a "drama". On the one hand, the use of the individual by others can be defined by '…the fact that the entire universe of work activity is a universe in which all types of norms reign: be they scientific, technical, organizational, of power…". On the other, there is the use of the individual by the individual herself or himself "…because there permanently arises … the emptiness or deficiencies of norms" …that insist on choices being made according to individual life criteria, one's own references, a private synthesis of values (SCHWARTZ, 2007 a).

In analyzing how the various staff members expressed their own evaluation of the maintenance system adopted by the university, this particular manner of perceiving and understanding the work situation was evident, such as the examples from part of interviews with three of the staff members:

"... there is maintenance, it is the responsibility of Physical Plant to perform what is essentially corrective maintenance... the concept of maintenance in the university is clear, both with regards to preventative as well as corrective...,in Physical Plant..., corrective maintenance is basically practiced., there is not yet a definate form of carrying out preventative maintenance in the buildings..., however in the public sector, I don't believe that maintenance projects work, for this reason, budget questions. ...";

"… this is here only for putting out fires..., but those activities which would be interesting to do..., that would be preventative, so that you could reduce the cost of maintenance..., that doesn't exist here, ..., that there is something that people set up, ... In reality, the function of this planning chart is precisely to guide the actions of physical plant in a macro fashion..., so as to optimize the resources that the university makes available for maintenance…, it is a lot of things,… the priorities are always changing.., people have to be really flexible here in order to serve everyone…, because,…, there is a conflict of priorities…, but in fact, these actions here…, a large part of them are at the request of the units, and the rest, a good part of them, are actions ordered by the administration,… the higher administration, this is a way of the administration of reminding us how things are going…";

"...today we are working alone, without any policy. People hurry up, do what is possible; the decisions are as I said, "technical-people and there is no schedule ... many things that were done this year were because of personal insistence, … The structure is big…, at the beginning of the year... more that two hundred items to be evaluated were listed, many were carried out, but there was no plan of priorities set up , … they estimated the priorities and saw what they were … I think , the document was shelved .. they are going to do whatever shows up …";

"…in my case, it is general maintenance of the building, from this classroom right down to garbage collection...it is as if I were a building cleaner. All problems that occur are sent to me and I pass them on to campus physical plant or to the maintenance sub-contractors. First it goes by me, I look at the service and, if it needs the signature of the director, I have to pass it on to him, for him to authorize it… I am the intermediary between what is going on and the director and the head of physical plant on campus…"

What can be seen from these interviews is that the individuals involved in the university's maintenance sector live within a work dynamic that is under constant change and that, depending on their particular reasoning , be it technical, personal, or cultural, and on the level of responsibility that they occupy, of the experience acquired in the work place, of the values that guide their way of observing the world, etc., they become conscious or, in fact, do not even perceive the level of demands that this dynamic goes on to require. As well, such reports demonstrate the lack of a guide, something which would provide them with a reference on how to act.

Thus, it is not only working situations where the norms are clearly pre-established that constitute a pressure on the individual by others and by oneself. If the parameters are lacking, the individual cannot succeed in reinventing or respecifying the norm or what is expected of him or her in a work situation.

Faïta & Niero (apud Schwartz 2004) show that the emergence of a work situation impels a individual to improvise actions that, in truth, are the expression of a private attempt, normally guided by the imposition of ‘keeping up appearances....”. In the situation under investigation, it may be stated that, more than “keeping up appearances”, such attempts take shape as forms of survival when confronted by circumstances and that, individually, are the private expression of this conflicted relationship.

In such a situation, the individual sees himself obliged to create and regulate criteria for his functioning by means of his own resources that can justify or attribute value to his function and to himself; that is, the less an action and its requirements are anticipated and laid out, the more the work activity will require personal adjustment of the individual. This normally becomes problematic, as it requires something to be handled (the use of the individual by himself or herself), be it the ordering of priorities, be it in the choices that have to be made, that are, in truth, ways of choosing (Schwartz 2004).

5 FINAL CONSIDERATIONS

The results described above, prove, in a preliminary conclusion of the work in progress, the inadequacy of conceiving of the existence of a technical imperative in situations of human activity, particularly those relative to work; “...technology is only an absolute when not achieved...” In contextualizing technology, be it historically, be it geographically, it becomes necessary to understand it in terms of its use by man, of the intermediation of its action; in short, its relativization is required (Santos 2004).

In this sense, nowadays, while the alienation of the individual confronted by a work situation may be generalized, Schwartz (2007) warns of the fact that, individually, suffering at work acquires a relevant importance. Therefore, when considered, it must be ensured that such an observation does not involve explanations that, instead of contributing to a transformation, result in paralysis, leaving one with a sense of impotence when confronted by the drama of the use of oneself by others.

On the contrary, it is agreed with this author, when he states that if the activity is always a debate of norms between an individual and an environment “saturated with values”, the path to be taken is that of “debate of values”. Using an ergological approach, in order to understand and make human activity viable in a specific context, it is critical to permanently place life and work experience in debate and confrontation with the concepts that arise from these experiences, always configured in a manner both imperfect and provisional, but fundamental for the on-going attempt for a collective construction that makes possible the coexistence of differences (Schwartz 2007 a).

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A post occupancy evaluation of a BREEAM 'excellent' rated office building in the UK

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ABSTRACT: Designing a 'green' building by incorporating sustainable, low-energy technologies is one of the ways in which their energy demand and related CO_2 emissions can be reduced. In reality however, it doesn't necessarily follow that a 'green concept building' will perform as such during post occupancy.
At present, the performance rating of many buildings relies on values obtained during design stage and it does not necessarily follow that a building will perform as it was designed during post-occupancy.
Using a BREEAM 'Excellent' rated office building as a case study, this paper presents the in-use performance of some of its installed technologies. The building incorporates numerous green technologies and many of these are being monitored during post-occupancy. In addition to this, an occupant satisfaction survey has been carried out.
This paper presents the actual performance of a selection of the installed technologies and compares them with their design performance. The paper also presents the results of the occupant satisfaction survey.

1 INTRODUCTION

It is has been reported on many occasions that buildings are responsible for just under half of the energy use and CO_2 emissions in the UK (Turrent 2007). For this reason, sustainability and energy efficiency are major drivers in the design of all new buildings. In the UK, new government legislation has recently set targets to reduce 80% of carbon emissions from buildings by 2050, when compared with 1990s levels. Meeting these ambitious new targets and stricter building regulations will be challenging and will encourage designers to incorporate more 'green' technologies in future projects. However, designing a 'green' building is only one aspect needing consideration. They must also perform 'green' once occupied and in-use as the measured performance of a building can often be different from that predicted during design stage (Piette, Kinney et al. 2001). In the UK, probably the best know post-occupancy monitoring projects were those in the PROBE (Post-occupancy Review of Buildings and their Engineering) series (Cohen, Standeven et al. 2001). The results of these studies reported that the actual energy used in a building was often different to that predicted and that the best performing buildings were not always those expected to do so (Bordass, Leaman et al. 2001).

BREEAM (BRE 2009) is an environmental assessment method originating in the UK which rates a building's performance on information obtained during the design stage. A recent study reported that a BREEAM 'Excellent' rated building does not necessarily mean that it will deliver an excellent energy performance once in use (Sawyer, Wilde et al. 2008). A different study carried out in the USA, showed that green buildings can perform well when compared to their conventional counterparts (Newsham, Mancini et al. 2009). The few studies that have been reported show there is a general lack of post-occupancy evaluation and performance monitoring of buildings being undertaken (Way & Bordass 2005) (Palmer 2008) and on the few occasions when this has been carried out, the results are rarely published (Newsham, Mancini et al. 2009). Carrying out such routine monitoring of a building's performance should be the norm so that it can provide valuable feedback to the design team (Andreu & Oreszczyn 2004). Additionally, by routine monitoring and evaluation, the actual energy performance of a building can be assessed and optimised to deliver improved energy efficiency.

This paper investigates the in-use performance of a 'green' office building located in the UK that was awarded a BREEAM 'Excellent' rating of 87.55%. It reports on some of the installed technologies that have worked well and on those which have not worked as well as expected. The paper also evaluates the level of occupant satisfaction provided by the building.

2 BUILDING DESCRIPTION

The building monitored for post-occupancy performance was a 4350 m^2 office building located in the North-East of England, UK. The design, with its 'green' credentials was expected to produce an energy efficient office building having low carbon emissions when in-use. The construction phase of the project was carried out in a sustainable manner by using offsite prefabrication techniques for many of the building elements, segregation of construction waste on site together with energy and water management. The building materials used were, where possible, sourced locally and incorporated recycled materials including PFA, Lytag aggregate and recycled steel as reinforcement.

The building comprises of two 54m x 13m wings (a two storey east wing and a three storey west wing) separated by a central glazed atrium. The building was designed to provide flexible office space to be used as either open plan or as cellular offices. The building incorporates a number of green technologies which include an exposed thermal mass internally, a good level of air tightness, a low-volume vacuum drainage system using low-flush WC's which utilise rainwater harvested from the roof of the west wing, a 'green' sedum roof on the east wing, CHP with matching absorption chillers for tri-generation, a low energy lighting installation incorporating an atrium design and a low energy heating, cooling and ventilating 'Termodeck' system. The building is controlled by a Building Management System (BMS) with specifically designed control strategies to optimise the operation of the building so as to provide a comfortable and energy efficient work space. High levels of insulation were used in the external fabric to minimise heat loss from the building and typical U-values are shown in Table 1.

Table 1. Typical U-values.

Building component	Specified U-value (W/m^2K)
Floor	0.15
Walls	0.15
Windows	1.50
Roof glazing	1.76
Roof	0.15

The building was completed and opened in February 2007 and since then occupancy uptake has been slow. Now, after almost three years of operation, the occupancy is still only around 50%.

3 POST OCCUPANCY MONITORING AND EVALUATION OF THE GREEN TECHNOLOGIES

Throughout the period of occupancy to date, the in-use performances of the ‘green’ installed technologies have been monitored and evaluated and a selection of these are presented in the paper.

3.1 Total water use in the building – a comparison between the predicted and actual performance.

The typical water consumption for an office building, with no canteen, is quoted as 25.0 litres/full time employee/day (Envirowise 2009). In close agreement with this value, another source (WATER UK 2008) estimates the average water consumption in an office building to be 24.5 litres/full time employee/day (based on 253 working days in a year).

In an attempt to minimize water use in the building a vacuum drainage system for the WCs, waterless urinals and the low volume fittings in the hand wash basins were all installed. The low volume WCs used rain water harvested from the west wing roof and used only 1.2 litres per flush compared with around 6 to 9 litres per flush in a conventional system. The harvested rain water is stored in an underground tank and treated prior to use.

In the building being monitored, the water consumption was predicted to be around 1.27m^3/person/year, representing a water usage of 5.0 litres/full time employee/day. It was also predicted that the use of mains water for flushing would be virtually eliminated (King 2007).

Over the monitoring period, the average occupancy in the building was around 100 people. Based on current occupancy, Figure 1 shows the predicted, typical and actual water usage from May 2008 to May 2009. In February 2009, a fault occurred in the harvested rainwater tank and this caused an increase in mains water use over a short period of time. Due to the fault, the mains water data from February 2009 onwards has been extrapolated based on previous usage (see vertical dashed line at 01/02/09 on Figure 1).

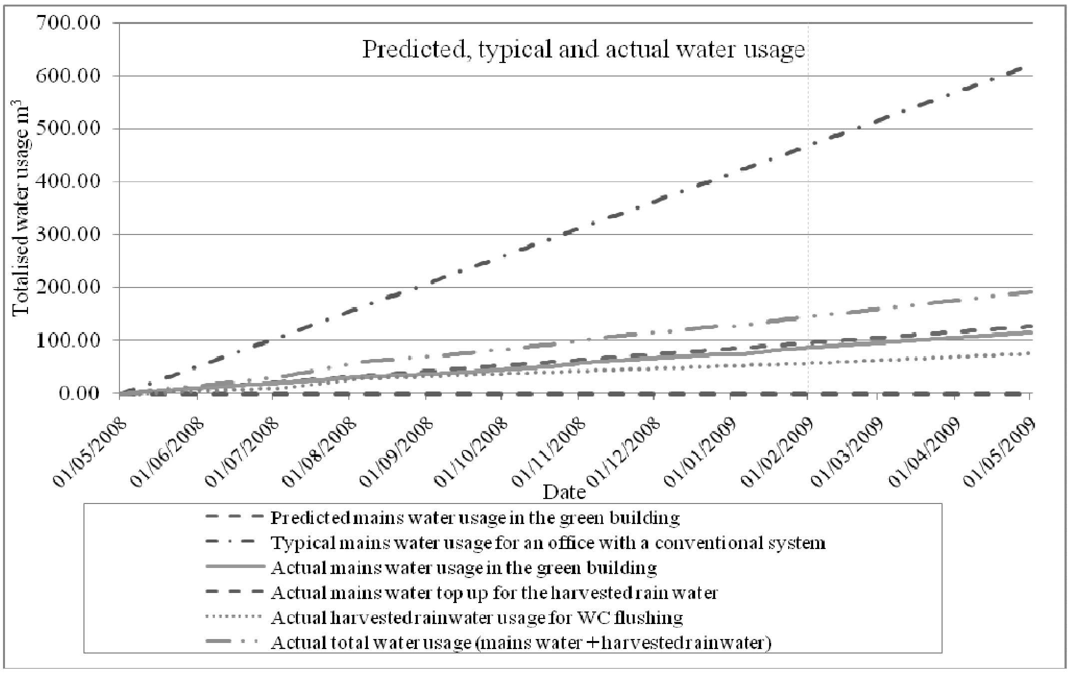

Figure 1. Annual predicted, typical and actual water usage in the building.

The results indicate that the annual amount of mains water used in the building was only 20% of the mains water used in an office with a conventional flushing system and was around 10% less than the predicted value. No mains water was required to supplement the harvested rain water, therefore the use of mains water for flushing the WCs was eliminated. The total annual water usage, for both mains water consumption and the harvested rain water, was 30% of the total water used in an office with a conventional flushing system. This reflects the effectiveness the low volume system and fittings. In summary, the water usage met the design expectations.

3.2 Air tightness – comparison between the specified and actual achieved.

One of the most effective ways to reduce the energy losses from a building is to minimize air infiltration by ensuring a well sealed building envelope. An air tightness test is a compulsory requirement on all new building constructed in the UK under Part L of its Building Regulations and the maximum allowable air permeability index must be less than, or equal to $10.0 m^3/h/m^2$. During the commissioning stage of the building an air tightness test was carried out according to CIBSE TM23:2000 and BS EN 13829:2001 when the air permeability index was measured to be $3.3\ m^3/h/m^2$ at 50Pa. The air permeability of the building was only 33% of its permitted maximum value and compared well against its predicted air permeability index of $5.0\ m^3/h/m^2$.

3.3 The low energy lighting system – a comparison between the predicted and actual energy performance.

The orientation of the building and the use of a central atrium allowed the building to take full advantage of any available natural daylight. A low energy lighting system using T5 luminaries is controlled by light sensitive photoelectric cells which dim down their output in response to any natural daylight. The artificial lights are also controlled by presence motion sensors.

In a normal air-conditioned office building, the artificial lighting typically accounts for 24% of the total amount of electrical consumption within a building (Action Energy 2003). During the design stage of the building being monitored and based on full occupancy, the total electrical demand for all the artificial lighting was predicted to be 75,266 kWh per annum (including office, corridor, atrium, toilet and ancillary fittings). The building was only partially occupied and in the occupied zones, the annual electrical consumption was predicted to be 29,670 kWh. Table 2 compares the predicted and actual annual amount of electrical consumption of the artificial lighting system in the various occupied office zones. The predicted amounts were obtained from documentation supplied by the design team and the actual electrical consumption was obtained from energy data measured by the BMS system over a 12 period.

It was found that the electricity consumed by the artificial lighting in the occupied zones accounted for only 14% of the total electricity consumed in the building. However, as previously noted the building was only partially occupied.

Table 2. Predicted and actual annual lighting electrical consumption.

Zones	Treated area* (m^2)	Predicted annual lighting electrical consumption (kWh)	Actual annual lighting electrical consumption (kWh)	% increase in actual electrical consumption
East wing ground floor	625.50	7045	11664	66
East wing 1st floor	687.36	5369	544	Unoccupied zone
West wing ground floor	506.10	6991	13563	94
West wing 1st floor	609.36	5622	27300	386
West wing 2nd floor	609.36	4644	894	Unoccupied zone
TOTAL	3037.68	29670	53965	82

Note: * areas were calculated from architects drawings supplied

From Table 2 it is clear that the occupied zones, which included the east wing ground floor, west wing ground floor and 1st floor; all consumed far more electricity than was predicted. In these zones, the percentage increase in the actual electrical consumption when compared to the predicted was 66%, 94% and 386% respectively, with an overall average increase of 82%. The electrical consumption within the unoccupied office zones was due to the artificial lights being on during cleaning periods and occasional use of the space.

The zone of most concern was the west wing 1st floor as this had the highest electrical consumption, and was only partially occupied. Analysis of electrical consumption data revealed that in all the occupied zones, except the west wing 1st floor, the office lighting appeared to be activated only during occupied periods. In the west wing 1st floor, the electrical consumption was much higher than expected and after analysis of the systems use it became apparent that the motion sensors in this area were not working as expected and on many occasions the artificial lighting would remained on overnight. Additionally, the occupant satisfaction survey and further discussions revealed that some of the occupants had been given hand held remote controls with which to over-ride the automated lighting controls.

The excessive electrical consumption in the two ground floor wings was partly due to the office occupants lowering their louvered window blinds to get privacy from people in the adjacent atrium space. This effectively reduced most of the natural daylight entering the office space from the atrium and necessitated the permanent use of artificial lighting.

4 OCCUPANT SATISFACTION SURVEY

4.1 The survey and methodology

A successful low energy building minimizes its environmental impact without compromising occupant comfort. A key element therefore, when evaluating the overall performance of any building is occupant feedback. Initially it was intended to develop new questionnaire however to allow comparisons to be made with other buildings and existing benchmarks, a well established occupant survey was selected (Building Use Studies (BUS) survey) with additional questions being added to suit the building being monitored.

The BUS survey was completed by the building occupants in June 2009 and included questions related to temperature, comfort levels, noise and lighting satisfaction levels, along with questions on health, productivity and travel to work. Most questions required a response on a 7 point scale with ‘1’ being unsatisfactory and ‘7’ being satisfactory, with ‘4’ being neutral.

4.2 Results from survey

There were 85 occupants in the building on the day of the survey and 67% responded. 52% were male and 48% were female. 23% were under 30 years of age and 58% had worked in the building for one year or more. The results of the survey are shown in Figure 2.

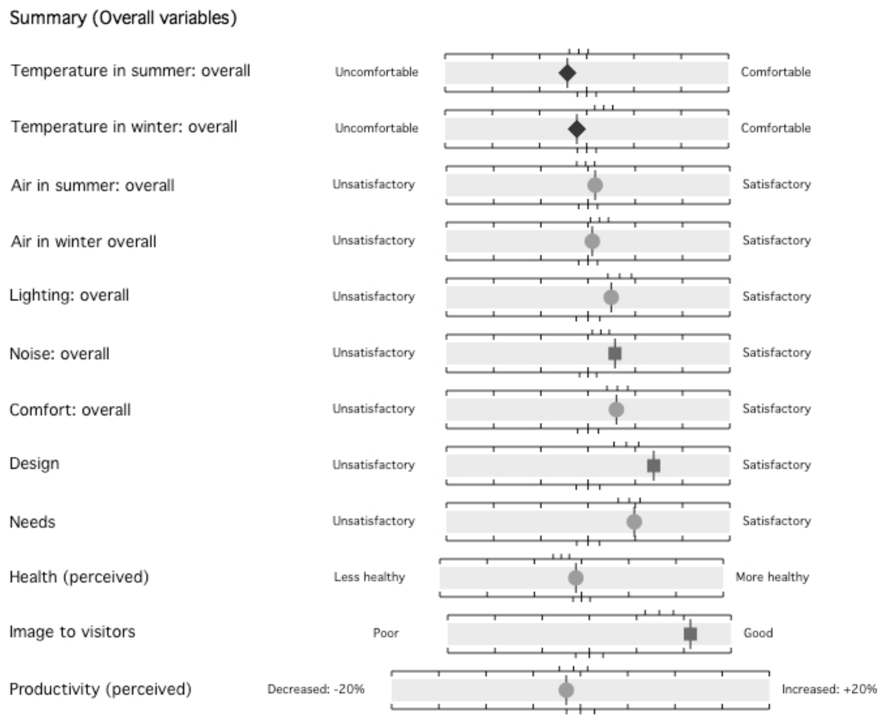

Figure 2: BUS survey results, overall variables (Building Use Studies (BUS) 2009)

The results of the survey are shown on the 7 point scale either by a diamond shape (indicating a design feature which failed to achieve a critical acceptance level of performance), a circle (indicating a design feature which achieved a critical acceptance level of performance) or a square (indicating a result which exceeded a critical acceptance level of performance).

The building is automatically controlled by the BMS and the occupants have little control over the internal environment apart from being able to open windows and control the window blinds within their office space.

The overall dissatisfaction with the general lack of control over the indoor temperature during both the summer and winter was evident and the occupant's response fell below the critical range. The occupants were not only dissatisfied with the overall temperature control in both the winter and summer periods, but also with the variations and stability of these temperatures which caused severe discomfort issues with the occupants.

Most other parameters including the air quality, lighting, comfort and health etc all fell within the critical design range. The artificial lighting in particular appeared to be not well received by the occupants. The more positive findings included the design and aesthetics within the building, the image the building conveys to visitors and the low noise intrusion from outside. The occupants were however unhappy about internal noise transfer and particularly the poor noise control through the office partitions.

By adding additional questions to the survey it was possible for the respondents to record additional comments. These revealed positive support for the amount of natural daylight admitted into some of the office spaces and into the atrium. The more negative comments were about poor temperature control in the building, smells from the vacuum flush WC's, annoyances associated with the artificial lights switching off after a period without movement, artificial lighting levels being too low and poor control of their automatic 'dimming down'. The kitchen areas were also criticised for being too small.

The BUS summary index calculates a result for the building's overall performance and this is displayed on one common, normalized scale in Figure 3. The overall result for the building is represented by the shaded circle, and the diamond, triangle and square superimposed on the figure represent results from other surveys done on UK 'green' office buildings. Within the existing benchmark data set it can be seen that the result for the building is in the 57th percentile and the occupant satisfaction result for the building was average overall. When compared to the other 'green' office buildings surveyed the building was the worst performing.

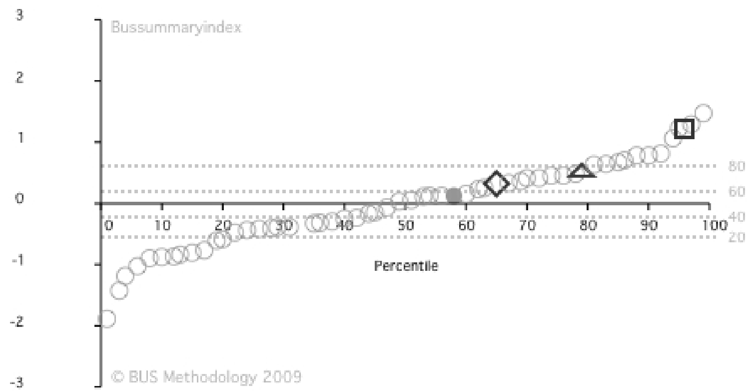

Figure 3. BUS summary index.

5 CONCLUSIONS

This paper has presented the in-use performance of a selection of the 'green' technologies installed in a BREEAM 'Excellent' rated office building in the UK.

Some aspects the building performed well such as the amount of mains water used in the building and its actual performance met design expectations. The air permeability index of 3.3 $m^3/h/m^2$ exceeded the design specification of 5.0 $m^3/h/m^2$ and was well within the required UK Building Regulation value of 10.0 $m^3/h/m^2$.

Some aspects of the building did not perform as well as expected and the results were disappointing . In the occupied zones, the energy consumed by the artificial lighting was far more than predicted and from the occupant satisfaction survey it was apparent that the control of lighting levels was often unsatisfactory. The major finding from the occupant satisfaction survey was that the heating and cooling control in the building was failing to provide comfortable conditions.

When compared to other buildings within the BUS dataset, the overall performance of the building was average and this was a further disappointment considering that the building was a green building with an Excellent BREEAM rating. Additionally, when the performance of the building was compared with three other 'green' office buildings in the UK, its performance was the worst.

The findings in this work supported the finding reported by others in that a BREEAM 'Excellent' rated building doesn't necessarily mean a green building in use.

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A Sustainable Development Centre: Xrobb il-Għaġin Nature Park, Malta.

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ABSTRACT: The Sustainable Development Centre is located within the Xrobb il-Għaġin Nature Park at Xrobb il-Għaġin in Malta. The scope of the project is to rehabilitate an existing complex of buildings used for other functions over the years, and to transform the buildings into a Sustainable Development Centre, within the Nature Park to accommodate a new scientific and educational facility. The sustainable rehabilitation of the buildings is based on a comprehensive approach, addressing the architectural value of the buildings, the functional requirements, structural interventions and repair of the structures, the conservation of resources, water conservation, waste water recycling and waste management, services, the inclusion of energy efficiency measures and the use of alternative and renewable energy sources.

1 INTRODUCTION

1.1 *The Xrobb il- Għaġin Site.*

The Xrobb il-Għaġin Nature Park & Sustainable Development Centre, is located on the Xrobb l-Għaġin peninsula, situated to the southeast of the island of Malta. The Park covers an area of 15ha. and is surrounded by agricultural land and the Mediterranean Sea, with the nearest village being Marsaxlokk, circa 2.5km to the west. Between 1974 and 1996, the Site was the location of a Relay Station of Deutsche Welle–Radio (DW-R), which covered the Near Middle East and North African Region for transmissions in different languages. Initially, the station was also used by Radio Canada International, and later by Voice of the Mediterranean. The station consisted of a complex of buildings which housed the main activities of the operation and three small outbuildings. Following the DW-R's departure from Malta, the station buildings and the surrounding grounds were made available for the Fish Farming Industry, and a company used to operate blue-fin tuna farming until 2006. The site was also used for limited agricultural activities, hunting and trapping. The existing buildings were left in a state of disrepair (Gauci, 2008).

1.2 *The Nature Park & Sustainable Development Centre*

The Ministry for Resources and Rural Affairs, with the collaboration of Nature Trust Malta (NTM), is transforming the Site into a Nature Park, through a rehabilitation project involving the afforestation of the part of the peninsula and the protection of an area of high ecological value. The buildings making up the ex-relay station complex are considered to be important examples of 1960 -70s architecture in Malta, and are being restored, to be used as a Sustainable Development Centre. The centre includes offices to be used by NTM who is responsible for the implementation of the afforestation project and the overall management of the Site, and the Department of Electrical Power and Control Engineering, Faculty of Engineering, University of Malta, who will be conducting research on renewable energy technologies. The complex also includes a hostel and will host an education facility in environmental management, including ecological rehabilitation, afforestation, and energy conservation.

2 THE EXISTING BUILDINGS

2.1 *General*

The station complex was designed by Deutsche Welle Architect Willi Schalenbach. It includes features typical of 1960-70s architecture and is considered to be of Architectural value. Furthermore the station buildings represent the regional development in international communications during the second half of the 20th century. The objective of the rehabilitation strategy is to restore the buildings in the complex, provide for flexibility of the spaces and adapt them to a new function through a structured intervention, whilst retaining the architectural integrity.

Figure 1. Representation of The Sustainable Development Centre after Rehabilitation.

2.2 *The Existing Structure*

The buildings consist of load-bearing masonry construction. In general, the buildings rest on reinforced concrete foundations with reinforced concrete ground slabs. Walls consist of globigerina limestone blocks. Various structural roofing systems were identified, and include mainly two typologies; reinforced concrete cast in situ slabs; and composite slabs consisting of precast pre-stressed concrete inverted T beams, with concrete blocks supported between them, and with overlying cast in place structural concrete. Different varieties of roof slabs were identified in the existing structures, namely slabs with a single or with a double beam system. Other reinforced concrete elements include the cantilever slabs and shading devices, the cornice and architectural features including the roof water drain details.

Figure 2. Existing deteriorated structure & reinforced concrete elements on façade prior to repair.

3 REHABILITATION STRATEGY

3.1 *General*

The Sustainable Rehabilitation strategy is based on a comprehensive approach, addressing the architectural integrity of the buildings, new functional requirements, structural interventions & repair, resource conservation, waste management, services, energy efficiency and renewable energy sources. The strategy also required the consideration of planning issues, accessibility and landscaping schemes. The project can be considered to be one of the first conservation interventions on the 20^{th} century architectural heritage in Malta. The rehabilitation of an existing building rather than reconstruction resulted in a larger challenge, in the adaptation of existing spaces for the new uses. In addition the project requires longer timeframes for completion, and particular skills in specific operations including dismantling and repair. The rehabilitation strategy also allowed for conservation of resources and reduction in waste generated. The investigation & design were carried out during 2006 & 2007, and rehabilitation works started in 2008.

3.2 *Structural Assessment Methodology*

The scope of the assessment was to investigate the buildings, and structural elements, and to assess the state of the structure and defects. The investigation was based on a detailed inspection of the buildings and elements, following a structured survey, including detailed visual investigation records; photographic survey records, records and assessment of the structural systems and structural element typologies, and records and assessment of defects. All the data was mapped out on detailed drawings and re-verified. The defects were classified with respect to type, location, extent and materials. A testing plan for materials and structure was prepared on the basis of the investigation carried out. The data of the investigation was used in order to identify and understand the actions on the structures, the failure mechanisms, and causes of deterioration (Borg, 2008).

3.3 *Structural Defects & Material Properties.*

Various defects were recorded in the existing buildings. All the services were non-functional and a new services network was required for the new functional requirements of the buildings. The finishes were in a bad state of repair, and most apertures were missing or damaged.

A number of defects were also noted in the structural elements, with the partial collapse of roof structural elements recorded. The main defects in reinforced concrete elements were cracked concrete, reinforcement corrosion and concrete spalling. In various instances, this resulted in detached concrete and exposed excessively corroded reinforcement and loss of elements and architectural features including the cornice and cantilevers on the façade. Specific roof structures were excessively deflected, in view of past actions on the roofs. Defects in the roof system included longitudinal cracks along the beam elements of the slabs, and defects and cracks in the concrete blockwork supported between beams in the roof slabs. Various defects were also noted in masonry wall structures namely hairline cracks and local defects in stone, due to impact and misuse, and defects as a result of inadequate interventions during past alterations to the buildings. Loss of finish and mortar on exposed surfaces was also recorded.

The investigation carried out included the testing of concrete. Concrete cores were extracted from various parts of the structure & different structural elements including beams and slab elements, following a plan. The concrete core strength, the concrete density, and the depth of carbonation were determined in the experimental investigation. Furthermore the investigation provided information on the roof structure and finishes. The compressive strength of cores extracted from the slab at ground floor varied between $23.5N/mm^2$ and $28.5N/mm^2$. The compressive strength of beam elements at roof level, varied from $20.5N/mm^2$ to $24.5N/mm^2$. However values of $15.5N/mm^2$ (reinforced concrete element), and $10N/mm^2$ (structural cast in place concrete over precast beams slab roof system) were also recorded. The depth of carbonation of the concrete in the cores varied between 25mm and 50mm. The cover to reinforcement was noted to vary, and in some case was less than 25mm.

3.4 *Repair & Rehabilitation*

In the appraisal of the existing structure, various aspects were taken into account including; the age of the structure, exposure of the building to an aggressive environment and proximity to the sea, deficiencies in materials used, defects in detailing, defects associated with workmanship, lack of maintenance of the structure and previous inadequate uses of the building, and actions which were not in line with the intended use. Therefore the scope of rehabilitation was to address the structural performance and structural integrity and also the durability of materials.

In specific cases, the intervention required the re-introduction of elements which were missing due to deterioration or past interventions. In various instances, it was required to replace elements which were excessively damaged and beyond repair particularly where repair was not possible due to the inferior quality of materials, inadequate details, or where repair was not feasible. The latter case refers also to the cantilever elements, various architectural reinforced concrete features on the facades and on the external envelope, and roof structures. Precast Prestressed hollow concrete slabs, together with cast in place reinforced concrete slabs in specific areas, were adopted to replace the deteriorated roof structure. Specific reinforced concrete elements required repair using appropriate materials and techniques, in particular patch repair. The extent of such repair depended on the state of these elements.

In the case of masonry elements, various parts of walls have been reconstructed and/or repaired. Stone masonry blockwork was used in all external areas to ensure the architectural integrity of the buildings. Concrete masonry blockwork was used in specific internal partitions and walls. Adequate pointing and rendering of walls is implemented through the application and use of the adequate materials, taking into consideration also the site exposure.

Various measures were proposed to ensure quality in the rehabilitation of the buildings, during the Design Phase, the Construction Phase, and also the Service Phase. A grade C35/45 concrete was adopted for the reconstructed reinforced concrete elements. An exposure class of XS-1 (EN 206-1, 2000) was considered in structural engineering design, referring to corrosion induced by chlorides from sea water; concrete exposure to airborne salts but not in direct contact with sea water. Particular attention was given to details including adequate concrete cover and waterproofing. A quality assessment plan was implemented and a site management team was responsible for operations, execution of works, and for ensuring good workmanship including adequate compaction of concrete and concrete curing. The buildings shall be used within the limitations set in the design brief, including design loads and other set criteria. A maintenance plan and inspection strategy have been proposed, and will be implemented.

4 WASTE MANAGEMENT & RESOURCE CONSERVATION

4.1 *General*

The repair of the existing buildings through a sustainable rehabilitation strategy, was considered, as against demolition and reconstruction. The objective was to adapt an existing building, to accommodate a new function. Rehabilitation as against reconstruction, addresses both the conservation of resources, and the reduction of Construction & Demolition waste.

4.2 *Construction & Demolition Waste*

The rehabilitation of the buildings required the replacement of various structural elements. However the minimum possible elements from the existing structure where replaced, whilst it was ensured that the repaired and rehabilitated buildings could reach the required functional and performance levels. This approach led to a reduction in the waste generated during rehabilitation. The waste generated during the repair and rehabilitation, was also considered for reuse and recycling. During rehabilitation it was necessary to dismantle the elements and part of the structure to be replaced, rather than demolition, particularly in order to safeguard the existing structure and elements which were retained. This methodology based on a different approach from demolition, supported further the reuse and recycling of waste generated from the rehabilitation of the buildings.

Figure 3. Dismantling and waste classification: RC roof elements and wall masonry elements.

The reuse and recycling required the separation and classification of the waste materials. The waste materials generated were identified and quantified and the methodology adopted followed the Waste Management Plan. The stone masonry blockwork was dismantled and stacked in a storage area on site. They were classified into two main groups; those suitable for reuse in secondary construction, and waste blockwork to be recycled for production of crushed stone for screed and other uses. The reinforced concrete elements were classified on site into two groups; concrete elements and reinforced concrete beams and slabs. These were transported for recycling. The reinforced concrete elements required the separation of the steel from the concrete for recycling, and concrete was crushed for the production of recycled concrete aggregate.

4.3 *Water Management and Waste Water Recycling*

The rain water and surface water runoff in the site will be collected in the existing water culverts and, and stored in the large water reservoir which will be repaired. The water will also be collected from all the roofs of the buildings. The rain water will be used as secondary water in the buildings and for irrigation purposes in the afforestation scheme. The new buildings will incorporate water saving features and accessories in the bathrooms.

The waste water generated in the complex, will be treated in a biological sewage treatment plant, built within the site. The expected daily maximum flow amounts to 10m^3/day. The sewage treatment plant will be installed below ground, and consists of different zones made up of glass reinforced polyester tanks. The treated effluent will be of the recommended quality for irrigation in the landscaping scheme and afforestation project.

5 ENERGY EFFICIENCY

5.1 *General*

The scope of the energy efficiency measures in the project, is to reduce the energy consumption within the buildings, to minimize internal cooling and heating loads and to maintain thermal comfort. The aim of the rehabilitation strategy is to exploit the features already existing on site and in the buildings, and introduce additional measures for improved energy efficiency. The various measures adopted can lead to satisfactory indoor comfort levels which can be achieved without the use of power consuming equipment.

5.2 *Thermal Efficiency*

The Thermal efficiency of the buildings depends largely on the building envelope i.e. the walls and roof elements. The external walls of the buildings are approximately 510mm thick and consist of two skin masonry construction each having a thickness of 230mm with a 50mm air space. The U-value of the walls is lower than that recommended for Malta.

Insulation will be introduced in roofs to reduce thermal losses; the expanded polystyrene insulation has low heat transfer characteristics and is lightweight. The use of reflective coating on the roof is also considered. A weather resistive barrier will be installed to maintain the R value, and to prevent air and moisture movement into and out of the conditioned space.

5.3 *Shading Devices, Apertures & Natural Lighting.*

The reinforced concrete cantilever structures, particularly along the south east and south west facades of the main building, are an important characteristic of the building. These elements provide effective external shading to windows, eliminating direct solar radiation particularly during the summer season. The building's roof shall also benefit from the shading provided by the photovoltaic and solar water heater roof installations thus reducing the roof's thermal gain.

Windows provide less resistance to heat flow than walls, roofs and floors. Double glazing will be used for all apertures in the buildings, to reduce the transmission of heat. The frame aluminium profile is specified to be sealed and air-tight. In addition, the use of louvers on the external face of the apertures allows for air movement and ventilation. The shutters are also designed to provide visual privacy and security.

Large openings provide for adequate natural day lighting in the main spaces & reduce the need of artificial lighting in buildings. Sun-pipes will be installed in specific spaces, to improve on the natural light from windows, and in the corridors & spaces were no windows are present. Light coloured finishes are to be used on roofs and external walls to reflect radiation. The internal spaces are to be finished in light colours to reflect maximum natural light in interiors.

5.4 *Ventilation, Site Conditions, and Buildings Configuration*

Cooling in summer is to be promoted through adequate cross ventilation within the buildings, achieved through the large openings, and the high level apertures in specific spaces. Sea breezes can be exploited in view of the disposition of the buildings on the promontory and their location. Furthermore the main building is elevated above ground level by c. 850mm. This improves further natural ventilation. Ventilated ground slabs will be installed in specific areas.

The trees and shrubs surrounding the buildings also act as windbreakers. The landform and vegetative cover influence the amount of reflected solar radiation. The discomfort caused by glare is reduced. Soil, trees and shrubs have the lowest reflection values and trees provide shade and shaded ground area around the buildings.

6 INTELLIGENT USE OF ENERGY AND RENEWABLE ENERGY SOURCES (RES)

6.1 *General*

At the design stage of the electrical and energy systems of this project, three types of commercially available RES technologies were considered. These were: photovoltaic (p.v.) electricity generation, wind electricity generation and solar water heating. Furthermore, the electrical system was designed to keep the use of electrical energy at a minimum.

6.2 *PV and Wind Energy*

An electrical set-up was designed to cater for the grid connection of both p.v. and wind energy sources. For the p.v. systems, the dc current produced by the photovoltaic panels shall be transformed via inverters into a single phase a.c. voltage to allow power to flow from the panel's d.c. voltage into the electricity supply. In the case of the micro-wind turbines, wind generator's output initially undergoes rectification and then conversion to a.c. voltage by means of an inverter similar to that used by p.v. systems.

A data-logging system shall be used to monitor and log various related environmental parameters & the performance of the p.v. & wind systems. The p.v. system was designed to have three types of p.v. technologies, mono-crystalline, poly-crystalline and thin-film.

The aim of having three different p.v. technologies installed under identical conditions was to be able to log the 'actual' generation performance of each technology over a number of years. Like this a 'practical' study of which technology is most suited to the Maltese Islands can be done. As concerns the micro-wind turbines, two technologies shall be installed: a vertical axis turbine and a horizontal axis turbine. It is well know that the latter technology is the more efficient, however it was decided to have a mix of turbine designs so as to expose the general public to both types of technologies and their suitability to the natural and the built environment. In this case the wind turbines will be installed in the same area and will be exposed to the same conditions and wind resource. Direct comparison between the performance of each turbine will thus be possible.

The p.v. and wind system of inverters is shown in Figure 4 and was designed to allow electrical energy generation in grid connection mode and in 'controlled' stand-alone mode. In the case of electrical grid failure, this systems makes it possible to power the building to a limited extent as long as the p.v. and wind are still generating electricity. Once installed the stand-alone inverter shall be programmed with a load shedding program so as to provide electricity only to the building's high priority loads (e.g. fridges and selected lighting). The building shall also host a system of solar water heaters (SWH) designed to provide the hot water supply of the showers/toilets with little demand on the electricity supply.

6.3 *Efficient Use of Electrical Energy*

The most responsible attitude towards the usage of energy is to reduce inefficiencies as much as possible and take corrective action in situations where there is energy wastage. Since the project of Xrobb l-Għaġin allowed for the redesign of some of the electrical and mechanical systems, this gave the opportunity to design for the most efficient use of energy. Electrical energy is mainly used for heating/cooling, lighting and power. It is planned that the building shall not make use of electrical air-conditioning but shall rely solely on natural ventilation and proper insulation. Further, energy saving lighting technologies shall be used wherever possible, and motion sensors shall be installed in common areas to turn on the lighting only when necessary.

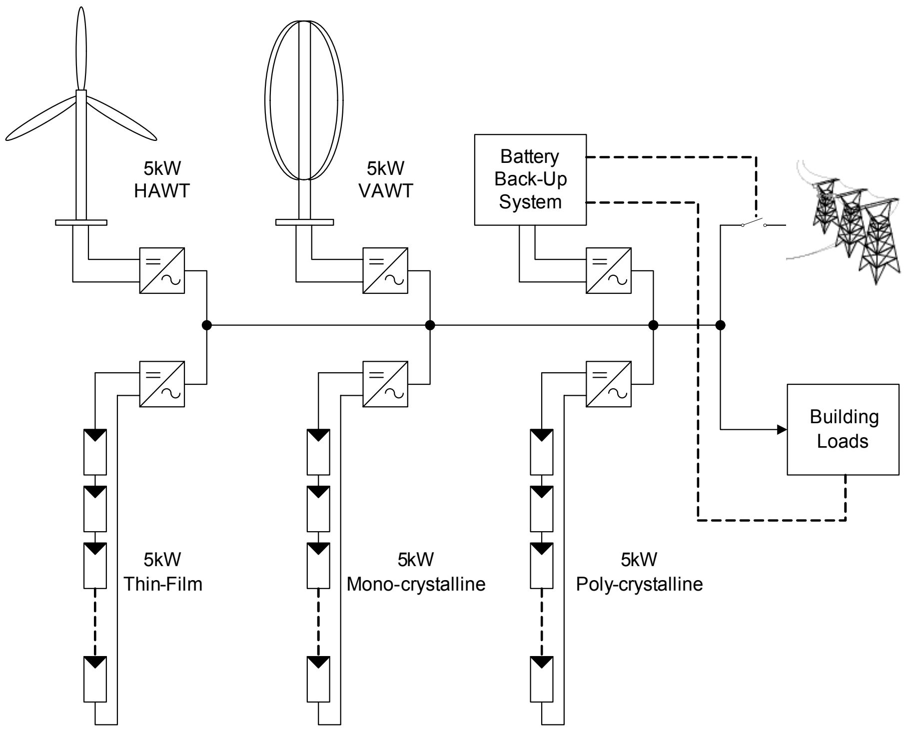

Figure 4. The Connected Grid and Standby RES System.

6.4 *CO_2 Reductions from RES Systems*

The annual energy generation by the photovoltaic (p.v.) sources (SMA) and the wind sources (Gipe, 2004) was estimated. Furthermore the energy saved by using solar water heating rather than electrical heating is shown in Table 1. Apart from reducing the electrical energy consumption, the Renewable Energy Sources shall also contribute to the reduction of CO_2 emissions as indicated in Table 1. (During 2006, it was reported that 0.8782kg of CO_2 were emitted for every kWh generated (Enemalta)).

Table 1. Annual kWh savings and reductions of CO_2 emissions.

RES Technology	Annual Savings	Annual Reduction of CO_2
	kWh	Tonnes
PV System	23500	20.5
Wind System	16000	14.0
SWH System	20075	17.5

7 CONCLUSIONS

The Sustainable Development Centre, within the Xrobb il-Għaġin Nature Park in Malta, is the first centre of its kind in the Maltese Islands, with the scope of addressing environmental management, ecological rehabilitation, afforestation, and energy conservation.

The Sustainable Rehabilitation strategy adopted is based on a comprehensive approach, addressed various fundamental principles, including the architectural heritage, functional requirements, structural interventions and repair of the structures, conservation of resources, water conservation and waste water recycling, waste management, services, energy efficiency in buildings, and alternative and renewable energy sources.

The strategy that is implemented is required to transform the existing buildings, into a functional and energy efficient Sustainable Development Centre, promoting environment and science education.

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Traditional vs selective demolition – comparative economic analysis applied to Portugal

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ABSTRACT: Selective demolition (sometimes called deconstruction) has been studied in the past few years, leading to reliable economic, material and environmental information. However, especially in economic terms, conclusions vary widely between regions, since economic conditions related to man labour, tipping fees and/or market prices for recovered materials are strongly dependent on the location. In a free market situation, the option between tradicional and selective demolition will essentially be an economic one, considering the financial and regulatory constraints apllicable in a certain region. Therefore, the present study is focused on the economic evaluation of both demolition types, within the framework of a particular case study located in Portugal. Several scenarios are evaluated, based on possible waste management options for that particular case study, some of which result in lower global costs for selective demolition, when compared with tradicional demolition.

1 INTRODUCTION

Deconstruction is an end-of-life building process that is gradually gaining weight in the demolition market, not only for environmental reasons (material recovery, reuse, recycling), but also (and from a pure market standpoint, essentially) for economical ones. In Portugal, the most recent legal standard relative to Construction and Demolition Waste (CDW), Law-Decree 46/2008 (2008), refers to the compulsory site waste separation or, when this is not possible, the waste route to a licensed waste operator, equipped to conduct the separation activity. Since the waste operators service market prices are widely dependent on input aggregate purity, it becomes attractive to deliver previously separated CDW to the central waste operator (with as few contaminants as possible), which acts as an incentive for selective demolition. In Portugal (excluding islands), waste operator central tipping fees vary between 5.5 and 129 €/ton (data from some operating centrals), for clean/pure aggregates (uncontaminated ceramics) and mixed CDW (not necessarily with hazardous substances) with global densities below 200 kg/m^3.

Some research work has been conducted in the past few years in Portugal (Lourenço 2007, Sousa et al. 2004, Santos & Brito 2007), focused on the general selective demolition area, as well as the market establishment of some companies which apply deconstructive techniques up to some degree. This last reality shows that there are economical conditions in Portugal to implement selective demolition, which does not necessarily mean full material recycling or its reuse, within new construction projects in the same site or in different ones. Internationally, a wide range of research studies have been conducted on deconstruction and its technical, economical and environmental implications (Dantana et al. 2005, Guy 2003, Guy 2005, Construction Technology Institute of Catalonia and Government of Catalonia 1995, Environmental Protection Agency 2008, Alameda County Waste Management Authority 2009, Roussat et al. 2009), although it is quite clear that, generally, it is still an unconsolidated idea in the demolition market, with questionable economical attractiveness (in many cases) and, above all, few practical demonstrations.

If, from an economical standpoint, selective demolition viability (with its decrease in material quantity sent to landfill) varies considerably with local conditions, resulting in viable or non-viable projects (Lourenço 2007, Dantana et al. 2005, Guy 2005, Environmental Protection Agency 2008, CIB Report 2005, New York Waste Match 2004), environmentally speaking there seem to be clear benefits in using this kind of approach to demolition (Alameda County Waste Management Authority 2009, Roussat et al. 2009), mainly due to the relatively straightforward reduction in material mass sent to landfill. Generally, the local conditions that most affect the deconstruction economical viability are labour cost, tipping fee value and market prices for selling recovered materials.

From a technical standpoint, on the other hand, there are many available deconstruction options, depending, for instance, on the construction type (which is closely related to building age), available work force, used mechanical equipment or tools and time constraints applicable to each case (Guy 2003, Construction Technology Institute of Catalonia and Government of Catalonia 1995, CIB Report 2005). These technical options affect, consequently, the quantity of recovered materials recycled/reused/incinerated, as well as the economical performance of the whole operation. Apart from other important aspects related with deconstruction activities, as security concerns, time constraints are usually a main issue to owners and contractors, being many times viewed as a barrier to the implementation of the deconstruction approach.

2 CASE STUDY DESCRIPTION

The case study refers to an urban renewal project named Cacém Polis (Phase 2), located within Lisbon outskirts. It has involved the removal of several townhouses built between 1900 and 1945, of low to average building quality, in an average of about 100 m^2 per house, within a total of 13.430 m^2 of removed gross floor area. The demolition/deconstruction activities were conducted by a specialized company, well familiar with such operations. However, to optimize costs, the chosen removal method was a mixed one, including an initial soft stripping activity, followed by a traditional demolition of the remaining materials, over which (already at ground level, working around the resulting mixed pile) some valuable items were recovered, mainly wood and metallic (iron and steel) elements. Soft stripping refers to the selective recovering of removable elements and surface materials such as floor coverings, ceiling plaster, wood surfaces, doors, windows, furniture, bathroom fixtures and wooden stairs.

The resulting mass, composed mostly by stone, ceramic and concrete blocks, shingles, mixed with small and pieces of other materials (elements like plumbing (mostly ceramic and lead) and electrical wiring (mostly plastic and copper)), was then transported to a dedicated landfill, where a simple crushing activity was performed. All other materials (recovered from the soft stripping and pile scavenging activities) were separated and sent to recycling operators. The work was conducted in a traditional demolition labour hierarchy, with regular non-specialized workers to perform the stripping and the scavenging, equipment operators to manoeuvre the excavator and the loaders and supervisors to address the technical and security overview of the works. As far as this paper is concerned, the terms selective demolition and deconstruction will be used alternatively, as equivalent denominations.

3 DECONSTRUCTION TIME FRAME CALCULATION

The time frame of the case study operations was calculated for a 100 m^2 house surface unit, based on the available work force and the work productivity data supplied by the contractor. The calculation was conducted using a standard operation scheduling computer program, using the supplied data (total operational costs were also calculated using this software tool). Figure 1 shows a sample image of the scheduled activities that resulted in a total duration of 6.5 days. To demolish (in the traditional way) the same built area, only one day would be necessary, which matches the duration supplied by the contractor, when questioned about an equivalent traditional demolition for this case.

Tables 1 and 2 show the calculations and input data used for the estimation, for which the following notes apply.

Deconstruction
- Carpet removal applies only to floors and assumes a 40% surface coverage;
- Plaster removal refers only to ceiling area, assuming a 100% surface coverage;
- Cork removal refers only to floor area and assumes a 15% surface coverage;
- Window removal implies separation of glass;
- Ceiling removal consists in cutting wooden joists;
- Traditional demolition refers to the following elements:
- Wooden and masonry walls;
- Concrete, stone (covering) or wooden floors;
- Roofs (wood elements and shingles);
- Water supply/drainage system (ceramic and lead).
- Traditional demolition phase in deconstruction is set by:
- Average demolition time (one standard 100m^2 house) - 1 h;
- Workers involved - 5 (1 excavator operator, 1 loader operator (to sweep the recoverable wood and metal), 1 hose operator (to humidify the demolition location, lowering dust emissions) and 2 workers for recovering wood and metal pieces from the large pile.
- Post separation of elements: implies the same man labour as in step 7.
- Cleaning and transport: workers involved - 5 (1 excavator operator (to further break demolished pieces and to load mixed materials in trucks), 1 loader operator (to deposit separated and mixed materials in the corresponding trucks), 1 truck driver (assuming successive truck journeys) and 2 workers for recovering wood and metal pieces from the large pile.

Demolition
- Demolition phase is set by:
- Average demolition time (one standard 100 m^2 house) - 1 h;
- Workers involved - 2 (1 excavator operator, 1 hose operator);
- Cleaning and transport: Workers involved - 2 (1 excavator operator (to further break demolished pieces and to load mixed materials in trucks), 1 truck driver (assuming successive truck journeys). Without wood and metal separation, it is assumed that this task lasts half as long as the equivalent task in deconstruction.

Average space area, elements area and total material weight per house unit m^2 was calculated on the basis of several measured buildings, which result from a previous study (Coelho, 2008), presented in Table 3.

4 COST CALCULATION

Total cost for deconstruction and traditional demolition was divided into five main categories:
- Yard installation;
- Direct labour;
- Indirect labour;
- Equipment operation;
- Transport (of CDW);
- Final disposal (of CDW).

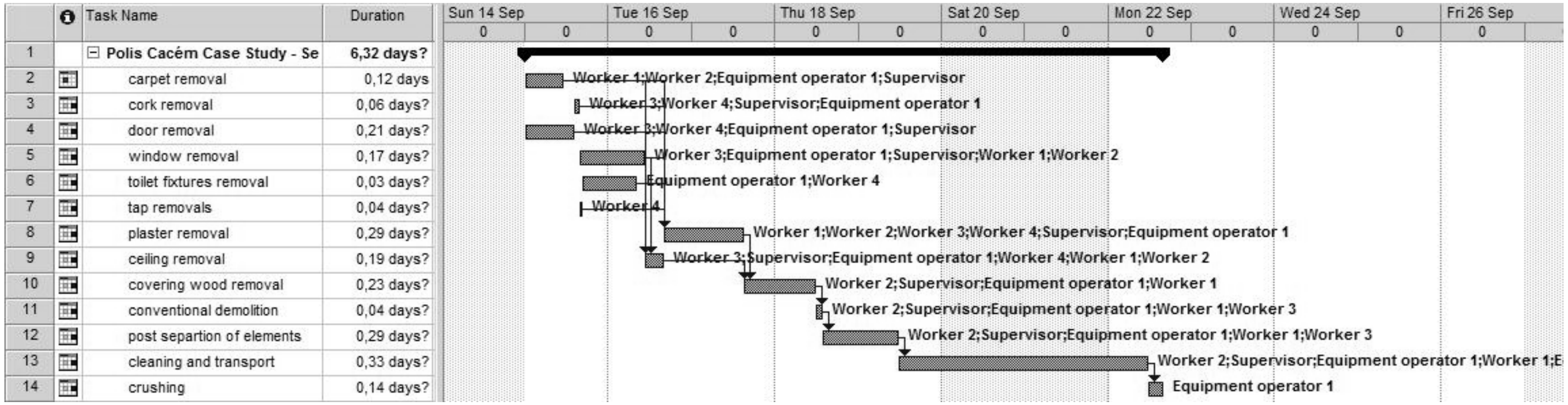

Figure 1. Extract from the deconstruction/demolition project (based on Cacém Polis) schedule program.

Table 1. Input data and calculations for estimating the case study deconstruction cost and duration.

Activity	Man labour						element area	Units	Productivity					Operation order
									Calculated			Contractor data		
	Unskilled worker	Hours	Equipment operator	Hours	Supervisor	Hours	m^2	un.	Man.h/m^2	Man.h/un	Man.h	Man.h/m^2	Hh/un	
carpet removal	2	3	1	0.4	1	0.1	40		0.16		6.5	0.16		1
plaster removal	4	7	1	1	1	1	100		0.30		30	0.30		2
covering wood removal	2	5.5	1	0.65	1	0.6	76.6		0.16		12.3	0.16		3
cork removal	2	1.5	1	0.1	1	0.1	15.0		0.21		3.2	0.20		1
door removal	2	5	1	0.5	1	0.5	22.6		0.49		11	0.50		1
window removal	3	4	1	0.5	1	0.5	19.3		0.67		13	0.66		1
ceiling removal	4	4.5	1	1	1	1	100		0.20		20	0.20		2
toilet fixtures removal	1	1	1	0.3				12.6		0.103	1.3		0.1	1
taps removal	1	1						9.73		0.103	1.0		0.1	1
traditional demolition	3	1	1	1	1	1	100		0.05		5.0			4
post separation of elements	3	7	1	7	1	2	100		0.30		30			5
cleaning and transport	2	8	2	8	1	2	100		0.34		34			6
aggregate crushing			1	3.27			100		0.033		3.3			7

Table 2. Input data and calculations for estimating the case study (equivalent) traditional demolition cost and duration.

Activity	Man labour						Element area	Units	Productivity Calculated			Operation order
	unskilled worker	hours	equipment operator	hours	supervisor	hours	m^2	un.	Hh/m^2	Hh/un	Hh	
Tradicional demolition	1	1	1	1	1	1	100		0.03		3	1
cleaning and transport	2	4	2	4	1	1	100		0.17		17	2
aggregate crushing			1	3.27			100		0.033		3.3	3

Table 3. Average zone and element area and total material weight per house unit m^2.

Kitchen + toilets average area /m^2	0.23	m^2/m^2
Door average area /m^2	0.23	m^2/m^2
Window average area /m^2	0.19	m^2/m^2
Toilet fixtures average units /m^2	0.13	un/m^2
Tap average units /m^2	0.097	un/m^2
Average total material weight /m^2	1.96	ton/m^2
Average weight of the elements to be demolished	196	ton

Several destinations were considered for the last two operation phases, transport and final disposal, not only because deconstruction implies recovering separated material fluxes which have to be sent to different locations (affecting transportation costs), but also because prices charged for collecting materials varied widely among waste operators and material collectors (affecting final disposal costs). However, yard installation, direct and indirect man labour and equipment operation were assumed to remain constant between scenarios (different transport and disposal destinations), since those costs depend mainly on the contractor.

The presented scenarios (Figure 2), or different transportation/final disposal locations, refer only to waste operators where the bulk aggregate mass was driven to, separated from most other materials (deconstruction) or mixed (traditional demolition). These operators differ from each other, in what respects this study, only in distance (location) and gate cost (tipping fee), as can be observed in Table 4.

Deconstruction

Yard installation cost was simply taken from real costs given by the contractor. These costs, proportioned down to a 100 m^2 house unit (the cost analysis, as the schedule analysis, was also conducted on a 100 m^2 house unit basis), resulted in 154.9 €.

Table 4 - Distance and tipping fees for different waste operators considered in the analysis.

Waste Operator	Distance from the site (Cacém Polis), km	Tipping fee for different materials, €/ton	
		"Clean" aggregates	Mixed CDW
Waste Operator 1	2	6.0	20.0
Waste Operator 2	61	15.0	59.0
Waste Operator 3	64	5.5	20.5
Waste Operator 4	21.5	12.5	30.0
Waste Operator 5	30	0	75.0
Waste Operator 6	219		
Waste Operator 7	30		
Waste Operator 8	253		
Waste Operator 9	8		

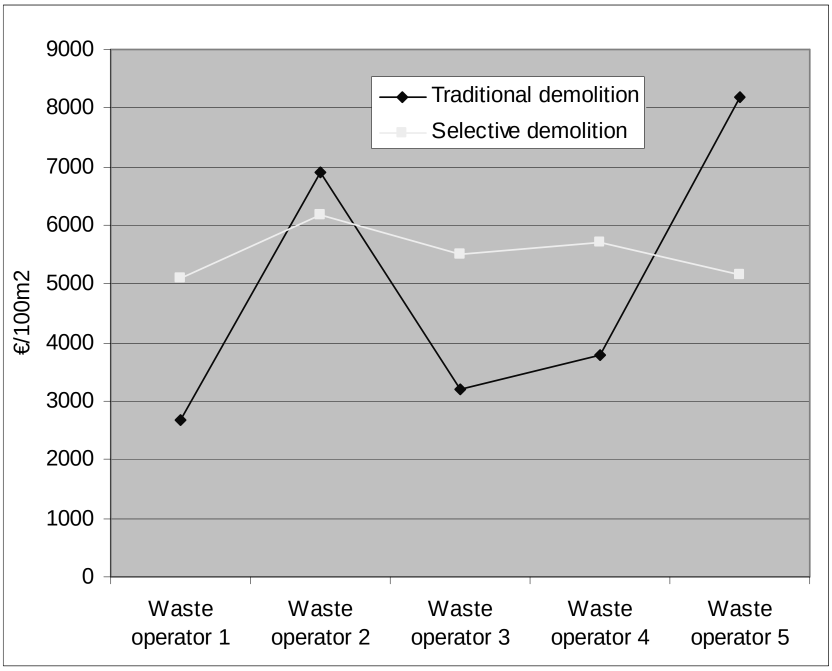

Figure 2- Global cost for different scenarios (waste operators)

As for direct (task/chore hours) and indirect (supervision) labour, total cost was derived from the same schedule analysis referred in §3, applying the following labour costs: general unskilled workers - 6.0 €/h; equipment operator - 10 €/h; supervisor - 12.8 €/h (these labour costs are valid for the (large metropolitan) Lisbon area, with possible variations for other parts of the country). This resulted in a total cost of 1212 €. As for equipment costs, the contractor given costs were applied, which translates into 65 €/h for the excavator operation, 30 €/h for the loader and around 20 €/h for the mobile crusher (located at the landfill site). These costs include fuel, maintenance and repairs. Table 5 depicts the total incurred costs in equipment operation (1100 €), from which a ratio of 0.52 is calculated, between equipment using hours and the total working hours, a measure of the level of mechanization used in this particular deconstruction case.

Table 5 - Operation equipment cost for deconstruction and traditional demolition

	Deconstruction		Tradicional demolition	
Equipment	Operation hours	Cost, €	Operation hours	Cost, €
Excavator	9	585	5	325
Loader	15	450		
Mobile crusher	3.3	64.8	3.3	64.8
Total	27.3	1100	8.3	390

Transportation costs were determined taking into account the actual destinations to which materials were sent, according to Table 6. The number of truck trips was calculated using a simplified carrying volume of 19.3 m^3 per truck, applied to all transportation needs. Transported volumes were defined using average volume weight for different “piled” materials, taken from online published references (Construction Materials Recycler and Australian Victorian Government sustainability resources). As for the unit transportation cost (€/km), two sources of information were considered: the contractor costs for transporting certain material categories and publication data (Lourenço, 2007), which can be observed in Table 7.

Table 6 - Transportation costs for the deconstruction operation

Average material composition	%	kg	m³	Destinations	Distance, km	Truck trips	Cost €/km	Cost € (/100m²)
Uncontaminated soils and rocks	51.1	13463531		used locally				
Concrete, masonry, tiles, shingles and other ceramics (clean aggregates)	37.2	9810840	6701	Waste Operator 5	30	347	2.76	213.9
				Waste Operator 1	2			14.26
				Waste Operator 2	61			434.8
				Waste Operator 3	64			456.2
				Waste Operator 4	21.5			153.3
Uncontaminated gypsum materials	4.47	1178883	1179	Waste Operator 2	61	62	2.95	83.10
Wood	3.33	878228	2927	Waste Operator 6	219	152	4.00	991.5
Potencially hazardous materials	2.57	677792	484	Waste Operator 2	61	26	2.95	34.8
Municipal Solid Waste	0.71	187250	1248	Waste Operator 2	61	65	2.95	87.1
Metals (except lead)	0.49	129229	144	Waste Operator 7	30	8	2.19	3.91
Glass	0.1	26373	76	Waste Operator 8	253	4	2.19	16.5
Plant wastes	0.05	13187	88	Waste Operator 9	8	5	2.19	0.65
Plastic	0.02	5275	406	Waste Operator 2	61	22	2.19	21.9
Total	100	26370588	13253	clean aggregates: Waste Operator 5		691		1453
				clean aggregates: Waste Operator 1				1254
				clean aggregates: Waste Operator 2				1674
				clean aggregates: Waste Operator 3				1696
				clean aggregates: Waste Operator 4				1393

Table 7 - Transportation costs for the deconstruction operation

Materials	Contractor	Lourenço (2007)
Clean aggregates (ceramics)	2,76	1,83
Mixed waste	2,95	-
Hazardous waste	2,95	7,1
Non contaminated gypsum materials	2,95	-
Wood	4,00	-
Tires	4,00	-
Other wastes	-	2,19

As for disposal costs, all values used in the calculations were derived from the waste operators and market values for some materials (given by a big established (general) contractor in Portugal), which are presented in Table 8. The values used are real market values at the moment, which does not mean variations may not be found in other situations. From these values, Table 9 was composed, which gives total cost values for the disposal operations conducted by several waste operators, similarly to the transportation costs presented in Table 6.

Table 8 - Waste disposal costs, per material flux

Average material composition		Unit disposal costs €/ton
Uncontaminated soils and rocks		used locally
Concrete, masonry, tiles, shingles and other ceramics (clean aggregates)	Waste Operator 1	6
	Waste Operator 2	15
	Waste Operator 3	5.5
	Waste Operator 4	12.5
	Waste Operator 5	0
Uncontaminated gypsum materials		55
Wood		0
Potencially hazardous materials		100,5
Municipal Solid Waste		60,5
Metals (except lead)		-150 (revenue)
Glass		0
Plant wastes		3,5
Plastic		-50 (revenue)
Mixed CDW	Waste Operator 1	20
	Waste Operator 2	59
	Waste Operator 3	20.5
	Waste Operator 4	30
	Waste Operator 5	75

Traditional demolition

It was assumed that yard installation cost is approximately the same for deconstruction and demolition works. Direct and indirect labour costs were directly determined from Table 2, multiplying the number of workers for a certain task by that task duration, applying then the corresponding labour wage. The sum of these labour costs results in 202.3 €. Equipment costs for traditional demolition can also be observed in Table 4 (390 €), from which a ratio of 1 is obtained for the relation between equipment operation hours and total hours, derived directly from the fact that this is a complete mechanized standard procedure, not requiring (almost) any manual work. Transportation costs are determined in a similar way as the deconstruction case, only considering all materials mixed, except for uncontaminated soils and rocks, which are given the same waste management option, since using these materials locally is a generally widespread practice among (traditional) demolition works, mostly to cut transportation and virgin material costs (Table 10). Finally disposal costs, using the corresponding unit disposal values presented in Table 8, were summarized for the different waste operators in Table 11. In this case all materials were considered landfilled, disposed of as mixed CDW.

5 COST COMPARISON

A global cost presentation table is presented (Table 12), from which Figure 2 is extracted and average global costs can be calculated for this case study: 4955 € for traditional demolition and 5519 € for deconstruction (averages associated with the following standard deviations: 2179 € and 394 € for the traditional demolition and deconstruction, respectively). Although the global cost average favours traditional demolitions, it is clear from Figure 2 that in some circumstances it is possible to conduct selective demolitions for a lower global cost. Not coincidentally, the two waste operators with which it is economically viable to perform deconstruction are the ones which are associated with higher mixed CDW disposal fees, even though these represent the lowest (0 €/ton for waste operator 5) and highest (15 €/ton for waste operator 2) clean aggregates disposal fee.

Table 9 - Waste disposal costs, per material flux

					Cost Other entities (waste operators and contractor)		Deconstruction Contractor		Revenue	
Average material composition	%	kg	Waste management option		€/kg	€	€/kg	€	€/kg	€
Uncontaminated soils and rocks	51.05	100250	Reuse							
Concrete, masonry, tiles, shingles and other ceramics (clean aggregates)	37.2	73052	Recycling	Waste Operator 1	0.006	438.3	0	0		
				Waste Operator 2	0.015	1096				
				Waste Operator 3	0.0055	401.8				
				Waste Operator 4	0.0125	913.1				
Uncontaminated gypsum materials	4.47	8778	Landfill		0.055	482.8	0.09	790.0		
Wood	3.33	6539	Recycling		0.00	0.00	0.015	98.1		
Potencially hazardous materials	2.57	5047	Landfill		0.101	507.2	0.075	378.5		
Municipal Solid Waste	0.71	1394	Landfill		0.061	84.4	0.075	104.6		
Metals (except lead)	0.49	962.2	Recycling						-0.15	-144.3
Glass	0.1	196.4	Recycling		0	0.00	0	0.0		
Plant wastes	0.05	98.19	Landfill		0.0035	0.34	0.0035	0.3		
Plastic	0.02	39.28	Landfill				0	0.0	-0.05	-2.0
Total	100	196356					0.26	1372	-0.20	-146.3

Global cost. €	
Waste Operator 1	1367
Waste Operator 2	2024
Waste Operator 3	1330
Waste Operator 4	1842
Waste Operator 5	1227

Table 10 - Transportation costs for the traditional demolition operation

Average material composition	%	kg	m^3	Destinations	Distance, km	Truck trips	Cost €/km	€ (100/m^2)
Uncontaminated soils and rocks	51.1	13463531		used locally				
Mixed CDW	48.9	12907056	9219	Waste Operator 5	30	478	2.19	233.9
				Waste Operator 1	2			15.6
				Waste Operator 2	61			475.6
				Waste Operator 3	64			499
				Waste Operator 4	21.5			167.6
Total	100	26370588	9219	clean aggregates: Waste Operator 5		478		233.9
				clean aggregates: Waste Operator 1				15.6
				clean aggregates: Waste Operator 2				475.6
				clean aggregates: Waste Operator 3				499.0
				clean aggregates: Waste Operator 4				167.6

Table 11 - Disposal costs for the traditional demolition operation

Average material composition	%	kg	Waste management option		Cost		Revenue	
					€/kg	€	€/kg	€
Uncontaminated soils and rocks	51.1	100250	Reuse					
Mixed CDW	48.9	96106	Landfilling	Waste Operator 5	0.075	7208		
				Waste Operator 1	0.02	1920		
				Waste Operator 2	0.05	5670		
				Waste Operator 3	0.021	1969		
				Waste Operator 4	0.00	2883		
Total	100	196356			0.041*	3930*	0	0.0

* Average values

Table 12 - Global cost for different scenarios (waste operators)

Cost category	Clean aggregates (selective demolition) and mixed CDW (traditional demolition) sent to waste operator									
	Waste operator 1		Waste operator 2		Waste operator 3		Waste operator 4		Waste operator 5	
	Traditional demolition	Selective demolition	Traditional demolition	Selective demolition	Traditional demolition	Selective demolition	Traditional demolition	Selective demolition	Traditional demolition	Selective demolition
Yard installation	155	155	155	155	155	155	155	155	155	155
Man labour	202	1212	202	1212	202	1212	202	1212	202	1212
Equipment	390	1100	390	1100	390	1100	390	1100	390	1100
Transportation	15,6	1254	476	1674	499	1696	168	1393	234	1453
Disposal	1920	1367	5670	2024	1969	1330	2883	1842	7208	1227
Total	2682	5087	6893	6165	3215	5493	3798	5701	8189	5147

From the cost structures (Table 13) it can be seen that traditional demolition costs are more sensitive to the final disposal site (waste operator), than selective demolition. This is mainly due to the fact that, in an overall impact, disposal has a much higher relative weight in traditional demolition (76%) than selective demolition (28%). On the other hand, labour costs are almost 6 times higher in the latter, which is a direct consequence of the extra time needed to complete the work and the reduced mechanical equipment utilization, when compared to traditional demolition. Furthermore, traditional demolition transportation cost is more sensitive to transportation distance than selective demolition (of the bulk mixed CDW and clean aggregate, respectively), since the primer depends solely on one destination/waste operator, even though transportation costs are always higher in the selective demolition scenarios, in which all materials separated from the ceramic aggregates were transported to several other locations, having remained the same for all scenarios.

Table 13 - Average cost category impact on total cost, %

Cost category	Traditional demolition	Selective demolition
Yard installation	3.13	2.81
Man labour	4.91	22.1
Equipment	9.47	20.0
Transportation	6.05	27.1
Disposal	75.8	28.0

Finally, it is important to acknowledge that traditional demolition cost distribution is very much dependent on disposal costs, as stated above (76%), while selective demolition cost structure is much more levelled in this respect, with 22% of cost in labour, 20% in equipment operation, 27% in transport and 28% in material disposal. This levelling is essentially caused by the lower disposal and higher transportation costs.

6 CONCLUSIONS

From the present case study analysis, it is possible to draw the following conclusions:

- Although an average based scenario gives economical preference to traditional demolition over deconstruction (as defined above), it is possible to achieve lower global costs for the latter, especially when mixed CDW disposal costs are particularly high (when compared to other scenarios);
- The traditional demolition costs are very much dependent on the final disposal cost (of mixed CDW), while selective demolition cost structure is more levelled between labour, equipment, transport and final disposal costs;
- To be able to sell out (or at least reuse on the spot or in other works), even at a low price, the total or partial bulk mass of “clean” aggregates, will certainly turn many presently uneconomical selective demolition projects into viable ones;
- To enhance the mechanization (equipment operation) of deconstruction activities, shortening schedules and cutting labour costs, maintaining high recovery rates is possible (Guy, 2003) and desirable, although it needs to be adapted to each type of building;
- Whenever possible, materials shall be recovered in a good enough condition to be reused, putting efforts into the commercial activity of selling those materials in order to guarantee a cost/revenue ratio as low as possible for each recovered material. Recycling, although positive in environmental terms and effectively diverting materials from landfill, may not be enough to gain an economical edge over traditional demolition: it may be necessary (and, most of the time, preferable) to search for actual revenue from selling materials and not only cutting costs in final disposal;
- The total labour costs are considerably higher in deconstruction activities than in traditional demolition (about 6 times more, in this case), as well as time needed to complete the work. Further mechanization, planning and optimized procedures will lower both these quantities.

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Building rehabilitation towards primary energy saving: case study

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ABSTRACT: This article deal of the rehabilitation of the BBVA building in Madrid, Spain, with the intention to reduce the primary energy consumption. The proposed intervention aims to be the least invasive for several reasons: the building is an iconic image that must be maintained; it is not sustainable to change their operating parameters, since it responds effectively to the needs; the type of construction allows making changes to some components without affecting the indoor and outdoor environmental. The intervention is based on the introduction of passive and active strategies that improve the building comfort, while decreasing the energy expenditure. With the proposed rehabilitation project, the total energy requirements of the building are reduced by 70%. This value reflected a decrease of 201.4 kWh/m^2 year. From the environmental point of view, this reduction of energy is equivalent to removing 2578 tons/year of CO_2 emitted into the atmosphere.

1 INTRODUCTION

In recent decades, the response to the urban populations' growth has been the tall buildings constructions, sustained by economic reasons, urban, demographic, etc. However, most of these structures were built before the oil crises and during a period where the conception of environmental impact was not even considered, consequently it was not taken into account the energy consumption of buildings. According to Tommerup and Svendsen (2006), 75% of the energy savings potential is in buildings built before the 80's. They are wasting more energy, but, if the energy efficiency is taking in account in their rehabilitation, it is possible to reduce 80% of energy needs. How the office towers, housing, hotel or other buildings are necessary to the modern cities and it is not simply to eradicate, the designer needs to seek solutions to maximize their energy efficiency, finding a balance between needs of urban planning and environmental constraints. However, more important than implementing new buildings in according to sustainability criteria is to rehabilitate the tall buildings that present low energetic efficiency. According to Yeang (2002), the skyscrapers are an effective green alternative to the familiar suburban decentralized structure and ordering of low density. Romano (2004) considers that looking forward, the utopias of one mile high tower could propose a vertical urbanism more concentrated and less polluting. The best models of rehabilitation are not those where are maintained only the buildings structure. In these cases there were a high production of construction materials wastes, debris and pollutants released into the atmosphere. Good practice of building rehabilitation should take into account passive strategies combined, if necessary, with the active strategies. In this way the service life of the building is extended and the energy consumption is reduced, by consequence the environment is protected of debris that would be launched during the demolition and the CO_2 emissions from the production of new building materials are reduced. In this context, this paper presents the outline of a study and a project to perform the energetic rehabilitation of an emblematic tall building in Madrid.

2 THE BBVA BUILDING CASE STUDY

BBVA building, designed by Francisco Oíza, was built in the 80's, when energy was plentiful and environmental problems were not yet concerned. Thus, it is a building with high energy consumption. The study of BBVA building was supported primarily on several visits, documents consultation, manuals and surveys in detail. The BBVA building is located in Paseo de la Castellana, in the AZCA Centre (Figure 1) and has coordinates 40° 3' N, 3° 4' W. Paseo de la Castellana is one of the main and wider avenues of Madrid. The building is an office tower of 107.8 meters high, set on 30 floors with an area of 39.60 x 29.04 meters per floor; four underground floors occupy the entire land surface of 64.84 x 48.00 meters.

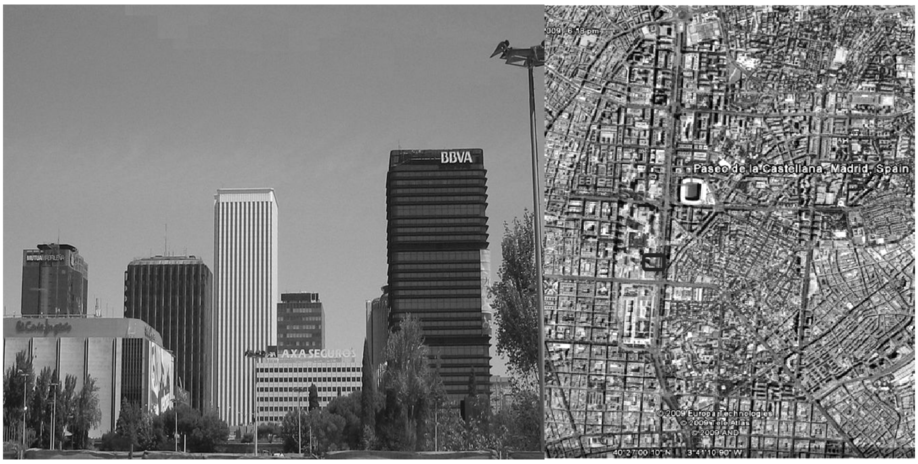

Figure 1. AZCA Centre (left); view of Castelhana Avenue, BBVA in black (rigth).

BBVA's facilities are divided into three technical floors (Figure 2), where the air conditioning equipment, which consist of an air conditioning cold-hot powered by four large cooling towers, placed on the roof of the building. The distribution of facilities is done through the vertical core, from the technical floor to the adjacent floors.

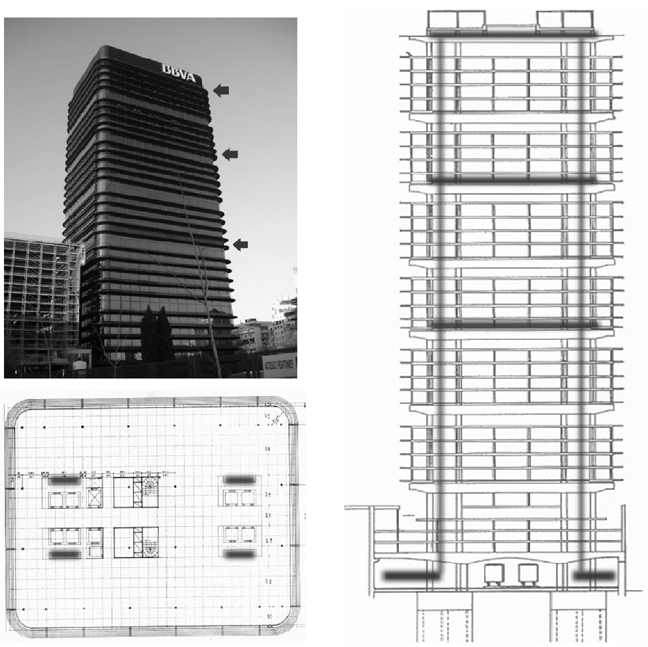

Figure 2. Facilities distribution

3 THE BBVA REHABILITATION

The proposal for the BBVA building energy rehabilitation aims to be the least invasive as possible, in view of the importance of maintaining the building image in the city. It is not sustainable to change their operating parameters, since it responds effectively to the needs of occupation. The intervention is based on the introduction of passive and active strategies that improve the comfort inside the building, while decreasing the energy expenditure.

3.1 *Passive strategies*

The original BBVA building makes little use of passive cooling strategies. Its use comes down to the insulation, double glazing and the use of brise soleil on the facades East, South and West. The air is delivered mainly by artificial air-conditioning equipment.

a) External conditions: climate data

The analysis of external conditions, made from weather data and geographic area of Madrid, were performed using the software ECOTECT (2009). It was possible to observe some parameters such as latitude, rainfall, the wind patterns, solar radiation, average annual temperatures, relative humidity (RH) and the topography of the city. Madrid is an example of Continental Mediterranean climate, characterized by extreme temperatures, a minimum of -5ºC during the winter and a maximum of 40ºC during the summer. In addition, the duration of warm periods (spring and autumn) was very low or even negligible, and it is considered, usually only the seasons of summer and winter. RH is high during winter, between 65% and 85%, and low in summer, between 20% and 45%. The solar radiation directly and indirectly is constant throughout the year and is more intense in the summer. The first is between 400 and 800 W/m^2 and the second is between 100 and 300 W/m^2. Thus, the buildings will have always an important dependence of the air conditioning system, whether for heating or cooling. It is therefore important to use strategies to optimize the energy consumption required for these two actions.

b) Indoor Conditions

As an office building, the comfort temperature was calculated for the parameters of sedentary activities. From the analysis of the comfort zone defined by the psychometric chart of Madrid, the sensation of thermal comfort is obtained for RH between 20% and 80% and temperature between 20º C and 25° C.

c) Control of solar radiation

The solar paths, the heat gains by solar radiation and the percentage of shading on the glazing caused by horizontal brise soleil of the building were observed by the solar charts analyses (Figure 3).

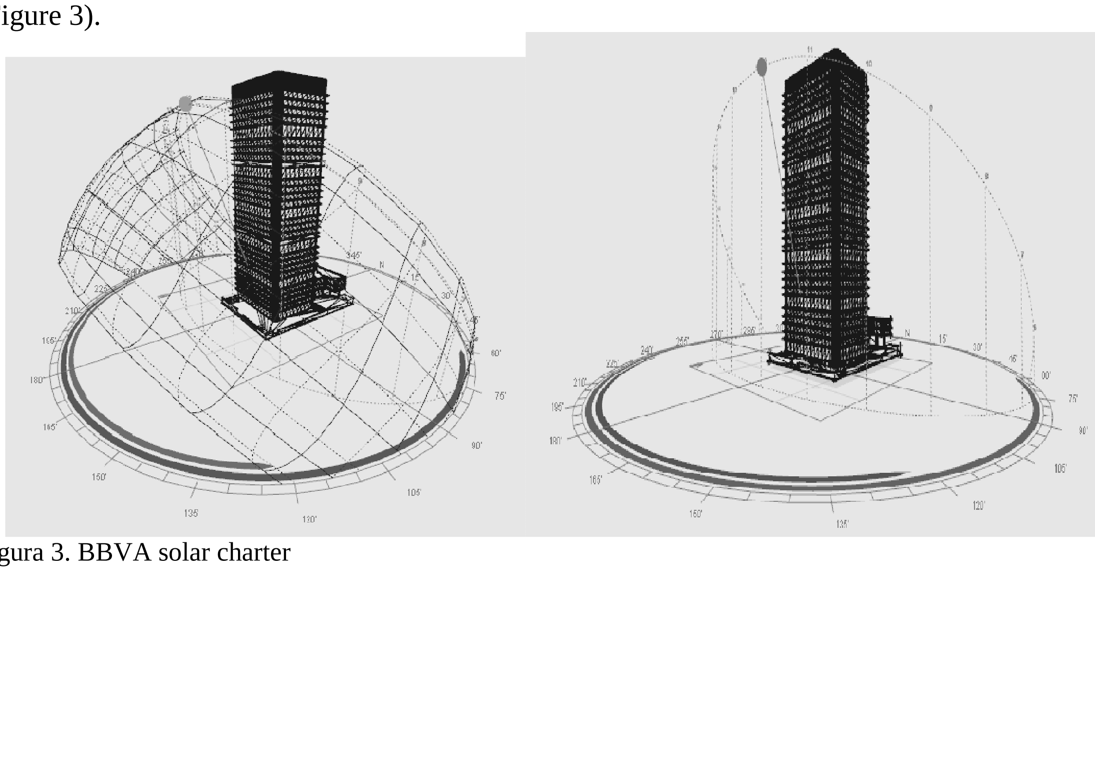

Figura 3. BBVA solar charter

It was concluded by the solar orientation studies that the building have a proper solar orientation, presenting its main façade oriented to the south. But, regarding the brise soleil function, it appears that during the summer only the south facade is protected of the radiation heat gains. How the building is composed of 32 floors, so on the whole there is a high radiation heat gain that is balanced through the use of air conditioning. This is confirmed by the shading percentage on the facades. During the summer the East facade has only 43.6% of shaded glazing area and the facade West has 44.9%. To avoid heat gains by directly radiation, in summer, these situation needs to be corrected. Hence, the most appropriate strategy is to create a vegetal barrier inside East facade and a system of adjustable brise soleil (also inside) in the West facade.

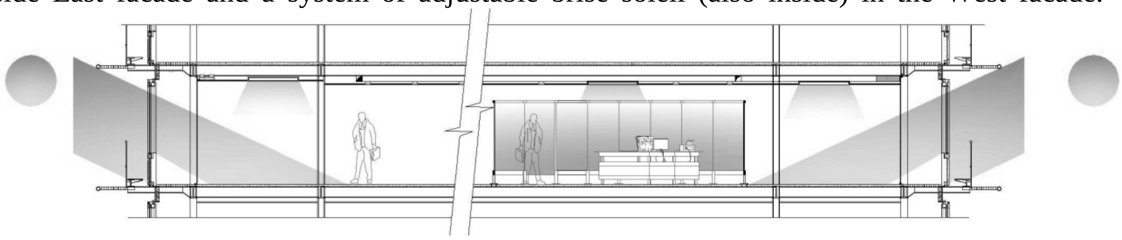

Figure 4. West-East facade. Representation of summer sunlight.

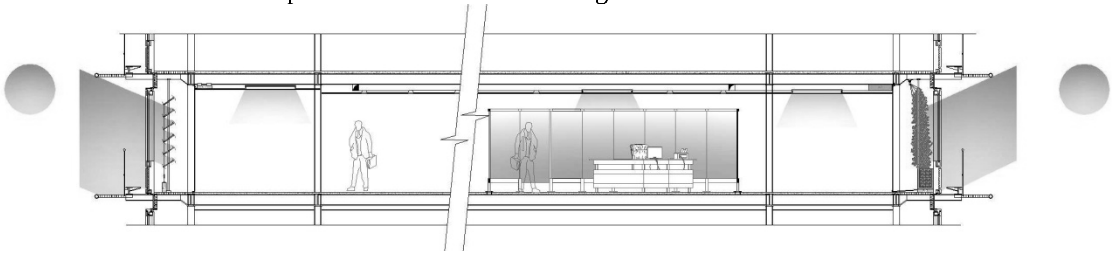

Figure 5. West-East facade. Representation of summer sunlight with the vegetal barrier in East and adjustable blades in the West.

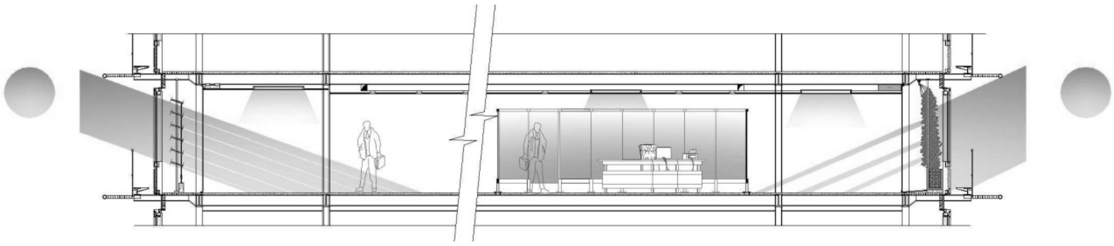

Figure 1. West-East facade. Representation of winter sunlight with the vegetal barrier in East front and adjustable blades in the West.

This strategy controls the sunlight during the summer and encourages it during the winter without affect the functional and spatial floors organization.

d) Vegetal and solar chimney chambers

Two inner chambers were introduced: one in the West facade with solar chimney function and solar barrier and other on the East facade as air filter and solar barrier. These chambers are essential for the building in terms of passive cooling and a great ally for active cooling. Moreover, these two chambers complement it to create the summer night ventilation and natural ventilation when outside conditions can permit. The vegetal chamber, highlight the fact that the plants are great humidifiers, air purifiers and absorbs some chemicals materials toxic to humans. The importance of vegetal chambers is that the plants not only process the carbon dioxide and release oxygen, but also eliminate elements such as formaldehyde, benzene, dust and germs from the air. (Wolverton, 1996). The ability of plant transpiration affects the facade microclimate by producing oxygen and absorbing carbon dioxide, which can simultaneously take advantage of the natural environment as an effective cooling." (Yeang, 2001). The English ivy (*Hedera helix*) was choose as ideal for growing in pots and in the office environment, due to the high capacity of this plant to filter benzene and TCE, the chemical compounds present in equipment such as computers, faxes and telephones. The vegetal chamber contributes to improve the acoustic properties of the facade; since the plants and the air can control as well the sound waves propagation. It is the case of East side oriented for the Paseo Castellana, where vehicle traffic is constant. The solar chimney chamber takes several functions, one of them is to control the solar radiation, the other is to create solar chimney for ventilation in summer and night natural ventilation when possible, during the spring and autumn.

In order to be able to reconcile the benefits and the possibilities offered by the chambers, but without compromising the building aesthetics and functionality, it has been take care that these additional elements could integrated with the building envelop, enriching the space, rather than stand out as an individual elements (Figure 7).

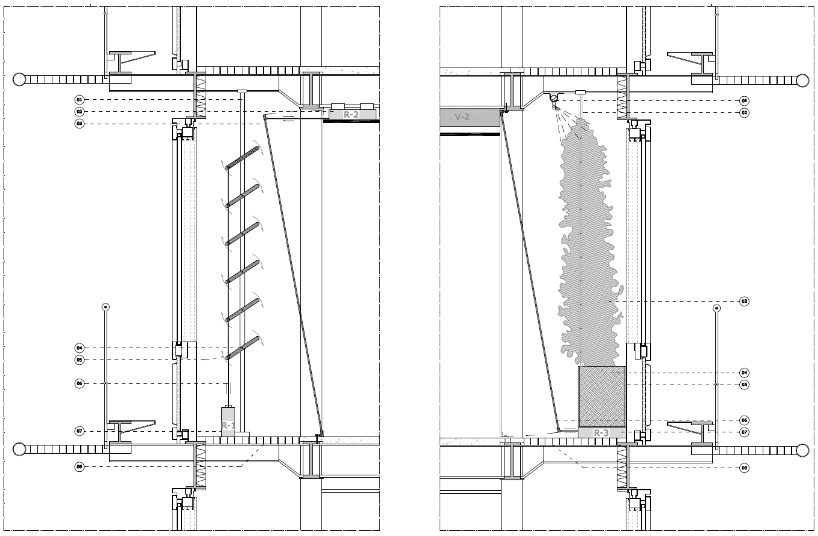

Figure 7. Chambers details: solar chimney (left), vegetal chamber (right)

e) Daylighting

In the BBVA building, the daylighting of the interior space is very effective in open space office settings. This is due to the fact that its entire outer perimeter is glass. In the settings more compartmentalized, the way of daylighting is more difficult. The percentage of light is stronger on the West side because of the possibility of brise soleil regulation, and weaker on the East side due to the plant chamber. The northern and southern sides have relatively the same values. The lower levels of daylighting are reported in areas surrounding the structural core. The only strategy adopted to promote the use of daylighting is to change the opaque partitions by translucent partitions (frosted glass) as shown in Figure 8.

f) Gray water and rainwater recycling

The rainwater that falls on the cover and the water from the sinks, toilets, will be used to supply water reservoir to toilets. To fulfill this objective, the strategies adopted will be: the rainwater collected on the roof is led to some deposits situated in the technical first floor existent under the roofing. A water line was created from the recycled water deposits that will supply by gravity, the toilets reservoir at the underlying floors. For best viewing of these processes, see the Figure 9.

Figure 8. Interior partitions. Current situation (left). Proposition, virtual image (right).

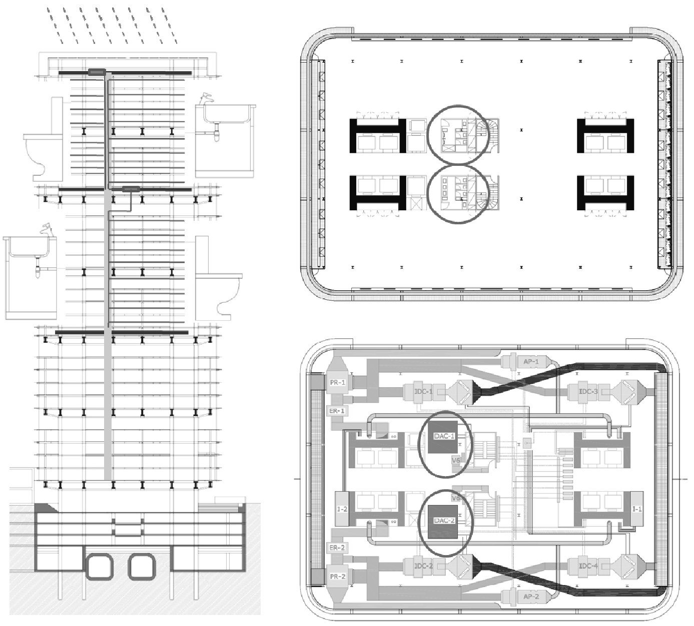

Figure 9. Schema of the gray water and rainwater reuse

3.2 *Active strategies*

The BBVA building hot/cold air conditioning equipment was fabricated in 1977, and therefore, the equipment have a high energy needs. This system is powered by a large gas boiler, which produces hot water, and four large cooling towers placed on the building roof, which produce cold water. A new system is proposed in this project: the cooling towers are eliminated and the boiler is replaced by new boiler with energy efficiency A +. A solar cooling system, with efficiency classed as A + +, will installed to cold, enhancing its efficiency. The cooling system is a solar technology developed by CLIMATEWELL, a Swedish company leader in research equipment driven by air solar thermal. The units of air handling will not be replaced, since their energy consumption not justifies the amendment.

a) Mechanical air conditioning

The mechanical systems of the cooling will be changed to be combined with the passive cooling strategies. The first major change is the elimination of the air handling in the inner East side and West side, with a view to incorporate the chambers and the elimination of two fans that conducted the primary air, for each technical floor. Then it will be necessary to conduct the air heated or cooled in the large air handling to the vegetal chamber. Fans will be used for air aspiration from the vegetal chamber, through pipes installed in the ceiling, to distribute inside the floor. Finally, stoves will be installed at the return extractors situated in technical floor. The air heated or cooled when passes by the vegetable chamber is converted into cleaner air enriched in oxygen and being removed dust, germs and toxic gases. A semi-closed circuit reduces the need of frequent air renewal.

b) Production of energy (photovoltaic panels)

The project includes the installation of photovoltaic panels, SunPower model 220, on the South facade. This is one of the highest efficient with a more attractive and uniform aspect than conventional photovoltaic panels. As the image of the building should never be disturbed by this equipment it means that the panels could not be visible to passers-by, they should be placed in the space created by the boundary of the glazing and the horizontal stripes (Figure 10). The areas where the panels will be placed have a large number of solar incidence hours. The panel's power is 180 W/m^2 with a total power peak of 4.4 kW per 25 m^2. Globally, the building contains 960 m^2 of photovoltaic panels that match the production of 169kW. Solar radiation in Madrid represents by year, about 2200 kWh/m^2. Thus, the 960 m^2 of solar panels corresponds to an annual production of 238 MWh. From the environmental point of view, the use of solar energy in this example corresponds to a reduction of 95 tons/year of CO_2 emissions.

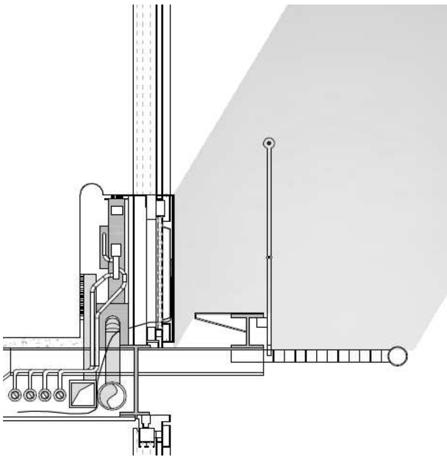

Figure 10. Photovoltaic panels integrated on facade

c) LED Lighting

The replacement of fluorescent light bulbs by LED markedly reduce the energy consumption, because each floor has 392 fluorescent lamps in total, accounting for all floors will be about 12 544 light bulbs.

4 REHABILITATION RESULTS

The estimative of total energy consumed was based on data from Energy Consumption Guide 19 (BRECSU 2000) taking into account the type of building. Table 1 shows the estimative of energy consumption values of BBVA and the values calculated after the building energy rehabilitation.

Table 1. Energy consumption of BBVA before and after rehabilitation (kWh/m^2 treated floor area)

	Energy Consumption before (kWh/m^2 by year)	Reduction (%)	Energy Consumption after (kWh/m^2 by year)
Cooling and heating	190	-80%	38
Lighting	60	-70%	18
Fans, pumps, controls	25		25
Office equipments	7		7
Production of energy (photovoltaic panels)	0		-7.4
Total	282		80.6

The rehabilitation will fall by 71% the total energy requirements of the BBVA building. This value is reflected in the decrease of 201.4 kWh/m^2 year, which means for an area of approximately 32 000 m^2, leads to a decrease corresponds to 6445 MW/year. To get a better idea of this value, 4.4 MW/year is the average consumption of a dwelling. From the environmental point of view, this reduction of energy consumption is equivalent to removing 2578 tons/year of CO_2 emissions. In terms of the efficiency level, this building, once rehabilitated, would be A+ because the maximum consumption value for this category is 81.9 kWh/m^2 by year and the building after rehabilitation will have 80.6 kWh/m^2.

5 CONCLUSION

The proposed rehabilitation provided, without major aesthetic and functional building changes, a significant reduction in energy consumption. The energetic rehabilitation of tall buildings, due their volume and dimensions relevance at urban scale, is a major contribution to improving the sustainability of the cities. The proposed rehabilitation energy, presented here, gives to BBVA building a rating of eco-efficient building.

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An Integrated Approach for Sustainability (IAS): Life Cycle Assessment (LCA) as a supporting tool for Life Cycle Costing (LCC) and social issues.

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ABSTRACT: SPEAR is the acronym for the European research project Seismic Performance Assessment and Rehabilitation of existing buildings, and the SPEAR building is the three-storey replica of an existing non-seismic building, full-scale tested at the ELSA Laboratory.
In previous studies, a practical cost-benefits analysis was used to compare the performance of the specimen in the two different rehabilitated configurations: GFRP-retrofitted specimen and RC-jacketed structure.
This paper presents a method to assess the best solution between alternative interventions including sustainability issues in the economic evaluation. The main aim of this study, in fact, is to create an integrated approach as the key to make choices in terms of life cycle cost benefits analysis.
Normally, Life Cycle Assessment (LCA) is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment (from the cradle to grave).
In the present study LCA methodology is calibrated as a decision support tool for economic analysis. At this regard, the first step was the environmental impacts analysis derived from the production (pre-use phase), installation (use phase) and waste treatment (end of life phase) of the two retrofitting measures. SimaPro software (version 7.1.8) was used to implement LCA model and to carry out the assessment in terms of tons CO2 emissions.
It is clear that environmental results are not compatible with cost analysis (expressed in Euro) for the two configurations; therefore, to define a global result, CO2 emissions are converted in Euro unit, considering both the costs of the expected damages and the benefits derived from global climate change.

1 INTRODUCTION

The term sustainable development can be described as enhancing quality of life and thus allowing people to live in a healthy environment and improve *social*, *economic* and *environmental* conditions for present and future generations.

The emergence of the Life Cycle Assessment (LCA) in construction is, therefore, the effect of the growing awareness that environmental problems can no longer be addressed in individual compartments, but they require a comprehensive assessment and intervention.

Objective of LCA is to guide the choices of the project through a full assessment ("*from cradle to grave*") of the materials performance, construction techniques and service that, in general and not as a single component, enables reduced consumption of resources, reduced emissions and waste. The LCA is not only a means to environmental protection, it can become an important tool for strengthening the competitive dynamics and to reduce and control costs.

In such a context, the paper presents an *integrated approach* to make choices based on economic and environmental factors.

2 LIFE CYCLE ASSESSMENT

2.1 *Conceptual basis of Life Cycle Assessment (LCA)*

The Life Cycle Assessment (LCA) methodology used in this study follows the stages outlined by International Organization for Standards (ISO) 14040.

The four major stages of the LCA applied contain:

1.Goal and scope definition, including the analysis of system boundaries;
2.Life cycle inventory;
3.Life cycle impact analysis;
4.Life cycle interpretation and suggestions for improvement.

1.The *Goal and Scope Definition* phase describes the overall objectives, the boundaries of the system under study, the sources of data and the functional unit to which the achieved results refer.

2. The *Life Cycle Inventory (LCI)*, defined by ISO14041, consists of a detailed compilation of all the environmental inputs (material and energy) and outputs (air, water and solid emissions) at each stage of the life cycle.

3. The *Life Cycle Impact Assessment (LCIA)* phase aims at quantifying the relative importance of all environmental burdens obtained in the LCI by analysing the relative influence on the selected environmental effects. According to ISO14042, the general frame work of an LCIA method is composed of mandatory elements (*classification* and *characterisation*) that convert LCI results into an indicator for each impact category, and optional elements (*normalisation* and *weighting*) that lead to a unique indicator across impact categories using numerical factors based on value-choices.

4. According to the ISO14043 standard, in the *Life Cycle Interpretation* phase, results of the LCI and LCIA stages must be interpreted in order to compare alternative scenarios.

SimaPro v. 7.1.8 software application was used as supporting tool in order to implement the LCA model and carry out the assessment. In particular IPCC 2007 GWP 500a methods was used here to compare the results (Lavagna, 2008).

2.2 *Stage 1: Goal and Scope Definition*

The Life Cycle Assessment methodology has been used to obtain a comparative and comprehensive environmental picture relevant to two different retrofitting strategies (GFRP-wrapping and RC-jacketing) applied to the *realistic* SPEAR building, located in Campedei (BL) Italy (Figure 1). In particular, this study was carried out by evaluating CO_2 emissions in the atmosphere, crucial to global warming.

Figure 1. Location and render of the building under study

The *functional unit* is formed by all technological units by which the two retrofitting interventions are characterized.

Three distinct phases, pre-use, use and end-of-life, were included in the *system boundaries* (Figure 2).

The *Pre-Use phase* consists of the manufacturing, the transportation and production of retrofitting materials. The quantities were estimated from building drawings.

The *Use phase* encompasses all activities related to the site construction. In particular it includes the transportation from plant to installation site and the installation of GFRP wrapping and RC-jacketing.

As the last step, the *End-of-life phase* includes the transportation from site construction to waste treatment plant and all activities related to recycling, landfill and incineration examined in this specific case study.

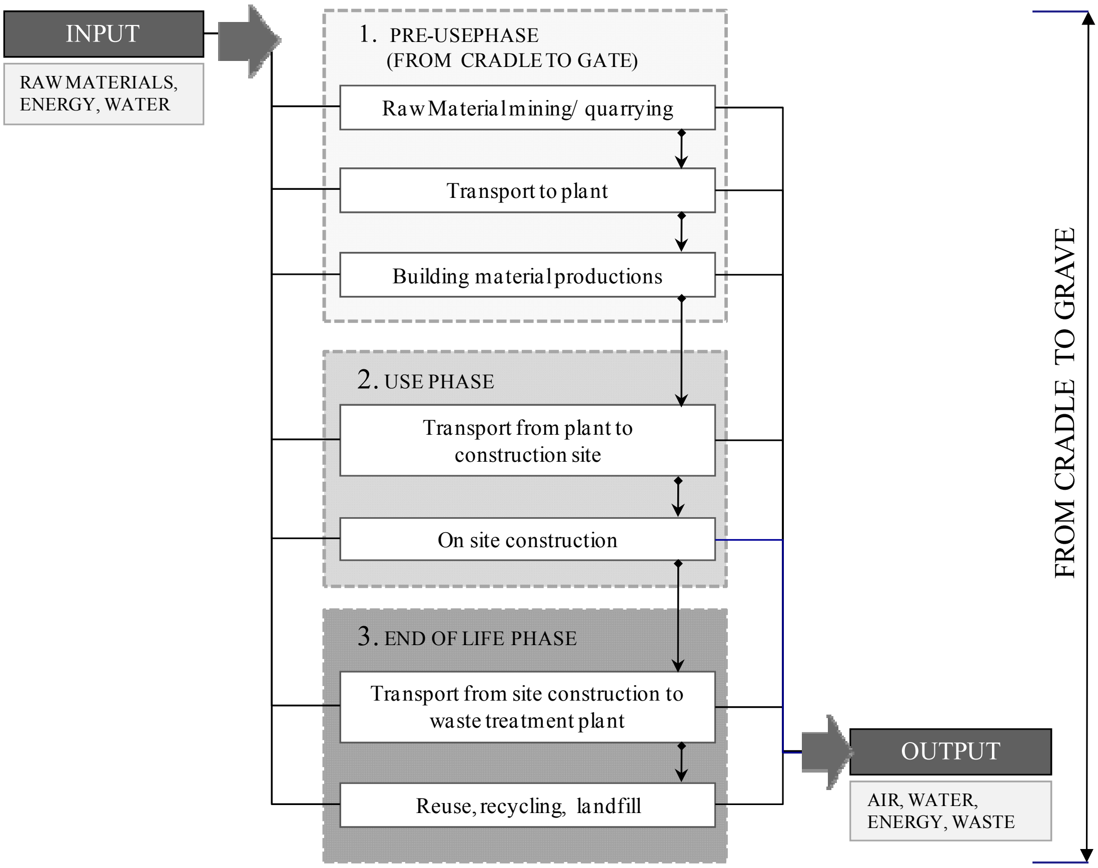

Figure 2. System boundaries

2.3 *Stage 2: Life Cycle Inventory (LCI)*

The input and output processes described into system boundaries must be quantified into the inventory. As a matter of fact, processes represent all activities, procedures and processes that lead to the implementation of each activity in the all stages of the life cycle, in terms of materials or energy. In this case the inventory data includes all the processes necessary to production, installation and waste treatment phases of GFRP wrapping and RC-jacketing.

Data for LCA were modeled from databases included in the SimaPro software package. In particular, the Idemat 2001 and ETH-ESU and Ecoinvent databases was the source for retrofitting materials, the BUWAL 250 database for transport operations, electricity and diesel use. Also inventory data for steel recycling were made available by Ecoinvent system processes used in SimaPro.

An example of inventory is described in Figure 3, in which network diagram shows the processes and materials to install GFRPs:

1. Sealing of the cracks;
2. Cleaning of the substrate;
3. Application of primer;
4. Application of the 1st epoxy resin layer;
5. Installation of the 1st GFRP ply;
6. Application of the 2nd epoxy resin layer;
7. Installation of the 2nd GFRP ply;
8. Application of the last epoxy resin layer.

The flow chart defines also the interaction and score (in Pt or in percentage) of each reported phases.

As far as production and transportation of concrete and cement are concerned, it was assumed that such products were manufactured in existing plants by local producers. Steel reinforcing bars were assumed to be produced according to the average processes that characterise the European steel industry.

About the transportation of retrofitting materials from production plant to construction site, distances to Campedei were calculated assuming that:

- GFRP wrapping and all material used for its installation were produced by MAPEI S.P.A. located in Milan, Italy;
- The materials to install RC-jacketing were produced by different plant; in particular concrete was transported from Vittorio Veneto (Treviso, Italy), steel reinforcing bars from Suzzara (Mantova, Italy).

Cracks checking

Seal the cracks

Application of epoxy resin layer

Installation of GFRP ply

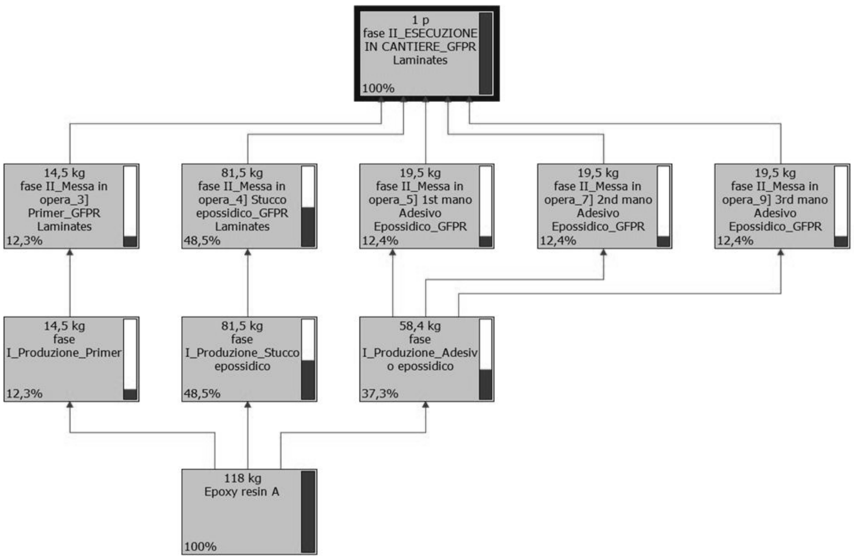

Figure 3. GFRP wrapping installation: example of SimaPro output in which the processes network are showed

For the waste scenario it was supposed that:

- the glass fiber and plastics were incinerated;
- the reinforced steel was recycled and the concrete was land filled.

Concerning the transportation, it was assumed that recycling station, land filing and incineration plant were situated in average at 200 km from the site; i.e. for each ton recycled, 200 km of transportation are accounted for. Track 16 B250 from database BUWAL 250 has been used in SimaPro.

2.4 *Stage 3: Life Cycle Impact Assessment (LCIA)*

Life Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment (SETAC, 1993). The *life-cycle* or *cradle-to-graves* impacts include the extraction of raw materials; the processing, manufacturing, fabrication of the product; the transportation or distribution of the product to the consumer; the use of the product by the consumer; the disposal or recovery of the product after its useful life.

In the present study, the analysis of environmental impacts, derived from the production (*pre-use phase*), installation (*use phase*) and waste treatment (*end of life phase*) of the two retrofitting measures, was carried out using *IPCC 2007 GWP 500* method, included in SimaPro v.7.1.8 software.

This method, developed by the Intergovernmental Panel on Climate Change (IPCC), was characterized by a system of equivalence factors to weigh the various substances as a function of their efficiency as greenhouse gases. In this way it is possible to calculate the so called Global Warming Potential" (GWP), considering the total effect given by the investigated substances in terms of CO_2 emissions. The conversion factors are calculated for three different time horizons: 20, 100 and 500 years.

For example, Table 1 includes conversion factors for 100 and 500 years; we can observe that when time horizon is higher the impact factor is lower, because it was assumed that they have a reaction in the atmosphere with the other components causing degradation and a lower effect.

In this case, environmental impacts are calculated for a climate change factor with a time-frame of 500 years.

Table 1. Characterization factors for greenhouse gases. GWP Potential

Chemical compound	Formula	Conversion factor	
		100 years	500 years
Fossil carbon dioxide	CO_2	1	1
Carbon monoxide	CO	2	2
Nitrous Oxide	N_2O	320	180
Methane	CH_4	25	8
Non-methane volatile organic	NM-COV	25	8

The results of LCA analysis, reported in

Figure 4, show that CO_2 emission produced by GFRP wrapping (1,35 tons CO_2) are higher than those formed by RC jacketing (0,817 tons CO_2): the incineration of glass fiber has an important environmental impact (97,8%).

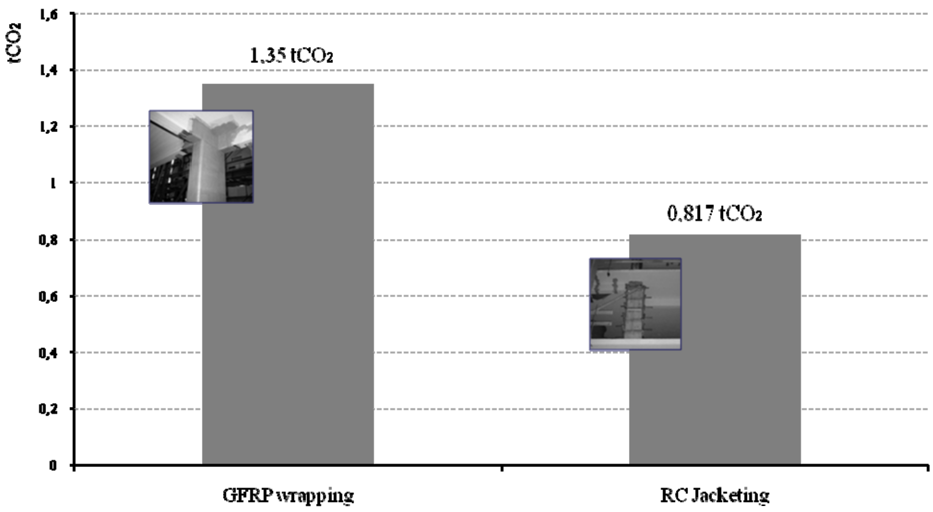

Figure 4. SimaPro output: results of impact assessment using the IPCC 2007 GWP 500a method

2.5 *Stage 4: Life Cycle Interpretation*

The interpretation of an LCA results is not simple: the conclusions and improvement suggestions are often subjective, and this makes it difficult to find and choose the best environmental solution among alternatives in comparison.

For this reason, the present study implements the LCA methodology as a decision support tool for the economic analysis, carried out in previous studies.

As a matter of fact, cost-benefit evaluation showed that none of the rehabilitation measures proved to be economically justifiable (Table 2). In terms of reduction of total expected losses, the GFRP-wrapped solution turned out to be by far the most effective, since the total expected loss was reduced to one fourth of the one of the original structure.

In terms of return of investment, it had to be noticed that none of the rehabilitation strategies had economic justification. However, it had to be recalled that neither possible casualties were accounted for in the analysis, nor the risk of loss of the contents was considered (Negro, Landolfo et al. 2008).

Table 2. Total expected losses and investments in 20 years for the two configurations

	GFRP Wrapped	RC Jacketed
Total Loss (Euro)	9,990	34,211
Investment (Euro)	107,500	39,500

It is clear that environmental results (Paragraph 2.4) are not compatible with cost analysis (expressed in Euro) for the two configurations; therefore, to define a global result, CO_2 emissions are converted in Euro unit, considering the costs of damages and benefits derived from global climate change, the social cost of carbon expressed in terms of future net benefits.

Concern over the impact of anthropogenic carbon emissions on global climate has increased in recent years. The development of environmental themes linked to CO_2 emissions took hold especially when the Kyoto Protocol came into force (16 February 2005) and the European Union Emission Trading System (EU ETS) had become operational.

The EU ETS is the largest multi-national, emissions trading scheme in the world, and is a major pillar of EU climate policy. Under the EU ETS, the governments of the EU Member States agree on national emission caps which have to be approved by the EU commission, allocate allowances to their industrial operators, track and validate the actual emissions in accordance against the relevant assigned amount, and require the allowances to be retired after the end of each year.

Like the Kyoto trading scheme, the EU scheme allows a regulated operator to use carbon credits in the form of Emission Reduction Units (ERU) to comply with its obligations. Thus one EU Allowance Unit of one ton of CO_2, or "EUA", was designed to be identical ("fungible") with the equivalent "Assigned Amount Unit" (AAU) of CO_2 defined under Kyoto. Of course, the Member State's plan can, and should, also take account of emission levels in other sectors not covered by the EU ETS, and address these within its own domestic policies. Unfortunately the approval process of National Allocation Plans (NAP) is long and tortuous.

In 2008, despite an explosion of transactions in June and a record share price at 32,25 Euro per ton of CO_2, the EU ETS showed signs of breathlessness after August. In particular, at the end of 2008 the EUA fell down to around 15 Euro, while in February 2009 the cost of a ton of CO_2 was about 9 Euro (Cretí 2009). Therefore, starting from LCA results (CO_2 emissions produced by GFRP wrapping and RC jacketing) and considering the cost of one ton CO_2, we can combine both values in terms of Euro (Table 3).

Table 3. Cost analysis in terms of CO_2 emissions

Hypothesis of cost	Retrofitting strategies	CO2	CO2
		ton	Euro
	GFRP wrapping	1,350	12,15
1 ton $CO_2 \cong$ 9 Euro	RC jacketing	0,817	7,35
	Differences	0,533	5,15

In this way, summing the *economic costs* and *ecological costs* (Table 4), it is possible to obtain a *global result* and to justify that the GFRP wrapping is the best rehabilitation strategy.

Table 4. Global result of life cycle cost benefit analysis

	GFRP Wrapped	RC Jacketed
Investment (Euro)	107,50	39,50
CO_2 costs (Euro)	12,50	7,35
Total (Euro)	120,00	46,85

3 CONCLUSIONS

A combined approach able to include both monetary terms (costs and associated expected losses) and environmental effects was presented in this paper.

This process was based on LCA methodology used as a decision support tool for cost benefits analysis and was tested in order to compare the two alternative structural solutions (GFRP-wrapping and RC-jacketing) in terms of CO_2 emissions impacts for SPEAR Building.

Starting from previous economic studies and considering the unitary cost of the ton of CO_2 emission, it was possible to identify the best solution between the two retrofitting alternatives by considering both economic and environmental aspects.

It can be concluded that an integrated design is a collaborative process for designing buildings which emphasizes the development of a holistic, multidisciplinary and sustainable design.

4 ACKNOWLEDGEMENTS

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Is the Portuguese Energetic Certification System of Buildings an efficient tool to achieve the sustainability?

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ABSTRACT: This paper analyses the sustainability of the Portuguese Energetic Certification System of Buildings, using a sensible analysis, based on the HEXA building, developed by LiderA. Firstly, it is made a review of sustainability and energy. Then, these concepts are related with the new Portuguese Thermal Regulation. Finally, the sensible analysis is made, using passive and active measures, answering the paper's title question in the last two chapters.

1 INTRODUCTION

During the last century, the world population increased from 1650 to nearly 6000 million and it is still increasing (PPDESA, 1999).

Joining this issue with the rapid growth of the Economy (with a five factor since 1950), based on a massive exploitation of the natural resources and the continuous emissions of GHG (Greenhouse Gases), it is simple to conclude, that Earth is not prepared to receive such pressing, without any consequences (Pinheiro, 2006).

Indeed, according to the Ecological Footprint Atlas, Earth would need 1.3 planets to restore all the resources consumed daily by the Humankind. In Portugal, this problem is even bigger, because it would need more 180 % of its area to achieve the environmental balance (Pinheiro, 2006; Wackernagel & Rees, 1996).

Therefore, in order to reduce this problem, it was assigned the Kyoto Protocol in 1997, with specific reduction targets of the Greenhouse Gases.

With this assignment, the EU proposed itself an 8 % reduction of the GHG between 2008 and 2012 (UN, 1997), so the Community has approved several efficient energetic policies, like the EPBD Directive (Directive 2002/91/EC).

This Directive imposed the use of an energetic certification system for the buildings, in order to reduce their energy consumption, estimated in 40% of the global Community Energy (European Parliament, 2002).

Since Portugal is an EU member, the Laws 78, 79 and 80 of 2006 transposed this Directive to the Portuguese Legislation, creating a new Thermal Regulation.

This paper will discuss if this new regulation applied to the residential sector (RCCTE) is an important step to achieve the sustainability, so the new buildings are able to reduce significantly their consumptions and their emissions, according to the bioclimatic principles.

As the Directive has been recast in 2009, it will be transposed in the future to the Portuguese legislation, so now it is the perfect time to point out some modifications that should be considered in this review.

2 SUSTAINABILTY AND ENERGY

As it was explained in the Introduction, the world has assisted to several Mankind environmental aggressions during the two last centuries. Thus, in 1987 it appears a new concept of development – the sustainable development – “to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987).

Since that date until now, several Authors discussed the means of achieving that objective, and nowadays there are two visions of sustainability, which describe two different ways of acting (Dietz & Neumayer, 2006):

- Weak Sustainability – tries to obtain the optimal use of the income generated from the exploitation of the non-renewable resources, establishing the rules of consumption and the usage of the capital (including the natural capital).
- Strong Sustainability – divides the natural capital in four categories of functions and assumes that natural capital cannot be substituted by other forms of capital. This way, it should be afforded special protection.

To apply these views to the buildings, it could be said that the first one tries to reduce the consumption, comparing the capital invested on its reduction, which should be the same of the natural capital wasted.

The second tries to create a construction that can substitute the exploitation of non-renewable resources, by renewable ones, in order to create carbon neutral solutions, protecting the natural capital. This view also needs an investment on reduction energy parameters.

Introducing these concepts in the EPBD Directive, it is possible to conclude that the 2002/91/EC focused a weak sustainability, as it wanted uniquely to reduce the buildings energy consumption. However, there is an evolution on the EU objectives on the 2009 recast, when there is a firstly reference on carbon neutral buildings, proposing for 2020 some targets for “buildings which both carbon dioxide emissions and primary energy consumption are low or equal to zero” (European Parliament, 2002; European Commission, 2008).

To reduce the environmental impact of the buildings, it is being discussed a new construction paradigm, named as sustainable construction. This philosophy was firstly debated in 1994, and defined by Kibert as “the responsible creation and management of a healthy built environmental, based on the ecological principles and the efficient utilization of the resources”(Pinheiro, 2006; Kibert, 2003).

In fact, when adopting this type of construction, people are thinking of all the life cycle of the building and its energy and resources consumptions. Moreover, it is characterized by (Tirone & Nunes, 2008):

- Less quantifiable parameters:
  - A healthy and a good environmental comfort;
  - A valorization of its natural resources, instead of wasting them;
  - Multifunctional areas nearby the living places;
  - Flexible buildings, that can be changed during its life cycle;
  - Functional architecture.
- Quantifiable parameters:
  - Thermal and acoustic comfort;
  - Less energy consumption (with a neutral tendency) ;
  - Less water demand;
  - Less carbon emissions (with a neutral tendency).

Like it was referred, the reduction of energy and carbon impact is a priority of the sustainable construction, which can be accomplished by two complementary ways, the passive and the active.

The first one deals with the bioclimatic and ecological principles, that when well used together can reduce significantly the thermal energy consumption. Actually, it is estimated that a passive house can reduce nearly 90% of this kind of consumption, when using the maximum of the solar energy, a good solar orientation, solar protections during the summer, an efficient thermal insulation and natural ventilation, a rational use of the thermal inertia and a good usage of the glazing windows (Gonçalves & Brotas, 2007).

The second one could complement the other, reducing the consumption of other sources (using house automation systems and efficient lamps and household electrical equipment) and providing electric energy produced by mechanical renewable systems.

With these two parts working together it is possible to reach neutral carbon and energy buildings. In other words, these are the steps that shall be given towards the buildings strong sustainability.

If it is possible to create neutral constructions, the energy and carbon sustainable building can only be a neutral one. Thus, the next chapters will discuss how the Portuguese Energetic Certification System of Buildings focuses this issue and what information it is giving to the construction market.

3 THE PORTUGUESE ENERGETIC CERTIFICATION SYSTEM OF BUILDINGS

The EPBD Directive was transposed to the Portuguese legislation by the DL 78/2006, creating the Portuguese Energetic Certification System of Buildings (hereafter SCE), supervised by the DGGE and managed by the ADENE. The calculation methodology and the regulations are sent to the DL 79/2006 and DL 80/2006 (Conselho de Ministros, 2006a).

The first one (RSECE) limits the energy consumption (imposing a maximum power of the HVAC systems) and requires minimum parameters for air quality in service buildings (Conselho de Ministros, 2006b).

The DL 80/2006 (RCCTE) is applied to the residential buildings with an area not higher than 1000 m^2, and the service buildings with an area lower than 1000 m^2 or 500 m^2 in case of supermarkets, swimming pools and shopping centers. Otherwise, they are subject of the RSECE (Conselho de Ministros, 2006c).

This last regulation (RCCTE) is the concerning point of this paper. In fact, the common residential buildings are subject of this regulation, that stipulates a maximum consumption of heating energy (winter), cooling energy (summer), energy for heating sanitary waters and primary energy, as a conversion of the last three parts in *kgoe*(hereafter Ni, Nv, Na and Nt respectively).

Known these maximums, the RCCTE points out a calculation methodology to estimate the real consumption of the building, which shall be lower than them in case of new constructions (hereafter Niv, Nvc, Nac and Ntc respectively).

The Nt is the base level for the classification (class B-). When the Ntc is 25% lower, the building is B, 50%– A, 75% or more– A+. The existing buildings do not have to respect the Nt, so they can be C (until 50% more), D (50-100%), E (200-250%), F (250-300%) or G (>300%).

When analyzing the text of RCCTE it is possible to find out some new thermal impositions that can lead to a sustainable construction defined above. Indeed, it divides the country in three winter climatic zones and other three summer climatic zones. In those zones, it imposes maximum U-values for current enclosure elements and maximum solar factor for windows with an area higher than 5% of the serving room.

Moreover, it is written that plain thermal bridges shall be treated, so they cannot have a U-value higher than the double of the U-value of the enclosure element, and they shall respect the legal maximum imposed. This is an important imposition, as it was estimated that the thermal bridges are the responsible for 20 % of the final thermal energy consumption (Valério, 2007).

On the other hand, it is the first regulation that obligates the introduction of 1 m^2/person of solar thermal panels for heating sanitary waters, reducing the energy consumption.

To conclude this review of the regulation, several authors conclude the fact that the calculation methodology is a good estimative, when compared with the results of the usage of simulation tools such as *Energyplus*, *equest* and *VisualDOE* (Silva et al., 2007; Silva, et al. 2009).

This paper will evaluate these parameters of the RCCTE. Therefore, it will conclude if they are adequate to the sustainability principles and for what solutions it is leading to.

4 CASE-STUDY

The last chapter finished with the aim of the analyses developed in this paper – verify if the impositions of the RCCTE are well proposed to achieve a sustainable construction. To accomplish it, this study will be based on a building developed by LiderA Architecture Team – the HEXA Building.

This building appeared from an architecture comparison study of several existing buildings in Lisbon, Oporto and Faro, so it could be similar to the common constructive and architecture practice.

In fact, it does not exist; it is a design from a building type, inserted in a block of houses, also developed by LiderA. This is not a problem because the HEXA aim is not to be constructed, but to test several sustainable measures that could be implemented to improve its environmental perform.

This way, it was chosen a highest floor dwelling with no adjacent building (T3), to consider-er the worst thermal situation. Its design drawing could be seen on the Figure 1, exposed as fol-lows:

Figure 1. Case-study dwelling (it was chosen the left one)

5 SENSIBLE ANALISYS

5.1 *Base HEXA*

Known the architecture, the next step is to define HEXA thermal characteristics, to calculate its energetic consumption. Therefore, it is followed presented the Table 1, which describes the principal parameters considered in the Base HEXA, estimated in order to accomplish the regu-lation minimums:

Table 1. Principal thermal characteristics of the Base HEXA

Characteristic	Description	Value
Location	Lisbon	Zone I1 V2
Altitude	-	h=100 m
External walls	Double brick 0.11+0.15	U=0.96 W/m^{2o}C
Internal concrete walls to Lna	Concrete + 3cm of outside XPS	U=0.86
Roof	Plain gardener roof + 3 cm XPS	U=0.78 W/m^{2o}C
Thermal Inertia	Strong	It=705.34 kg/m^2
Glazing windows (sliding)	Metal frame, double glazing	U=3.1 W/m^{2o}C
Solar orientation	N(kitchen) – S(living room)	-
Ventilation	Natural ventilation (NP 1037-1)	Rph=0.6
Solar panels*	1m^2/person	A=4 m^2 E_{solar} =2527 kWh/ano
Conventional water heating syst.	Gas water-heater	η_a=0.5
Heating system	Electrical resistance	η_i=1.0
Cooling system	Freezer machine (absorption cycle)	η_v=0.8

*It was not directly used the software *Solterm*, but an estimative from on Rodrigues et al.(2009). In this reference it was considered η=0.80, South orientation, no shadow, a 45^o inclination, a losses coefficient equals to 3.8 W/m^{2o}C and a deposit with 200 L (with a losses coefficient equals to 1 W/m^{2o}C).

With these characteristics, the energy needs of the Base HEXA were calculated as follows (Table 2):

Table 2. Energy needs of Base HEXA

Energetic Need	$kWh/m^2.year$	$kgep/m^2.year$
Nic (Ni=58.65 $kWh/m^2.year$)	58.03	1.683
Nvc (Nv=32.00 $kWh/m^2.year$)	6.85	0.218
Nac (Na=37.95 $kWh/m^2.year$)	28.77	2.474
Ntc (Nt=5.94 $kgep/m^2.year$)	93.65	4.405

Consequently, the energetic class of this dwelling is a B class (R=0.742), nearly a B- class.

In the next sub-chapters, it will be studied parametrically some sustainable measures, predicted in the RCCTE, like it was explained previously. This way, there will be compared different thermal insulations, different solar orientations, different window solutions and, finally, the active systems.

At the end, all of the best measures will be summed to see how sustainable the final HEXA is.

5.2 *Thermal insulated HEXA*

During this sensible analysis, there were studied 3+1 different kinds of solutions all of them using XPS. The first one was internal 3 cm insulation, the second 3 cm in the interior of the double wall, the next one external 3 cm insulation.

Finally, as the external insulation has thermal inertia advantages, it was proposed another one – external 6 cm insulation – to conclude about a double thickness increase of the best thermal insulation solution.

To report the obtained values, it is following exposed the Table 3:

Table 3. Energy needs of thermal insulated solutions

Solution	Nic ($kWh/m^2.year$)	Nvc ($kWh/m^2.year$)	Nac ($kWh/m^2.year$)	Ntc ($kgep/m^2.year$)	Energetic Class
Internal 3 cm*	55.20	6.70	28.77	4.32	B
Middle 3 cm	51.06	6.82	28.77	4.20	B
External 3 cm*	50.48	6.95	28.77	4.19	B
External 6cm*;**	45.39	6.62	28.77	4.03	B
Base HEXA	58.03	6.85	28.77	4.41	B

* The external walls are with only one brick 0.22

** The internal concrete walls to Lna are external insulated with 6 cm of XPS

Consequently, the best choice is the external insulation with 6 cm of XPS.

5.3 *HEXA with different solar orientations*

The HEXA base is oriented as N (kitchen) – S (living room). In this paragraph there will be studied other seven orientations, disposed in the Table 4, where K means kitchen and L means living room:

Table 4. Energy needs of different HEXA solar orientations

Solution	Nic (kWh/m^2.year)	Nvc (kWh/m^2.year)	Nac (kWh/m^2.year)	Ntc (kgep/m^2.year)	Energetic Class
S(K) – N(L)	56.53	7.34	28.77	4.38	B
E(K) – W(L)	58.26	10.89	28.77	4.56	B-
E(L) – W(K)	58.26	10.05	28.77	4.53	B-
SE(K) – NW(L)	57.34	9.59	28.77	4.48	B-
SE(L) – NW(K)	58.58	8.98	28.77	4.50	B-
SW(K) – NE(L)	57.34	9.50	28.77	4.48	B-
SW(L) – NE(K)	58.58	9.53	28.77	4.52	B-
Base HEXA	58.03	6.85	28.77	4.41	B

Consequently, the best choice is the S (kitchen) – N (living room).

5.4 *HEXA with different window solutions*

The windows of the Base HEXA are double glazing windows with 6 mm of air spacing, with metal frame. In this point, there will be seen the thermal increases of the air spacing (16 mm), of the thermal cut (metal and 6 mm of air spacing), of the plastic frame (6 mm of air spacing) and, finally, the best solution, that is the plastic frame with 16 mm of air spacing.

These measures can be compared in the Table 5, exposed as follows:

Table 5. Energy needs of different HEXA window solutions

Solution	Nic (kWh/m^2.year)	Nvc (kWh/m^2.year)	Nac (kWh/m^2.year)	Ntc (kgep/m^2.year)	Energetic Class
16 mm of air spc.	57.16	6.97	28.77	4.38	B
Thermal cut	56.30	7.09	28.77	4.36	B
Plastic frame	55.00	7.28	28.77	4.33	B
Best solution	53.71	7.47	28.77	4.30	B
Base HEXA	58.03	6.85	28.77	4.41	B

5.5 *HEXA with some active systems*

During this work, there were studied some active measures like the use of better solar thermal panels (B. s. t. p.), the use of an electrical thermo accumulator with 100 mm of thermal insulation, the use of one heating and cooling pump, the use of a house automation system that can control the indoor temperature and fixing it 0,5^{o}C lower than the RCTTE in the winter, and a photovoltaic panel, producing energy for the fridge.

When using only the RCCTE (the aim of this paper), it was not possible to consider the new indoor temperature, that could reduce the energetic needs. On the other hand, like the photovoltaic panel is not used, neither to prepare sanitary waters, nor to produce heating, it was not possible to consider this energetic gain in the RCCTE. Therefore, the consumptions of these two measures are the same as the Base HEXA.

The other results of this analysis can be seen in the next table (Table 6):

Table 6. Energy needs of different HEXA active measures

Solution	Nic (kWh/m^2.year)	Nvc (kWh/m^2.year)	Nac (kWh/m^2.year)	Ntc (kgeo/m^2.year)	Energetic Class
B. s. t. p.*	58.03	6.85	9.81	2.77	A
Thermo ac.	58.03	6.85	5.54	2.41	A
h. c. pump	58.03	6.85	28.77	2.96	A
Base HEXA	58.03	6.85	28.77	4.41	B

* It was not used the software *Solterm*, so this data is only an estimative, considering that 80 % of the sanitary hot waters are produced by solar thermal systems.

Consequently, the best choice is to use a thermo accumulator with 100 mm of thermal insulation and to use a heating and cooling pump.

5.6 *Final HEXA*

To conclude the sensible analysis, all of the best measures explained above were summed in a sequence of three steps. Firstly, only the passive measures, then, only the active measures, and, finally the Final HEXA, with all the measures. Thus, the final energetic needs are described in the Table 7:

Table 7. Energy needs of the Final HEXA

Solution	Nic (kWh/m^2.year)	Nvc (kWh/m^2.year)	Nac (kWh/m^2.year)	Ntc (kgeo/m^2.year)	Energetic Class
Passive HEXA	39.67	7.82	28.77	3.91	B
Active HEXA	58.03	6.85	5.54	0.96	A+
Final HEXA	39.67	7.82	5.54	0.84	A+
Base HEXA	58.03	6.85	28.77	4.41	B

6 DISCUSSION OF RESULTS

When analyzing the obtained results, it can be concluded that the only use of Active Systems can change a class from a B (nearly a B-) into a class A+. On the other hand, the correct use of a solar orientation, can, also, change the class of the dwelling. In fact, the orientations S(kitchen) – N(Living room) and S(Living room) – N(kitchen) were the only two B classes, all the other ones were B- classes.

Comparing the two S-N solutions, the best thermal regulation solution is obtained when orienting the kitchen to South and the Living Room to North, which is a wrong architecture choice, and also thermal, because the kitchen is the room that produces more heat in the winter.

When comparing the 3 cm XPS thermal insulation, there is a 4.72 kWh/m^{2o}C difference in winter needs between the internal insulation and the external insulation that can be explained with the thermal linear bridges, which are better treated in the second solution, than in the first one. The Nvc are very similar in the four solutions experimented.

Related to the windows analysis, the only use of a better thermal solution (double glazing with 16 mm of air spacing and a plastic frame), reduced the consumption in 0.11 kgeo.

However, is the use of much more efficient active systems that produces a great change in the dwelling's class, either the thermo accumulator, or better solar panels, or a heating and cooling pump, changed the class from B to A.

In order to summary this analysis, the following Figures 2 and 3 describe the evolution of the HEXA building during the study:

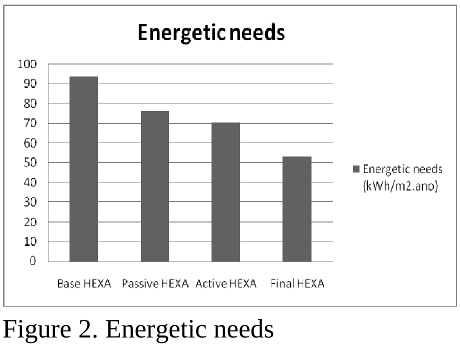

Figure 2. Energetic needs

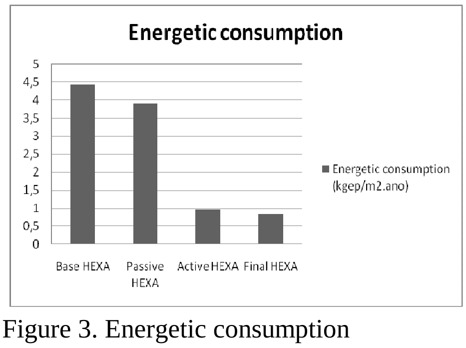

Figure 3. Energetic consumption

7 CONCLUSIONS

In this paper it was made a sensible analysis, testing passive and active parameters, using the HEXA building. Its aim was to conclude if the Portuguese Energetic Certification System of Buildings (SCE) is in fact an efficient tool to achieve the sustainability.

As it was seen in the last chapter, it is possible to have an A+ class, using the thermal minimums imposed (Active HEXA). This way, it is possible to construct without the bioclimatic principles, only using efficient active systems, that the dwelling becomes an A+ class.

On the other hand, the Passive HEXA has a Nic=39.67 kWh/m^2.year and a Nvc=7.82kWh/m^2.year. These values are far from the Passive House Norm, where it is said that is possible to construct a building with a Nic=5.9 kWh/m^2.year and a Nvc=3.7 kWh/m^2.year.

Moreover, when joining it with the active measures, the dwelling has a 0.84 kgep/m^2.year energy consumption, still far from the zero energy consumption and carbon emissions (but much better than the base HEXA – 4.41 kgep/m^2.year).

Therefore, it can be concluded that, in this case, the SCE is achieving a weak sustainability, described in chapter 2, but has to be changed in order to achieve the strong sustainability. In fact, it was described above that it is possible to create a building with nearly zero thermal consumptions (Nvc and Nic), which complemented with efficient active systems can lead to a zero consumption building.

As the strong sustainability was the definition adopted in this paper to describe the buildings sustainability, the SCE does not look for it. However it is a good initial step, because it searches the weak sustainability, so it needs a further modification to seek the next sustainable level.

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Assesment of Hexavalent Chromium stabilization in artificialy contaminated soil using Geosta as a secondary binder

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The aim of this study was to investigate the effect of a secondary binder (Geosta) as a stabilizer on the geotechnical properties of Cr+6 contaminated soils with the use of S/S technology and to evaluate the efficacy of different mix designs via the Static Diffusion Test. Artificial contamination with Cr+6 was applied in four representative samples of soil material, weighting approximately 15 Kg each. The initial chromium concentration per cube was estimated at 128.5 mg/l and all mix designs studied were shown to be capable of reducing hexavalent chromium concentrations from 96 to 99%. The mix design which contained 400 g of Geosta, proved to be the most effective since the lowest release of chromium with maximum chromium retention (99.4%) was documented. Mix designs with 200 and 300 g of Geosta were considered to be successful in Cr+6 immobilization (with a total of 99.1 and 99% retention ability, respectively), however it was proved that the quantity of secondary binder used in a mix design is not proportional to its chromium retention capability.

1 INTRODUCTION

Millions of tons of chromium wastes are discharged from tanning, electroplating, wood treatment, metallurgy and plating industries each year (EPA United States, 2000). Sites adjacent to these industries could be highly contaminated with Hexavalent Chromium and the only reason for that is the improper handling of wastes from these industries. Excess deposits of hexavalent chromium in the fields can impose major risks to human and livestock occupying the surrounding area (Alloway, 1995; Bell, S. & McGillivray 2007). These areas could be identified as areas with a high potential for groundwater contamination since they impose a great risk to potable supplies of the surrounding ecosystem. Hence, there is an emerging need to develop a treatment method to minimize the risk of chromium contaminated land. As such, environmentally motivated remediation efforts have become increasingly relevant to solve this problem.

Treatment techniques such as Solidification and Stabilization (S/S) are becoming increasingly important in the contaminated land sector while they increase awareness of the environmental impact arising from its activities and resulting materials. The principal behind the S/S technology is based on its ability to reduce or even eliminate the mobility of hazardous contaminants -within a hazardous waste stream- while its effectiveness is measured via the application of leaching tests in the final material. Environmentally acceptable S/S materials can also be used for construction purposes such as bricks for pavements, secondary road sub-base systems, car park facilities and many others. What seems to be of high importance prior to the implementation of S/S technology is the treatability study, during which the appropriate binder system is selected. The binder system is site and contaminant specific and is dependent upon the properties of the end products, the nature of the material in use and the specific target values for the desired contaminant (Dermatas and Meng, 2003).

In the current investigation, Geosta was chosen as a secondary stabilization agent and which exists in a powder form. It contains zeolites, alkalis and a mixture of other complex elements in minor concentrations and its chemical composition is shown on Table 1.

Table 1. Chemical composition of Geosta

Chemical Compound	Proportion (%)
NH_4Cl	5
NaCl	20
$FeCl_3$	2
C	1
$MgCl_2$	22
KCl	25
$CaCl_2$	15
Others	10
Total	100

An aqueous solution of Geosta liberates exchangeable ions including K^+, Na^+, Mg^{2+} and Ca^{2+} which through isomorphous substitution replace the R-OH and R-COOH ion groups in organic soils (Omotosho, 2005). When Geosta is used with Portland cement it enhances complete hydration and strength development (Paria *et al,* 2006).

The main aims of this study were to investigate the effect of Geosta as a stabilizer on Cr (VI) artificial contaminated soil with the use of S/S technology and also to evaluate the efficacy of various secondary binder quantities via the Static Diffusion Test (in accordance with the norm EA NEN 7375:2004 protocol).

2 MATERIALS AND METHODS

The experimental program for solidified and stabilized soils consisted of the combination of one primary binder (Portland cement) at stable quantity (5% by dry weight of the soil) and one inorganic secondary binder (Geosta) at 1.3, 2 and 2.6 % (by dry weight of soil).

For the purpose of this study, a known concentration of Chromium Hexavalent (Cr (VI)) (522 mg/kg or 900 mg/l) was prepared in order to artificially contaminate 15 Kg of concrete sand (sandy soil). Solidification of the S/S specimens was achieved by adding Portland cement (type I 35/A) while stabilization of the samples was attempted with the use of a commercially available product (Geosta). Various proportions of Geosta were tested in a total of three admixtures while their stabilization effectiveness (treatment performance) was determined via the Static diffusion test (tank test) and compared versus a cement-based S/S mixture. Table 2 summarizes the mix design of the total 4 admixtures with Geosta being the only variable component.

Table 2. Mix design of each batch

Mixtures	Contained Materials	Proportions
Mix No1 (Control)	Soil	15 Kg
	Portland Cement	750 g (5%)
	Chromium solution	522 mg/kg or 900 mg/l
	Water	1.2 litres
Mix No2	Soil	15 Kg
	Portland Cement	750 g (5%)
	Chromium solution	522 mg/kg or 900 mg/l
	Water	1.2 litres
	Geosta	200 g
Mix No3	Soil	15 Kg
	Portland Cement	750 g (5%)
	Chromium solution	522 mg/kg or 900 mg/l
	Water	1.2 litres
	Geosta	300 g
Mix No4	Soil	15 Kg
	Portland Cement	750 g (5%)
	Chromium solution	522 mg/kg or 900 mg/l
	Water	1.2 litres
	Geosta	400 g

Standard proctor compaction tests were carried out on each composite soil-cement-geosta mixture. Following the production of the S/S material, the compacted soil samples remained in the mould for an additional 24 hours (solidification stage) and then were placed in transparent polyethylene bags in order to reduce/avoid moisture loss.

In total 28 moulds of S/S treated material, were produced (7 moulds for each mix design). Including the duplicates, a total of eight (8) solidified cubes were selected to proceed to the next laboratory stage for the assessment of Cr (VI) leaching behavior. The solidified samples, were immersed in eight (8) different clear plastic containers, with W (mm): 240, H (mm): 180 and L(mm): 290 dimensions, which were filled with distilled water at a Liquid to Solid (L/S) ratio equal to 5. More specific, the volume of each specimen (100x100x100mm) was one (1) litre while the volume of the added distilled water was 5 litres. According to the protocol, the water in each tank needed to be replaced eight times and at specified intervals. The times at which the water had to be replenished were 0.25, 1.0, 2.25, 4.0, 9.0, and 16.0 days. Before, the scheduled replenishments of water, leachant samples were obtained and the pH of the leachant was measured. The samples collected for chemical analysis, were preserved after collection in Envirobottles and at a temperature between 18 and 22^{o}C.

In total 48 samples were collected for further chemical analysis. 12 samples corresponded to each of the four (4) different mix designs, which in their turn represented 6 samples for each selected S/S specimen.The presence of Cr(VI) in each sample was measured by Ultra Violet-visible (UV-Vis) Spectrophotometry. The spectrophotometric approach that was chosen relied on the specific reaction of Cr (VI) with 1.5-diphenylcarbazide (1.5-DPC). The colorimetric method is based on the oxidation of 1.5-DPC to diphenylcarbazone by Cr (VI), leading thus to the formation of a red-violet complex, while its absorbance is measured through UV/Vis spectrophotometry. When the reaction is performed in alkaline solution, Cr (VI) partially reacts with 1.5-DPC and a red color solution is produced. However, as the pH solution becomes lower, Cr (VI) is more inclined to oxidize another substance (Bone *et al*, 2004) and for this reason fully oxidation of 1.5-DPC is achieved only in acidic solutions where the red-violet color is produced. For this reason samples were acidified with H_2SO_4 (pH~1) prior further analysis. This method measures only the presence of diphenylcarbazone complex (and therefore, Cr^{+6} concentrations**)** and conversion of trivalent to hexavalent chromium was not required.

3 RESULTS AND DISCUSSION

As part of the test procedure, pH, Cr (VI) concentration, Geosta variability and time cycles are compared and further discussed. The results of leaching tests are accompanied by table and figure presentations in order to interpret information in a quick and easy manner. For identification purposes, samples that were tested for their leaching behavior were labeled as shown on Table 3, and they will be referred as such throughout this section.

Table 3. Sample labeling

Mixtures	**Sample Identification***
Mix No1 (No GEOSTA present)	B_1S_1
	B_1S_2
Mix No2 (200g of Geosta)	B_2S_1
	B_2S_2
Mix No3 (300g of Geosta)	B_3S_1
	B_3S_2
Mix No4 (400g of Geosta)	B_4S_1
	B_4S_2

3.1 *pH variation*

The pH values in the static diffusion test in Table 4 show that there is not a considerable difference between the samples. The average pH values of the leachant throughout the tank test ranges between 10.7 and 11.7, presenting thus, much greater values than the initial pH of the distilled water (pH~7). Mix design parameters seem to not have any effect upon pH variation among the samples and the small differences in pH values could be attributed to the pore structure of the material surface.

Table 4**.** Average pH values between 0.25 and 16 days.

Sample	**Average pH**
B_1S_1	10.8
B_1S_2	11.7
B_2S_1	11.4
B_2S_2	10.7
B_3S_1	11.2
B_3S_2	11.3
B_4S_1	11.2
B_4S_2	11.2

3.2 *Hexavalent Chromium*

The leaching characteristics of hexavalent chromium in the static diffusion test are very similar, between samples of the same group, in terms of the metal release versus time (Table 5).

Table 5. Chromium Hexavalent concentrations (mg/l).

GROUP	**Sample**	**Days**					
		0.25	**1**	**2.25**	**4**	**9**	**16**
B_1	B_1S_1	0.179	0.473	0.754	0.599	0.701	1.266
	B_1S_2	0.762	0.274	0.725	0.701	1.447	0.968
B_2	B_2S_1	0.156	0.237	0.241	0.147	0.269	0.174
	B_2S_2	0.145	0.217	0.427	0.158	0.371	0.145
B_3	B_3S_1	0.154	0.473	0.096	0.099	0.226	0.176
	B_3S_2	0.244	0.154	0.127	0.088	0.172	0.194
B_4	B_4S_1	0.296	0.122	0.066	0.079	0.072	0.118
	B_4S_2	0.439	0.127	0.09	0.057	0.109	0.099

It is evident that the samples of group B_4 showed a greater effectiveness in chromium immobilization than the other three groups since they contained higher concentrations of hexavalent chromium within their matrix. B_4 samples demonstrated a uniform chromium release throughout the whole leaching procedure this could be taken as an evidence of almost identical preparation and curing conditions (Figure 1).

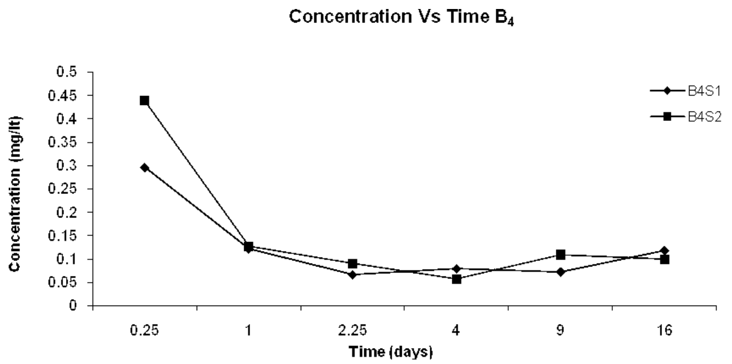

Figure 1. Relation between the amount of leached hexavalent chromium (mg/l) and test duration (days), in Group B_4

The fact that group B_4 showed an intense leaching status at the beginning of the test, followed by drastic chromium retention around the values of 0.1 mg/l can also be used as proof for the above statement. The initial increased presence of hexavalent chromium in the water could be attributed to either carbonation of the specimens or premature zeolite crystallization. The latter however, seems to be more probable since the quantity of Geosta contained within these specimens was greater than that of the B_2 and B_3 groups, for this reason it needed more time to reach full hydration. Portland cement requires 28 days (Bone *et al,* 2004) of curing in order to reach full hydration while Geosta 90 days. While curing time seemed to have affected the B_4 group specimens, it was also evident that even a partial hydration (after 1.25 days of contact with the hydrating agent) of the Geosta powder was capable of immobilizing and "locking" the hexavalent chromium within its zeolite matrix. The overall performance of B_4 specimens in chromium retention can be seen in figure 2, which shows the accumulative leaching for all eight samples.

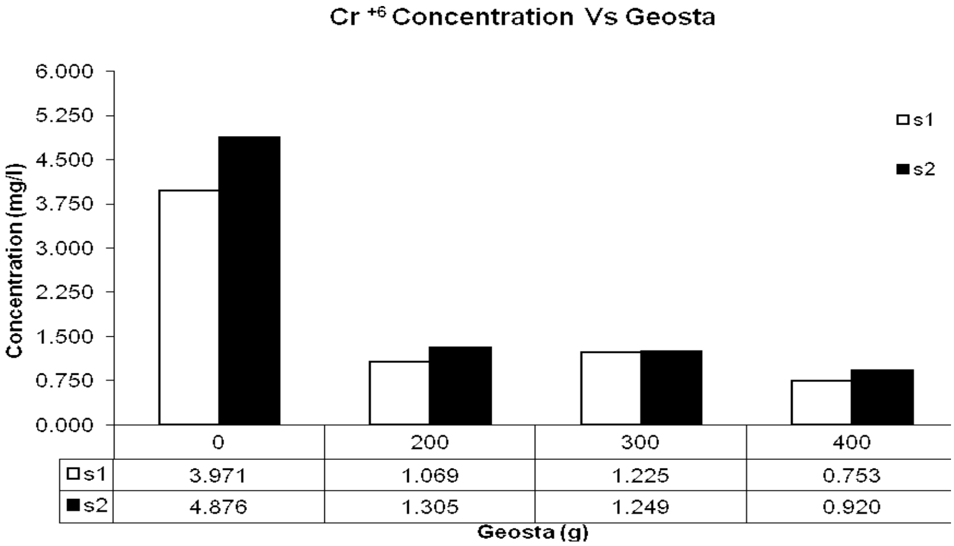

Figure 2. Total Hexavalent chromium concentration versus Geosta quantity

Since Group B_4 maintained the overall chromium leaching level below 1 mg/l it can be argued that it achieved optimum performance in chromium retention. However, all four (4) mixture designs managed to retain chromium contamination within the overall study quantitative target of 25mg/kg Cr+6 (ICRL, 1987) while the most effective mixture was proved to be the one with 400g of Geosta.

Taking into consideration the almost identical leaching behavior of the B_3S_1 and B_3S_2 samples we can assume that faults during the material preparation were kept to a minimum. Furthermore study of Figure 3 which demonstrates the average daily leaching rate (ADLR) per each sample can support the above statement. The ADLR was calculated by dividing the accumulative chromium concentrations of each sample, with the total duration (in days) of the leaching test. What was observed was that B_3 samples exhibited an identical ADLR while B_2 and B_4 samples showed a small variation (between 0.05 and 0.07 mg/l/day). B_1 group samples on the other hand, show a much greater deviation of 0.028 mg/l/day. Therefore, it could be argued that sample preparation and material density could play an influential role in the leaching behavior of S/S products. It is important to mention that ADLR values represent the chromium leakage rate only within the specified period of the test, since they do not reflect field conditions. The leaching rate of S/S field materials depends on more complicated mechanisms such as weathering and temperature therefore any data regarding ADLR values should be taken cautiously into consideration (Van Der Sloot, 1997).

As it has been stated previously, the leaching characteristics of groups B_2 and B_3 can be considered an unexpected finding. Figure 3 demonstrates that the overall leaching performance of sample B_2S_1 proved to be more effective in chromium retention than samples B_3S_1 and B_3S_2. A possible explanation behind this result could lie within the sample preparation procedure, the carbonation effect, the correct performance of the leaching test or even the treatment period of the samples. For this reason, interpretation of the results for B_2 and B_3 groups should be made with caution since it requires further experimentation for the acquisition of a solid conclusion.

In general, it cannot be assured that the overall effectiveness in chromium retention by the four (4) different mixture designs will be maintained when applying different test conditions. Different test conditions may have implications on the surface area of S/S samples, leachant characteristics, L/S ratio and/or pre-treatment of samples (Bone *et al*, 2004). Therefore, it needs to be stated that the results presented in this thesis are only valid for the specific conditions on which the methods (S/S and leaching test) were performed.

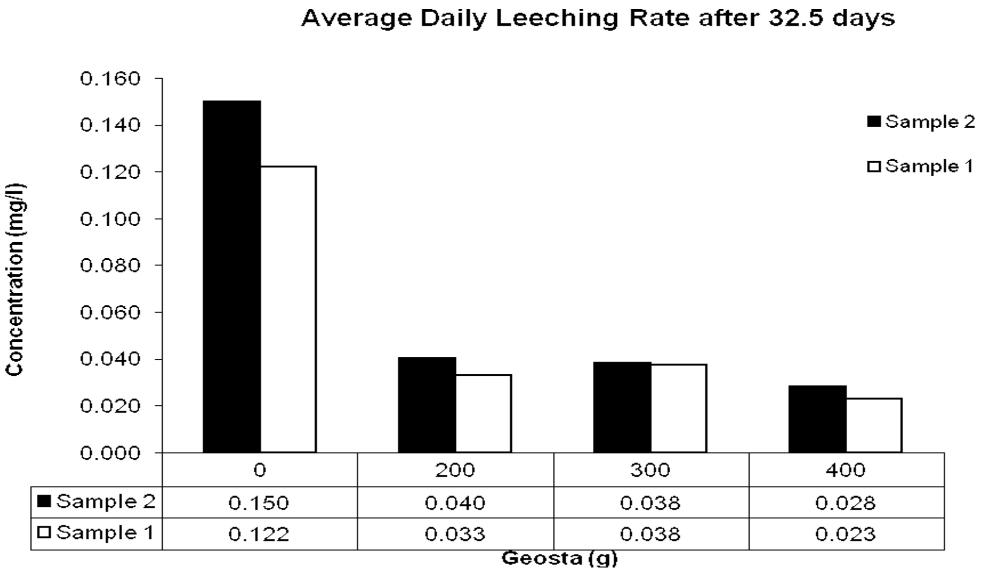

Figure 3. Average daily leaching rate per each sample versus Geosta quantity.

4 CONCLUSION

S/S treatment is a very effective method in reducing potential hexavalent chromium leakage and it would be applicable primarily to sites where the principal risks concern humans and surrounding ecosystems. S/S treatment could be defined as a low-tech technology and it seems to be applicable were relatively fine to granular materials are to be treated.

All mix designs studied in this project have shown to be capable of reducing hexavalent chromium concentrations by up to 99%. B_1 mix design is the least effective when compared to the other three designs since it shows the largest release of chromium in both of its samples. On the other hand, B_4 mixture is the most effective, presenting the lowest release of chromium amount and a maximum performance of 99.4% chromium retention.

Mix designs B_2 and B_3 were considered to be successful in hexavalent chromium immobilization with a total of 99.1 and 99.0 retention ability, respectively. It was initially expected that the quantity of secondary binder would be proportional to its chromium retention capability. However, the tank leaching method revealed that both B_3 samples demonstrated lower chromium "fixation" in comparison to B_2S_1. The weaker performance of B_2S_2 could indicate faults during the preparation and/or leaching procedure and for this reason a cautious approach is essential during the analysis of the obtained results.

Although pH variations tend to be one of the most important parameters that control leaching behavior of S/S materials, in the present study pH variations were not observed. The presence of the binders (Portland cement and Geosta) in the mix designs were considered responsible for the presence of the high alkaline pH environment. It is believed that the alkaline environment favored or accelerated the crystallization of the zeolite matrix of Geosta.

Geosta binder systems can be considered as effective stabilizing agents in S/S treatment. In laboratory conditions, the combination of 750g of Portland cement and 400g of Geosta was proven to be the most effective mix design regarding chromium retention. This observation however was noted in comparison with the other three (3) mixtures. The addition of 200g and 300g of Geosta was found to be less effective when compared to that of 400g.

Faults during the preparation, leaching assessment and chemical analysis of the samples, could affect their behavior and alter their physical and chemical properties. Regarding the sample preparation procedure, these faults could be related to inappropriate compaction, ineffective plastic bag sealing, unintentional plastic bag damage during material transportation, incorrect sample storage temperature and/or short curing period. In relation to the tank leaching test, errors might have occurred during water replenishments lading to prolonged contact of the sample with atmospheric CO_2 (carbonation effect). The case of leachant aeration by an unintentional container lid removal could also be considered, although it is unlikely. Finally, in relation to sample chemical analysis, the prolonged preservation of the samples could lead to pH alterations, which in their turn could result in changes in the relative concentrations of the oxidation states of chromium.

Hexavalent chromium was successfully incorporated within the C-S-H matrix of Portland cement and the addition of Geosta powder in the mixture designs, demonstrated a further incorporation of hexavalent chromium in the zeolite crystals of Geosta.

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Selecting insulating building materials trough an assessment tool

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ABSTRACT: Buildings are responsible for a large consumption of energy and the most significant part is consumed for heating and cooling. There is an increasing awareness regarding the financial and ecological benefits that building environmental assessment tools offer to the construction industry.
This paper presents an environmental and economical evaluation and comparison of different exterior thermal insulation focusing on the insulation materials selection. An assessment tool was applied to a traditional insulated cavity brick wall and to the External Thermal Insulation Composite Systems (ETICS) using different insulating materials (natural and synthetic). Using a specific evaluation method the influence of the thermal insulation material choice was assessed regarding the heating energy consumption, the environmental impact and the main cost or benefit in the different wall systems. The result, in the form of a score system, enables to perform a more adequate comparison and selection of building insulating materials.
This study intends not only to assess the environmental impact of different insulating materials, but also analyze the impact of choosing natural materials.

1 INTRODUCTION

Increasing awareness of the environmental consequences for human activities triggered a growing concern about the availability of natural resources and the future of our planet. The decrease of fossil fuel reserves and the effects on world climate as a result of global warming acted as an instigator for a discussion that began in the 90's and continued until our days. Many definitions of sustainable development have emerged in the literature but the most commonly used is the one that result from the United Nations report Agenda 21: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [Bourdeau, 1999].

The built environment, as a consequence of heating, cooling and lightning necessities, represents an important part of the global energy intake. The energy demanded for heat, cool and ventilation is defined as operational energy, the energy required to produce building materials and components (raw materials extraction, transport and manufacture) is designated as embodied energy [Paulsen, 2001]. The energy demand depends on how well the building is insulated and a proper selection of the insulation material can be crucial in reducing the operational costs. It is possible to build a more sustainable and cost-effective manner by reducing the environmental loads. Establishing a set of universal criteria that remain applicable for the most commonly used building materials is still one of the great challenges in this field of research. Select insulation materials turn out to be a complex task and to support the decision process, numerous assessment tools have been developed [Papadopoulos, 2007].

Based on the review of several life cycle assessment methods, it is possible to specify a set of principles for the sustainable selection of construction materials and products [Lucas, 2008]:

- Improvement of energy efficiency –products that contribute to reduce the operational energy in buildings
- Low embodied energy – low processed or natural materials have lower embodied energy (cork is an example of a natural material suitable as a wall insulation product)
- High durability and low maintenance demand – selecting materials that become obsoletes in a short term increases the costs and generate more waste
- Salvage materials –in the deconstruction process a considerable amount of materials are dismantled, some of them can be recovered and used in new constructions avoiding the consumption of new materials
- Materials derived from renewable resources – prevents the depletion of natural resources like fossil fuel reserves
- Recycled and recyclable materials – materials totally or partially produced with post-consumer components can reduce the extraction of raw materials
- Safety for the human health - materials with low emission of hazardous materials
- Safety for the environment – high emission materials cause the ozone layer depletion contributing to the global warming
- Local production – through preferring locally produced materials it is possible to diminish the cost and the environmental pollution associated to their transport and, at the same time, act as a stimulus for the local economy

These criteria combined with the use of assessment or classification tools can determine the sustainability and environmental impacts of the materials selection for a given project. These assessment tools can cover a wide range of systems, starting from life cycle analysis of building materials to a more comprehensive classification system of buildings [Kibert, 2007].
Table 1 describes some common classification systems and life cycle analysis methods for building products and systems [Ding, 2008].

Table 1 - Sustainability assessment tools for building products [Lucas, 2008, Diogenes, 2006]

	ATHENA	ECOQUANTUM	BEES	SimaPro	MARS-H
Country	Canada	Netherlands	U.S.A.	Netherlands	Portugal
Target	Promote strategies for materials selection concerning the environmental impacts	Life cycle analysis for building products and materials	Decision framework for a wide range of materials	Life cycle tool for industrial processes and products	Evaluation tool based on social, economic and environmental parameters, allowing a life cycle cost analysis

These tools can provide an objective evaluation of resources use, ecological loadings and performance, allowing a more accurate comparison of different building systems and materials. It is possible to consider aspects like the extraction of raw materials, the embodied energy or the operational performance of building materials. This leads to a more conscientious choice of building materials improving the social, economic and environmental indicators of sustainability. Nevertheless, one must always take into account the databases of these tools and there adequacy to the region where the application is performed, otherwise selection can be mislead.
In some specific scenarios, where a particular building system or material is being evaluated, a specially designed classification and evaluation method need to be applied. The tool MARS-H stands as an example for a sustainability evaluation method where several building solutions can be compared regarding a set of parameters divided in three dimensions [Mateus, 2009]:

- Environmental dimension – environmental load for local and global environment,
- Social dimension– impacts in local society,
- Economic dimension – cost/benefit appraisal considering the materials life cycle.

These three dimensions are divided in major categories and for each one several sustainability indicators are considered and classified according to a specific quantification system. The aggregation of parameters determined by a weighting method delivers the final score for each building solution [Mateus, 2009].

This study focuses on the environmental and economical payback of alternative insulation materials (natural and synthetic) in two distinct wall systems. The insulation material selection undertakes an important role in sustainable construction. An accurate choice, due to the high energy saving potential, has a strong impact reducing the environmental loads and the operational costs throughout the building life cycle.

There are numerous benefits for using thermal insulation in buildings, such as [Papadopoulos, 2007]:

- Energy savings: reducing the reliance on electricity to maintain thermal comfort therefore conserving energy and natural resources.
- Environmental gains: reducing the use of mechanical appliances for air conditioning results in lower pollutants emissions.
- Economic advantages: from operational cost reduction and initial investment attenuation due to reduced HVAC equipment size.
- Higher market value: decreasing costumer costs and improving building comfort conditions.

Most commonly used thermal insulation materials falls into one of the subsequent basic types:

- Organic materials: polystyrene, polyethylene, polyurethane, cork, wood and cotton.
- Inorganic materials: fiberglass, mineral wool, slag wool, vermiculite and perlite.
- Reflective membranes: aluminum foil and ceramic coatings.

The selection of insulation materials requires a multiple criteria approach taking into consideration [Al-Homoud, 2005]:

- Exterior environmental and health effects – contribution to global warming, acidification, eutrophication, ozone formation and waste handling.
- Energy consumption – incorporated energy that includes consumption from fossil fuels and renewable sources.
- Applicability – materials performance considering thermal conductivity, thickness, etc.
- Cost factor – cost as a function of the aforementioned parameters.

2 ASSESSMENT METHODOLOGY

Apart from these advantages for the use of insulation materials, their application entails environmental consequences and implies costs that must be considered and evaluated. In this work, the methodology MARS-H was chosen as an evaluation tool because it represents an effort of adaptation to local conditions and solutions [Mateus, 2009]. Although this method is used for buildings assessment, it provides with proper adjustments, a reliable evaluation for constructive systems and materials. Furthermore the evaluation does not focus only on the environmental consequences. A comprehensive analysis allows relating this dimension with the social and economic impacts; hence, it is possible a more accurate selection grounded not only on those concerns.

The evaluation process is divided into three stages. In the first phase, for each indicator, the level of performance is measured. Later, after grouping the indicators by each category (environmental, social and economic) the level of sustainability is quantified. The quantification of parameters was done using the MARS-H evaluation guide and the materials database [Mateus, 2009]. All parameters are subject to a normalization process that allows an appropriate comparison with the performance reference and a proper aggregation of indicators. The described methodology is based on a weighting system that aggregates the selected indicators delivering a performance overview of each studied solution [Mateus, 2009].

This work specifically aims to compare an External Thermal Insulation Composite System (ETICS) and a traditional insulated cavity brick wall, using in both options two different materials, extruded polystyrene (XPS) and agglomerated cork. Simply stated, a cavity wall consists in a double pane of 15 cm brick separated by a 4 cm width cavity with insulation material inside (figure 1). The ETICS system (figure 2) is based on a single 22 cm brick wall with a 5 cm thermal insulation panel on the exterior. Both walls have a 2 cm finishing coating [Lucas, 2008].

For the evaluation of the environmental parameters, the effects on the quality of the outdoor environment, the embodied energy and the recycled content of the selected materials were considered. In assessing the solutions performance the initial investment was considered. Since the evaluation concerns constructive solutions and not a building project, some parameters of the MARS-H tool were not considered. For that reason the indicators aggregation and the final grade are based only on the evaluated parameters, resulting in a comparative performance analysis.

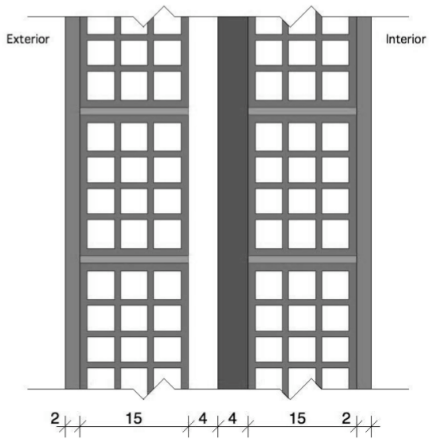

Figure 1 - Schematic representation of the double wall

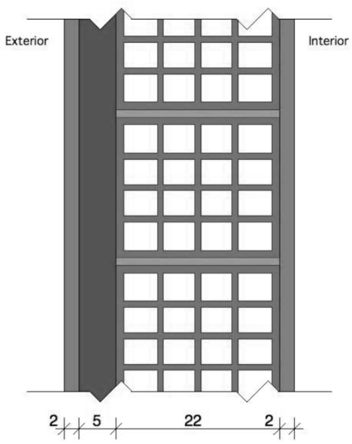

Figure 2 - Schematic representation of the ETICS wall system

3 RESULTS AND DISCUSSION

For the accounting of environmental impacts the following categories of MARS-H methodology were considered: global warming potential (GWP), ozone layer depletion (ODP), acidification potential (AP), photochemical oxidation potential (OPAP) and eutrophication potential (EP) [Mateus, 2009]. These categories were normalized and aggregated and the resulting graph is shown in Figure 3. Using the same database, the embodied energy for every constructive solution was evaluated and the result is presented in figure 4. The analysis of Figure 3 and 4 allow concluding that the best environmental performance is that of the ETICS wall system with cork based insulation. In fact, the use of cork as a thermal insulation option helps to reduce the environmental impact in both wall types. It is clear that, even in the double wall system, the selection of a natural material will improve the environmental performance.

To sum up, considering the environmental loads and embodied energy, the solution that presents the best result is the ETICS wall insulated with agglomerated cork.

The assessment of economic performance was determined based on the initial cost of each solution (figure 5). The ETICS wall implies a higher initial investment compared to the traditional double wall and since the agglomerated cork is more expensive, the use of this insulation material contributes to increase the initial investment in both construction systems. However, massive production of cork for this kind of application could contribute for a reduction on this product price and general decrease for this insulation solution.

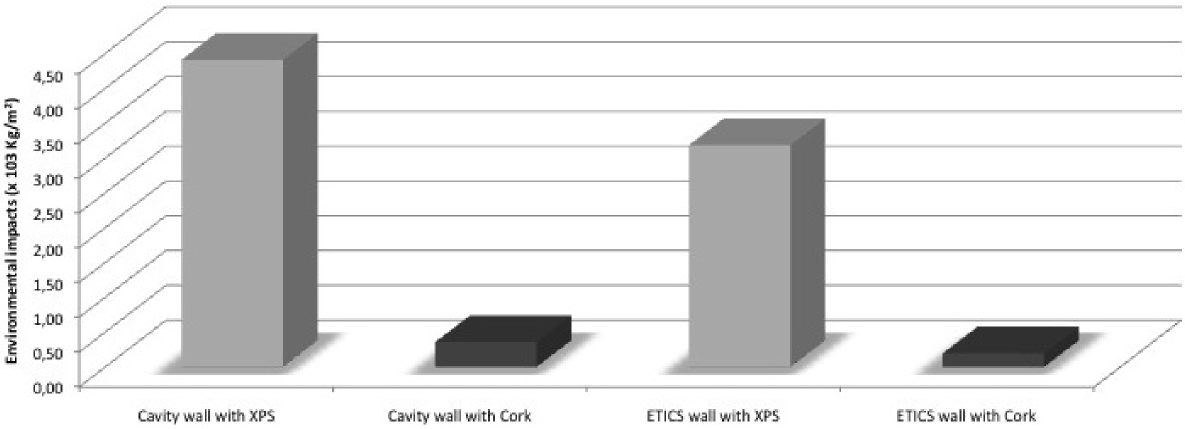

Figure 3. Environmental impact for each of the solutions under study (grey bars – walls with and without ETICS with XPS as insulating material; black bars – same as previous but with cork as insulating material)

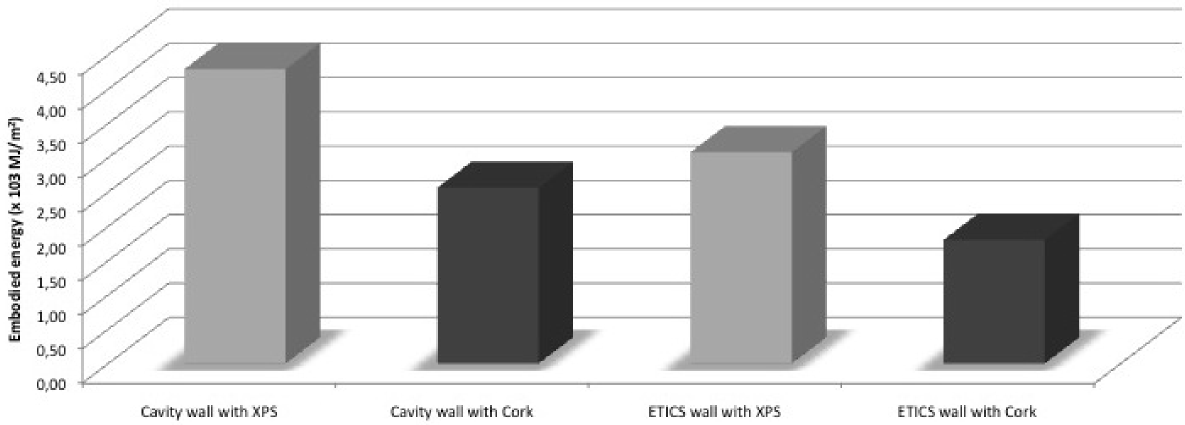

Figure 4. Embodied energy for each constructive solution (grey bars – walls with and without ETICS with XPS as insulating material; black bars – same as previous but with cork as insulating material).

The assessment of economic performance was determined based on the initial cost of each solution (figure 5). The ETICS wall implies a higher initial investment compared to the traditional double wall and since the agglomerated cork is more expensive, the use of this insulation material contributes to increase the initial investment in both construction systems. However, massive production of cork for this kind of application could contribute for a reduction on this product price and general decrease for this insulation solution.

After evaluating the different dimensions, these are aggregated following a weighting system that assesses the level of sustainability for each solution considered in this study. According to the study leading to the MARS-H evaluation system [Mateus, 2009], the environmental dimension was given a weight of 40% and to the economic a weight of 30%. In this work the same weights were adopted. The evaluation of the social dimension would only be possible in a complete building project, for that reason, this dimension was not considered in this study.

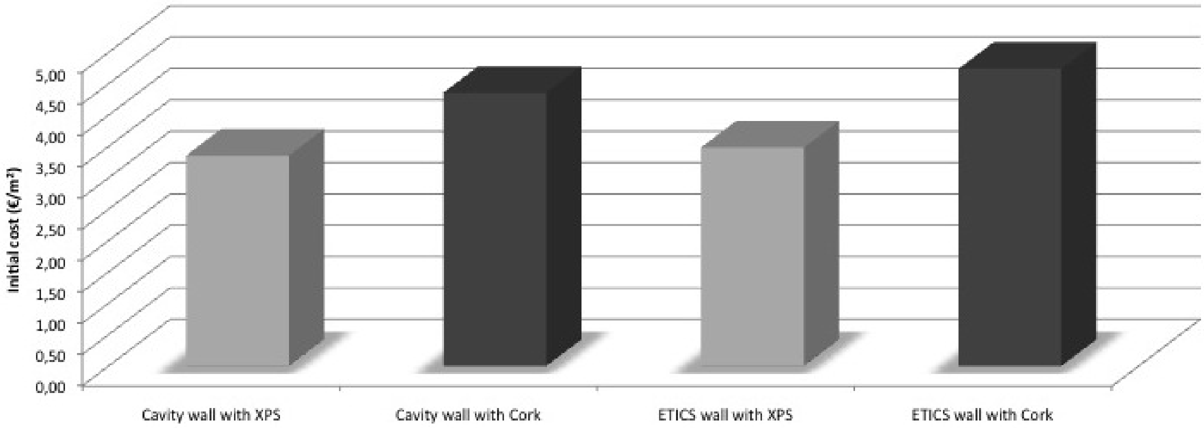

Figure 5. Initial cost for each wall system (grey bars – walls with and without ETICS with XPS as insulating material; black bars – same as previous but with cork as insulating material)

The global performance on the environmental and economic dimensions, considered in this study, is presented in Figure 6 in a form of final classification for the different constructive solutions considered. Despite the higher initial price, when the parameters are aggregated in the final classification, the choice for insulation with agglomerated cork always presents a superior sustainability level regardless the wall system.

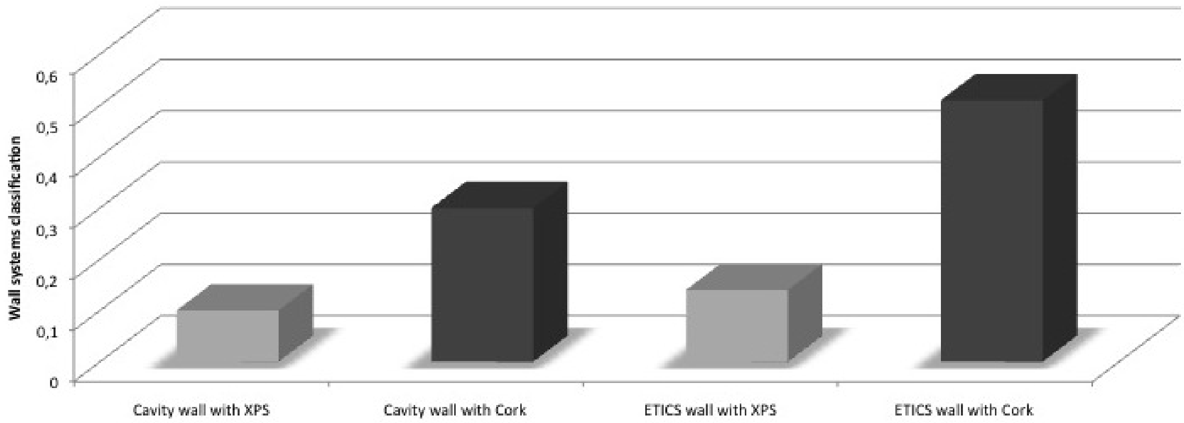

Figure 6. Global classification of the constructive solutions (grey bars – walls with and without ETICS with XPS as insulating material; black bars – same as previous but with cork as insulating material)

Hence, the ETICS wall with cork achieved the best global result, concluding that after evaluation of the environmental benefits, the embodied energy and the initial investment, this solution turn out to be the most suitable.

4 CONCLUSIONS

The materials selection process is a crucial stage for planning sustainable and long-term affordable buildings. The use of a proper assessment tool can be a powerful resource for builders and designers, sustaining the decision process and supporting an assertive choice. The MARS-H methodology as proven to be such a tool, allowing not only sustainable buildings classification, but also materials evaluation for different constructive solutions which provides important complementary information for the design process.

The results indicate that the ETICS system is a better solution regardless the insulation material chosen. The use of natural materials in the insulation of buildings contributes to an equal thermal comfort while improving its overall performance. Despite the fact that the agglomerated cork involves nowadays a higher initial investment, this material presents great environmental advantages since it is a natural material derived from renewable sources. This is a natural material very abundant in Portugal, thus its use also contributes to promote local economy, with a positive social impact in local communities. The economic benefits of using natural materials should not be considered taking into account only its initial cost. It must be looked as an investment with a long-term payback, including protection of fossil fuel reserves, higher durability and lower emissions.

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Bioclimatic interventions in the refurbishment of educational buildings

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ABSTRACT: The aim of this paper is to investigate ways to intervene in the shells of subordinate existing buildings, in order to improve their bioclimatic behavior and take advantage of environmental conditions. The case study involves a building of the A.T.E.I. of Patrai, Greece. The analysis of the present condition shows that the building's thermal behavior and the prevailing thermal and visual comfort conditions are not acceptable. The thermal analysis indicates that several changes in the shell are impending. The creation of an atrium space is suggested in order to improve daylighting and ventilation. Shading problems which emerged from the analysis can be dealt with the fitting of appropriate, external louvers. It is concluded that the addition of passive systems to an existing shell, is possible. The principles of bioclimatic design are applied as well as the users appreciate the acquired advantages and contribute to its right use.

1 INTRODUCTION

Public buildings in Greece often exhibit high energy-consumption patterns. This also applies to educational buildings of all levels and is, in most cases, directly related to several parameters in their design and construction, in addition to obsolete maintenance and control features. Besides excessive use of conventional energy sources for heating, cooling and lighting and the resulting environmental impact, such parameters can also have considerable influence on the comfort and well-being of people who work in these buildings. (Triantis, et al., 2006)

The present study focuses on educational buildings, because of their ability to function as means of education of their students, and the general public, on issues of energy conservation and environmental protection, in order to investigate the possibilities and the means of intervention within the scope of bioclimatic design. These interventions aim at improving thermal and visual comfort conditions, as well as the overall environmental performance of the building. A building of the Technological Educational Institute (A.T.E.I.) of Patrai is chosen as a case-study, because it was not initially designed as an educational building, but accommodates this function since 2001.

2 METHODOLOGY

The applied methodology involves two distinct parts. First, the present state is analyzed through the calculation of the thermal properties of the building shell, the analysis of insulation and shading conditions and a questionnaire study. Following the analysis, retrofitting interventions are proposed in order to address and remedy the most pressing problems that were pointed out by the analysis of the present state. Proposals include the shading systems that can be fitted to the existing shell in order to improve its bioclimatic behavior in terms of thermal and visual comfort conditions and other interventions. These are evaluated in terms of energy conservation and internal conditions improvement, as well as in terms of architectural modification of the form of the existing building.

3 BUILDING ANALYSIS

3.1 Description of the building

The building is constructed on four floors of an almost rectangular plan, without a main axis or orientation and without any differentiation of the exteriors (Fig.1a, b).

Figure 1. a. Southeast view b. Northwest view

The floors are typical, covering 965,00m^2 each. It was constructed in 1975 to be a clothes factory. With the modifications made for the change of usage, the offices and the classrooms were placed on the perimeter of all floors, while students' assembly areas were placed centrally. The premises enjoy daylighting and ventilation only on the 1st and 2nd floor (fig. 2a, b, c). The clear space of the building is paved with cement without any shaping. There is total absence of green or water. Conventional materials have been used for the construction of the building, i.e. reinforced concrete, internal walling from bricks or floating screeds and aluminum frames.

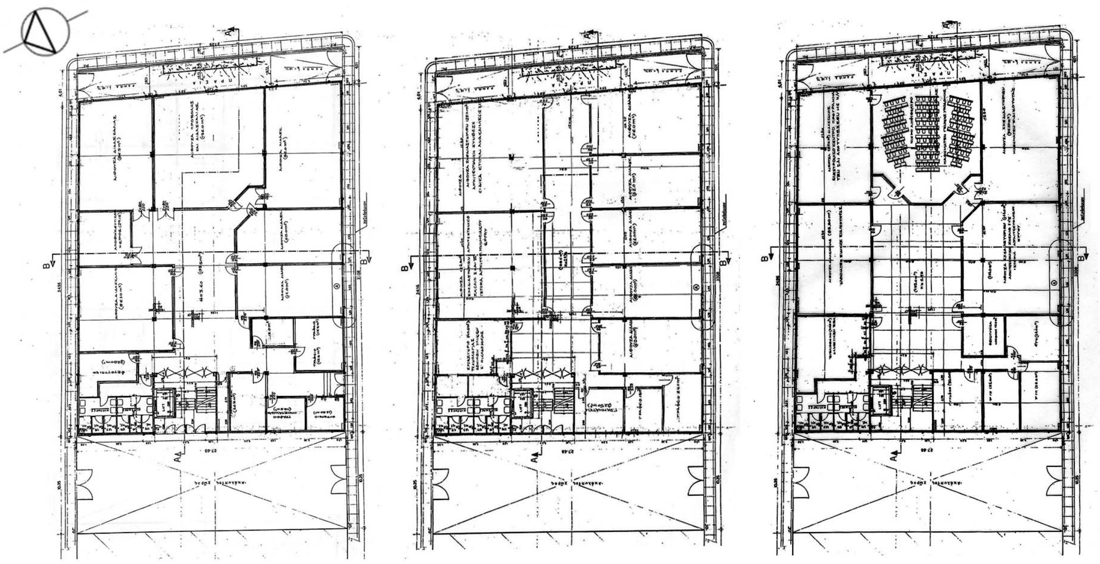

Figure 2. a. ground floor plan b. 1st και 2nd floor plan c. 3rd floor plan

3.2 Thermal analysis

The analysis was conducted according to the Greek Regulations of Thermal Insulation (ΦΕΚ 362/4-7-79) as well as the Ministry of Public Constructions Instructions regarding Thermal insulation (19/9/78 Α.Π. 26354/476). Following in table 1 are the rates of K (thermal properties factor) of each construction element of the building.

Table 1. Thermal Properties Factor of the construction elements of the building.

	External walling	Columns - Beams	Ceiling	Flooring
K (Kcal/m^{2}hc)	3,286	3,004	3,004	2,877
K (W/m^{2}κ)	2,825	2,582	1,825	2,473

The average thermal properties factor Km for the building is:
Km=3,096>0,962kcal/m^{2}hc (permitted) ή Km=2,662>0,827w/m^{2}κ (permitted).
We conclude that the building does not respond to the requirements of thermal insulation set by the Regulation.

3.3 Daylighting analysis

3.3.1 *Managing daylight*

The building meets the standards of Construction Regulation (article 354) regarding daylighting - ventilation sufficiency. However, in some areas, the openings are bigger than 20% of the space, which may cause thermal loss in winter, overheating in summer and risk of intense brightness (Axarli, 2001, p. 226). In some cases, the depth of the space exceeds the height by 2,5 times up to the top of the opening, causing insufficient lighting at the rear in terms of both quantity and quality (Ander, 1995, p. 14).

3.3.2 *Shadowing – sunlight in relation with the neighbouring building*

The height of neighbouring buildings in combination with the widths of streets does not cast a shadow on the surrounding space. The building is exposed to sunlight many hours a day, all year round (Fig. 3).

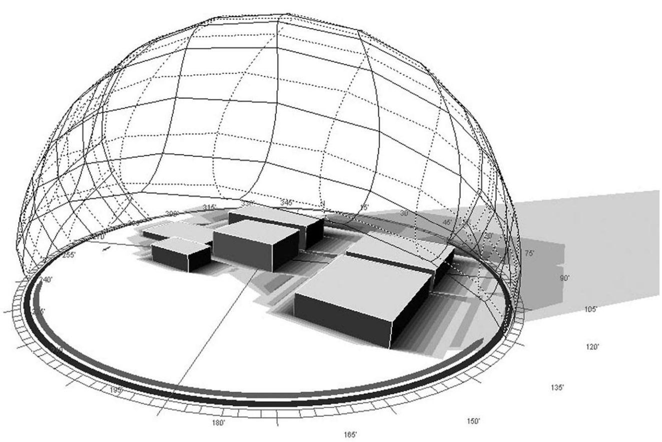

Figure 3. Yearly sun diagram (Source: Ecotect v. 5.5)

3.3.3 *Shadowing – daylight of each view of the building*

The position of the sun for the solstices (21/12 and 21/06) and the equinoxes (21/03 και 21/09) for the hours 09:00, 12:00 and 15:00 and for spring/summer/autumn18:00 hours is figured out from the cylindrical diagram for the city of Patrai (Fig. 4a). The needs for shadowing during the summer months is not big in the early afternoon hours as the sun is really high and only the occupants near the big openings confront shadowing problems. Due to the sun’s bigger orbit at that time of year, the problem is evident in the morning and afternoon hours when the sun is lower in the horizon. In the winter months the sun is positioned lower in the sky but, due to lower temperatures, its entry into the area is desirable with the aim of passive solar heating. Regarding visual comfort, intense brightness may be caused when there is direct incoming daylight in the interior of classrooms or offices (Fig. 4b).

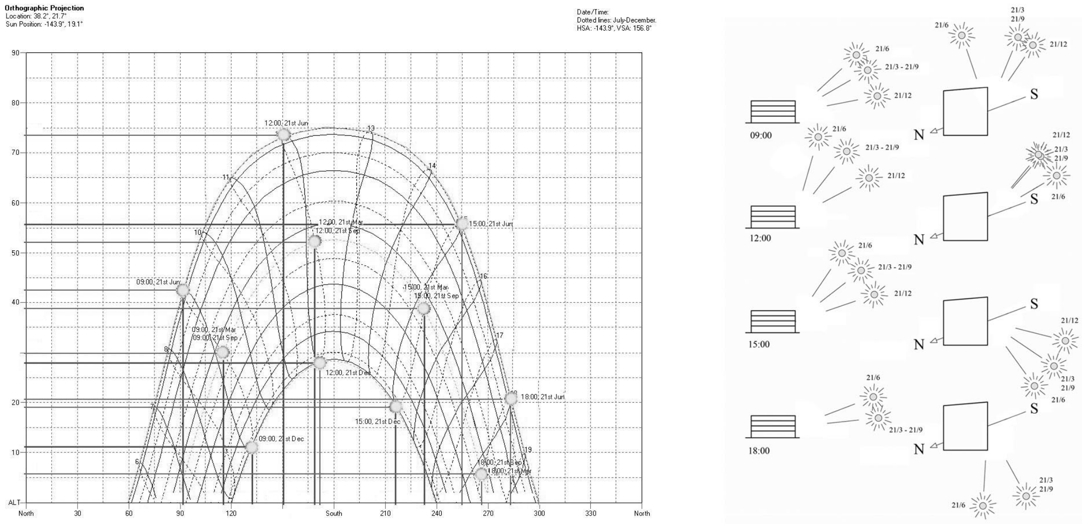

Figure 4. a. cylindrical diagram for the city of Patrai b. daylight of the views of the building
(Source: attribution from Ecotect v. 5.5)

Demers (2002) presents a method based on experiment which confirms the interaction between daylight and surfaces as well as its abundance in an interior space. According to Demers, contrast is the variable which gives the most understandable indications for the quality of light in an area. The general contrast of the total of a picture and not just punctual measurements relate to the most explicit of the quantifying methods of contrast data. With the digital separation of five layers of light in a picture there are five zones of brightness: 100%, 75%, 50%, 25% και 0%. The end result offers a clear picture of the interaction between light and surfaces. The separation of two levels: 100% and 0%, although abrupt as a representation, is even more representative (Demers, 2002, p.139-144).

There follows an attempt to apply the above method on an assembly area (Fig.5a) and on a classroom (Fig.5b). During the digital separation of the layers of light, there are sources of intense brightness in areas with big openings on the south and east view. These areas require intervention regarding shadowing

Figure 5. Digital separation of 2 and 5 layers of light
a. on an assembly area b. on a classroom

3.4 Questionnaire study

The questionnaire was based on the one presented in (Triantis, et al., 2006) and is separated into four sections:

A. general information (age, gender, floor of workplace, number of people in the same room);
B. environmental conditions (thermal comfort, quality of internal air, differentiations in temperature, natural and artificial lighting and noise);
C. other elements (possibility of control - adjustment of light, cleanliness, presence of smokers);
D. comments.

93 people took part in the survey and the sample participants were students, teaching staff and working staff of the department. The first thirteen (13) questions asked the participants to choose one of the seven possible answers of table 2.

Table 2. Range of answers.

Totally disagree	Disagree	Partly disagree	Don't know	Partly agree	Agree	Totally agree
1	2	3	4	5	6	7

Indicatively the graphs present the percentages of answers to two of the questions:
Question 1: The temperature of the workplace/classrooms is considered satisfactory
a. in winter (Fig. 6a) , b. in summer (fig.6b).
Question 3: The temperature of the building is preserved stable in all areas (fig. 6c).

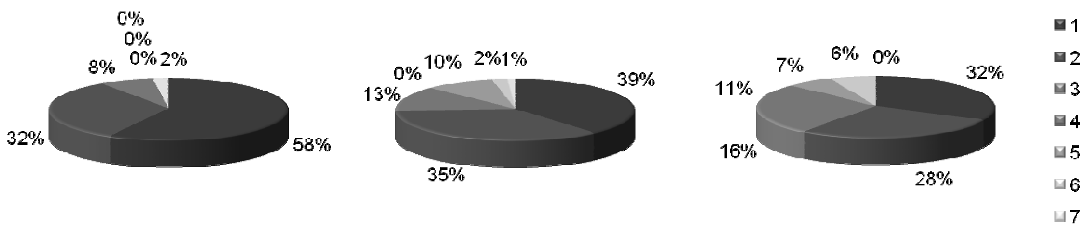

Figure 6. Graphs of percentages of questionnaire replies
a. satisfaction from temperature in winter
b. satisfaction from temperature in summer
c. satisfaction from the preservation of temperature

It is concluded that the building does not satisfy its users in terms of thermal comfort, external noise and management of temperature and ventilation.

In section D, the last two (2) questions asked for specific proposals for areas missing in the building according to their opinion and what needs to be done for its improvement.

Some of the areas suggested in question 14 are: an amphitheatre, a canteen, a green area, a presentation-exhibition room, an area for using the internet, a smoking area.

Question 15 asked for 5 actions that need doing for the improvement of the building .The total of answers to question 15 relates to our field of study: measures of improving its bioclimatic behavior. Some of the measures suggested were: sound insulation, thermal insulation, installation of heating and cooling systems, replacement of old window-door frames**,** an elevator, shading system, installation of roof fans, ventilation.

4 REDESIGN PROPOSAL

4.1 Improvement of thermal behavior

The main construction material of the building, which is reinforced concrete, holds a big heating capacity. Due to the lack of thermal insulation it cannot function according to its properties.

It is of primary interest to decrease thermal loss of the building owing to the insufficient thermal resistance of the materials of its shell (Fig 7a, b).

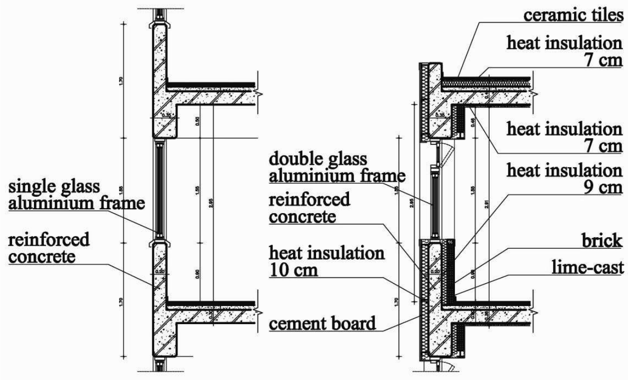

Figure 7. Constructional detail of the shell
a. Existing condition b. Proposal of improvement

The decrease of the surfaces of openings to 2/3 of the existing condition is suggested in order to avoid exceptionally big thickness of thermal insulating material. Table 3 presents the new prices of K for each constructional material of the building.

Table 3. Factor of thermal properties of the constructional materials of the building.

	External walling	Columns - Beams	Ceiling	Flooring
K (Kcal/m^{2}hc)	0,175	0,248	0,359	0,761
K (W/m^{2}κ)	0,150	0,213	0,308	0,654

The average thermal properties factor achieved for the whole of the building :
$Km=0{,}823<0{,}962 kcal/m^2hc$ (permitted) ή $Km=0{,}707 <0{,}827 W/m^2κ$ (permitted)

4.2 Improvement of daylighting conditions

4.2.1 *Daylight – ventilation*

It is impending for the improvement of daylight and ventilation to create an atrium space in the centre of the building, spreading from the ground floor to the terrace. Through the atrium space, daylight can reach areas insufficient in terms of lighting, thus reducing the need for artificial lighting. Openings should be created at the top of the staircase. The shape of the staircase is such that makes it function like a solar chimney contributing to the circulation of air in its interior. Internal openings should be also created in the classrooms on the side neighbouring assembly areas. Thus, improved lighting and ventilation is achieved. There is an upward movement of air created which contributes to natural cooling. In the summer months when temperatures are high, it can be additionally supported by artificial means established (roof fans). Reflection surfaces (light shelves) should be fitted to the external as well as the internal openings at the height of skylights (Fig. 8). This would enable the light (diffused and direct) to enter the areas to a greater extent and illuminate their ceilings.

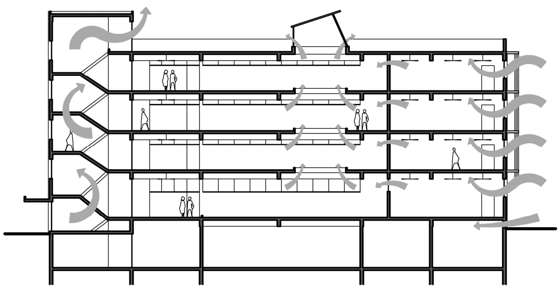

Figure 8. Air circulation

The latter simulation (Fig. 9a, b) shows the effect of the creation of the atrium space on the lighting of the building comparing to the existing situation. There is now adequate lighting in areas such as assembly areas which are important to the function of the building. The internal windows on the walls of the classrooms seem to work effectively, increasing the extent of lighting. Furthermore, they illuminate parts which were dark before and distribute light more evenly in the area. We also observe that the reduction of the openings suggested for thermal purposes does not affect the efficiency of daylight in the areas. The direct result of the above is the reduction of the demand for artificial lighting.

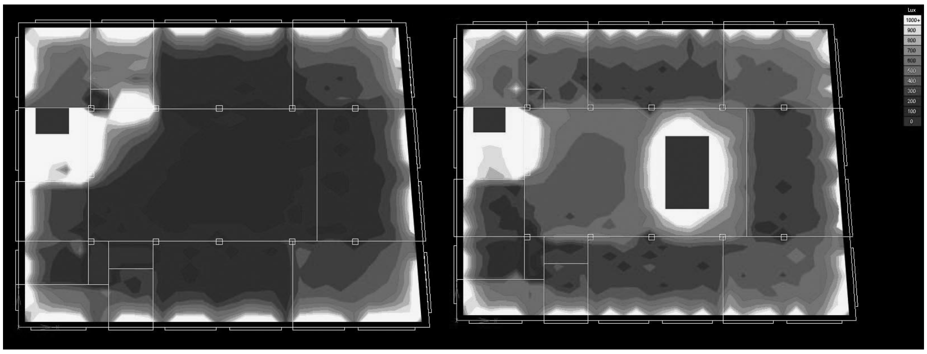

Figure 9. Natural light simulation (Source: Ecotect v. 5.5)
a. before b. after the creation of the atrium space

4.2.2 *Shading –sun protection*

For the effective and controlled shading of the areas, the fitting of movable systems of louvers outside the shell of the building (double skin) is proposed. The type of louvers is selected on the basis of the benefits it offers. The semi-transparent photovoltaic louvers seem to satisfy the building demands, since they can partly satisfy its energy needs along with shading. Finally, an elevating-movement mechanism is proposed which lets the louvers in front of the metal frame, so when they stay shut during winter months, there is a constant panel. To avoid damage or malfunction from the addition of sensors and complex systems of automatic movement, the manual change of their inclination is suggested twice a year:

- Winter period (21st September -21st March) : the sun is low in the sky and its entering the building is desirable so as to have the maximum possible benefits. The louvers remain shut (parallel to the wall of the building). Thus, they form a double-shell formation of glass which, on the one hand, allows sun-ray penetration and, on the other, it creates an interspace of stopping between the building and the external environment (Fig. 10a).
- Summer period (21st March – 21st September): the sun is high in the sky and shading in the areas of the building is essential. The louvers are inclined almost vertically against sun rays while photovoltaic elements produce the maximum possible quantity of energy (Fig 10b).

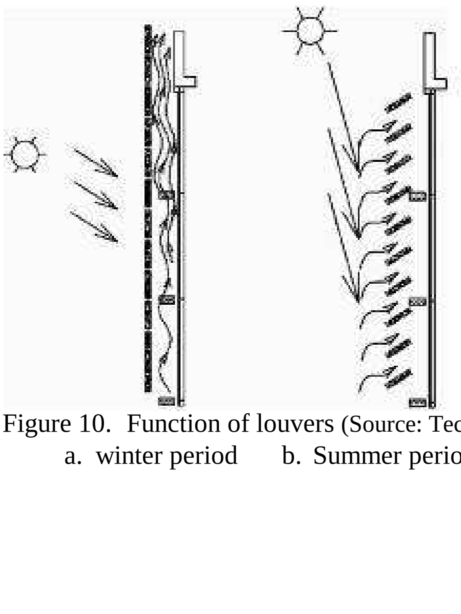

Figure 10. Function of louvers (Source: Technical matters, 2008, p. 126)
a. winter period b. Summer period

On the grounds of the above, the redesign of the views of the building is as follows. Indicatively the south (fig.11a) and the east view (fig. 11b) are presented.

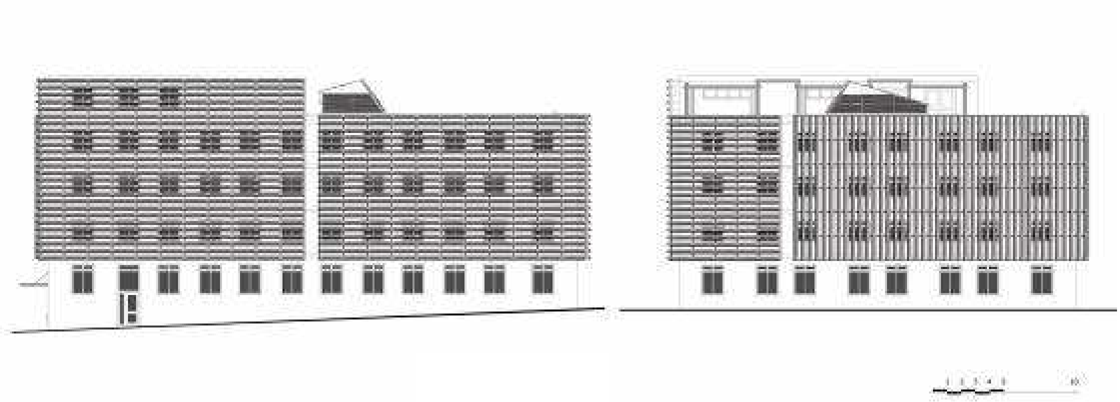

Figure 11. Building views after the changes in the shell

a. south view b. east view

5 CONCLUSIONS

5.1.1 *Regarding the case study*

All the above proposals seem to have the possibility to change the behaviour of the building regarding climatic (environmental) conditions and make it environmentally more flexible and effective. Thus, they secure desirable working conditions for its users. With the use of passive systems, energy consumption is seriously reduced and wasting energy is avoided. This has positive financial and environmental consequences.

5.1.2 *Generally about education buildings*

Generally, the use of passive systems in public buildings must pave the way towards sustainable development. Specifically, education buildings can play an essential role towards that direction since they can encourage environmental awareness among young people which is essential for life.

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The bioclimatic dimension in the Modern residential architecture in Cyprus

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ABSTRACT: The bioclimatic dimension of residential architecture in Cyprus is examined on the basis of buildings, designed in the period 1952-1974 by the Cypriot architect Neoptolemos Michaelides. The selected projects are of a high national architectural significance, as they represent in a most distinct way a critical introduction of modern architecture in Cyprus. In architectural terms, the designs follow the functional disposition, without relying on symbolic or decorative parameters. Following an overview of modern architecture in Cyprus the main climatic conditions of the region and the thermal comfort criteria are briefly presented. The analysis of five residential buildings refers to the architectural design strategies, and the construction materials and systems, applied for achieving human comfort, as regards cooling and natural lighting. The study proves that a series of strategic design actions ensure thermal improvements of the buildings and lead to optimum levels of thermal comfort, enabling thus substantial energy savings.

1 INTRODUCTION

In terms of energy efficiency, bioclimatic architecture aims at minimizing the energy consumption of the building and at achieving control of the microclimate of the indoor spaces (Fanger 1973, Givoni 1976, Markus & Morris 1980). The bioclimatic approach aims at re-establishing the links of architecture with the principles of traditional building techniques (Michaelides 1993). This approach reduces or even eliminates the waste of energy in controlling the microclimate within a building. At the same time, it restores the contact of humans with nature, the idiosyncrasy of a place and the quality of life (Givoni 1976, Michaelides 1993, Olgyay 1963).

In Cyprus, bioclimatic architecture may apply to the climatic conditions over the entire year. In addition, the year-round sunlight and the high solar radiation make the need for exploiting solar energy even more mandating (Givoni 1994, Goulding et al 1994, Markus & Morris 1980). The bioclimatic dimensions of residential architecture in Cyprus are examined on the basis of five selected residential buildings, designed in the period 1948-1992 by the architect Neoptolemos Michaelides (Economides 1992, Michael 2003, Michael & Papanikolaou 2002). The selected projects are of high national architectural significance, as they represent in a most distinct way a critical introduction of modern architecture in Cyprus (Michael 2003). In architectural terms, the designs follow the functional disposition, without relying on symbolic or decorative parameters. (Figures 1-5)

2 METHODOLOGY

The selection of the buildings was based on criteria that aim to reduce the plethora of parameters that affect the thermal comfort of the users. The sample includes only residential buildings, all situated in the broader area of Nicosia (flat area with mean altitude of about 160 m) for obtaining similar climatic conditions. It consists of five residential buildings with continuous function during the entire year. The buildings have one storey, two storey or split levels. As regards the year built, the buildings sample covers the entire time-span of the work of the architect and signify the multiple parameters of his architectural work.

For the data acquisition, registration equipments of temperature and relative humidity of the type NOMAD Data Logger were placed for 24 hours in the selected residences. The measurements were conducted from July 19th until August 26th of 2003. The registration equipment was placed in closed spaces of the ground floors, usually in the living room, at a height of 120 cm above the finished floor. The spaces have no technical climatic support. The temperature was measured at 12:00 hrs at both, the ground floor and the first floor for obtaining possible differences over the height.

Registration equipment was also placed in a reference building that was selected as suitable for comparison after registration of the temperatures of a broader possible reference buildings sample. The reference building is of similar materials, construction and size as the buildings selected for the analysis. It is a two storey building with open spaces. The roof and the external walls of the building are insulated with polystyrene. Data for the temperature and the relative humidity of the external environment was collected from the Meteorological Service of Cyprus, in particular from the Athalassa station (altitude: 162 m, latitude 35º 09' north, longitude 33º 24' east).

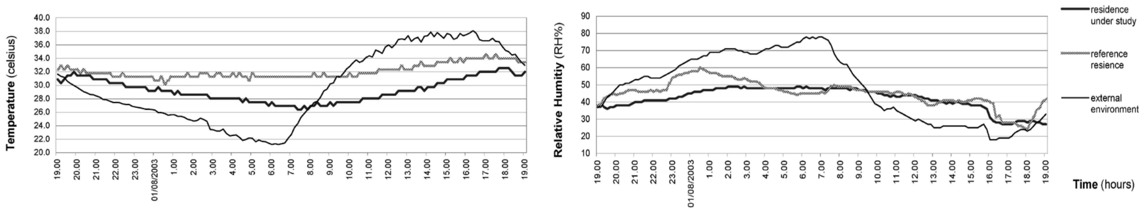
Figures 1-5. The selected projects residences of Theodotos Kanthos, Telemachos Kanthos, Andreas Koumoulis, Panos Eliophotou, Nicos Georgiou, respectively.

3 BUILDINGS AND CLIMATIC CONDITIONS DATABASE

The documentation of each residential building in the analysis refers to the applied design strategies for the improvement of microclimatic conditions (Givoni 1994). In addition, the measurements of temperature and relative humidity for the time span of 24 hours are presented for each case, as well as the respective measurements for the reference building and the external environment.

3.1 *Theodotos Kanthos Residence, design 1949, construction 1952*

The residence building of Theodoros Kanthos is the first constructed design of the architect and the first building in the island within the frame-conditions of contemporary construction (Figure 1) (Economides 1992, Michael 2003, Michael & Papanikolaou 2002). Apart from the residential spaces it contains a painting studio. The usage spaces are clearly divided into two levels. The common spaces are on the ground floor, the private ones on the 1st floor. The passage into the interior of the building contains three stages: The covered foreground, the glassed entrance space with the vertical circulation and the closed interior space. The differentiation of the building volumes over the height determines concrete visual connections and allows for a high level of natural lighting of the spaces. During the summer period the activities of the closed living room are transferred into the outer covered space that is defined by the structural grid, the water pond and the curved wall, encasing the painting studio. The data logger was placed on site at 19:00 hrs, 31st July 2003, for a time span of 24 hours. The results are presented in Figures 6, 7 and Table 1.



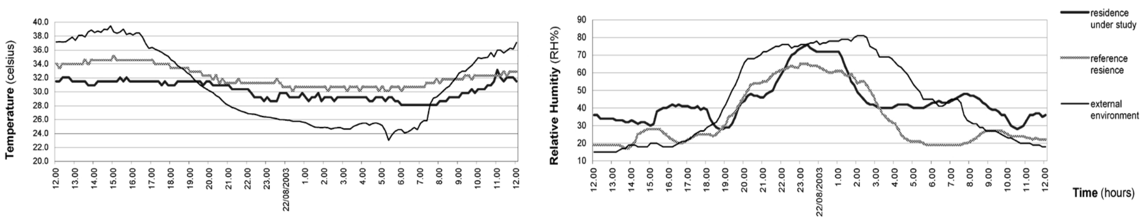
Figures 6, 7. Temperature and relative humidity data of building in 3.1.

Table 1. Results of data analysis of building in 3.1.

Temperature Co	Residence	Reference	External
Max	32.6	34.6	38.1
Min	26.4	30.2	21.2
average	29.3	32.1	29.8
fluctuation	6.2	4.4	16.9
Humidity RH%			
Max	49.0	60.0	78.0
Min	27.0	24.0	18.0
average	42.0	45.1	49.0
fluctuation	22.0	36.0	60.0
Differences between reference and residence under study			
	Max	min	average
Temperature C^o	2.0	3.8	2.8
Humidity RH%	11.0	-3.0	3.1
Temperature Difference across floor levels			2.1 C^o

3.2 *Telemachos Kanthos Residence, design 1959, construction 1960*

The spaces of the building are divided in two levels, while the residence is situated on the ground floor, and the workshop of the painter within the upper volume, on the back-side of the plot (Figure 2). The large polygonal space of the living room comprises the main organization element of the floor plan. The access to the workshop is achieved through an independent external staircase, so that privacy of the space is obtained. The inclined roof of the space and the large north glass facade that enables an uninterrupted view are most interesting elements of the composition. The semi-open air ground space underneath of the workshop is used as semi-open air living space in the summer. The vertical differentiation of the residence spaces and the workshop enables intensive visual connections towards all directions (Michael 2003). The data logger was placed on site at 12:00 hrs, 21st August 2003, for a time span of 24 hours. The results are presented in Figures 8, 9 and Table 2.



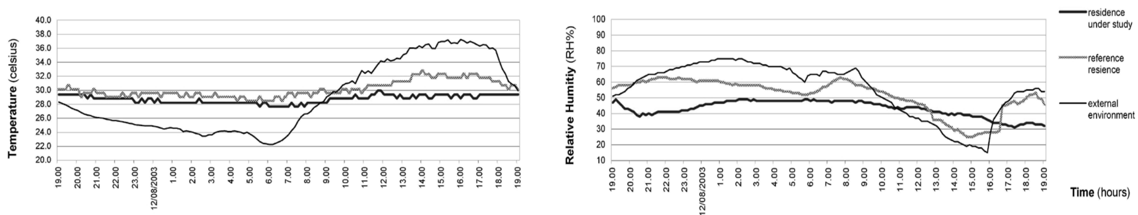
Figures 8, 9. Temperature and relative humidity data of building in 3.2.

Table 2. Results of data analysis of building in 3.2.

Temperature Co	Residence	Reference	External
Max	33.2	35.1	39.5
Min	28.1	30.2	23.0
average	30.2	32.2	30.8
fluctuation	5.1	4.9	16.5
Humidity RH%			
Max	76.0	65.0	81.0
Min	28.0	17.0	15.0
average	44.1	34.3	45.0
fluctuation	48.0	48.0	66.0
Differences between reference and residence under study			
	max	min	average
Temperature C^o	1.9	2.1	2.0
Humidity RH%			
	-11.0	-11.0	-9.9
Temperature Difference across floor levels			-----

3.3 *Andreas Koumoulis Residence, design 1964, construction 1966*

The residence of Koumoulis Andreas is a two storey building, constructed on a highly inclined plot with the lower level at the back (Figure 3). The unified open spaces of the ground floor are articulated in their functions through altitude differences. The spaces with high energy consumption are situated on the south for maximum solar gains. The ground floor area contains a winter garden that is used as living room in the winter. The covered space at the southeast corner of the building is used as semi open space and as outdoor living room in the summer. All ground floor spaces are directly related with the open spaces (Michael 2003). The data logger was placed on site at 19:00 hrs, 11th August 2003, for a time span of 24 hours. The results are presented in Figures 10, 11 and Table 3.



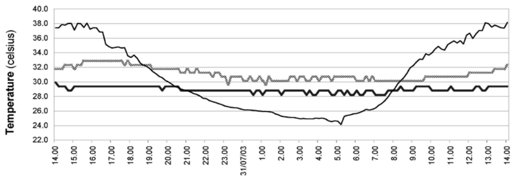
Figures 10, 11. Temperature and relative humidity data of building in 3.3.

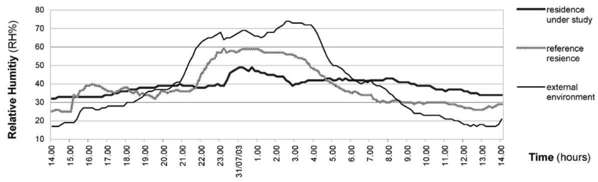
Table 3. Results of data analysis of building in 3.3.

Temperature Co	Residence	Reference	External
Max	29.9	32.8	37.3
Min	27.7	28.5	22.3
average	28.7	30.1	28.9
fluctuation	2.3	4.3	15.0
Humidity RH%			
Max	49.0	63.0	75.0
Min	31.0	25.0	15.0
average	43.0	51.6	55.5
fluctuation	18.0	38.0	60.0
Differences between reference and residence under study			
	max	min	average
Temperature C^o	2.9	0.8	1.4
Humidity RH%	14.0	-6.0	8.6
Temperature Difference across floor levels			2.1 C^o

3.4 *Panos Eliophotou Residence, design 1965, construction 1966*

The plot is situated at a height of about 2.5m from the street level (Figure 4). The building develops at a horizontal level above the inclined ground section, while the parking places and the external staircase are at the level of the street. The entrance of the building is formed through the inclination of the dining room in the floor plan. The ground floor spaces are organised around an internal yard, forming thus a «Π» shape with the south-east side open. This space comprises the main open space of the residence; in addition it divides the functional spaces of the building between social and private (Michael 2003).The data logger was placed on site at 14:00 hrs, 30th July 2003, for a time span of 24 hours. The results are presented in Figures 12, 13 and Table 4.





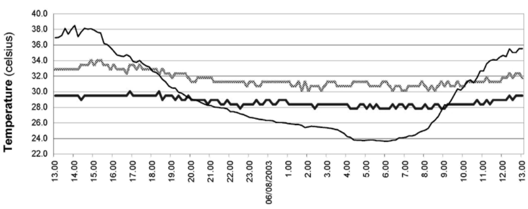
Figures 12, 13. Temperature and relative humidity data of building in 3.4.

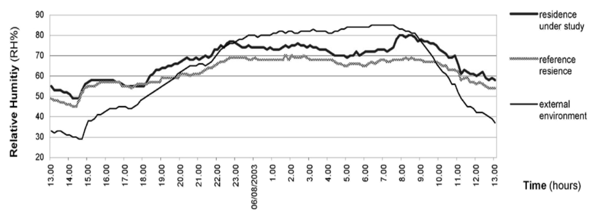
Table 4. Results of data analysis of building in 3.4.

Temperature Co	Residence	Reference	External
Max	29.9	32.9	38.2
Min	28.2	29.6	24.2
average	29.0	31.1	30.7
fluctuation	1.7	3.3	14.0
Humidity RH%			
Max	49.0	59.0	74.0
Min	32.0	25.0	17.0
average	39.2	38.8	41.1
fluctuation	17.0	34.0	57.0
Differences between reference and residence under study			
	max	min	average
Temperature C^o	2.9	1.4	2.2
Humidity RH%	10.0	-7.0	-0.3
Temperature Difference across floor levels			2.1 C^o

3.5 *Nicos Georgiou Residence, design 1967, construction 1968*

The building houses, the residence and the doctoral practice of the owner.. The built-up volume on the ground level forms a «C» shape with the side towards the street open, while the first floor has an «L» shape (Figure 5). This disposition enables intensive visual connections. The two floors are connected through the atrium that comprises the central space of the floor plan, containing also the vertical circulation. Through the placement of the atrium on the east side of the entrance, the spaces of the residence are divided effectively from the practice that functions independently. The two residence levels are characterized by a clear functional division (Michael 2003). The data logger was placed on site at 13:00 hrs, 05th August 2003, for a time span of 24 hours. The results are presented in Figures 14, 15 and Table 5.





Figures 14, 15. Temperature and relative humidity data of building in 3.5.
Table 5. Results of data analysis of building in 3.5.

Temperature Co	Residence	Reference	External
Max	30.1	34.0	38.5
Min	27.8	30.2	23.6
average	28.7	31.6	29.5
fluctuation	2.2	3.8	14.9
Humidity RH%			
Max	80.0	70.0	85.0
Min	49.0	45.0	29.0
average	67.4	62.2	64.2
fluctuation	31.0	25.0	56.0
Differences between reference and residence under study			
	max	min	average
Temperature C^o	3.9	2.3	2.9
Humidity RH%	-10.0	-4.0	-5.3
Temperature Difference across floor levels			1.6 C^o

4 ANALYSIS

4.1 *Bioclimatic Design*

Having in mind the rules and structural forms of modernism in architecture, Neoptolemos Michaelides attempted to materialise a modern architecture in Cyprus, strongly related to the climatic conditions and idiosyncrasies of the Cyprus landscape, as well as to specific spatial characteristics, such as the internal yard and the gradual passage towards the internal spaces (Economides 1992, Michael 2003, Michael & Papanikolaou 2002). In Neoptolemos Michaelides' work, the sun becomes a composed element, with the residences being opened or shielded against it; the wind determines the position and sizes of the openings, while vegetation and water become part of the buildings. Residences cease to be passive receptors of the weather conditions, but are composed so as to operate dynamically based on them (Michael 2003). A series of design strategies that appear from the beginning of the design process, ensure thermal improvements in the conditions of the buildings, approaching optimum levels of thermal comfort. The definition of these parameters is attempted as follows, based on qualitative observations related to the summer and winter period (Figure 16):

The residence buildings have south or southeast orientation. The main spaces are situated towards the south, but when this is not possible, sunlight from the south is obtained through the use of skylights. The exterior walls have no openings towards the west and north, minimizing thus the thermal losses and preventing the cold winds during the winter season. Small-sized openings are suitably placed to ensure cooling during the summer months. The small openings increase the speed of wind in the interior of the buildings, improving the results of cooling.

Sun protection for the openings is achieved through projections, venetian blinds, pergolas and planting. Particular emphasis was given in avoiding an overheating of the spaces during the summer period.

Cooling plays perhaps the most important role for ensuring thermal comfort in the residences. It is achieved through openings on both, the external and internal walls that enable the flow of air throughout the residence. During the night it is achieved through openings on the roof and evaporation of water from reservoirs, waterworks and water pools.

Suitable planting guarantees sun-protection and cooling of the interior of the residences. The presence of deciduous plants, trees and climbing bushes on the exterior walls supports the cooling and shading of the building, both horizontally and vertically. The fall of leaves during the winter months allows the entry of sunlight and consequently the heating of both, open-air and interior spaces. The presence of evergreen trees prevents, or directs the flow of air. Atriums and internal patios contribute to the improvement of the climatic indoor conditions, due to the existence of vegetation and water in the core of the residences, while the non-compact configuration of the ground plan layouts ensures better ventilation of the interior spaces.

The thermal insulation of the building envelopes serves for the protection of the buildings from the outside weather conditions, increasing at the same time their thermal inactivity.

Appropriate measures were taken for maximum natural lighting of the interior spaces. Large openings, atriums and rich vegetation ensure optical comfort, high level of lighting and pleasant views, criteria that affect the sentimental and psychological situation, as well as the thermal comfort of the occupants.

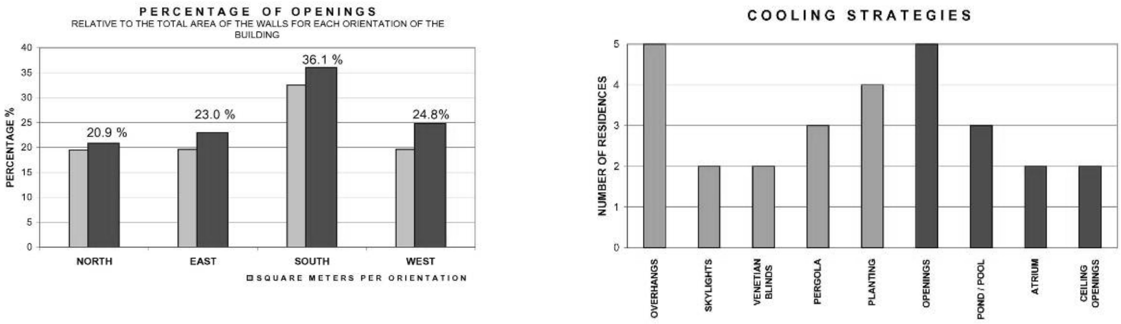
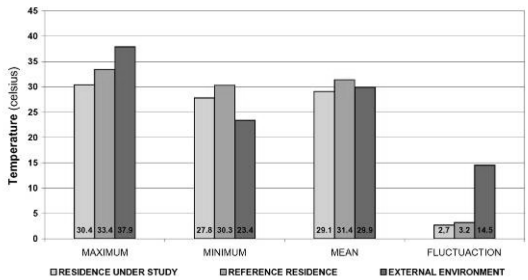


Figure 16. Bioclimatic design strategies, applied in the buildings sample.

4.2 *Buildings Thermal Performance*

The mean maximum temperature of the buildings sample is 30.4 ºC, i.e. 3.0 ºC lower than the mean maximum temperature of the reference building. The respective temperature value of the external environment at the same time period is 37.9 ºC. The mean minimum temperature of the buildings is 27.8 ºC, i.e. 3.2 ºC lower than the mean minimum temperature of the reference building. The respective temperature value of the external environment is 23.4 ºC, thus significantly lower than the temperatures in the interior spaces. The mean temperature fluctuation for the buildings is 2.7 ºC and for the reference building, 3.2 ºC. The similarity in these results is due to the fact that the buildings under review and the reference building are constructed with relatively heavy-weight materials of high heat inertia (> 400 kg/m^2). The mean temperature fluctuation of the external environment is 14.5 ºC (Figure 17).

The buildings sample provided a mean maximum relative humidity of 57.6 RH%, a mean minimum value of 37.6 RH%, i.e. a mean fluctuation value of 20.0 RH%. The mean maximum relative humidity of the reference building is registered 4.4 RH% above the respective value of the buildings sample, and its mean minimum value is registered 5.6 RH% below the respective value of the buildings sample. These values give an increase of the mean fluctuation of 30.0 RH%. For the same time period the external environment had a mean maximum relative humidity of 75.8 RH% and a mean minimum relative humidity of 22.2 RH%. The respective fluctuation is 53.6 RH% (Figure 18).



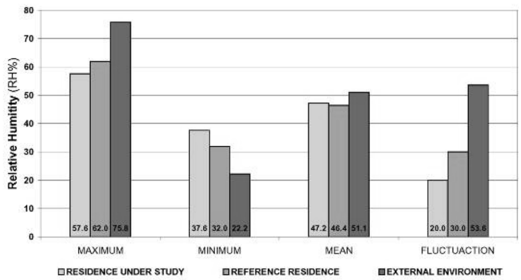
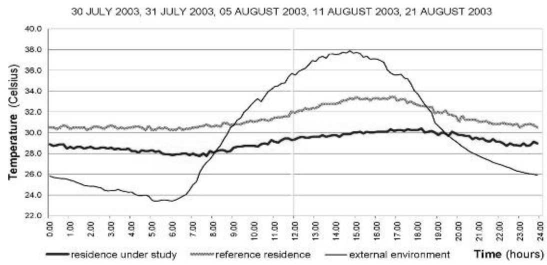


Figure 17, 18. Comparison bars of mean temperatures and mean relative humidity.

The diagrams of the mean temperature and the mean relative humidity for the entire time period provide information on the respective time-dependent fluctuations. In the case of temperatures, the fluctuation curves are similar. The buildings sample curve has significantly low values compared to the respective curve of the reference building, with 3.5 ºC at 14:40 hrs and 1.5 ºC at 20:30 hrs. The corresponding curve to the external environment temperatures has high fluctuation, with a mean minimum value of 23.4 ºC at 05:40 hrs and a mean maximum value of 37.9 ºC at 14:40 hrs. Minimum temperatures in the buildings develop at 06:00 hrs and maximum ones, at 18:10 hrs. Although the external environment has a temperature fall from 14:40 hrs until 17:40 hrs, at the same time span the buildings under review and the reference building show a temperature increase (Figure 19). This is due to the thermal mass of the building envelope and the contribution of solar radiation in the interior spaces.

The graphic presentation of the mean relative humidity shows for the buildings sample a fluctuation value of 20.0 RH%, for the reference building, 30.0 RH%, and for the external environment, 53.6 RH%. The registered mean values are almost constant, within a range from 47.2 RH% to 51.1 RH%. Maximum values develop during the evening hours (between 23:50 hrs and 00:50 hrs) and minimum values during the afternoon hours (Figure 20). This proves the reciprocal relation between temperature and relative humidity.



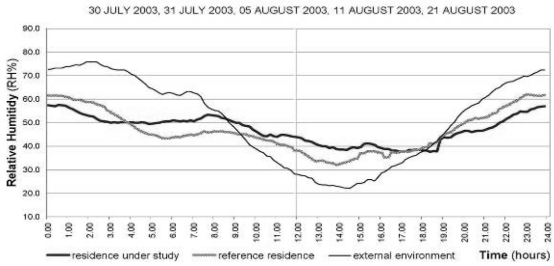


Figure 19, 20. Mean temperature fluctuation curves and mean relative humidity fluctuation curves.

5 CONCLUSIONS

The architect Neoptolemos Michaelides aimed through his architectural work at environmentally and climatically sensitive designs, even though in the past years energy efficiency was not a primary case of concern. The bioclimatic principles, applied by the architect from the first stages of the design process, determine extensively the composition and the spatial configuration of the buildings (Givoni 1994). This can be confirmed by the satisfactory results, obtained as regards the temperature and relative humidity of the five buildings reviewed for the summer period in this paper. The collection of relevant data for the entire period of the year can provide a more rounded-up documentation of the thermal performance of the buildings. The research may be extended to include an evaluation of the level of natural lighting in the interior spaces and other parameters that contribute to the improvement of the energy efficiency of the buildings and the human comfort of the occupants.

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Earth, wind and sun: Bioclimatic parameters in an architectural proposal

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ABSTRACT: This study presents the process of the design proposal for the new Town-Hall of Deryneia, Cyprus. Deryneia is a "divided" municipality since 1974 and for this reason the proposed building had to satisfy, apart from the afore-mentioned environmental and architectural demands, the need to express symbolically the political situation. The aim of the study is to evaluate bioclimatic behaviour of the proposed architectural design. More specifically, this evaluation concerns the thermal behaviour of the building shell, the passive heating and cooling strategies that are integrated to the design, as well as the achieved daylighting conditions. Daylighting conditions are analysed with the use of software for both overcast (winter) and clear (summer and intermediate seasons) sky conditions, in order to evaluate the influence of the roof skylights.

1 INTRODUCTION

Public buildings in general can help inform and educate the public on environmental issues and energy efficiency. At the same time, public buildings constitute city landmarks, and, especially if they are selected by a competition jury, their design and construction tend to follow, to some extent, contemporary architectural trends. Town halls are buildings, which house administration, information, exhibition and recreation activities, and aim at providing the general public with assistance concerning various aspects of local administration. As such, their design seeks to combine the demand for standing out as symbols of the democratic processes, with the need to create a healthy and welcoming interior environment for both employees and visitors. In addition, the proposed building will ultimately promote and enforce the relationship between the citizens and the local administration.

In the last years, the continuously growing concern for climate change and environmental degradation has inevitably lead to the introduction of bioclimatic and environmentally-friendly design principles to the already complex and demanding architectural design of public buildings. This led to the high-quality design projects, such as the London City Hall (Foster+Partners, 1998-2002) (http://www.fosterandpartners.com) and the Bologna Civic Offices (Mario Cucinella Architects, 2003-2009) (http://www.e-architect.co.uk), which incorporate passive heating and cooling, daylighting and renewable energy sources features that aim at minimizing conventional energy consumption and promoting sustainability at the same time.

For the new Deryneia Town Hall (DTH), the competition brief (Municipality of Deryneia 2008) asked for a building that would actively comply with the principles of sustainable development as stated by the Brundtland Commission. A building in which comfortable thermal and visual comfort conditions and interior air quality would be achieved primarily with careful bio-climatic design, which would have reduced energy demand for heating, cooling (< 30 kWh/m^2) and lighting (< 8 kWh/m^2) and where the proposed building materials would assure the maximum possible longevity with the least possible maintenance. It is important to note that there was an additional prerequisite that practically excluded the integration of high-tech energy conservation elements, stating "that the environmental performance of the building should derive mainly from the simplicity and rationality of the architectural design". It was this last point of the competition brief that actually defined in whole the design proposal that is presented in this paper and received an honourable mention in the homonymous Cypriot Architectural Competition.

2 ARCHITECTURAL DESIGN PRINCIPLES

2.1 *Integration to the existing urban fabric*

Deryneia is a small (7500 inhabitants), coastal town situated at the eastern part of the island of Cyprus (Latitude 35.1N, Longitude 34E), near the city of Famagusta. Since the Turkish invasion in 1974, a large part of Deryneia (75%) falls within the occupied zone, and the town has been deprived of its contact with the sea and Famagusta (Municipality of Deryneia 2008).

The proposed project for the new town-hall of the semi-occupied community of Deryneia seeks to create new connections while strengthening the existing ones. (Figure 1) The building frames the occupied coast, visually connecting the here and there, past and present, presence with absence. The urban passage through the building connects the town centre, the heroes' memorial and the open-air theater with the coastal zone. The building shell (epidermis) regulates its contact with the environment, the view and the climatic elements (sun and wind).

Frame - Urban Passage - Building Shell

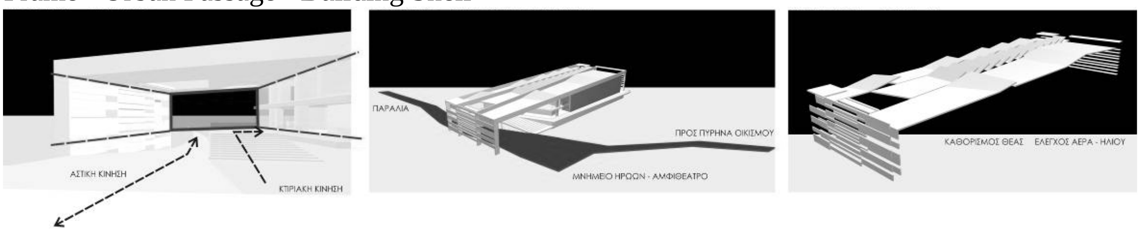

Figure 1. Architectural design principles of the proposal.

2.2 *Functional organisation and design of open spaces*

The goal was to create a welcoming large yet sheltered open space that can reflect the symbolic and administrative character of the building and then arrange the interior spaces on two main levels and a basement for secondary uses.

The access from the street to the ground floor (level $\pm$0.00) is achieved through a spacious exterior staircase. (Figure 2) The entrance space leads to an open, central atrium space with transparent boundaries and clear functional organisation. The dynamic relationship between the interior spaces and the surrounding environment is accomplished through extensive glazed surfaces which are nevertheless protected with the appropriate shading device each time. The central atrium space is the main connecting and unifying element, acting as a movement distributor, and at the same time allowing the immediate perception of the building's structure both functionally and symbolically. The multi-purpose hall is separated from the other building functions and is in direct functional contact with the exhibition space, which is placed close to the building exterior facade in order to achieve the best possible projection.

The floor (level $\pm$3.95) includes solely office-spaces. The connection with the ground floor is achieved through a central, open staircase placed in the atrium, and two closed stairwells. The design of the individual open spaces promotes flexibility and functionality.

The surrounding space of the building constitutes an integral part of the proposed design. It allows the easy access and free entrance of the citizens to the building, and forms its immediate open space. As part of the open spaces, the entrance area is the main space for gathering and social interaction.

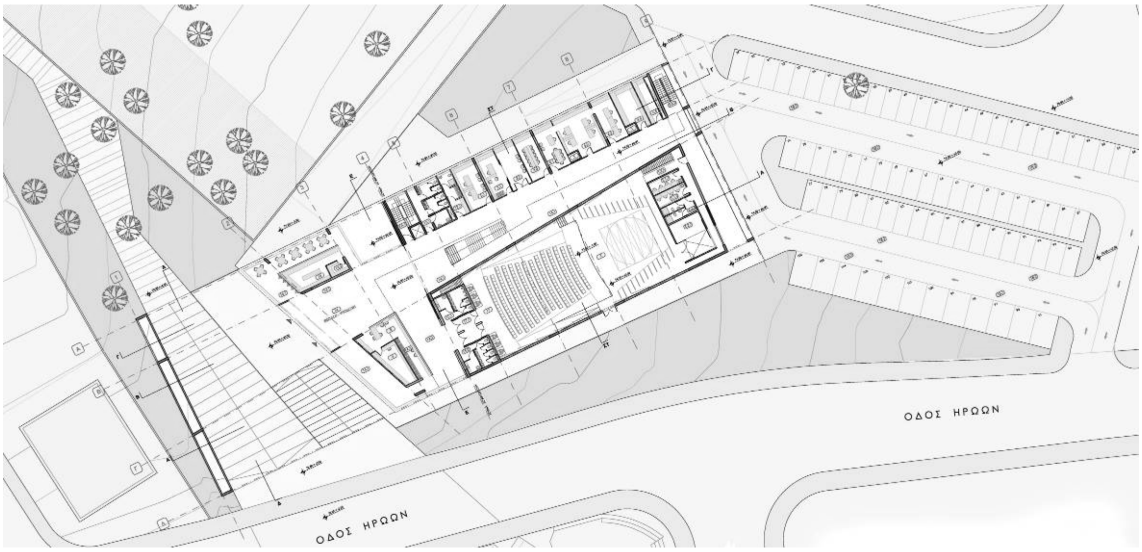

Figure 2. Ground floor plan of the building and open spaces.

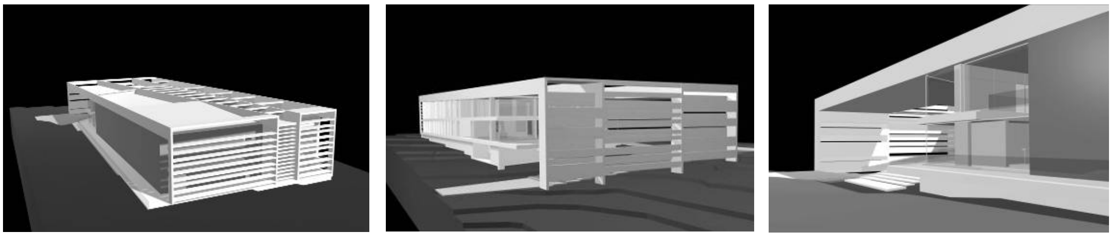

Figure 3. Three-dimensional aspects of the building.

2.3 *Construction and materials*

The building is constructed of reinforced concrete framework, very similar to the current building practice in Cyprus. The vertical supporting elements, the majority of which are share walls, are placed on a grid, which corresponds to the functional organisation of the plan and the need to provide adequate seismic protection. The horizontal elements are 45-cm concrete slabs, which ensure the diaphragmatic function of the horizontal surfaces and, at the same time provide significant thermal mass.

3 BIOCLIMATIC DESIGN AND ENVIRONMENTAL APPROACH

3.1 *Climatic analysis*

The environmental approach of the design proposal is directly linked to selected bioclimatic design principles, which were derived from the climatic analysis of the area. Due to the lack of detailed, local climatic data, an hourly weather data file for Deryneia was generated with the Meteonorm software and was then used in the Weather Tool software in order to create climatic charts and psychrometric diagrams.

The climate of Deryneia is characterised by mild winters and warm winters. Consequently, during the heating period, the contribution of solar radiation to the passive heating of the interior spaces and the reduction of conventional energy consumption for heating is very important.(Figure 4.a) During the hot, summer period, the climate is characterised as warm and humid, and the selected bioclimatic strategies are primarily efficient shading and natural ventilation, as well as exploitation of the building’s high thermal mass. (Figure 4.b)

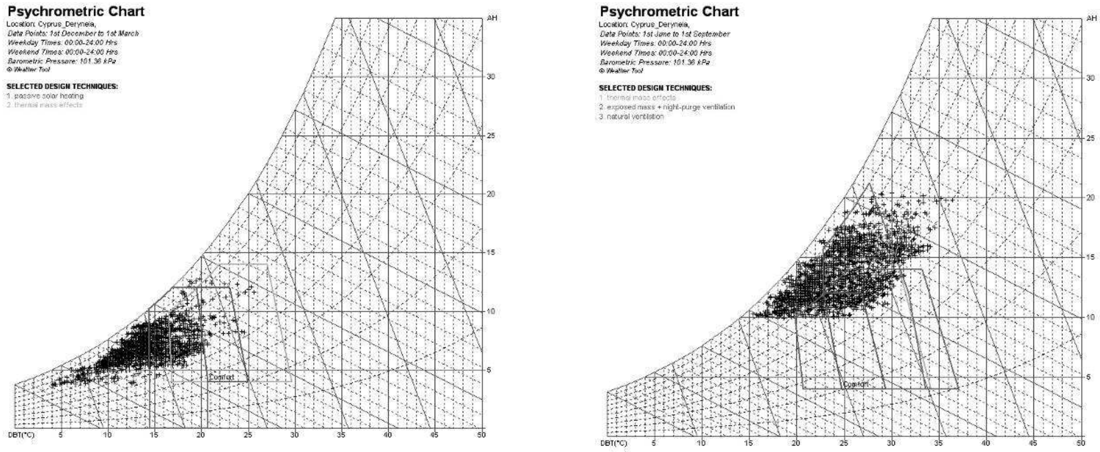

Figure 4. Psychrometric diagrams for: a. the heating and b. the cooling period with selected bioclimatic strategies. (Weather Tool v.2.0)

The applied bioclimatic strategies form an integral part of the architectural design, and, in a passive way and thus compliant to the competition brief, provide improved thermal and visual comfort conditions. The building shell is formed by elements of appropriate geometric characteristics, which ensure winter southern insulation, provide adequate summer shading, enhance natural cross-ventilation and stack effect and contribute positively to the acoustic performance of the design. (Figure 5)

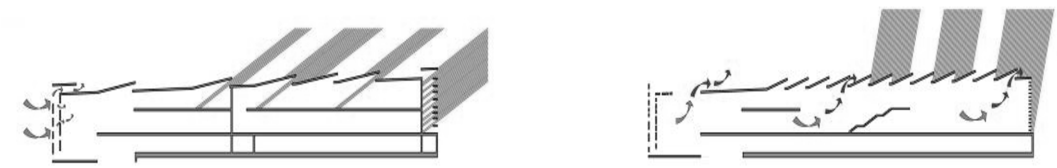

Figure 5. Bioclimatic behaviour of the building shell during the heating and cooling period.

3.2 *Heating period – Passive solar heating*

Given the fact that the building site does not allow the design of a building with a main axis running from east to west, the exploitation of the year-long favorable southern orientation is achieved through the design of the building shell and the creation of the central, atrium space.The southern sun is directly introduced to the atrium space and the office spaces through various south-facing skylights, which contribute to passive heating, improvement of thermal comfort conditions and energy conservation.

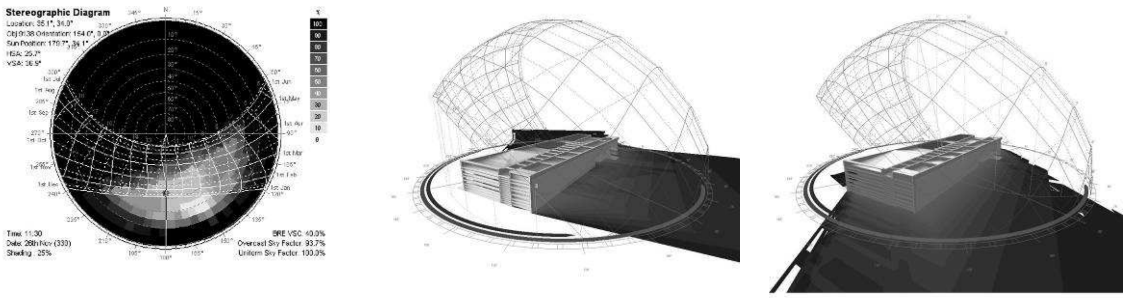

Figure 6. Shading mask and shadow range for the winter and the summer. (Ecotect v.5.5)

3.3 *Cooling period – Shading, Cross-ventilation, Night-time ventilation*

During the cooling period, the shading of the glazed surfaces of the building mainly depends on their orientation. East-facing surfaces are shaded by external, vertical, reflective louvers, which block solar radiation, whereas the south-facing skylights are shaded from direct solar radiation by their proper structure and geometry. The south-facing façade of the central atrium is shaded by external horizontal louvers. In order to further minimize thermal loads, the multi-purpose hall is placed in the west in order to act as a buffer space.

The enhanced natural ventilation of the building is primarily achieved with its placement at an angle to the prevailing winds. The central atrium space plays an important role in the overall ventilation of the building during the summer, as the opening of the skylights promotes stack ventilation (Bernoulli effect). The same principle applies for the office spaces on the upper storey. There is also the possibility of cross-ventilation, which is promoted with operable ventilation openings placed on the partitions separating the office spaces and the atrium. During night-time, when environmental temperatures are lower, increased ventilation rates assure the adequate cooling of the building’s thermal mass (concrete slabs and building shell).

3.4 *Daylighting*

The daylighting analysis was performed with the combination of Ecotect and Desktop Radiance and was based on isolux contour diagrams and daylighting simulation of selected interior views. The analysis (Figures 7 and 8) shows that daylighting levels and distribution are adequate, even with overcast sky conditions, as a result of the appropriate choice of vertical and roof openings in combination with the external shading elements.

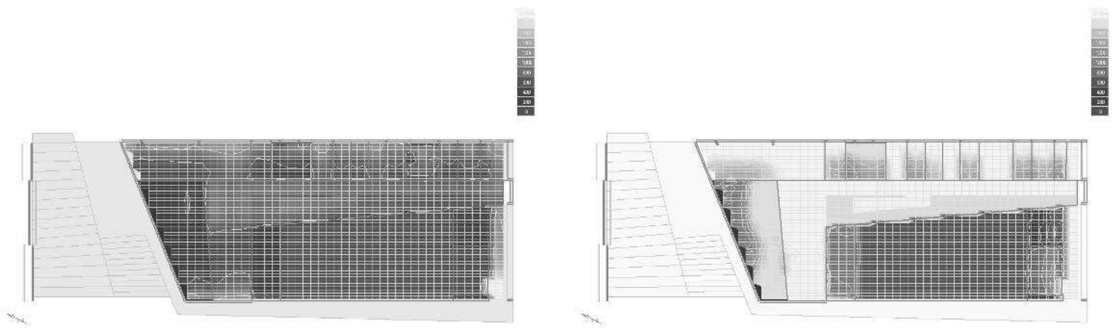

Figure 7.Daylighting analysis (isolux contours) of the upper storey, a. December 21st, 12:00, overcast sky conditions and b. June 21st, 12:00, clear sky conditions. (Ecotect v.5.5, Desktop Radiance v.1.02)

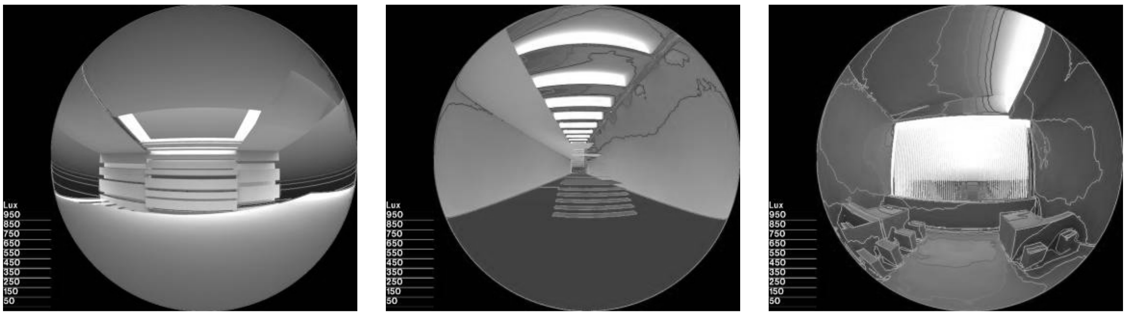

Figure 8.Daylighting analysis and simulation of: a. the entrance area, b. the central atrium space and c. a typical upper-storey office space. (Ecotect v.5.5, Desktop Radiance v.1.02)

3.5 *Materials and building techniques*

The bioclimatic approach to the design of the new Deryneia town-hall also includes the selection of materials and building techniques. Reinforced concrete, the main building material, has low maintenance needs and can be recycled, both in terms of the steel reinforcement (recycled steel) and the concrete mass (production of second-hand aggregate). The other metal parts of the building (aluminium window frames and external louvers) can also be recycled without down-cycling. The applied building technique for the interior spaces is mainly based on dry-wall construction, which allows the dismantling rather than the demolition of the building, and employs elements of low embodied energy and low maintenance cost.

3.6 *Microclimatic modification*

The surrounding open space is appropriately designed in order to improve both summer and winter microclimatic conditions. The existing trees are preserved and the proposed vegetation involves local or indigenous plants which are able to with-stand local summer conditions (increased temperatures and lack of water). Irrigation needs are partly covered with the collection of rainwater in an underground reservoir.

3.7 *Renewable energy sources and energy management*

The building's electricity demands is covered by a photovoltaic installation placed on the flat roof. For the efficient energy management of all the functioning systems, a Building Management System (BMS) is proposed in order to monitor exterior environmental conditions and adjust the functioning systems accordingly.

The surrounding open space is appropriately designed in order to improve summer microclimatic conditions. The existing trees are preserved and the proposed vegetation involves local or indigenous plants, which are able to with-stand local summer conditions (increased temperatures and lack of water). Irrigation needs are partly covered with the collection of rainwater in an underground reservoir.

4 CONCLUSIONS

Public buildings in general and town hall in particular, can help inform and educate the public on issues of environmental protection and energy efficiency. For this reason, their design and construction is of utmost importance.

The presented design proposal for the new Deryneia town hall tried to fulfill, in the best possible way, the afore-mentioned needs and demands. The project shows that it is possible to combine the principles of bioclimatic and environmentally-friendly architecture with the need for contemporary architectural design. For this to happen, designers have to take into consideration issues of climate, landscape and materials from the first stages of the design process.

The proposal has to be continuously reviewed and validated in terms of thermal and visual comfort in order to design the spaces and define the details of systems and components.

While initially exited with the emphasis the competition brief put on environmental issues, the design team has sadly observed that the committee's emphasis in judging the proposals shifted significantly to the formal and the fanciful, qualities which are not necessarily negative by themselves but are rendered so if they tend to displace other perhaps more vital qualities.

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Life cycle energy and environmental assessment of alternative exterior wall systems

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ABSTRACT: Buildings have a major determining role both on energy consumption and on environmental impacts. One critical factor is the building envelope, which is very important for the buildings' thermal energy requirements, but that requires a considerable amount of materials, with associated embodied energy and environmental burdens. The main motivation for this study is to assess alternative building envelope options with the goal of supporting decision at project level of new buildings in Portugal. A life cycle (LC) model for a single-family house in Portugal has been developed. Two alternative functional units have been considered: the building living area over the life span period and a square meter of living area over a year. The LC primary energy requirements and Greenhouse Gas (GHG) emissions of the house have been calculated. Seven alternative exterior wall solutions with different materials (brick, concrete block and wood) have been assessed.

1 INTRODUCTION

The buildings sector account for 40% of total energy consumption in the European Union (EU). This has motivated the implementation of the Energy Performance Building Directive 2002/91/EC. In this context, Portugal started recently to apply a new Regulation of the Buildings Thermal Behavior Characteristics, known as RCCTE (2006), aiming at achieving interior comfort with lower energy consumption levels; however RCCTE (2006) disregards the embodied energy and the life cycle (LC) environmental impacts of construction materials, which according to Bribián et al. (2009) should be included in the building energy certification process. To address current energy and environmental concerns LC thinking must be used to assess building's environmental performance and to support improved materials selection, design and operation of buildings. Selecting materials with low LC environmental burdens and good insulation properties can lead to important energy savings and reduced environmental impacts, Ortiz et al. (2009). Previous Life Cycle Assessment (LCA) studies of residential buildings compared the various LC phases and identified the use and the building materials production as the two most significant phases in terms of energy consumption and environmental impacts, e.g. Sartori & Hestnes (2007). In fact, the building envelope is very important for the overall performance of buildings thermal energy requirements, but the construction requires a considerable amount of materials, with associated embodied energy and environmental burdens. Therefore, it is very important to find optimal LC solutions and to identify trade-offs. The main goal of this paper is to assess alternative building envelope options with the aim of supporting decision at project level of new buildings in Portugal, regarding the selection of exterior walls with reduced LC energy requirements and environmental impacts. This article is organized in 4 sections, including this introduction. The next section describes the LC model developed and presents the inventory. The third section presents the main results, namely the Cumulative Energy required and GHG emissions. The final section draws the conclusions together.

2 LIFE CYCLE MODEL OF A SINGLE FAMILY HOUSE IN PORTUGAL

2.1 Goal and Scope Definition

This section describes the development of a life cycle model for a single family house in Portugal. The main goal was to assess alternative building envelope options with the aim of supporting decision at project level of new buildings in Portugal, regarding the selection of exterior wall systems with reduced life cycle energy requirements and environmental impacts. More specific goals include: i) to estimate the life cycle primary energy requirements and Greenhouse Gas (GHG) emissions of a single-family house located in Coimbra; ii) to characterize the various life cycle processes; iii) to identify the relevance of the construction components to the building overall environmental performance. In addition, a scenario analysis was performed to assess seven alternative exterior wall solutions with different materials (brick, concrete blocks and wood). The various exterior wall solutions studied were defined to have similar thermal coefficients (U-values between 0.47 and 0.51W/m².ºC), and thus similar heating and cooling requirements (a maximum variation of 3%), to permit a straightforward comparison of the building's energy and environmental LC performance.

The model developed was based on the Life Cycle Assessment (LCA) methodology, (ISO 14040, 14044). The LCA methodology has four stages that are interrelated: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation. In the present study, the LCIA results were obtained with two methods: the Cumulative Energy Demand (CED) and the Life Cycle GHG emissions, following the method developed by the Inter Panel on Climate Change (IPPC 2007). The CED calculates the total (primary) energy use (MJeq) throughout the life cycle based on the Higher Heating Value (HHV) and distinguishes renewable (R) and nonrenewable (Non-R) energy sources. The Life Cycle GHG emissions ($kgCO_2eq$) were calculated using IPCC (2007) characterization factors for global warming potential of airborne emissions, for a time perspective of 100 years.

Two alternative functional units have been considered: i) the building living area ($132m^2$) over the life span period (50 years) and ii) a square meter of living area over a year, to allow a comparison with other studies with different residential buildings. The house was assumed to be occupied by a 4-people family. Following the RCCTE (2006), heating/cooling set-points of 20ºC/25ºC, respectively, were considered as well as $4W/m^2$ of internal heat gains (from lights, electrical appliances and occupants). As the main motivation was to assess the LC performance of alternative exterior wall solutions, only heating and cooling energy requirements were accounted for the operational phase, because only these vary with the thermal properties of the chosen walls. Energy required by electrical appliances, cooking, heating water as well as domestic water consumption was not evaluated, as it is out of the scope of this research.

The model developed is schematically represented in Figure 1. The model was implemented in the LCA Simapro 7 software (www.pre.nl). It includes the construction phase and the use phase. The end-of life phase was not considered for two reasons: first, according to a large recent European study (Nemry et al. 2008) is of minor importance (for single-family south European houses it accounts for less than 3.2% of the overall environmental impacts); second, data on possible scenarios of dismantling, recovery and disposal of building materials is not easily available as it is difficult to forecast these scenarios in 50 years.

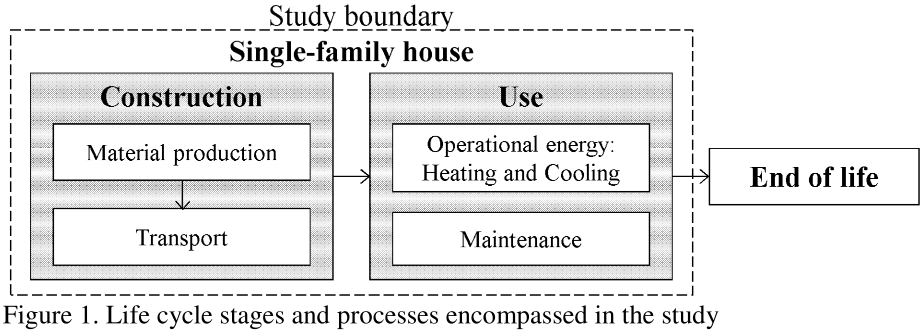

Figure 1. Life cycle stages and processes encompassed in the study

2.2 House specification and Life Cycle Inventory

2.2.1 Construction Phase

The object of the study is a typical single-family house located in Coimbra, Portugal, with an expected life span of 50 years and 132m^2 of living area. Figure 2 presents the house's technical drawings. The living area comprises two floors: the ground floor with a living room, a kitchen, a bathroom, and a storeroom; the first floor with three bedrooms and two bathrooms. In order to focus on the living area and building exterior wall characteristics, no basement, garage, loft, exterior spaces and landscaping were included in the model.

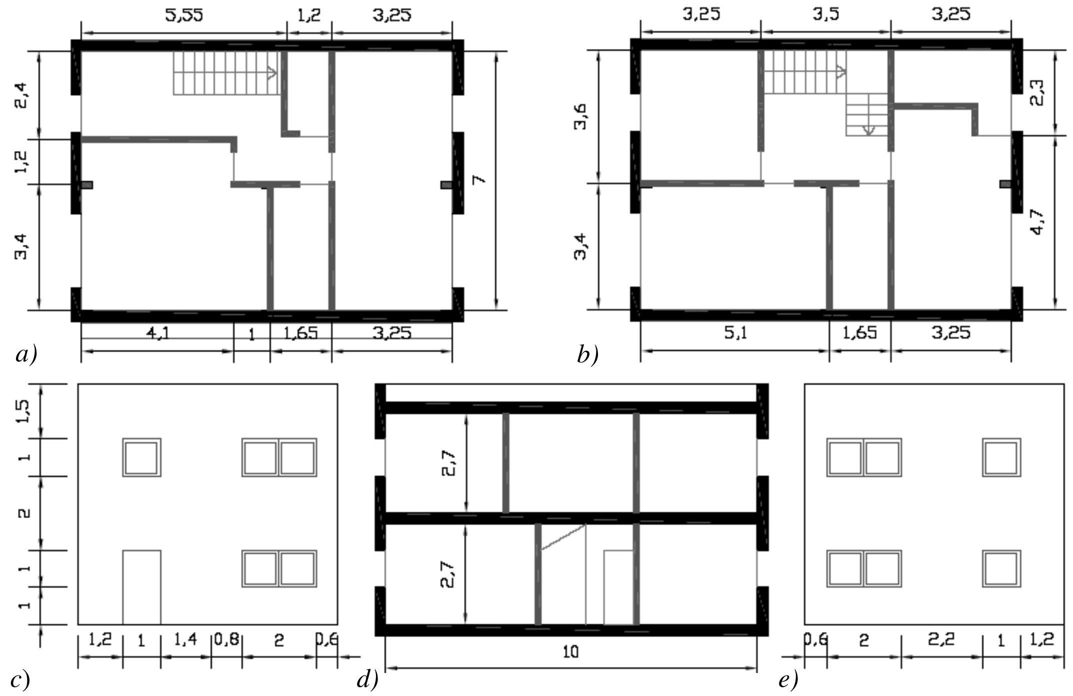

Figure 2. Case study plans: *a)* ground floor, *b)* first floor. Facades: *c)* East, *e)* West. Section: *d)*

All openings are located both on East and West façades, with similar modularity of 1 m^2. The North and South facades are modelled as exterior walls in a detached home although the model could be adapted to a semidetached or attached house. The defined height between slabs is 2.7, resulting in a total volume of 356.4 m^3. Construction materials and techniques used in Portugal were assumed, and all the envelope elements were defined in order to fulfil the requirements of RCCTE (2006). A reference exterior wall solution was adopted: double hollow brick wall, because it is a common solution in Portuguese building practice. Six other alternative scenarios for the exterior walls have been considered in this study. These are described below in section 2.2.2. To minimise the thermal bridges structural columns do not intercept the facades East and West. The house has reinforced concrete slabs (roof, first floor and ground floor) because this type of structure is becoming common and there were not available data for lightweight slab structures.

Table 1 summarizes the different building components. To allow easier tracking of materials, energy and burdens, the inventory of building elements was divided into the following eight components: exterior walls, interior walls, roof, first floor, ground floor, structure, windows and doors. Material production and transport (from producers/distributers to site) characterize the construction phase. An additional 5% of materials (by mass) were accounted to consider losses of material on site due to cutting and fitting processes. Some simplifications were adopted resulting in the disregard of ancillary materials as screws, and some binding elements of the considered components. Interior furniture, electrical appliances, HVAC equipment and sanitary ceramics were out of the scope of the study.

Table 1. Description of building components inventoried

Building components	Area (m^2)	Material layers	Thickness (m)	Volume (m^3/m^2)	Weight (kg/m^2)
Exterior walls (#0)	222	Masonry: hollow brick (30x20x11)	0.110		79.90
		- Cement mortar			22.00
		- Water			3.30
	222	XPS – extruded polystyrene	0.400		1.20
	201	Masonry: hollow brick (30x20x15)	0.150		107.10
		- Cement mortar			30.00
		- Water			4.50
	184	Base plaster	0.040		66.00
Interior walls	110	Masonry: hollow brick (30x20x11)	0.110		79.90
		- Cement mortar			22.00
		- Water			3.30
		Base plaster	0.040		66.00
Roof	74.4	Gravel	0.050		90.00
		Felt PP	0.002		0.13
		XPS – extruded polystyrene	0.050		1.50
		Bitumen	0.010		10.50
		Anhydrite screed	0.050		50.00
		Concrete C25/30	0.150		360.00
		Reinforced steel*			12.00
		Lime mortar	0.02		20.00
First floor slab	76.4	Wood floor (planks)	0.020	0.020	-
		Wooden square joist	0.040	0.003	-
		Anhydrite screed	0.030		30.00
		Concrete C25/30	0.150		360.00
		Reinforced steel*			12.00
		Lime mortar	0.020		20.00
Ground floor	80	Wood planks	0.020	0.020	-
		Wooden square joist	0.040	0.003	-
		Lightweight anhydrite screed	0.050		50.00
		Concrete C25/30	0.120		288.00
		Reinforced steel*			9.60
		Gravel	0.200		360.00
Building components	**Units**	**Material layers**		**Area/un (m^2)**	**Mass /un (kg/un)**
Structure					
- Beam (0.3x10x0.2)	6	Concrete C25/30			1440.00
		Reinforced steel*			48.00
- Column (6x0.2x0.3)	9	Concrete C25/30			864.00
		Reinforced steel			28.80
- Foundation (2x0.3x0.4)	9	Concrete C25/30			576.00
		Reinforced steel			19.20
Windows	11	Aluminium frame		3.24	
		Double glazing (U=1.1)		7.95	
Doors	1	Exterior wooden door		2.00	
	8	Interior wooden door		1.60	

*(80kg/m^3 of concrete)

The main building construction data was obtained from Kellenberger et al. (2007), which have collected average European data for the production of construction and building materials. The material production background data accounts only for processes till packaging of products at gate. Transportation of the construction materials to building site was included in the model, based on the modes of transportation and distances from manufacturers' gate to the construction site. The following total transportation values were determined: 17630 ton.km travelled by lorry transportation, assuming European fleet average characteristics. Technical information about the products' characteristics and the construction quantities were based on the ITE50 reference manual (Santos, 2006), technical data available from companies in Portugal (Lusoceram, Weber, Maxit, Ytong, Cin) and from the AICCOPN database (http://prc.aiccopn.pt/). The following aspects were found to be not very important and, thus, were not included: equipments used in the construction operations; transport of construction laborers to the construction site. According to Nemry et al. (2008) the relevance of these processes is minor in residential buildings and thus neglect them do not impair the study

2.2.2 *Alternative scenarios for the exterior wall solutions*

Seven scenarios for alternative exterior wall solutions (with similar thermal coefficients) have been defined: two are based on double wall with brick masonries; three have single masonries of concrete blocks, and the last two include wood in their composition. The base scenario #0 has double wall with hollow brick masonries (11 and 15 cm) and 4 cm-thick insulation layer (polystyrene extruded). The first scenario (#1) has a double wall with solid facing brick (11 cm) and hollow brick (15 cm) masonries and the same insulation than base case. The three following scenarios are composed by 20 cm single masonries with concrete blocks and an External Thermal Insulation Composite System (ETICS): #2 has pumice lightweight concrete blocks and 5 cm insulation; #3 has expanded clay lightweight concrete blocks also called thermal blocks and 4 cm insulation; while scenario #4 has autoclaved aerated concrete blocks with 3 cm of insulation. The two last scenarios include wood in their composition: #5 has exterior wood cladding with 15 cm hollow brick masonry and 4 cm insulation and the #6 has a timber frame structure, 5 cm insulation and wood cladding.

2.2.3 *Use Phase*

The heating and cooling system of the house is a 10 kW heat pump with a coefficient of performance (COP) of 2.8 for heating and 2.0 for cooling. The annual operational energy (heating and cooling) was calculated based on the RCCTE (2006) simplified method. The various exterior wall solutions studied were defined to have similar thermal coefficients (U-values between 0.47 and 0.51W/m².ºC), and thus similar heating and cooling requirements, were obtained: on average 71.8kWh/m^2.year for heating and 3.8 kWh/m^2.year for cooling (a maximum variation of 3% among the various scenarios). Table 2 describes the maintenance activity and schedule for each building component. This has been established based on producers' information and on Blanchard & Reppe (1998); Kunzel et al. (2006).

Table 2. Maintenance activity

Component	Maintenance activity	Area (m^2)	Vol/act (L)	Mass/act (kg)	Years	Times in LC
Exterior walls	Exterior paint (1.5kg/m^2)	261.3	-	391.95	10	4
	Interior paint *	183.6	26.23	36.43	20	2
Interior wall	Interior paint *	218.8	31.26	43.42	20	2
Roof	Betumen	74.4	-	781.20	25	1
First floor	Interior varnish**	67.0	4.47	6.83	10	4
Ground floor	Interior varnish**	65.0	4.33	6.63	10	4
Windows	Glass replacement 100%	7.95	-	-	25	1
Doors	Exterior varnish***	4.0	0.80	0.82	4	12
	Interior varnish**	25.6	2.56	2.61	10	4

*(7m^2/L and 1.39kg/L); **(10m^2/L and 1.02kg/L). ***(5m^2/L and 1.02kg/L)

3 ENERGY AND GHG EMISSIONS RESULTS

3.1 *Single-family house life cycle stage and process*

The Cumulative Energy Demand (CED) and Greenhouse Gas (GHG) emissions for the various life cycle processes of the dwelling are presented in Figure 3. The total CED amounts to 375 MWh (1.35 TJ) for the single family house over 50 years. In terms of energy use per living area over a year, a value of 204 MJ/m2.year was calculated. CED results include both renewable and non-renewable cumulative energy demand (in primary energy terms). The use phase is the most energy consuming stage, with 55% of the entire building's CED (41% to heating, 11% to maintenance, and 3% to cooling). It is worth to note that embodied energy in the construction phase (materials and transportation to the construction site) exceeds heating energy requirements, if a 50 years life span is considered and current thermal regulation requirements are met. This shows the importance of embodied energy in the buildings' overall performance and justifies the further study of construction components, which most of the time are neglected in buildings' energy performance studies. Concerning life cycle GHG emissions, the dwelling is responsible for more than 85 tons of CO_2eq over 50 years, or 12.9 kg CO_2eq/m^2.year. The two most significant processes are heating (43%) and materials production (40%). Transport and maintenance hold about 7% of CO_2 emissions each, and cooling is the less significant process.

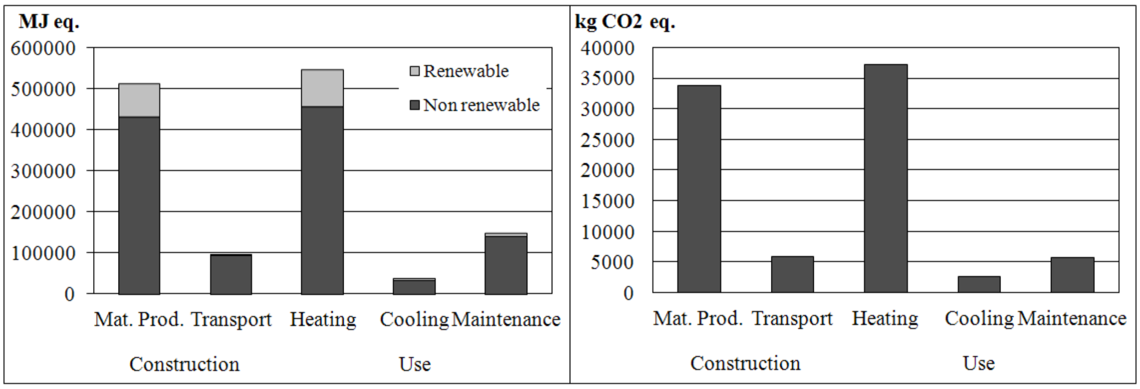

Figure 3. Cumulative Energy Demand (a) and GHG emissions (b) per life cycle stage and process

3.2 Single-family house construction components

Embodied energy and CO2eq emissions of material production are presented in Figure 4 per construction component. It can be seen that exterior walls have a great impact both on embodied energy and GHG emissions of the building (35% and 43%, respectively), being responsible for more than 160 GJeq of non renewable energy and almost 15 tons of CO2eq emissions. The roof is the second more energy demanding component with 16% of building's embodied energy and has a similar share in terms of GHG emissions accounting nearly 6 tons CO_2eq emissions.

It can be noticed that some components (first floor, ground floor, and doors) have a relevant share of renewable embodied energy that is mainly explained by the inclusion of wood elements in their composition. In terms of CO_2eq emissions, Figure 4 depicts that the dwelling have positive and negative values. Negative values correspond to a credit of CO_2 that characterizes the carbon fixation in wood. For this reason the two floors present fewer CO_2 emissions when compared with the roof, and the doors have a negative value. Doors, windows and structure are the components with less impact.

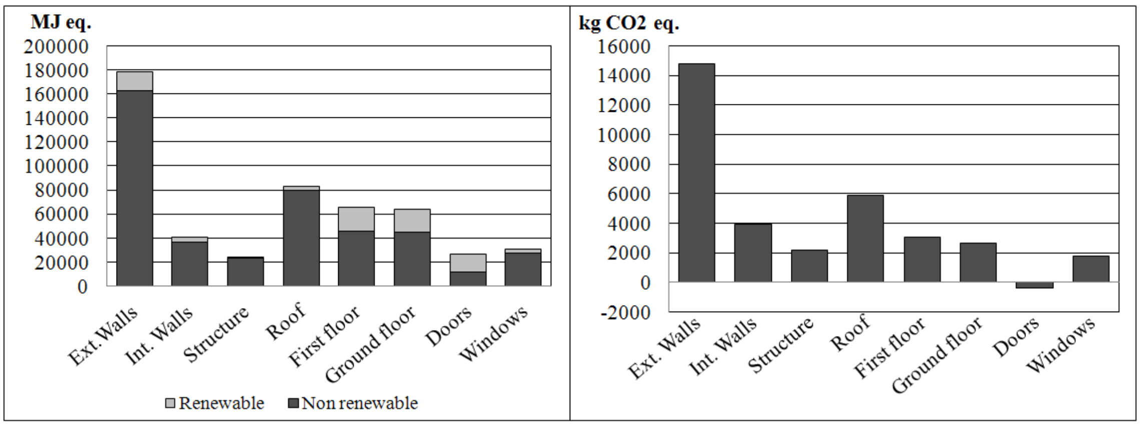

Figure 4. Cumulative Energy Demand (a) and GWP (b) per construction components

3.3 Scenario Analysis: comparison of alternative exterior wall solutions

As shown in the previous section, the exterior walls are by far the most significant building component. Thus, single-family houses with seven alternative exterior wall solutions were modelled and assessed in terms of energy and GHG emissions. Table 3 presents the scenarios and compares CED and GHG emissions for each building scenario, per square meter of living area and year. Total (50 years) CED and GHG values for the various building components in each scenario are shown in Figure 5. Results show similar trends when considering non-renewable primary energy and CO2eq emission. Scenarios #6, #5, #2, and #4 present lower burdens both on non-renewable energy and CO2eq emissions, but the best performing solutions are those that include wood in their composition (#5 and #6). Wood sequesters CO_2, which results in a negative embodied CO_2 value that partially annuls CO_2 emissions from other construction components. Wood wall scenario (#6) cuts 61% of building's GHG emissions, while the wood cladding scenario (5#) reduces by 28% the buildings' CO_2eq emission when compared with base case scenario (#0).

In terms of non renewable (Non-R) primary energy, the best solution (#6) saves 25% Non-R energy relatively to the base scenario #0, but if considered total CED (R and Non-R) this solution has slightly higher energy demand than #0 (more 2.5%). Two solutions have a worse performance than the base scenario: #1 (double wall with facing brick masonry) and #3 (single wall with thermal concrete blocks). Scenario # 4 is very close to #0 base solution.

Table 3. Single-family house CED and GHG emissions. Seven alternative exterior wall systems

Ref.	Exterior wall description	CED (R.) MJ/m^2.year	CED (Non-R.) MJ/m^2.year	GHG kg CO_2/m^2.year
# 0	Double hollow brick masonry (base scenario)	12	65	5.13
# 1	Double facing and hollow brick masonry	13	74	6.07
# 2	Lightweight concrete blocks masonry	11	56	4.35
# 3	Thermal concrete blocks masonry	11	68	5.30
# 4	Autoclaved aerated concrete block masonry	11	64	5.09
# 5	Hollow brick masonry and exterior Wood cladding	22	57	3.67
# 6	Wood frame and cladding	30	49	2.00

R. (Renewable); Non-R. (Non renewable)

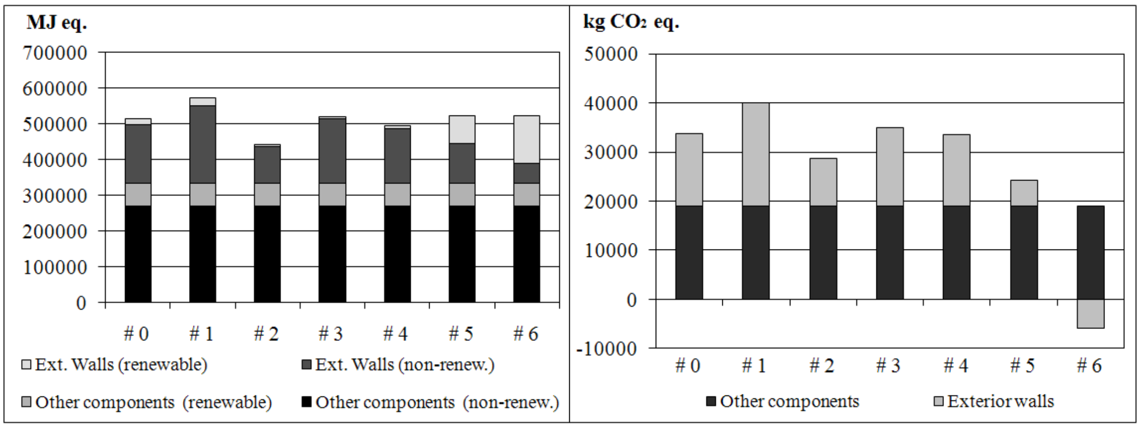

Figure 5. Cumulative Energy Demand (a) and GWP (b) for the various alternative constructions.

4 CONCLUSIONS

A life cycle model for a single-family house in Portugal has been developed to assess alternative building envelope options with the aim of supporting decision at project level of new buildings in Portugal, regarding the selection of exterior wall systems with reduced life cycle energy requirements and environmental impacts. Seven scenarios for alternative exterior wall solutions (with similar thermal coefficients) have been assessed: two are based on double wall with brick masonries; three have single masonries of concrete blocks, and the last two include wood in their composition. The results obtained with the LC model developed show that the two more important processes in terms of energy and GHG emissions are heating the house, during the use phase, and material production, during the construction phase. Although heating presents the highest values (39% Non-R energy and 43% GHG emissions), material production is responsible for 37% of primary energy (Non-R) and 40% of the GHG emissions. In dwellings that abide by current thermal regulations, embodied energy tends to be an expressive part of building's life cycle CED, and therefore must be carefully studied.

Concerning materials production, exterior walls are by far the most significant component both in terms of Non-R embodied energy and GHG emissions (35% and 43%, respectively). The results from the scenario analysis show important differences for the various exterior wall systems. We conclude that solutions with wood in their composition allow significant reductions in building's GHG emissions (61% in wood wall scenario and 28% in wood cladding scenario) and also decrease the requirements for non renewable embodied energy (25% in wood wall scenario). The solutions that present the worse life cycle performance are #1 (double wall with facing brick masonry) and #3 (single wall with thermal concrete blocks), both having worse performance than the base scenario #0. Special attention must be given when choosing solutions similar to #1 and/or #3. It should be noted that the scenarios were defined to have similar thermal coefficients (U-values between 2.0 and 2.1W/m².ºC), and thus similar heating and cooling requirements (a maximum variation of 3%), to permit a straightforward comparison of the building's energy and environmental LC performance.

5 ACKNOWLEDGMENTS

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Potential solutions to glazed facades in the tropics

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ABSTRACT: This study verified two office buildings in the metropolitan are of the city of São Paulo, Brazil. Both of them have the same plate and number of stories, but one is oriented north-south, whilst the other is east-west. The main façades are all glazed without any kind of sun protection. Considering that glazed façades are responsible for solar heat gain and penetration of sunlight on people, work plan and equipment, the application of this study was undertaken in order to obtain the design of a system of sun protection and check it in terms of reducing heat load and its possible effects in the energy consumption of the air conditioning system. Different solutions were checked and compared, including brise-soleil, film coated and screens. First, it was determined the need for masking the sky, for each of the façades involved in order to preserve the maximum possible visibility to the outside and natural light, determining the dimensions of the brise-soleils. The next studies aim to check the penetration of direct solar radiation in the openings of different façades, for the case of winter and summer. For the quantification of daylighting system it was calculated the Daylight Factor (FLD), considering the celestial component, the external and internal reflection component, being the sum of these components weighted by frame, maintenance and light transmission of glazing coefficients. Thermal energy simulations, based on the annual climate, aimed to compare the reduction in heat load and thus energy consumption by the system of artificial air conditioning for different interventions in the buildings. Considering the results presented, the solutions found to the first building (facing North and South) show results with small reductions in energy consumption for air conditioning, respectively 1.5%, 2.3% and 3.6% for solutions with film coated, screen and brise-soleil, whereas the estimation of total energy reduction in this building are respectively 0.5%, 0.8% and 1.2%. When considering the results for the second building (facing East and West), the results show more significant reductions in energy consumption for air conditioning: 8.0%, 12.2% and 16.1% for the respective solutions, whereas the estimation of total energy-reduction for this building are 2.7%, 4.1% and 5.4%.

1 INTRODUCTION

This study verified two office buildings in the metropolitan are of the city of São Paulo, Brazil. Both of them have the same plate and number of stories, but one is oriented north-south, whilst the other is east-west. The main façades are all glazed without any kind of solar protection. Considering that glazed façades are responsible for solar heat gain and penetration of direct sun radiation on people, work plan and equipment, this study was performed in order to obtain the design of a system of sun protection and its check in terms of reducing heat load and its possible effects in the energy consumption of air conditioning system. Different solutions were checked and compared, including film coated, screen and brise-soleil.

In order to perform simulations of thermal energy, it was used an annual weather database on hourly basis. Given the lack of specific data to the place where the buildings are under study, it was considered the availability of existing data, focusing on its reliability and proximity to place of study. Thus, the database project Solar and Wind Energy Assessment Resource (SWERA, 2004) was chosen to be used. The database refers to the meteorological station of Congonhas (WMO Station 837800, IAG-USP, 2007), S23°37',W46°39',GMT-3.0,803M above sea level, standard atmospheric pressure of 92043Pa. Data were collected from 1973 to 2002, having been treated statistically to the creation of one year from the months typically representative of climatic conditions of the period. Table 1 presents a summary of climatic data used.

Table 1. Climate Data Summary

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Monthly statistics for air temperature (°C):											
Maximum	34.0	35.0	32.0	31.8	29.5	26.0	27.0	31.0	32.0	33.0	32.0	31.0
Minimum	14.0	16.0	16.0	13.6	11.5	7.0	8.0	5.0	10.0	12.0	14.0	14.0
Mean	22.8	22.7	22.5	20.4	18.0	16.2	16.0	17.6	17.6	18.9	20.0	21.9
	Monthly statistics for relative humidity (%):											
Maximum	100	100	100	100	100	100	100	100	100	100	100	100
Minimum	31	18	36	40	37	29	26	20	17	24	29	37
Mean	78	80	77	81	78	79	77	70	77	79	78	78
	Monthly statistics for wind speed (m/s):											
Maximum	14.4	40.0	10.3	6.7	10.3	7.2	7.7	20.6	8.2	28.8	11.8	20.5
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	2.3	3.5	2.4	2.0	2.6	1.3	1.5	2.0	2.5	3.0	3.7	2.8
	Monthly statistics for solar radiation (Wh/m^2):											
Normal Direct Avg.	3560	3336	3533	3651	3261	3550	3574	4098	3283	3191	3542	3335
Normal Direct Max.	9023	7130	6543	7697	7060	6491	6914	8171	7482	7606	8113	6449
Difuse Max.	2992	2870	2358	1948	1557	1274	1375	1652	2369	2655	2891	3312
Global Max.	5646	5386	4855	4272	3344	3132	3330	4154	4630	5059	5576	5852

2 SOLAR ANALYSIS

2.1 *Solar protection*

In the solar analysis, firstly, it was determined the need for masking the sky, for each of the façades involved, in order to take advantage of daylighting and preserve the maximum possible visibility to the outside, determining the dimensions of the brise-soleils.

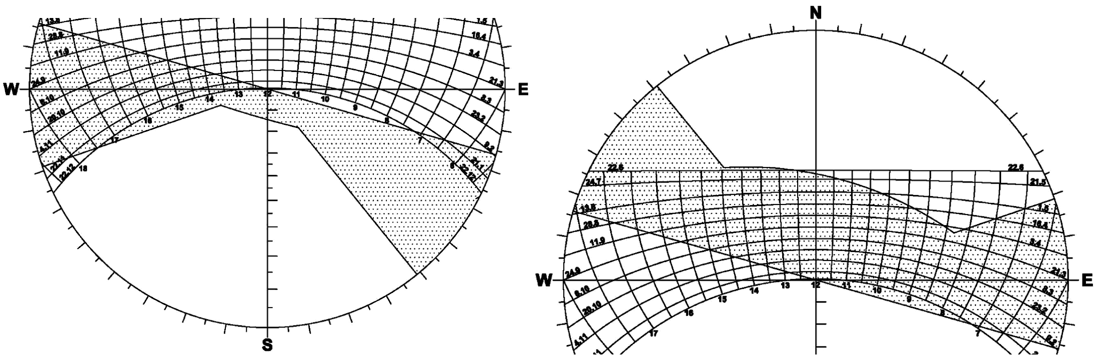


Figure 1. Solar mask provided by brise-soleil for the south façade (azimuth 196°) and north façade (16°).

As can be seen from Figure 1, the mask proposed for the south façade allows the penetration of sun in the summer solstice after 18:30. Considering the conditions of the surroundings (other buildings), a considerable part of the building will not even receive this incidence. Moreover, that time is outside the period of occupation provided by the client (Monday to Friday, from 8:00 to 18:00). In geometric terms, we have then an angle $\beta = 55$ ° (angle of vertical brise protection in relation to the normal of the facade) and about an angle $\alpha = 75°$ (angle of protection of the brise horizontal to the horizon). In fact, the solution of brise-soleil in the south façade, as will be seen, needs no horizontal plates, only one grid for each floor, which serves as the "closure" to the vertical brise and allows the maintenance of the façade. As can still be seen from Figure 1, the mask proposed for the north facade allows the entrance of the solar rays especially during the fall and winter. In the limit of the winter solstice (22/06), the penetration of direct solar radiation is from 6:45 until 12:30. In the months before and after (from early April until mid-September) the period that receives direct solar radiation decreases, to the extent that it penetrates only a small slit for a moment at 8:20. In geometric terms, it has remained the same angle $\beta = 55°$ (angle of vertical brise protection in relation to the normal of the facade) in order to standardize the two solutions brises in the north and south facades, also using the same solution grid to maintain the facades. However, due to higher solar incidence, it was determined an angle α = 75° (angle of protection of the horizontal brise to the horizon). Thus, in the south façade vertical brises are enough for solar protection, whilst in the north facade horizontal brises are also required.

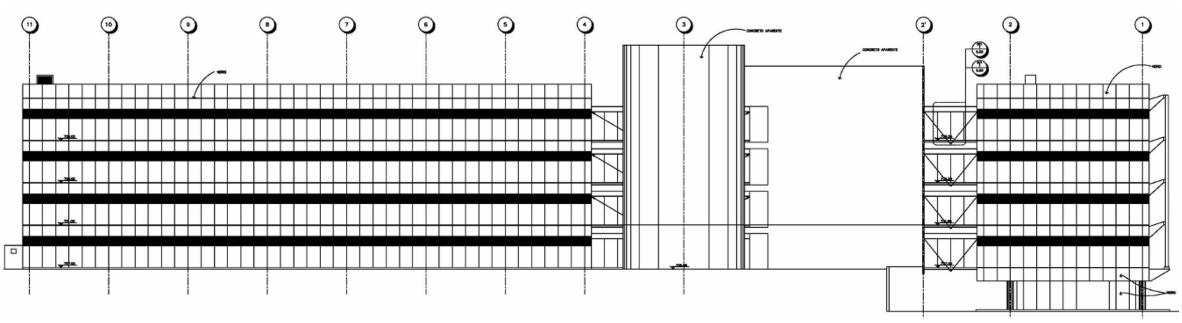
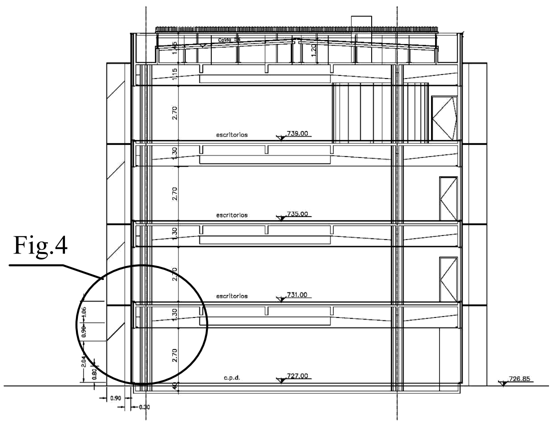


Figure 2. Elevation of North Façades, with Horizontal Brise-Soleil (black stripes) and Vertical-Brise Soleil (thin vertical lines)



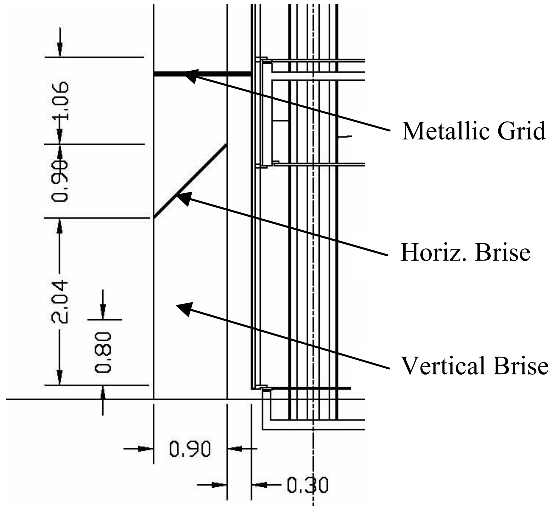


Figure 3. Section with the brise-soleil solution

Figure 4. Detail with the brise-soleil (North Façade)

2.2 *Solar penetration*

The next studies aim to check the penetration of direct solar radiation in the openings of different façades, respectively for the case of winter and summer. The goal was to compare the penetration of direct sun penetration to the current situation and the situation with the use of the proposed systems of brise-soleils. Figure 5 and 6 show the results.

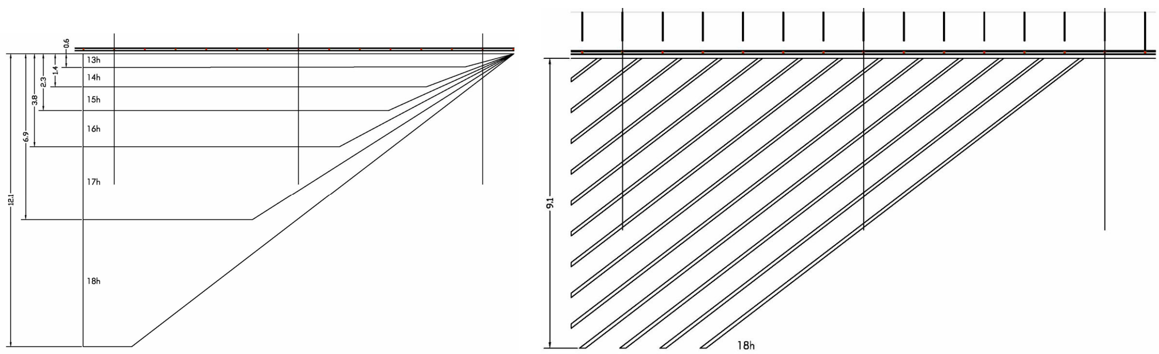


Figure 5. Solar penetration in the summer (South Façade) without brise-soleil (from 13h to 18h) and with brise soleil (only at 18h).

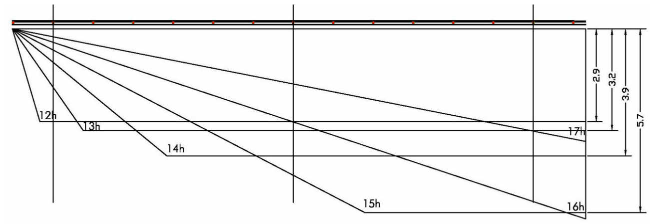


Figure 6. Solar penetration in the winter (North Façade) without brise-soleil (from 13h to 17h). With brise soleil there is no solar penetration in this period.

3 DAYLIGHTING ANALYSIS

3.1 *Daylighting assessment*

For the quantification of daylighting system, it was considered the availability of daylight in the order of 20,000 lux for the frequency of occurrence of 67% of daylight hours of the year in the city of São Paulo. To calculate the Daylight Factor (DF), it was considered the celestial component, the external and internal reflection components, being the sum of these components weighted by frame, maintenance and the light transmission of glazing coefficients (Alucci, 2007). It were studied the following spots (see Table 2) to determine the values of sky component and availability of daylight.

Table 2: Results of Daylight Factor and iluminance in different spots of the two studied buildings

	North Façade (2m from façade)		North and South Façades (8,2m from façades)		South Façade (2m from façade)	
Building A	DF	Ep	DF	Ep	DF	Ep
Actual	5,7%	1140 lx	3,3%	660 lx	-	-
Film	3,8%	760 lx	2,2%	440 lx	-	-
Screen	3,0%	600 lx	1,7%	340 lx	-	-
Brise-Soleil	2,8%	560 lx	2,0%	400 lx	-	-
Building B						
Actual	5,2%	1040 lx	1,6%	320 lx	4,7%	940 lx
Film	3,5%	700 lx	1,1%	220 lx	3,1%	620 lx
Screen	2,6%	520 lx	0,8%	160 lx	2,3%	460 lx
Brise-Soleil	1,5%	300 lx	1,1%	220 lx	1,9%	380 lx

As it can be seen, in building A, the three solutions provide sufficient daylight, for office activities, considering the NBR 5413 (1992), which recommends values between 300 and 700 lx, and one may note that the three solutions satisfactorily meet this criterion in situations of the studied sky conditions. With respect to Building B, the three solutions also comply with that in the facades, with values between 300 and 700 lx. Note that the dimensioning of horizontal plates in the previous topic was done exactly based on meeting the criterion of 300 lx in this situation. Regarding the situation of the inner situation in building B, it should be noted that the results have been between 160 and 220 lx. They appear quite favourable, since, although not sufficient for the practice of labour activities, they are sufficient for general lighting or for lighting for circulation. Finally, we emphasize once again that the adoption of the value of 20,000 lx refers to a situation of overcast or partly cloudy and when there is sun exposure, the availability of daylight will be up to five times greater than that shown in the results. Thus, it is considered that the intensity and distribution of solutions of daylighting proposals are appropriate, but may reach values much higher than necessary on a clear day. Thus, the brises solution proved to be more advantageous to minimize the situations of glare by blocking the direct solar radiation, as shown earlier in this article.

3.2 *Exterior visual access*

Among the three solutions in verification, the application of film coated is the one that least affects the visibility of the exterior, just causing some changes in terms of tone colours. The use of the screen remains visible outside, but its quality is impaired, reducing, for example, recognition of details of the external environment. The option for brise soleil also significantly alter the external visibility, but in a different manner. The visibility is reduced vertically by the lower horizontal edge of the plates (which is above the eye level of people), while the presence of vertical elements segments the visual as a whole. These consequences can be seen in the drawings presented earlier in this article, when considering the solutions proposed for the brise soleil.

4 THERMAL ENERGY ANALYSIS

4.1 *Thermal Loads*

Thermal energy simulations, based on the annual climate database, aimed to compare the reduction in heat load, and thus energy consumption by the system of artificial air conditioning, for different interventions in the buildings.

Table 2: Material properties used for the annual hourly basis thermal energy simulations

Components: façades, ceilings, and pavements	Thermal conductibility λ (W/m°C)	Density d (kg/m³)	Specific heat c(J/kg°C)	Global Heat transmission U (W/m°C)	Solar absorption α	Emissivity ε
Exposed concrete	1,65	2200	1005	3,196 (↔)	0,65	0,90
Structured concrete	1,75	2400	1005	3,226 (↔)	-	-
Corrugated metal roof	43	7800	500	4,759 (↓) 7,137 (↑)	0,53	0,25
Epoxy	0,31	1381	1600		0,60	0,90
Concrete	1,28	2000	1005		-	-
Air layer	-	-	-	0,391 (↓) 0,413 (↑)	-	-
Glassfiber	0,04	64	754		-	-
Veil of white glass	-	-	-		0,40	0,90
Carpet	0,06	186	1360		0,60	0,90
Felt	0,04	150	754		-	-
Concrete	1,28	2000	1005	0,384 (↓) 0,405 (↑)	-	-
Air layer	-	-	-		-	-
Glassfiber	0,04	64	754		-	-
Veil of white glass	-	-	-		0,40	0,90

The internal heat sources considered were: A) Occupation: According to data supplied by the client, Building A has capacity for 362 people and Building B to 370 people. Thus, considering the activity of office, which has metabolic rate of 130W, in which 65W are sensible heat and 65W are latent heat, it was calculated the internal heat load factor, resulting in the 7W/m^2 for sensible heat and 7W/m^2 for latent heat. B) Equipment: Specific data regarding the thermal loads of equipment were provided only to a lab of the 4th floor of Building A. Thus, for the generalization to other environments, it was assumed that each user has a computer, with an estimated load of 120W, resulting in 13W/m^2 sensible heat. C) Lighting: considering all the fixtures, lamps and their powers, it resulted in 13.5 W/m^2; considering all the lighting system, ie, the power of the lamps, plus their control equipment used in conjunction (ballast, ignitor, transformer, etc), it resulted in 21W/m^2. Once finalized the computer simulations, considering all the hygrothermal trades of energy balance, Table 3 show the thermal loads to be removed respectively from Building A and B, considering the system of artificial air conditioning operating in a way to provide environmental conditions with air temperature at 24°C, relative humidity 50%, Monday to Friday, from 8h to 18h, with a total of 2.600 conditioning hours per year (approximately 60% of daylight hours of the year).

4.2 *Energy Savings*

In order to verify the savings in the consumption of air conditioning it is required the coefficient of performance (COP) of air conditioning system and the pricing adopted by the energy supplier. According to available data, the value of the contract price is R$0.256/kWh. (1R$=0.56US$= 0.39 EURO, in Dec 15th 2009). The HVAC in Buildings A and B is composed of a central chilled water of 360 TRs, supplied by 4 refrigeration units (chillers) with air condensers and scroll type compressors. The expansion system is indirect, by cold water and fancoils, with no cooling towers. The chillers are Trane, model CGAD090-90TR. The cold water at 5°C is pumped to the buildings for bombs with spin control to keep the pressure at 6 kg/cm². Each floor has two fancoils, except the ground floor of Building A and the 1st floor of Building B that have only one each. Adjustment of temperature environments is done by controlling the volume of air blown by flow control valve installed in the distribution pipeline. The return air is full of the liner, or without ducts to the fancoil. Considering the description provided by the client, it was adopted the coefficient of performance of the system COP = 3.0.Considering an area of 3500m^2 per building, the values, presented before in this article, can be applied to forecast electricity consumption for artificial lighting system and equipment, considering the period from 8 to 18h from Monday to Friday throughout the year. Tables 4 and 5 present the results.

Table 3: Thermal loads to be removed monthly by the HVAC system in Bulding A and Building B and respective reductions according to the adopted solutions (film coated, screen and brise-soleil).

	Building A (MWh)				Building B (MWh)			
	actual	film	screen	brise	actual	film	screen	brise
Jan	97,0	96,0	95,5	95,0	94,9	88,6	85,3	83,4
Feb	125,2	123,9	123,2	122,2	122,7	114,5	110,2	107,2
Mar	93,7	92,4	91,7	90,5	93,9	87,1	83,6	79,7
Apr	76,8	75,4	74,6	73,3	80,1	73,3	69,7	65,6
May	64,9	63,6	62,8	61,6	68,7	62,6	59,3	55,7
Jun	54,6	53,1	52,2	51,0	59,8	53,3	49,9	45,8
Jul	52,8	51,3	50,5	49,1	57,1	50,8	47,5	43,2
Aug	63,6	62,2	61,5	60,2	65,3	59,2	56,0	51,7
Sep	58,0	57,1	56,6	55,8	57,8	52,7	50,1	47,6
Oct	76,9	76,1	75,6	75,0	74,7	69,3	66,5	64,7
Nov	79,8	79,1	78,7	78,3	77,7	72,4	69,7	68,2
Dec	85,2	84,3	83,9	83,4	83,6	77,6	74,5	72,9
Year	928	914	906	895	936	861	822	785
Reduction	-	1,5%	2,3%	3,6%	-	8,0%	12,2%	16,1%

Table 4. Annual Energy Costs and Savings for Building A (1R$=0.56US$=0.39EURO, in Dec 15th 2009)

	Actual	%	Film	%	Screen	%	Brise	%
HVAC	R$ 79.226	33,3	R$ 78.020	33,0	R$ 77.381	32,8	R$ 76.403	32,5
Lighting	R$ 97.844	41,2	R$ 97.844	41,4	R$ 97.844	41,5	R$ 97.844	41,7
Equipments	R$ 60.570	25,5	R$ 60.570	25,6	R$ 60.570	25,7	R$ 60.570	25,8
TOTAL	R$ 237.640		R$ 236.434		R$ 235.795		R$ 234.817	
Reduction	-		0,5%		0,8%		1,2%	
Savings			R$ 1.205		R$ 1.845		R$ 2.823	

Table 5. Annual Energy Costs and Savings for Building B (1R$=0.56US$=0.39EURO, in Dec 15th 2009)

	Actual	%	Film	%	Screen	%	Brise	%
HVAC	R$ 79.894	33,5	R$ 73.508	31,7	R$ 70.181	30,7	R$ 67.038	29,7
Lighting	R$ 97.844	41,1	R$ 97.844	42,2	R$ 97.844	42,8	R$ 97.844	43,4
Equipments	R$ 60.570	25,4	R$ 60.570	26,1	R$ 60.570	26,5	R$ 60.570	26,9
TOTAL	R$ 238.308		R$ 231.922		R$ 228.595		R$ 225.452	
Reduction	-		2,7%		4,1%		5,4%	
Savings			R$ 6.386		R$ 9.714		R$ 12.856	

4.3 *Thermal comfort analysis*

For the evaluation of thermal comfort, ASHRAE 55 (2004) was used. Thus, considering the climate-controlled environments, PMV model was applied, which considers the air temperature, relative humidity, air velocity, mean radiant temperature, user activity and type of clothing. Considering the studies that were conducted, the following variables were considered for verification of thermal comfort: air temperature = 24°C (kept constant by the system of artificial air conditioning); Relative humidity = 50% (kept constant by the system of artificial air conditioning); Air velocity <0.2 m/s (at the user level, given the conditions of system); metabolic rate = 1.3 Met (rate of metabolic heat on the daily activities of office); clothing insulation = 0.5 clo (summer clothing: pants and social shirt). Therefore, it remains to determine the mean radiant temperature to see if the conditions are, or not, providing comfort. These values were obtained by the thermal energy simulations performed. As a result, the curves of mean radiant temperature for the first and fourth floor of each building proved to have lowest and highest values, whilst the results of the second and third floors are intermediate to the previous curves. Thus, the results are going to be considered in terms of the extreme cases. For the given conditions was calculated the operative temperature, which, for the typical situation in question, was estimated from average of the mean air temperature and mean radiant temperature, as recommended by the standard. Performing the procedures prescribed by the standard, it is observed that for the conditions listed above, the operative temperature which provides comfort conditions (percentage of people dissatisfied with the environment in general, considering the criteria of less than 10%) is ≤ 27.2ºC (represented by the strong black line in graphics of operative temperature). Figure 7 and 8 present the final results of thermal comfort in terms of operative temperature, comparing the current situation with the three solutions tested for the case of Buildings A and B.

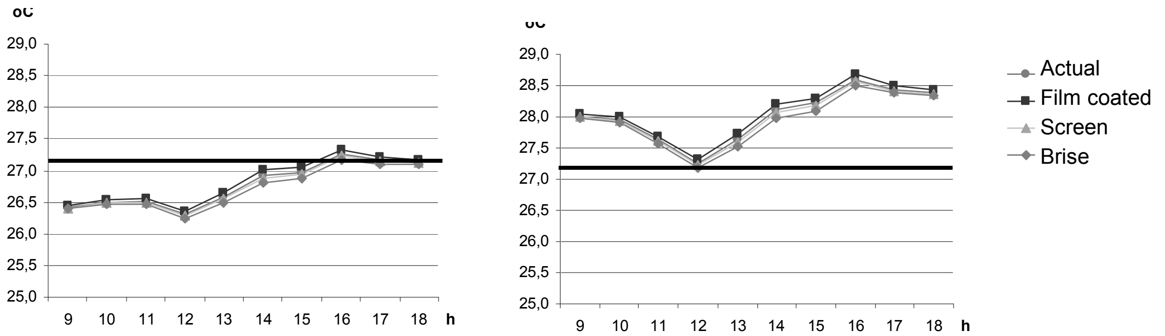


Figure 7. Operative Temperatures for Floors 1 and 4 of Building A

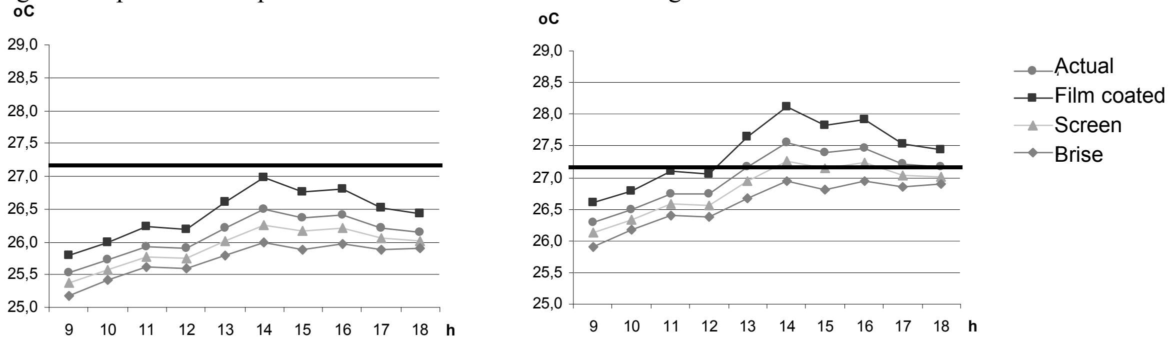


Figure 8. Operative Temperatures for Floors 1 and 4 of Building B

5 DISCUSSION

Considering the proposed solutions, and the energy saving provided, one may also see the different impacts in terms of thermal comfort considering the maintenance of the initial 24ºC and 50% rh. These parameters could be reconsidered, but for now, the discussion is going to analyze the solutions is term of operative temperature. As can be seen in the graphs of operative temperature of Building A, the use of different solutions of solar protection does not involve significantly the results, with variations of only ±0.1ºC. This result is the verification for a hot summer day, and there is no occurrence of direct solar radiation on the north facade of Block A, for which solutions were studied. With respect to Building B, the operative temperature charts showed the most disparate results between the various solutions. This is because the glazed facades of north and south make the most significant for the rest of the building and mainly due to the different performance obtained with regard to blocking the direct solar radiation on the south facade, since it is a summer day. Looking at the chart to the first floor, the current situation and all the proposed solutions provide a level of comfort. However, one must emphasize that the solution of film coated presents performance well below the current situation, without it. Considering the situation of peak at 14h, the current situation presents operative temperature of 26.5ºC while the adoption of the film coated increase operative temperature to 27.0ºC. Throughout the day, on average, the adoption of the film coated increases by 0.3ºC the average operative temperature. As for the situation on the fourth floor, as argued for Building B it also becomes more critical. In this case the graph shows very different results for different solutions, indicating that the current situation is outside the comfort zone from 14h to 16h. The use of film coated takes the operative temperature from 27.6ºC up to 28.1ºC. The consequence is that from 13h to 18h it is outside the comfort zone. Since the solution of the screen provides comfortable conditions virtually throughout the day (only at 14h it has a peak operative temperature of 27.3ºC). Finally, the brise soleil solution presents itself as the most favourable, providing all day comfort conditions, with a maximum operating temperature of 27ºC, within the comfort zone.

6 SUMMARY

Table 6 presents a synthesis of the results found considering the solar and daylighting analysis, exterior visibility, energy saving and thermal comfort for different solutions (film coated, screen and brise-soleil) for the façades of the two different studied buildings. Considering the results presented, the solutions found to the first building (facing mainly North and South) show results with small reductions in energy consumption for air conditioning, respectively 1.5%, 2.3% and 3.6% for solutions with film coated, screen and brise-soleil, whereas estimates total energy reduction in respectively of 0.5%, 0.8% and 1.2%. When considering the results for the second building (facing mainly East and West), the results show more significant reductions in energy consumptions for air conditioning: 8.0%, 12.2% and 16.1%, estimating total energy reduction for respectively of 2.7%, 4.1% and 5.4%.

Table 6. Final results for solar, daylighting, exterior visibility, energy saving and thermal comfort (R$=0.56US$=0.39EURO, in Dec 15th 2009)

	Film	Screen	Brise-Soleil
Solutions	Prestige Line Model P70 Brand 3M	Generic (to be produced) Luminuous transmission and solar transmission: 50%	According to drawings presented in this article
Daylighting	Satisfactory to excessive Reasonable homogeneity Façade: North, Centre, South Bldg.A: 760, 440, - lx Bldg.B: 700, 220, 620 lx	Satisfactory Reasonable homogeneity Façade: North, Centre, South Bldg.A: 600, 340, - lx Bldg.B: 520, 160, 460 lx	Satisfactory Adequated homogeneity Façade: North, Centre, South BlocoA: 560, 400, - lx BlocoB: 300, 220, 380 lx
Exterior Visibility	Practically no alteration	Alteration in quality	Alteration in quantity
Energy Saving	Bldg.A: Very Low Bldg.B: Low HVAC Energy Saving Bl.A: 1,5% Bl.B: 8,0% Total Energy Saving Bl.A: 0,5% Bl.B: 2,7% Annual Financial Saving Bl.A:R$1.205 Bl.B:R$6.386	Bldg.A: Very Low Bldg.B: Considerable HVAC Energy Saving Bl.A: 2,3% Bl.B: 12,2% Total Energy Saving Bl.A: 0,8% Bl.B: 4,1% Annual Saving Bl.A:R$1.845 Bl.B:R$9.714	Bldg.A: Very Low Bldg.B: Considerable HVAC Energy Saving Bl.A: 3,6% Bl.B: 16,1% Total Energy Saving Bl.A: 1,2% Bl.B: 5,4% Annual Financial Saving Bl.A:R$2.823 Bl.B:R$12.856
Thermal Comfort	Worse than actual (heating of glasses due to greater solar absorption of the film) Discomfort (hot summer): Bldg.A Pav1: 16h Bldg.B Pav4: 13h to 18h	Better than actual (cooling of glasses due to their partial shading by the screen) Desconforto (hot summer): Bldg.A Pav1: None Bldg.B Pav4: 14h	Far better than actual (better cooling of glasses due to their shading by the brises-soleil) Discomfort (hot summer): Bldg.A Pav1: None Bldg.B Pav4: None

Considering the results presented, the film coated solution provided an excessive daylight penetration, although does not alter the exterior visibility. On the other hand, it provides very low to low energy savings, worse thermal comfort conditions than the actual ones. The screen solution provides satisfactory illuminance levels and reasonable homogeneity, but with some alterations in the exterior visibility. Energy savings can be very low to considerable ones, providing better thermal comfort conditions than the actual ones. Finally, the brise-soleil solution proved to be the most adequate one in the relation between energy and environment. It provides satisfactory illuminance levels and adequate homogeneity, although reduction in exterior visibility. Energy savings vary as well from very low to considerable, but are the most significant among the three studied solutions and, considering thermal comfort, it provides the better results. As a conclusion, based on the results found for the specific case studies, despite the difference in the amount of energy savings in each buildings, in both of them the results point out to the film coated as the weakest solution, the screen as a quite good one, and the brise-soleil as the more adequate of them.

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Demonstrating cost-effective low energy solutions in Denmark – Results from the Class 1 EU CONCERTO project

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ABSTRACT: The EU Concerto project commenced in 2007 and involves 5 Member States: Denmark, Estonia, France, Italy and Romania. In Denmark approximately 400 dwellings will be designed and constructed as "low-energy class 1" houses according to requirements set by the Municipality of Egedal. This means that the energy consumption is 50% below the existing energy regulations. Sixty-five dwellings have been constructed with a yearly heating demand of 15 kWh/m². The Concerto community also includes a kindergarten (completed) and a senior citizens centre. The Class 1 project uses these stronger energy requirements to drive the technological development of different components covering 3 areas: Eco-buildings, Renewable Energy Supply and Intelligent Building Energy Management System (BEMS). The technologies cover: windows, slab and foundation insulation systems, biomass gasification, local district heating distribution networks, ventilation heat recovery combined with heat pumps and BEMS. This paper describes the status of the project preliminary results and developments.

1 PROJECT OBJECTIVES

1.1 *Introduction*

The intention of the project Class 1 is to use the strengthening of the energy requirements to boost and drive the technological developments and to prove the economic and environmental benefits of ultra-low energy buildings (50% below the new requirements in the Danish Building Regulations) integrated with a renewable energy supply based on biomass and solar heating. The Class 1 project focuses on the optimisation of sustainable energy systems in local communities through an innovative integration of Renewable Energy technologies with ultralow-energy buildings.

The project also puts special focus on the Indoor Environmental Quality (IEQ) to make sure that the energy savings are met without reducing the IEQ standards set out in the design specification phase. The IEQ focus is one of the areas in which the Class 1 project involves partners from other EU member states (MS) who are experts in lighting and thermal comfort issues. Also trans-national cooperation is introduced for the socio-economic research part of the project, which deals with the user point of view (priorities, etc.) in the participating MS.

The Class 1 project demonstrates improvements within 6 individual technologies (windows, slab and foundation insulation systems, biomass gasification, local district heating distribution networks, ventilation heat recovery combined with heat pumps and BEMS) and an innovative integration of these technologies (with solar heating) which leads to improved cost effectiveness.

1.2 *Objectives*

There are 5 scientific, technical and "political" objectives of the Class 1 project:

1.2.1 *Optimise the integration of low-energy building technologies with supply (renewable and conventional) and distribution (heating and electricity) technologies.*

The heating season is reduced considerably when houses are designed for ultralow-energy use. The supply from a solar heating plant with seasonal storage is very difficult to achieve for a whole settlement in a cost-efficient way when some of these single-family houses are geographically "spread" over a larger area. *The original idea of the Class 1 project was to combine district heating from a biomass CHP plant and a central solar heating plant for the new dense, low-rise housing projects with heat-pump heating of the single-family houses, but currently the demonstration project is been changed to cover also some existing municipal buildings and to have them covered by the biomass CHP and the solar plants*. The objectives are to:

- Illustrate that a local distribution network can still be a viable option even when supplying ultralow-energy houses.
- Integrate and use the solar heating system storage tank(s) as buffer tanks for the CHP-produced heating.
- Demonstrate how this integrated supply system can be monitored and controlled by an advanced, yet easy to use, BEMS.

1.2.2 *Advance selected technologies within the 3 areas: low-energy building, renewable energy supply and distribution*

Six technologies that are crucial for the overall goals of achieving ultralow energy houses with a high proportion of renewable energy supply integrated in the supply system have been selected for further development in the project. The 6 technologies are:

- Windows.
- Foundation and floor slab insulation.
- A biomass plant CHP plant
- Low-loss cost-efficient piping system for local district heating distribution systems.
- Integrated heat-recovery and heat-pump system.
- Advanced user-oriented BEMS

1.2.3 *Improve the design, checking and verification procedures.*

Stipulating and checking special energy requirements to a certain neighbourhood is not an easy task. In many MS, the implementation of the Directive on Energy Performance in Buildings (EPBD) introduces new, stringent requirements to the energy performance of buildings or at least new requirements for showing how to comply with the existing requirements. To handle these new provisions in practice requires a certain set of procedures. Based on lessons learned, it is the objective of the Class 1 project to develop procedures that are both useful when a local authority decides to introduce tougher energy requirements (as is the case with Stenloese community) as well as for the general handling of the practical implications of the local implementation of the EPBD.

1.2.4 *Integrate the European eco-label in the building projects (houses and components)*

This objective addresses specifically the environmental considerations which concern the selection of products for the project and reducing the environmental impact of these products by incorporating the EU eco-label in the project.

In this objective, the EU eco-label will be incorporated in the various stages of the project from design and planning to construction and management.

The EU eco-label will be integrated through contractors and community officials so that the final users of the settlement (the residents) will be ensured a supply of less environmentally damaging products and knowledge to understand the EU eco-label, Paxevanos, and Mørck (2009).

1.2.5 *Demonstrate large-scale implementation close to market technical and economic conditions*

The implementation of new, tougher requirements is always met with scepticism from the building market professionals. Architects, contractors and manufacturers see things from different perspectives and they are instinctively almost always against new requirements.

To convince these groups and to pave the way for forthcoming tougher general energy requirements in the building regulations, it is imperative to demonstrate in a large scale and close-to-normal (business as usual) situation that the design and construction of ultralow-energy houses with a high degree of renewable energy supply is indeed a viable option.

In conclusion the objective is to pave the way for a faster introduction of the demonstrated ultralow-energy building technologies and the integrated renewable energy supply – in this case the biomass CHP plants in combination with solar heating systems.

2 STATUS OF WORK

The municipality of Egedal has advertised the construction sites at the new settlement area Stenloese South for sale with special energy requirements for all buildings to be built according to the Danish low-energy standard class 1 or better. Furthermore, the usage of solar energy for hot water preparation and heat pumps for heating in the single-family houses is required.

During the first year of the project, the municipality itself constructed a kindergarten in compliance with the above restrictions and a social housing association (KAB - Copenhagen Social Housing association) has completed an ultralow-energy house project – comprising 65 dwellings. Besides, the construction of the senior citizens centre and 30 single-family houses have commenced.

The photos below present an overview of the Stenloese Syd settlement from the air.

Figure 1. Photo of the Stenloese South settlement.

2.1 *The demonstration buildings*

The Class 1 project encompasses 5 different types of building demonstration projects:

- 65 ultralow-energy social housing units – the KAB social housing project;
- A kindergarten;
- A centre for senior citizens;
- About 90 single-family houses;
- 4 dense low-rise building areas;

Of these targets, the first two have been met, the third is almost finished and about 30 single-family houses have been built. The first of the 4 plots for low-rise housing areas have been sold and a project is being developed.

2.1.1 *The KAB social housing project*

The project comprises 65 dwellings in two sizes: 82 and 110 m². The houses are built as row-houses and the construction is prefabricated room-size elements – meaning that each apartment consists of two elements put together at the building site. Thus construction time at the site is very short. The dwellings have been designed for a net heating load of 15 kWh/m²/y. This is well below the Danish low-energy class 1 standard which generally leads to net heating loads of about 25 kWh/m²/y. The first year's measurement shows a heating load of about 20 kWh/m²/y, which is probably due to leakage on the assembling lines. This is being mended in the last months of 2009. The dwellings are primarily heated by the ventilation air from a mechanical ventilation system with heat recovery. One-two radiators have been mounted to ensure that heating can maintain comfort temperatures in very cold winters. The houses are to be supplied with heat from the district heating network fed by the planned biomass CHP plant and a central solar heating system (also part of the Class1 CONCERTO project).

Figure 2. Photo of the KAB-ultralow-energy housing project.

2.1.2 *The kindergarten*

The new kindergarten for the Stenloese South area has been designed for low energy class 1 according to the Danish Building Regulations. The kindergarten has 2 heat pumps in series for space heating and one separate heat pump for hot water heating. Space heating is a floor heating system and it is striking to observe the very low temperatures were needed to heat the kindergarten – even in winter months. A mechanical ventilation system with heat recovery ensures good quality indoor air.

Figure 3. Photo of the kindergarten.

2.1.3 *The centre for senior citizens people*

An activity centre for designed for elderly people of the municipality and allowing them to relax with hobbies and other indoor activities. The centre has been designed for low energy class 1 and a net heating load lower than expected for this class. It is also heated by a heat pump and has mechanical ventilation with heat recovery. The construction principle is steel plates buried about 1 m in the ground and then insulated on both sides, reaching very low U-values with no thermal bridges.

Figure 4. Photo of the centre for senior citizens – under construction.

2.1.4 *Single-family houses*

About 30 single-family houses have been constructed or are under construction. They are all designed for low energy class 1 standard according to the Danish Building Regulations. They have a minimum of 3 m² thermal solar collector and are heated by individual heat pumps.

Figure 5. Photo of two single-family houses.

2.1.5 Intelligent *building* control

All the buildings of the Class 1 project will be monitored and controlled by an advanced BESM. The system will be targeted at users enabling them to monitor and control their own comfort and energy consumption. The system will be internet-based to reduce costs and enable residents to use their own computers for direct access to all data related to their own home and to comparative data from the other households. This will e.g. enable them to compare their own energy use with the average of all similar households. The users will have a number of different options, e.g. to set up a vacation period, where temperatures can be kept lower. If they return home earlier than expected, they can turn on the heat from an internet café anywhere in the world. The system will also hold a budget for the energy consumption and therefore allow the residents to compare their actual use with the budget.

2.1.6 *Evaluation of user preferences*

One part of the demonstration activities deals with the evaluation of the user preferences to improve targeting of future buyers/builders of low-energy houses. During the first 12 months of the project the methodology was determined and the initial interviews carried out, Quitzau, Munthe-Kaas, Hoffmann and Elle (2009).

The project in Stenloese South has been groundbreaking for Danish low-energy building projects. Though hampered by the financial crisis, the project has shown that it is possible for a municipality to promote low-energy building on market terms. The project is important as a showcase for low energy buildings in various ways. Firstly, it is an example of proactive municipal involvement in environmental issues, secondly it is an example of how low-energy dwellings do not have to compromise when it comes to comfort and thirdly it has given important experiences with user preferences and the role of the building industry. Finally, it has contributed to develop the competences of building industry.

The project is to be viewed as a success as it has documented it possible to promote low-energy dwellings for ordinary people on market terms. The newcomers, clients as well as tenants, seem to be perfectly ordinary inhabitants in those types of dwellings. Their main motivations for moving to the area, was the price and location and the possibility to live in a newly built home. It is also worth to mentioning that a great deal of the newcomers has moved primarily because they were obliged to, for example by a divorce, or because of dissatisfaction with their former dwelling. It is evident that environmental standards by themselves will hardly work as a motivating factor for the main part of clients or tenants outside the greenest segment. Even though it is generally viewed as a positive asset of a dwelling, the low-energy aspect does not seem to have been the main priority for any significant part of the population of Stenloese South. From other research on moving habits and dwelling preferences, we see that moving mainly has to do with changes in the life of the individual or family, which makes the current dwelling inadequate. The choice of a new dwelling is also dependent on several factors, such as economy, location and transportation, before people consider the environmental profile.

However, though not the main driver, it is worth mentioning that a big majority of the respondents in this survey seems to like the idea of municipal environmental involvement. Generally, low-energy dwellings and environmentally sound projects are viewed as positive.

Legislative measures seem to be an effective way to ensure a more environmentally sound building industry as the client/industry relation seems to create deadlocks where neither part is willing to take the initiative to innovate voluntarily when it does not seem economically profitable. As new opportunities emerge - it is now possible to include environmental demands in local planning - it is much easier for municipalities to stipulate low energy requirements through legislation, though it still requires quite a lot of work to manage the developmental processes as neither clients nor industry have much experience with low-energy requirements.

Information about the consequences of building and living in low-energy dwellings might be a central issue. Construction budgets of 5 to 10 years might help visualize the benefits of energy efficient housing. Also, specific guidance in the choices of technology might be a good idea, as long as the building industry does not have sufficient experience to give competent advice. In the case of single-family houses it might be a good idea to involve the clients in the new residential area in the early stages of the process, as collective solutions might mean even less energy consumption than in individual low-energy dwellings. This kind of project might also mean that the impact on society through “ambassadors” might increase, as the clients (or tenants for that sake) have more ownership of the project. This is of course conditional on the process and the dwellings running smoothly.

On one hand, it is problematic that the newcomers to Stenloese South did not choose the area because of the environmental profile, as it makes it difficult to sell new building projects with energy efficiency as an argument. On the other hand it seems that the newcomers to Stenloese South are perfectly ordinary people and the project thus documents that it is possible to work with low-energy building projects on market terms.

2.2 *The development of products*

During the first 12 months period the development work for the windows - Haulrik and Mørck (2008) and the heat recovery heat pump system - Svendsen and Mørck (2008) have been completed and a considerable part of the development work for the district heating network innovation and the bio-mass CHP-plant have been undertaken.

2.3 *Participant list*

The main part of the project is carried out in Denmark and the 4 associated MS receive the results and lessons learned and convey and implement them in their national municipalities. The table below lists the participants of the Class 1 project.

Table 1. Participant list.

Entity	Country
Municipality of Egedal	Denmark
Cenergia Energy Consultants	Denmark
Danish Building Research Institute, Aalborg University	Denmark
Dept. of Civil Engineering, Tech. Univ. of DK	Denmark
PRO TEC Windows A/S	Denmark
Dansk Leca A/S	Denmark
BioSynergi Proces ApS	Denmark
Genvex A/S	Denmark
Logstor A/S	Denmark
Electronic Housekeeper A/S	Denmark
IB Aksiaal OÜ	Estonia
Valga Town Government	Estonia
Ente per le Nuove Tecnologie l'Energia e l'Ambiente	Italy
I Istituto Cooperativo per l'Innovazione	Italy
Commune di Bologna	Italy
Sustainable Urban Development European Network	France
Municipality of Begles	France
Association of the Local Development Promoters	Romania
Municipality of Odobeşti	Romania

3 CONCLUSIONS

In the coming months (the project runs for 60 months) the next demonstration buildings are to be completed, the biomass CHP plant combined with a large array of solar collectors is to be implemented and the monitoring initiated. The users will be followed and assisted and the lessons learned will be documented. Also the development of the next 4 key technologies will be completed. The training and dissemination will be carried out. One possible development is that one or more of the associated communities will also begin the implementation of new CONCERTO demonstration projects.

It is expected that the experiences, lessons learned and R&D carried out as part of the Class 1 project will pave the way for the development, design and construction of sustainable, low or zero CO_2-emission communities in the future. A guideline activity was to review existing design guidelines in the participating MS. The aim of this investigation was to evaluate the cross applicability of existing guidelines in participating MS and how they fit with national implementations of the Directive on Energy Performance of Buildings. The first step was to do a survey on the existence and the contents of national or local guidelines in the participating MS: Denmark, Estonia, France, Italy and Romania, (Castellazzi, Citterio, Mørck, Thomsen, Kase, Charlot-Valdieu, and Balica, (2009).

The conclusions are that in general the Danish guidelines have been evaluated to have a good applicability in all the other MS. The summer conditioning with absorbing cooling systems (from Italian guidelines) have been considered to be not applicable in Denmark and Estonia. This can be explained by the facts that in Estonia and in Denmark there is a low solar radiation and a low summer cooling demand, but in France (not in the metropolitan area), solar cooling should have a good potential and is being developed.

The items that had a consensus from all experts were the following:

- Building envelope and thermal insulation;
- High-efficiency boilers;
- High-efficiency air-conditioning systems;
- Thermostats and radiator valves to prevent overheating;
- Cooling demand assessment;
- Lighting systems efficiency standards and control systems;
- Water accounting and water saving;
- Low temperature floor heating systems;
- High-efficiency heat pumps;
- Design process check.

All the guidelines proposed by the Danish, Italian and Romanian experts fit with the national implementation of EPBD in their respective MS, Castellazzi et al., (2009). In general there seems to be a lack of up-to-date design guidelines for dwellings of different categories. With present low-energy requirements and wishes for sustainable buildings the guidelines developed 10 or more years back are outdated.

The Danish Energy Research Programme is also supporting the project.

Further information about the Class1 project is to be found on the project website: *www.class1.dk*

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Solar XXI building: proof of concept or a concept to be proved?

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ABSTRACT: Solar XXI building is a prototype of low energy office building where passive and active solar strategies have been applied to reduce the use of energy for heating, cooling and lighting, combining also an extensive photovoltaic façade for electricity production.
Solar XXI was built in 2006 and is considered a high efficient building, close to a net zero energy building (NZEB), because the difference between the energy consumed and that produced is 1/10th of the energy consumed by a standard new office building. Its design includes a large number of energy efficiency concepts, such as a high insulated envelope, south sun exposure, windows shading, ground cooling or stratification and cross ventilation.
The windows solar gains and the effectiveness of shading devices were proved correlating solar radiation, external and indoor air temperatures. It was also verified that ground cooled air has a temperature close to that theoretical expected.

1 INTRODUCTION

Solar XXI building is a prototype of low energy office building located in Lisbon (38º46'N, 9º11'W) where passive and active solar strategies have been applied to reduce the use of energy for heating, cooling and lighting, combining also an extensive photovoltaic (PV) façade for electricity production (Rodrigues et al. 2008).

Lisbon climate is characterized by monthly average temperatures that swing between 10.6ºC for the coldest month (January) and 22.6ºC for the hottest (August). During summer solar radiation is high, more than 6.5 kWh/m^2 per day, and maximum average air temperature is around 28ºC; however extreme values, air temperatures higher than 35ºC, can be observed during a sequence of days. Winter is less severe because the average minimum temperature is between 8 and 10ºC and precipitation days are not frequent.

Solar XXI was built in 2006 and it has been intensively monitored ever since (Gonçalves et al. 2008). It is considered a high efficient building, close to a net zero energy building (NZEB), because the difference between the energy consumed and that produced is 1/10th of the energy consumed by a standard office building. Solar XXI building design includes a large number of energy efficient concepts, such as a high insulated envelope, south sun exposure, windows shading, ground cooling or stratification and cross ventilation.

Considering that Solar XXI's design is based on the concept of integrating passive solar strategies for heating and cooling in a single building, in this paper, such integration is explored and analyzed in order to assess if the results obtained so far constitute a proof-of-concept, or else further research is required to improve it.

2 SOLAR BUILDING CONCEPTS

2.1 *Direct gain*

Direct gain concept, applied in solar buildings, consists of enlarging windows area in south façade so that winter solar energy is easily collected during the daytime hours. In cooling season these windows should be properly shaded. This strategy includes the minimization of windows area in the east, west and north façades to the strictly necessary in terms of natural lightning proposes.

In the Solar XXI building, offices are south oriented and have large windows providing heat and natural light to these rooms during heating season. South façade is totally covered by windows and PV panels by equivalent proportions (Figure 1). Each window area is 4.4 m^2 and the glazing system area (without frame) is 3.6 m^2 corresponding to 22% of room floor area.

Figure 1. Direct gain and PV panels in south façade of Solar XXI building.

The remaining rooms located in the north part of the building, such as laboratories, auditoriums, bathrooms and occasional offices, constitute the building buffer zone.

During winter sunny days, the total amount of energy collected by each direct gain system (window) is about 35 MJ. Because floor is a light element in terms of thermal inertia, a small part of that energy is stored in built elements and the remaining part causes an increase of the sensible temperature during day time hours which is a desirable behavior for an office building.

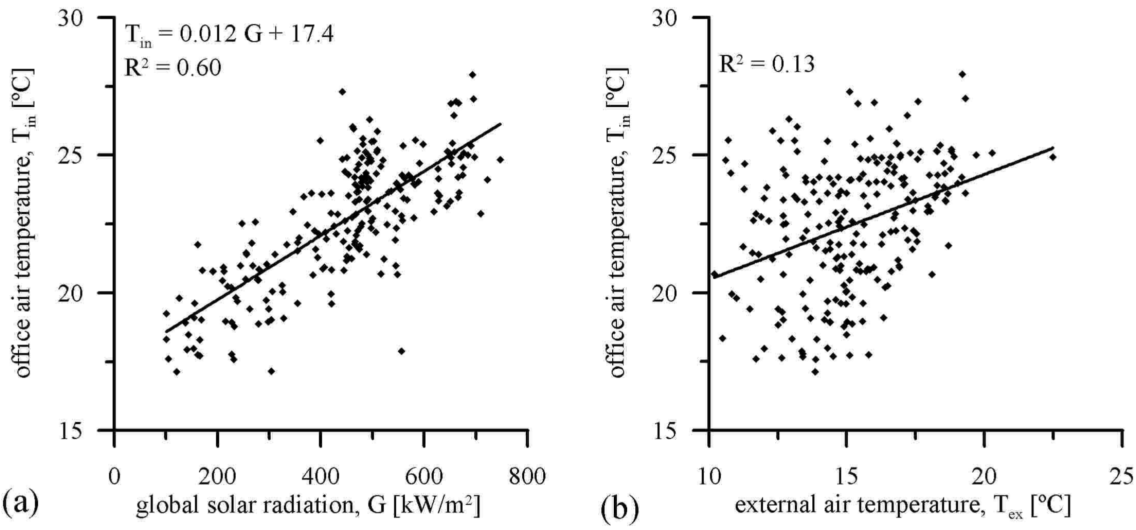

Figure 2. From December to February of 2007, 2008 and 2009, linear correlation of measured daily maximum values of (a) global solar radiation and office air temperature and (b) external and office air temperatures.

During a three-year monitoring period (2007-2009), from December to February, daily maximum values of office air temperature are plotted against daily maximum global solar radiation (Fig. 2a) and external air temperature (Fig. 2b). The results show that, when compared to external air temperature, global solar radiation is correlated with the office air temperature and solar gains through window office contribute to an increase of office air temperature of 1.2ºC for each 100 kW/m^2 of daily maximum global solar radiation.

2.2 *Thermal insulation*

In solar buildings, thermal insulation elements are fundamental because they reduce thermal exchanges by conduction trough external envelope. This preventive strategy is useful in winter season by blocking heat (solar gains, internal gains due to occupation and boiler produced) from leaving or, in summer season, from penetrating.

Brick walls are externally insulated by 0.06 m of expanded polystyrene, the roof is externally insulated with 0.10 m of expanded and extruded polystyrene (0.05+0.05 m) and the ground floor is perimeterly insulated by 0.10 m of expanded polystyrene. Thermal bridges are reduced in spite of the position of insulation elements. Double glazing is also used in order to reduce thermal losses by windows.

Considering all this elements, a global U-value of 1670 WK^{-1} is estimated for Solar XXI building. The compactness of Solar XXI building, expressed by a shape factor of 0.33 m^{-1}, is also an important characteristic to prevent thermal losses.

2.3 *Shading elements*

During summer season, in spite of natural light requirements, windows shading is very important for preventing excessive solar gains. Preferably shading elements should be externally positioned, but different façades require different types of shading elements.

In this building, south windows have moving external blinds, manually operated. Windows in other façades are shaded by internal and light roller shades. Some of them, including roof skylight, do not have any type of shading device.

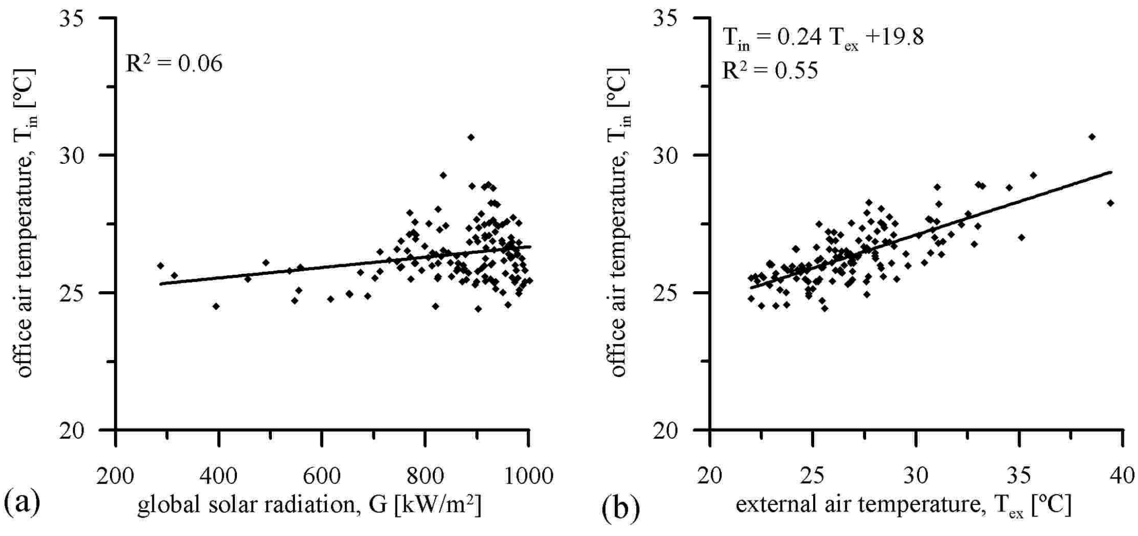

Figure 3. From July to September of 2007 and 2008, linear correlation of measured daily maximum values of (a) global solar radiation and office air temperature and (b) external and office air temperatures.

In summer season, unlike winter, room temperature is more sensitive to the external temperature than to solar radiation as Figure 3 shows. In fact, external air temperature is the parameter most correlated with office air temperature (R^2 = 0.55). The fact that room temperature is better correlated with external temperature than to solar radiation shows that other phenomena besides solar gains, such as heat conduction and infiltration of external air, are dominant in the energy balance. It is also noteworthy that these results show that south windows position conjugated with shading devices are sufficiently efficient for neutralizing the summer solar radiation.

2.4 *Ground cooling*

No air conditioning system is used in Solar XXI building; however, for hot summer days, buildings users can "turn on" the ground cooling system making use of the ground high thermal inertia. This system consists of two concrete pipes for each office room with a diameter of 0.30 m and a fan which insufflates air into the office. The air is collected 15 m from the building, travels at a depth of 4.6 m and is finally fanned into the office room after crossing the pipes circuit; the fan flow rate is 200 m^3/h.

Ground temperature throughout the year varies from 13 to 19ºC; ground is therefore an excellent cooling source during summer season. Using the theoretical formulation of Hollmuller (2003), for the summer period of Lisbon's climate, with an average maximum external temperature of 28.9ºC, it is estimated an average maximum temperature for the air exiting the ground cooling pipe system (air insufflated into the room) of 21.5ºC, representing a decrease of 7.4ºC. However, as Figure 4 shows, this difference increases with external air temperature, therefore, in hot days with a external air temperature of 30ºC, the air crossing the ground pipes can be insufflated into the room at 22ºC.

The comparison of model results with experimental data is compromised by the intermittent use of the ground cooling system. However, for the period where fans are turned on (some afternoon hours during five summer days), the air is insufflated into the room at a temperature close to the expected by Hollmuller's theoretical formulation, as shown in Figure 4, where the temperature difference between external and insufflated air is plotted against daily maximum air temperature.

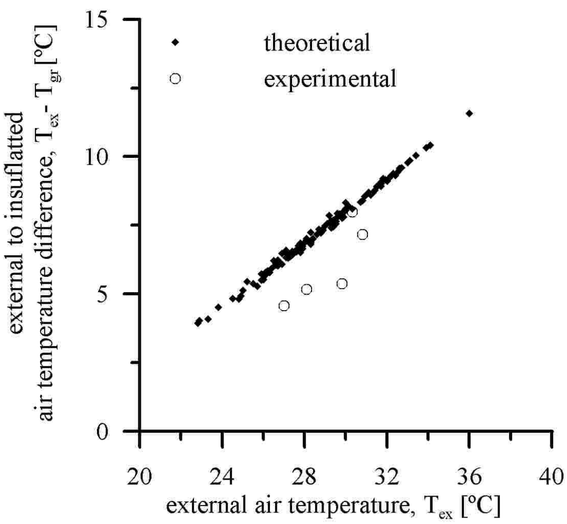

Figure 4. Difference between daily maximum external air temperature and calculated daily maximum temperature of the air exiting the ground cooling system against daily maximum external air temperature using a four month period of Lisbon climate (theoretical) and some monitoring days (experimental).

2.5 *Stratification*

In the middle of the building, there is a three-floor atrium with the double function of natural lighting and air exhausting for circulation areas. As the atrium communicates with the office room, the air is naturally exhausted from the lower to the upper floor as well as from the office to the circulation areas. During summer, skylights opening cause the hot air exhaustion from the building.

An air temperature gradient is expected in the atrium, with higher temperatures in the upper floors. During summer and winter periods, the three floors air temperatures were measured and differences between floors are presented in Figure 5, taking as reference the ground floor.

In the first and second floors the gradient is always positive for both seasons. During winter, the air temperature in the first floor is 1 or 2ºC higher than the ground floor. In the second floor the gradient is higher, with differences around 2 and 4ºC. For both floors, during night period, differences are smaller and less than 1ºC (not observed in Figure 5).

During summer, despite some few exceptions where differences are very small, the temperature gradient observed has values close to those measured in winter. Therefore, from these results it can be concluded that stratification of the air inside the atrium is verified for both periods with a large intensity during daytime period.

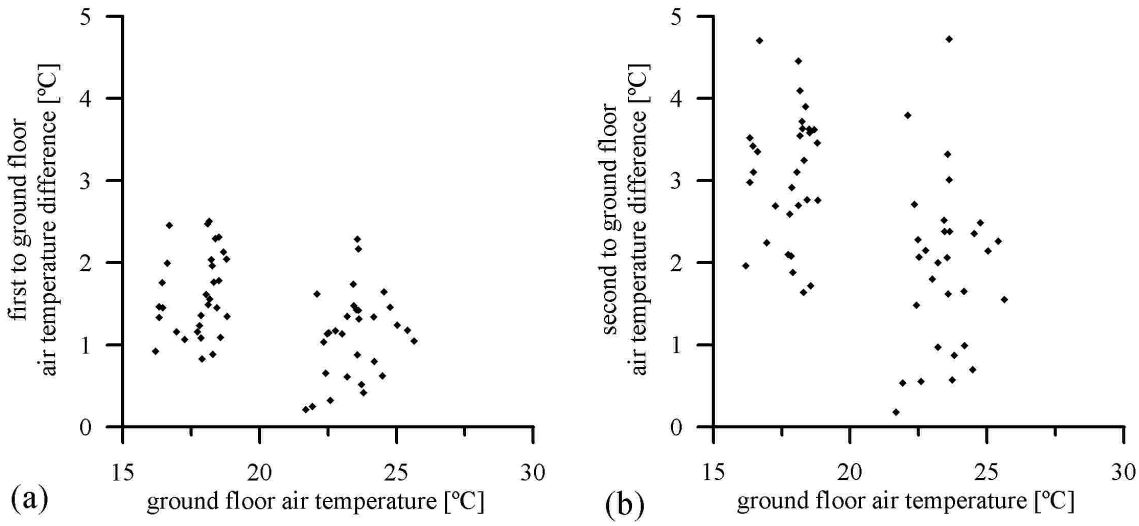

Figure 5. Daily maximum air temperature differences between (a) first and ground floors and (b) second and ground floors.

3 ENERGY CONSUMPTION

3.1 *Final energy use*

Solar XXI uses natural gas for heating and electricity for office equipments and lightning. Estimations based on inquiry and simulations indicate that 69% is used in office equipments (computers, printers, photocopiers and fax machines), 19% in lightning and 13% for heating (natural gas boiler). These percentages refer to primary energy use. It is important to emphasize that lighting use would be much higher in a standard office building without natural lighting strategies. In fact, besides some darker days or late hours, south offices and indoor circulations rarely need electric lighting. Photovoltaic panels integrated in the south façade and parking areas produce about 12 MWh/year which is about 67% of the primary energy and 70% of total electricity used in the building.

The above figures result on an energy efficient index (IEE in Portuguese legislation) of 2.5 kgoe/(m^2.year) which is about 1/10th the total use of energy of a standard new office building. Solar XXI is therefore a high energy-efficient building close to a net zero energy building (NZEB), because of the very small difference between the energy consumed and that produced.

4 FINAL REMARKS

Solar XXI building is occupied since the beginning of 2006. The three year utilization and monitoring made possible to make a first proof of the concepts which sustain the building design. South façade is equally divided into direct gain systems and photovoltaic panels for electricity production. The windows of the office rooms contribute with solar gains during winter sunny days, as the correlation between solar radiation and indoor air temperature showed. The effectiveness of shading devices is also proved by the correlation between external and indoor air temperature, instead of solar radiation.

Besides the small amount of monitoring days where ground cooling system worked, it was verified that the air insufflated into the room has a temperature close to the theoretical predicted by Hollmuller's (2003) model.

In terms of energy balance, this building is an example of a low energy building, consuming about $1/10^{th}$ of a standard new office building, according to Portuguese legislation.

Future monitoring should be orientated for the ground cooling functioning in order to have a more accurate assessment of its effectiveness on removing heat from the offices, as well as the optimized schedules.

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Integrated Design of low-energy houses in Selvino, Italy

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ABSTRACT:In 2007, the “passive house” concepts were applied at the construction of 16 houses in Selvino Bergamo, Italy. This small mountain village was designed with the aim of minimizing the energy consumption. Using a holistic design process characterized by the integration of architectural and technological choices, the ambitious target of 30 kWh/m^{2}a was reached. Passive strategies are used to keep the indoor comfort: very high insulating levels (a combination of traditional and thin multifoil insulation layers); high winter solar gains; small window area in the north façade with high performance; large openings and conservatory space in the south façade. Mechanical systems and PV panels were designed to exploit as much as possible the renewable energy sources, thus limiting CO_2 emissions. In particular, the mechanical system is composed as following: solar photovoltaic panels installed on the south-facing roof; electrical radiant floor heating system; high efficiency electric boiler; mechanical ventilation with heat recovery. This paper shows a practical example of a holistic design process integrating architectural, technological and energetic issues; the result is a low-energy building with a contemporary architecture that suite perfectly to the specific context.

1 INTRODUCTION

1.1 *Motivation*

In Europe 40% of energy is used in buildings, more than by industries or transports. In the residential sector, especially in mid temperate climate, about 57% of the total final energy consumption is used for heating space, 25% for domestic hot water and 11% for electricity. Moreover, it offers a large potential for energy efficiency with low investment costs. According to the United Nations Environment Program (UNEP), over a fifth of energy consumption and more than 45 million tons of CO_2 could be avoided in Europe by 2010 applying more ambitious standards to new buildings. This could represent a considerable contribution to meeting the Kyoto targets.

Several standards already exist in Europe like the Passive house standard, Minergie, CasaClima and much more (Masera, 2004). Because all these standards are climate dependent, the design group of this settlement in Northern of Italy decided to follow the CasaClima standards that is a promising solution in winter dominated climate (Imperadori et. al, 2004).

1.2 *Aims and methodology of the work*

The new settlement in Selvino was born after the approval of the new local energy code (*Regolamento per l’Efficienza Energetica degli Edifici*) in 2006. Selvino is a small village in the north of Italy (it is lies at more than 900 m above the sea level) where about the 70% of the house are for vacation. The winter period is predominant together with the heating season. The aim of the new construction regulation the administration of the city, developed by a group of the Politecnico di Milano (Regional Campus of Lecco), was to give guidelines to support the architects during the design stage of the project to achieve ambitious low energy targets. The municipality decided to join the CasaClima standard and to promote the large use of renewable energy sources, passive strategies and ecological traditional material (like stone and wood). The design group answered to these goals and in particular:

- Satisfying the need of social housing,
- Providing a good example of low-energy architecture,
- Testing innovative construction and systems services technologies.

Properly designing the built environment has become a complex matter. Comfort expectations and energy efficiency imperatives require the control of environmental conditions by adjusting room temperatures, luminance levels and ventilation rates. This requires a very strict integration of building envelope and technical services, in order to reduce the use of non-renewable energy. Every building should be suited to climate, function and local technical standards (Isaksson et al. 2006). In order to answer to this challenging situation, it was important to bring together the architect, the mechanical engineer, the municipality and the energy consultant at the very short of the project. The holistic approach, adopted by the group, permits to define immediately different energy and architectural concepts and to save time afterwards to adjust the design (Fig.1).

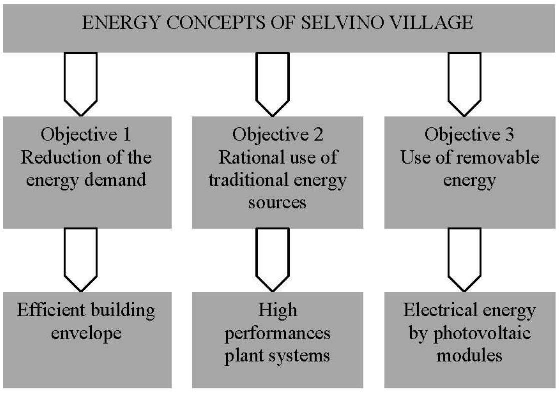

Figure 1. Energy concept of the settlement.

2 URBAN PLANNING AND ARCHITECTURAL PROJECT

The ecological settlement in Selvino (Fig.2) is an ambitious initiative aiming for a sustainable development of the village. The climate is characterized by cold winters and temperate summers. This is represented by 200 heating days and 3433 heating degree days (the design temperature is equal to -9 °C).

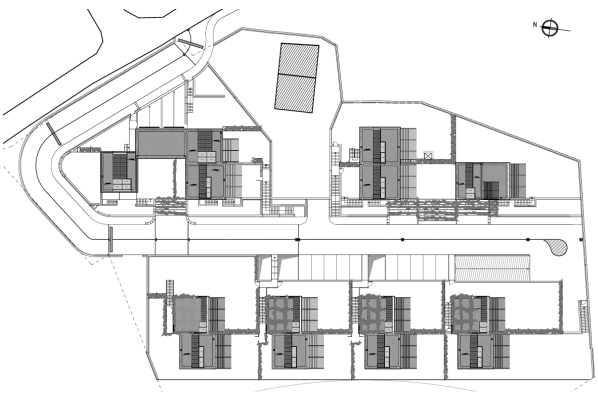

Figure 2. Plan view of the Ecological Selvino district.

From the sustainable point of view the project aimed for a high level of comfort, allowing at the same time a significant reduction of energy consumption and CO_2 emissions.

The project consists of 16 residential units of different sizes (from 50 to 115 m²) (Fig.3), located sideways to the district street.

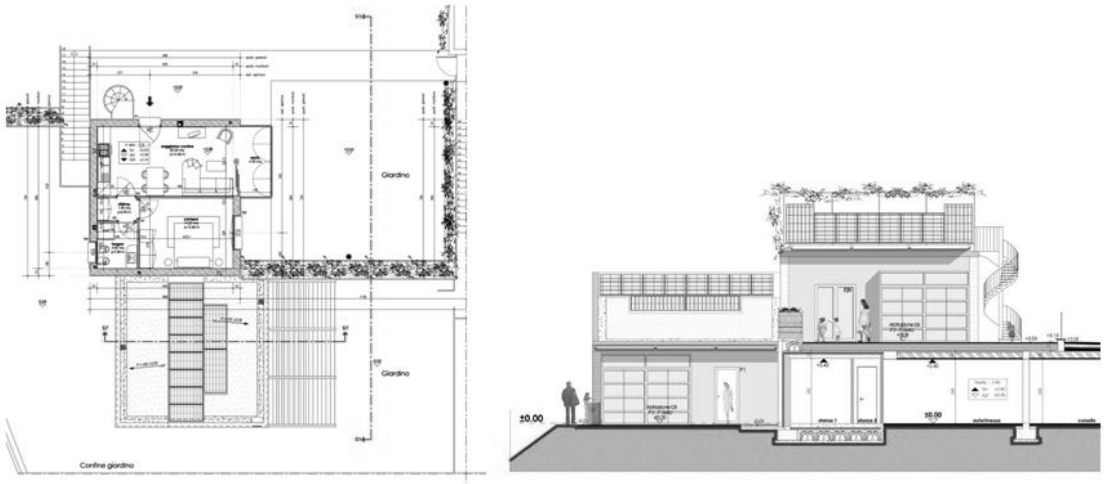

Figure 3. Plan and section view of two modules.

The aim of the architectural design was to establish morphologically innovative buildings with the capacity to maintain comfortable internal conditions in every season, through direct control of some parameters including: building orientation, use of solar radiation in winter and solar protection in summer, reduction of heat losses through good insulation and using a high efficiency heat recovery.

First of all the design group focused the attention to the urban planning studying the relationship between the settlement and the environment. The group would like to gains, as much as possible, from the environment and on the other hand established a good relationship with it. As consequence the shadow design was planned dependent from the sun path for maximise the sun penetration (minimising the reciprocal shadows between the houses) in winter and the light in summer.

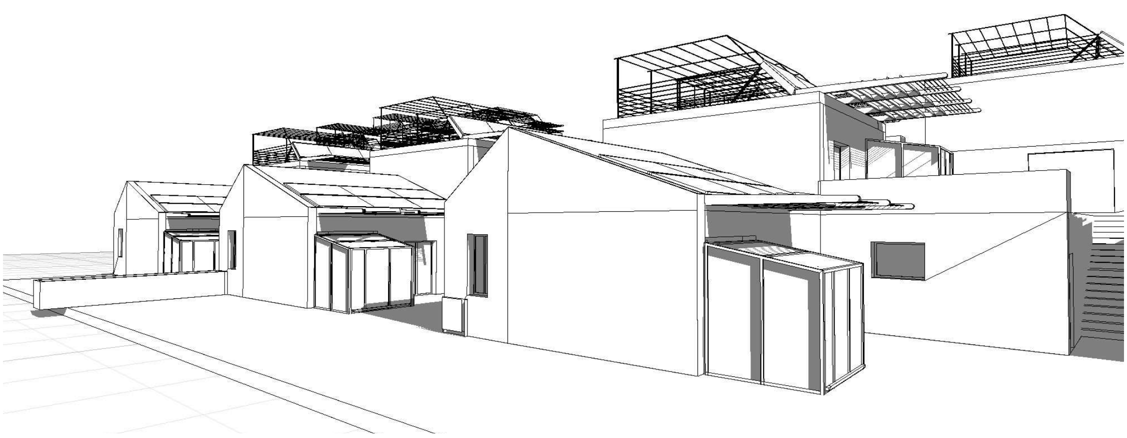

Figure 4. 3D model for sun-shading study during the month of January. It is possible to see how during the winter period the architect try to get the maximum solar gains through the windows and the green house.

Thanks to the close cooperation between designers (architectural and mechanical), the owner and the building constructor, the project is scheduled, in according with CasaClima labeling, as "Class A" with an energy demand (for the winter seasons) lower than 30 kWh/m²a. Moreover, the buildings will also have the “ECO” label due to the material quality, the use of renewable energy sources and the environmental impact (Zambelli et al. 2002).

From the architectural point of view, the buildings are characterized by a large windows facing south, with a greenhouse to maximize the solar gains in winter and to reduce the heating energy demand of about 5 kWh/m²a (an horizontal shading device reduces the summer solar gains and the possibility to tilt the windows reduces the risk of overheating) (Persson et al.2006) (Salvalai, 2008). The greenhouse (Fig.5) has an important function in terms of spatial distribution allowing the extension of living room to the south facing garden. The north and east façades are opaque in order to minimize the transmission losses and improve privacy. The internal spatial distribution is done optimizing the space; the result is simple but really comfortable: each module has a living room-kitchen (20 m²) expandable through openings windows to the greenhouse (4.5 m²), a bedroom (14 m²) and a toilet (4 m²). Laundry and storage facilities take place into the basement, connected by external stairs.

Sloping roof (Fig.5) is designed considering the sun path, in order to maximize the solar gains. It is treated with extensive green layer on the north surface in order to increase the thermal insulation and protects the structure from the ultraviolet radiations while on the south surface different solar thermal collectors and photovoltaic panels are integrated.

Figure 5. Two pictures during the construction phase: from left to right, the north and the south façade with the conservatory space.

2.1 *Building envelope*

According to the design strategies, to reduce as much as possible the heat loss (due to the envelope transmission and to the infiltration), the building is designed with high insulation layers and accurate construction (Zambelli et al. 1998).

Specifically, the houses are assembled using prefabricated panels, with solid wood substructure, floorboards, polystyrene (EPS) for thermal insulation and static functions and externally closed with a concrete layer. The concrete layer works together with the wood structure thanks to several small holes placed in the upper part of the beams. Within this new system it is possible to save time during the installation phase and no more extra systems for the rigidity of the structure are needed (with consequently less use of building material). The combination of polystyrene (resistive layer) and concrete (capacitive layer) guarantees high thermal insulation, minimizes the thermal bridges and last but not the least permits high quality of the industrialized production.

Depending on the wall exposition and on the floor area the building envelopes are designed with at minimum 200 mm EPS insulation or adding an additional thin reflective insulation layer. The solution reaches a U-value of about 0.1 W/m²K (Fig.6).

The vertical external wall is composed as follow:

- Double layer of plasterboard 12.5 mm
- Reflective multilayer insulation 21 mm
- 10 x 20 cm timber joists with maximal distance of about 250 cm
- OSB 15 mm
- Polystyrene insulation density 60 Kg/mc 200 mm thick
- OSB 15 mm

- Concrete Rck 400 50 mm

The same timber/concrete structure is used for the roof structure (Fig.6).
The following layers are combined:

- Double layer of plasterboard 12.5 mm
- Floorboard wood 20 mm
- 12x32 cm timber joists with maximal distance of about 60 cm
- Polystyrene insulation density 60 Kg/mc, 200 mm
- Concrete Rck 400 50 mm
- Waterproofing layer, soil and sedum 12 cm.
- Sedum roof

A green roof provides valuable unsealed surface in the green context, mitigates the summer climate in the main floor and it also guarantee a good microclimate environment.

The windows are double glazed units with plastic frame (U-value of 1.4 W/m²K). The facade claddings are treated differently depending on their orientation: coat and plaster in the south and north sides and pine with ventilated gap in the east and west.

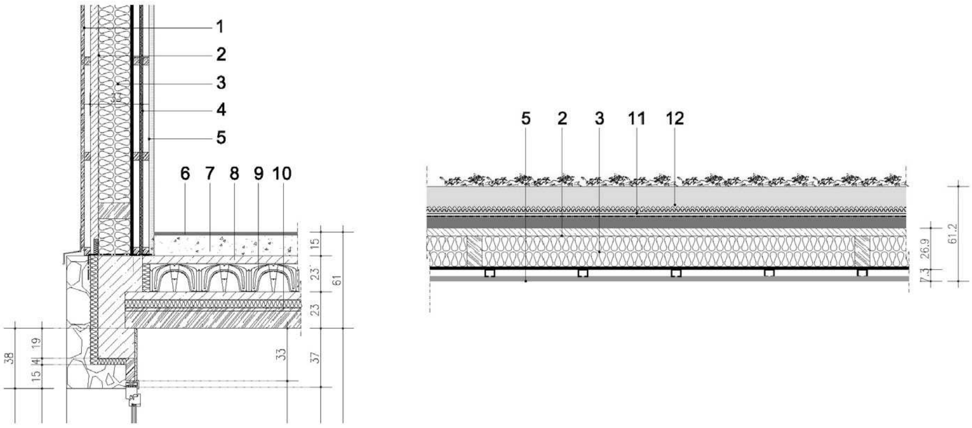

Figure 6. Construction details. 1- Floorboards pine, 2- Concrete, 3- Polystyrene, 4- Reflective multilayer insulation, 5- Double plasterboard, 6- Ceramic floor covering, 7- Light concrete, 8- Concrete, 9- Air gap, 10- Wood floor structure, 11- Membrane protection and root barrier, 12 – Sedum roof.

Figure 7. Prefabricate external wall panels.

The adopted building envelope allows achieving the goals in terms of energy efficiency, defined in the preliminary phase of the project (Objective 1 of Fig. 1). In fact, the transmission losses are significantly reduced and the solar gains maximized. At this point, since the reduction of the heating load (Fig. 8) the size of the plant system can be reduced thus take advance of the renewable energy resources (i.e solar energy).

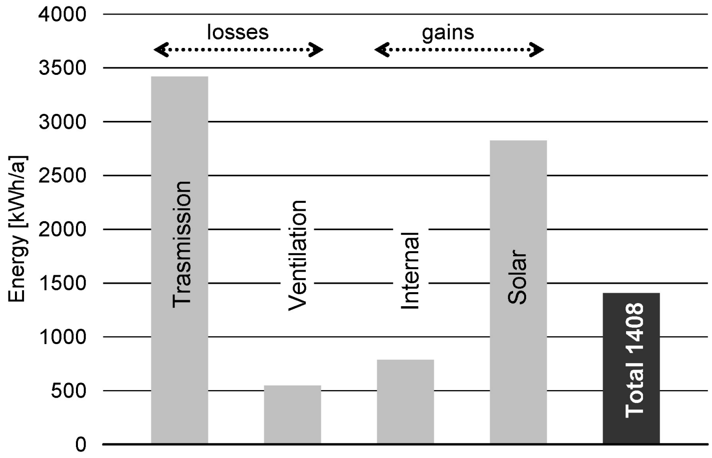

Figure 8. Energy needs of a single house. The heating energy demand related to the floor area is 22.9 kWh/m²a.

2.2 *Plant systems*

Considering the ambitious target of the houses, characterized by long unused period (the settlement is planned to be use for vacation and holidays), the mechanical system is designed to take advance from the solar energy, thus limiting CO_2 emissions (Fig. 9). The PV panels convert directly the solar energy in electricity to meet the energy needs (heating and electrical use) of the building.

With this strategy it is possible to use directly the electrical energy when the user are at home or sell it to the grid (40 Euro cents per kWh) when it is not needed or is over-produced (summer time mainly). In detail the system is designed as following: solar photovoltaic panels installed on the south-facing roof with an energy peak production of 2.5 kW, electrical radiant heating system placed in the floor, high efficiency electric boiler producing domestic hot water, mechanical ventilation with heat recovery (90% efficiency) to reduce ventilation losses and improve the air quality.

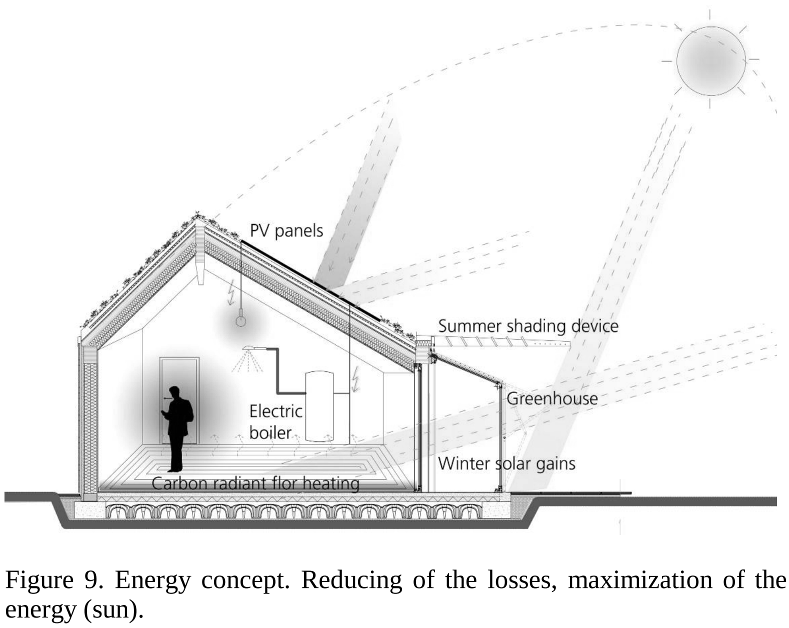

Figure 9. Energy concept. Reducing of the losses, maximization of the gains and use of the renewable energy (sun).

3 CONCLUSIONS

This paper showed a practical example of a holistic design process integrating architectural, technological and energetic issues; the result is a low-energy building (heating energy demand below 30 kWh/m²a) with a contemporary architecture that is suited to the specific context. The settlement is now in the final construction phase. Up to now the authors have not monitoring data to assess the real behavior of the houses, but the first inspection reveals the good quality achieved by the design group.

To pursue the CasaClima ClassA standard the team adopted different active and passive solar strategies since the early design stage, together with a large use of renewable energy sources and ecological traditional materials.

4 ACKNOWLEDGMENT

The design process was led by AIACE S.r.l. (Milan, Italy), that was also responsible for the technological design.

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Contribution for improving energy efficiency in Malagueira Quarter

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ABSTRACT: Malagueira is a urban quarter located in Évora, the capital of the Alentejo region, designed by architect Álvaro Siza. Malagueira is a large, low-rise, high density complex of about 1200 dwellings built on a 27 hectare site. The dwellings at Malagueira are patio or atrium types with an "ell"-shaped group of rooms on two sides of a small interior patio. The most of them are built on an 8m x 12m plot with the courtyard in front. It has living, dining and kitchen spaces at the courtyard level with an interior stair leading to bedrooms and terraces above. In this work it was evaluated the energy efficiency of Malagueira dwellings, by the means of the RCCTE – Building Code on Thermal Performance Characteristics (Decree Law n.º 80/2006). It was studied the feasibility of some refurbishment measures and quantified its impact on the energy labelling. Aiming the achievement of a good energy label, this work comprises a characterization of the actual situation. This characterization covered issues such as insulation level, glazing and shading devices. Each of these measures was first quantified in a one-by-one scenario and later in a final analysis integrating simultaneously all of those measures. To perform these assessments, most usual kind of Malagueira dwellings were studied using the RCCTE calculation spreadsheets in order to express the energy indicators: Nic/Ni, Nvc/Nv, Ntc/Nt witch values represent the fraction energy needs for Winter-time, Summer-Time, and Primary energy, compared with the maximum admissible for each, respectively. The results achieved indicate that this type of buildings can, generally, obey to all of the regulation demands and also achieve a high energy label ('A').

1 INTRODUCTION

The negative impact on our planet caused by some human activities is of great concern and discussion nowadays. Excessive energy consumption, particularly energy produced from fossil fuels, can cause serious environmental problems, by releasing gases into the atmosphere, and lead to the extinction of such natural resources. It is therefore essential to minimize the impact of such kind of pollutant energies, by reducing the needs of energy consumption, and make progresses concerning the production of clean energies. Among these energy consumption activities there is the construction and use of buildings. The way buildings are designed can contribute decisively to the reduction of energy consumption and help solving some environmental problems that now exist.

During the twentieth century a number of innovations in materials and construction techniques have led to the abandon of the traditional building methods, which normally had a great care in adapting to the local conditions, including the climate, providing this way, thermal comfort inside the buildings as naturally as possible. These innovations, however, were not adapted to the needs of a particular place and led to problems of thermal discomfort. The use of active solutions, such as air-conditioning systems has increased, as well as the energy consumption.

Built in the late 1970's, the Malagueira Quarter adopted a series of measures that indicate a concern in terms of site and climate adaptation. These were important aspects that influenced the energetic efficiency of this type of buildings. Despite the reduced budget available for the construction of this quarter and lack of labour force at the time, the choices made, have proven to be worth of attention for future building constructions. This options, like the use of a compact urban morphology and the patio house types that were adopted, had its roots in a careful look and understanding of the old walled city of Évora, Portuguese UNESCO World Heritage City, and the vernacular architecture of the region of Alentejo, as well as other regions with climate similarities.

2 MALAGUEIRA QUARTER: THE SITE, THE CLIMATE AND THE ARCHITECTURE

2.1 *Évora: Urban context*

Situated in the west side of Évora, the Malagueira Quarter was built in the old Malagueira farm lands, which had been recently expropriated soon after the Portuguese revolution, in 1974 (Molteni, 1997), that ended with Salazar's dictatorship. Replacing a former plan, which had been drawn in line with the Athens Chart (Duarte, 2001) and was only partially implemented, the new Malagueira Quarter wfas assigned to architect Álvaro Siza in 1977. First of all, it was built to solve the problems of insufficient legal quarters outside the old walled city (Simplício, 1997), anyway, the Malagueira Quarter was thought to provide accommodation for lower class population and resumed some of the principles of the already extinct SAAL project (Serviço de Apoio Ambulatório Local), that in the post-revolution period was meant to improve housing conditions in Portugal. The future residents were organized into groups, the so-called "Cooperativas de Habitação" so they could have an active participation in the project process.

2.2 *Regional climate*

The Portuguese Mainland territory is situated in the extreme southwest of Europe, along side with the Atlantic Ocean. Despite its relatively small size, it comprehends some climatic diversity, mainly, due to the influence of the Atlantic Ocean and the Mediterranean Sea (Ribeiro, 1980).

Évora is located in the southern interior part of Portugal, in a region called Alentejo. The climate in this region is characterized as being Mediterranean temperate. The average annual rainfall is low, and concentrated specially during the winter months, while the summer period is dry and hot, easily reaching temperatures of 40 °C, or more, in the hottest months. The relief in this region around Évora can be considered relatively flat and uniform that can vary between the 200 m and the 400 m of altitude approximately.

2.3 *Évora walled city: climatic adaptation strategies*

Bounded by the defensive wall built between the 14th and 15th centuries, which extended the limits established by the former Roman wall, the city of Évora reveals some characteristics of climatic adaptation that are aimed, mainly, to mitigate the effects of a long hot summer with high solar radiation intensity.

In the old walled city of Évora we can find an urban compact design with a high density construction. This is an important feature that allows reducing the areas exposed to solar radiation and increases the number of surfaces in shadow. By this way it's possible to reduce the temperatures within the city and promote thermal "urban" comfort and, at the same time, reduce solar heat gains in buildings which will impact on interior thermal comfort. The winding form of the streets will also help climatic regulation, by forming spaces, which will have a courtyard effect, reducing the areas exposed to solar radiation and promoting the ventilation, allowing a decrease in temperatures.

The use of vegetation is also an important factor to consider, and often used in the city of Évora, in courtyards inside urban blocks or in public spaces. "Vegetation around the building is important (...). Besides creating shade, vegetation transpires water and thus provokes natural cooling through evaporation. "(Gallo et al., 1998). The existence of water, that we find sometimes associated with the use of vegetation, is another factor that increases the moisture content of the air and the ensuing drop in temperature. The use of arcades is another characteristic that we can find in Évora and allow the shading of both people and buildings.

2.4 *Alentejo's vernacular architecture*

Although not very large, the Portuguese Mainland has within its borders quite substantial differences in regard to traditional forms of building, that are associated, among other things, to the existence of different climatic regions. As in the urban design of Évora, the traditional architecture we find in Alentejo, is built, mainly, to respond and minimize the effects of the high temperatures that are registered during summer in this region.

One of the most commonly used materials is rammed earth (moulded and compressed earth compressed between removable formworks). As a result of its construction process, walls can easily reach the 70 cm thickness or even more, obtaining a high thermal inertia. The construction of thick and heavy walls is appropriate in hot climates with large diurnal temperature ranges, which happens in Alentejo during the summer period. The heat is accumulated and held in these walls during the day and released during the night when temperatures are lower.

The roof, responsible for a high percentage of building heat gains, it is, in the Alentejo's vernacular architecture, usually built with ceramic tile coverage. In some cases, especially in the Southern Alentejo, a cane layer is used under the tile coverage (AA. VV. – Arquitectura popular em Portugal, 1988), providing a much cooler surface then the ceramic tiles that are exposed to the sun. The small sized windows are also used in this region, allowing a significant reduction in the heat gains as well as the use of light colors for covering the walls.

With no apparent solutions to promote solar heat gains during the winter period, the vernacular architecture of Alentejo uses a heat loss restriction strategy for the colder periods. Having a thick wall, which is important to cool down the house during the summer period, can also promote a thermal comfort in these buildings during the winter. With a 70 cm wall thickness, this material has a heat transfer coefficient of approximately 1.24 $W/m^2.^0C$. Despite this value does not reach the reference indicated by the RCCTE law, of 0.70 $W/m^2.^0C$, is clearly under the maximum limit, which is 1.80 $W/m^2.^0C$. The cane layer, used for summer heat gains protection is also efficient during winter, providing thermal insulation created mainly by a still air layer.

3 MALAGUEIRA QUARTER: ENERGETIC EFFICIENCY

3.1 *Urban planning*

Unlike the former plan, that offered separated residential areas, divided into high-rise buildings areas and low-rise isolated residences, the new Malagueira Quarter plan consists of a unique low-rise high-density complex. This type of compact urban morphology reflects the old walled city of Évora and plays an important role in adaptation to local climate, reducing the areas of exposed surfaces to solar radiation and increasing the shadowed areas. The use of large green areas and water lakes or fountains is another urban strategy used for this quarter in order to reduce the "heat island" effect that usually takes place in urban areas, by taking advantage of the climatic regulation characteristics of vegetation and water.

The Malagueira Quarter is organized from a main structural element, which not only carries the main services (water, power, gas), but is also the element from which all urban design is created, resembling the "Água de Prata" aqueduct that organizes a part of the old walled city. In the Malagueira Quarter, this elevated concrete "aqueduct" is also used as a gallery, providing shelter for both sunny and rain conditions.

Although it was not a priority for the definition of the urban design in the Malagueira Quarter, the orientation through the solar path, plays an important role in creating thermal comfort conditions in an urban setting. This will influence directly the thermal comfort inside buildings and influence it's energetic efficiency. Depending on the orientation of building blocks, solar heat gains can be favoured or restricted, according to the needs of each season. A building orientated to the south will receive the maximum hours of sun heat gains. In the Malagueira Quarter there was given no priority to solar orientation, being the relation with pre-existence quarters and urban continuity preferred is this case and given most care to the study of the dwellings typologies in order to better respond to the climate characteristics of this region.

Figure 1. Malagueira Quarter.

3.2 *Housing typologies*

The dwellings at Malagueira Quarter are patio or atrium types. This indicates that these buildings were thought to better adapt to the high temperatures we can find in Alentejo's summer, which was also the main concern reflected by the vernacular architecture of this region.

Most of the dwellings are built on an 8x12 m plot along a main predefined axis. With only one side of facing the street, each house will be surrounded by adjacent constructions in the other three sides, unless they are built at the tops of each urban block, having in this case two sides facing exterior public space. Thus it is assured a continuous residential fabric, adapted to the hot weather by reducing the built surfaces exposed to solar radiation. During the winter this is also a favorable situation, as the same built surfaces in direct contact with the outside lower temperatures will be fewer, limiting the heat losses by this elements.

Despite being part of a continuous fabric each housing module can be built independently from each other. These modules are also of an evolving type; each house can be built with only one room and may reach the top number of 5 rooms. These are key features for a low class social quarter that can be built according to the needs and available funds.

There are two basic types of housing throughout the Malagueira Quarter. In the first, type “A”, the patio is placed along the street, while the second, type “B”, the patio is located at the back of the plot. This distinction can have influence in the ventilation systems of each type. In type “B” there will be cross ventilation, while the type “A” is ventilated mainly by stack effect In time the initial types “A” and “B” evolved, creating a range of sub-type categories.

The patio is the most important element in the Malagueira Quarter dwelling typologies. The patio will allow a most close contact with the exterior spaces while maintaining the privacy of its occupants. This will also be an important element as it ensures a better natural lightning of interior spaces and guarantees a better ventilation system, as each module housing has, mainly, only one side facing the exterior environment. Moreover the patio has an important role in providing these houses a better thermal performance and improving the interior thermal comfort.

The patio is often used in hot dry climates (Koch-Nieklsen, 2007-2008), which is perfectly adaptable to the summer weather conditions in Alentejo. As an internal space, surrounded by built elements and open to the sky, the patio system assures shading for both its floor and for the buildings walls, reducing this way solar heat gains. During the night the heat accumulated by theses elements is released to the sky by radiation, cooling all built surfaces. The interior spaces of the building will benefit the lower temperature reached in the patio during the night, which is maintained, at least, during the first hours of the day. The microclimate created by this system allows an efficient system of ventilation to cool the interior spaces effectively during these cooler periods.

The use of vegetation in the patios will also be beneficial for achieving better thermal comfort conditions inside each house, being important in obtaining largest shaded areas and due to their capacity of absorbing solar radiation. The use of deciduous vegetation will be particularly effective as it won't create an obstacle for obtaining solar gain benefits during the winter period. The use of vegetation is also frequently seen in the interior of the old walled city urban blocks.

3.3 *Materials and constructive techniques*

In response to the reduced financial situation in which Malagueira Quarter was developed, prefabricated materials were chosen for the construction of the dwellings, mostly made of concrete. This was a cheaper solution and required also "friendly" construction technologies.

On the walls were used 20, 10 and 7.5 cm concrete blocks. These walls are resistant and support directly the prefabricated concrete beams, placed each 60 cm.

The roofs are flat and have two different cover materials. For the accessible terraces were used square concrete prefabricated slabs and the non-accessible are covered with gravel. These are important elements that protect the waterproofing system form direct sun impact. Made of corrugated cement sheets, with 6 mm thick, this waterproof system is put over an aggregate concrete with clay layer, with 16 cm thick, very important for the thermal insulation of these houses. Layers with 20 mm thick of sand and 6 mm cork plaques were also used for the accessible terraces, respectively based under the corrugated cement sheets and the concrete slabs (Sobreira, 1978). The sand was also used as a filling material of the wall concrete blocks that separate the various dwellings, providing a better sound insulation between them.

The 1st and roof floor slabs are upheld by half wall, preventing possible areas of condensation and cracking by using an exterior concrete block that guarantees the material continuity. This situation will also happen in the rest of the structure, as there is no use of columns or lintels in the windows and doors.

For the outside doors and windows wooden frames were used. These elements are recessed in relation to the outer walls and a unique glass, with 5 mm thick, was applied. Interior wooden shutters were also used, which are important not only to reduce solar gains during summer, but providing a better thermal insulation during winter.

3.4 *Energetic efficiency of the Malagueira dwellings, by the means of the RCCTE*

Approved in April 2006, RCCTE – Building Code on Thermal Performance Characteristics (Decree Law n.º 80/2006) replaced the previous code from 1990 and is integrated in a set of legislative measures meant to improve energy efficiency of buildings in Portugal, transposing European Directive 2002/91/CE.

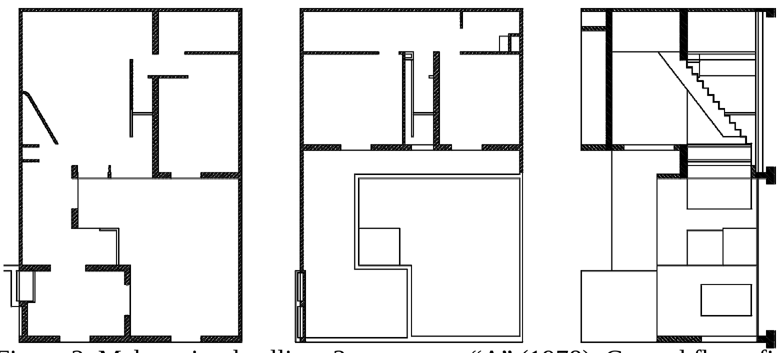

Figure 2. Malagueira dwelling, 3-room type "A" (1978). Ground floor, first floor and section thorough the patio (drawn form photocopies of the 1978 original drawings, for the RCCTE measurements.)

The application of the RCCTE at the Malagueira Quarter will allow the verification of its dwellings energetic efficiency. The 3-room type "A" house, first designed in 1978, was the chosen housing module to be studied. It was the first type to be built and the most representative in this quarter. For the comparison of several situations, the most representative 6 different orientations of this quarter were selected, and adapted to the 4 cardinal points and 2 intermediate points, being each of this 6, subdivided into two individual orientations, as this dwellings are mirror built type, totalling a number of 12 different situations.

According to the RCCTE climate division map, the city of Évora is located in the winter zone 1 (most mild winter zone) and the summer zone 3 (most severe summer zone). In fact the Malagueira project have had in the summer weather conditions the most concern, as the vernacular architecture of the region had in the past. For the means of RCCTE calculation method, were used heat transfer coefficients of 1.90 $W/m^2.^oC$ and 1.62 $W/m^2.^oC$ (Santos, 2006), respectively for the outside and inside walls, and was not considered the sand filling of the blocks between dwellings. With a thermal conductivity of 0.27 $m^2.^oC/W$ (Incorprera, *et. al.* 1992), the sand will have, with 5 cm thickness, a thermal resistance of approximately 0.18 $m^2.^oC/W$, i.e., very close to the air space gap thermal resistance values in the blocks (RCCTE, 2006).

For the roof were calculated, for both accessible and non-accessible areas, the respective heat transfer coefficient. For the accessible terrace it was used a value of 1.03 $W/ m^2.^oC$ and the remaining 0.90 $W/m^2.^oC$. The use of the cork in the accessible terraces, does not constitutes a significant improvement in terms of thermal performance, despite the low values of thermal conductivity for this type of material, 0.065 W/m.ºC. In this case the use of this material serves primarily as a support for the placement of the concrete floor slabs, and has only a 6 mm thickness.

For the glazed elements a 3.4 $W/m^2.^oC$ (Santos, 2006) heat transfer value was used, which corresponds to a wooden frame with simple glass and interior wooden shutters with low air permeability. Although there are no horizontal overhangs over the glazed windows, the presence of vertical shading elements becomes an important factor for the summer situation, especially in the most exposed dwellings to solar radiation, improving the obstruction factor, calculated individually for each orientation.

4 RESULTS ANALYSIS AND MEASURES TO IMPROVE ENERGY EFFICIENCY

4.1 *Results analysis*

The results obtained determine that these dwellings fail to comply winter-time and primary energy needs for all the 12 different situations analysed, despite most of the heat transfer coefficient values for constructive elements are below the RCCTE maximum values admitted, only the exterior walls are slightly above. The summer-time energy needs comply in all the 12 orientations.

Table 1. Heat transfer coefficients.

Constructive elements	Malagueira dwellings ($W/m^2.^oC$)	RCCTE maximum admissible ($W/m^2.^oC$)
Exterior walls	1.90	1.80
Roof	0.90/1.03	1.25
Interior walls	1.62	2.00
Interior slabs	1.00	1.65

By analyzing the primary energy needs, we can conclude, that in terms of the RCCTE, the orientation of these dwellings has little significance in terms of energetic efficiency. Still, better results are obtained for the south and southeast orientation, during the winter season, which are determined by an increase in the solar gains, in relation to other orientations.

It is for the summer energy needs that the most significant differences are obtained according to different solar orientations. In this case, heat solar gains through building elements are more visible. The north and northeast orientations have the lowest values in terms of cooling energy needs, and the southeast, east and west orientations the highest values. The south orientation has medium values.

Table 2. Energy indicators.

Orientation	Nic/Ni	Nvc/Nv	Ntc/Nt
West (south)	178%	93.18%	142.51%
West (north)	179%	89.49%	142.53%
Southwest (southeast)	169%	94.68%	140.00%
Southwest (northeast)	169%	89.29%	139.91%
South (east)	170%	79.41%	139.64%
South (north)	170%	79.17%	139.68%
East (north)	179%	90.29%	142.66%
East (south)	179%	94.00%	142.61%
Northeast (northwest)	183%	69.32%	142.76%
Northeast (southeast)	182%	74.64%	142.84%
North (west)	183%	62.76%	142.58%
North (east)	183%	62.98%	142.63%

4.2 *Measures to improve energy efficiency*

After comparing the energy indicators for the 12 orientations in the Malagueira most representative dwellings, a series of measures were analyzed in order to improve energy efficiency, by choosing two of these orientations: southwest (southeast) and north (east), which correspond to the worst situations, respectively the cooling energy needs and the heating energy needs. Table 3 shows the most unfavourable constructive elements in terms of heat losses during the winter period. By this way, it is possible to identify the areas where the improvement measures should be implemented. It is interesting to note that alone, the interior walls, in contact with other dwellings, is the highest. This situation is due to the fact that this project has a considerable area in this situation.

Table 3. Heat losses.

Heat losses through constructive elements (W/ºC)	
Exterior walls	61.39
Roof	50.32
Walls and pavements in contact with the soil	34.33
Linear thermal bridges	37.62
Interior walls (in contact with non used spaces or with other buildings)	116.05
Interior slabs (in contact with non used spaces)	3.03
Interior glazed surfaces	
Thermal bridges (for separation walls in contact with non used spaces with τ>0.7)	1.26
Exterior glazed surfaces	68.10
Heat losses by air renovation	77.45

Thermal insulation was then tested in all exterior elements such as walls, roof and glazed elements. For the walls and roof was used respectively an 80 mm thickness layer of expanded polystyrene foam (EPS) and an 80 mm thickness layer of extruded polystyrene foam (XPS). The heat transfer coefficient for these elements was then below RCCTE reference values.

Table 4. Heat transfer coefficients after thermal insulation improvements.

Constructive elements	Malagueira dwellings ($W/m^2.^oC$)	RCCTE reference values ($W/m^2.^oC$)
Exterior walls	0.40	0.70
Roof	0.32	0.50
Exterior glazed elements	2.20	4.30

Aluminium double glazed frames were used to replace the previous wooden frames with a single glass. According to the manufacturer, Arkial, these frames have a heat transfer coefficient of 2.90 $W/m^2.^oC$. This value can be improved for 2.20 $W/m^2.^oC$ if the interior shutters are activated. The heat transfer values for these aluminium frames are quite similar to other wooden or plastic frames. However, and due to the difficulty on finding air permeability classified frames in Portugal, these specific frames were used for verifying all RCCTE parameters, which consider a maximum classification of 3 that should be used in this case, despite the chosen frames have a classification 4.

After thermal insulation improvements on exterior elements were tested in the Malagueira dwellings, all energy indicators were reduced in both orientations. Still, the summer-time energy needs was the only indicator below the RCCTE maximum admissible.

Table 5. Energy indicators (exterior thermal insulation).

Orientation	Nic/Ni	Nvc/Nv	Ntc/Nt
Southwest (southeast)	104%	86.46%	122.11%
North (east)	117%	60.96%	124.54%

In order to place all energy indicators below the maximum admissible values, a 30 mm thickness layer of extruded polystyrene foam (XPS) was used in the interior walls in contact with the adjacent houses. Together with the exterior thermal insulation improvements, again all energy indicators were reduced, but only the summer-time and winter-time energy needs are now below the maximum admissible values. Primary energy needs are still over the respective maximum value.

Table 6. Energy indicators (exterior/interior thermal insulation).

Orientation	Nic/Ni	Nvc/Nv	Ntc/Nt
Southwest (southeast)	75%	88.27%	114.20%
North (east)	86%	62.55%	116.17%

Despite the improvements registered by the means of the RCCTE, when the interior insulation layer was used, we should note that the use of this solution has some problems and may not be responsible for a real improvement of thermal comfort and consequently reduction of energy consumption. First of all there is the reduction of interior areas, which are already small in these dwellings. On the other hand the decrease on the buildings thermal inertia that may cause some problems of over-heating. Finally the RCCTE indicates that in a multifamily building no heat losses should be considered to contiguous residences. In the Malagueira Quarter the losses to contiguous houses are considered as 60% if in its place we would have exterior temperatures. This is a quite punitive situation considering the fact that in the Malagueira dwellings, the surface areas in contact with contiguous houses is higher then the areas in contact with exterior air.

Even though summer-time energy needs were already below the admissible maximum values, an outside shutter system was tested in order to improve thermal comfort in theses dwellings during summer. It was confirmed the reduction of summer-time energy needs, by using outside wooden shutters instead of the interior that were used, but this reduction had little effect in the primary energy needs.

Table 7. Energy indicators (exterior/interior thermal insulation and outside shutters).

Orientation	Nic/Ni	Nvc/Nv	Ntc/Nt
Southwest (southeast)	75%	56.88%	112.99%
North (east)	86%	42.84%	116.42%

In order to reduce the primary energy needs, which were still above the maximum admissible, and help to improve the energetic efficiency of these dwellings, the hot water production system was replaced. The gas heaters used, that represented the most common technology used in the late 1970's in Alentejo, were replaced by a mural boiler system with 50 mm to 100 mm of thermal insulation. This measure alone was enough for reduce the primary energy needs below the maximum admissible, proving the influence given by RCCTE regulation to water heating systems in terms of achieving energetic efficiency.

The use of solar panels for production of hot water is now obligatory by the RCCTE, as long as there is favorable solar exposure, which occurs in Malagueira dwellings. It was therefore used a single solar panel (1.9 m^2), with high efficiency, and calculated its performance using the Solterm software. The chosen system is manufactured by Yazaki and has a tank of 200 liters.

Table 8. Energy indicators (thermal insulation, outside shutters, hot water production system and solar panels).

Orientation	Nic/Ni	Nvc/Nv	Ntc/Nt
Southwest (southeast)	75%	56.88%	48.52%
North (east)	86%	42.84%	50.93%

5 CONCLUSIONS

For the time it was built, and despite all financial difficulties that have led to the conception of this project, the Malagueira Quarter dwellings have a quite satisfactory energy label - 'C' - for the 12 orientations studied. The options taken in the latest 1970's have proven to adapt to the local climate. For this achievement contributed a close look to the old walled city of Évora main characteristics and the Alentejo's vernacular architecture, both well adapted, mainly, to the hot dry climatic characteristics of Alentejo's summer.

Combining all the energy improvement measures previously described, a high energy label - 'A' - was achieved for the southwest (southeast) orientation, and a 'B' energy label was achieve for the north (east) orientation.

For the architecture, site and climatic adaptation have always been a main design process concern. Forgotten during some periods in the 20th century, mostly due to some technical innovations, is now an area of major interest. The study of this quarter in Évora has proven that together, both learning with the past and make use of new technology, may be the way to improve energy efficiency in buildings and consequently to reduce the energy consumption that have led to so many environmental problems.

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An experience on applying sustainability and energy efficiency in undergraduate building design

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ABSTRACT: Contemporary buildings, as a general rule, have a responsibility in the increasing global warming and environment degradation, mainly through the intensive use of energy, and resources consumption. And therefore they can be seen as having a great potential in the mitigation of those problems they help create. According to environmental researches, there is an urgent need for the society to change its behavior, diminishing the production of waste, minimizing the use of resources and energy and enhancing the efficiency of its processes.
Issues like daylighting, natural ventilation, sun protection, environmental comfort and energy efficiency must be addressed in the first stages of the building design in order to generate sustainable and efficient buildings.
In the specific context of energy efficiency in Brazil, it was launched on July 2009 the National Energy Conservation Label (ENCE) for Commercial, Service and Public Buildings. The evaluation is valid for conditioned, partly conditioned and non conditioned existing or new buildings.
The School of Architecture of the Federal University of Minas Gerais, Brazil is already training its students to be able to face this new regulation and the design needs that are attached to the certification process, in order to enhance not only the energy efficiency of building but also their sustainability. The present paper shows two final graduation designs (TFG) made by students, based on concepts such as flexibility, environmental comfort, energy efficiency, resource conservation, and discusses the effort needed and the necessary changes in the conception process in order to fulfill these new needs in the design process.
One of the studies was the refurbishment of a building transformed in a convention center in Formiga (Minas Gerais), which was classified according to the new ENCE requirements. The other one is a sustainable housing of mixed use (residential and commercial) in Nova Lima, also in Minas Gerais. The design studies show the commitment of a new generation of architects to the principles of sustainable architecture and also to a more sustainable way of living.

1 INTRODUCTION

Buildings, over the last decades, have strongly contributed to the environmental degradation by a large usage rate of energy, though they may also present a potentially reasonable alternative for damage reduction. In order to achieve it, the likes of environmental comfort, energy efficiency and water consumption decrease must be taken into account from the beginning of the architectonic project, as means to develop an integrated process of building conception which leads to a low environmental impact.

In view of these parameters, two Completion of Course Works were developed – both considering, in its conception, the application of climatic variables for the purpose of energy efficiency, being later on detailed, thus enabling the refinement of decisions and specifications.

The evaluation presented high rating levels on commercial building and, if the same rules were applied to the residential rating, the results wouldn't differ much. This was made possible through previous consideration of climatic aspects, as the course of the article will show. The results obtained allowed both works to take part in national architecture contests, as one of them recently won the National Award for the Conservation and Rational Use of Energy (ELETROBRAS/CONPET).

2 PROJECT DESCRIPTION & METHODOLOGY

The first work concerns the design of a Cultural Center in Formiga, Brazil. The development of this project aims relocating schools to the former city foundry, which is currently abandoned. This is a refurbishment project, which not only looks towards the recovery of a historic building, but also attempts to provide a better infra-structure for the site, so it may be able to admit over 900 students, teachers and visitors.

The second work consists in developing a 30.930 m² housing condominium at Nova Lima, Brazil. Through the use of natural lighting and ventilation as well as many other bioclimatic strategies, the project suggests a reduction in the energy consumption for apartments and public spaces (such as lobbies and garages). Besides presenting an alternative to reduce the environmental impact, this work provides solutions to both operational costs and user productivity and comfort. In addition, as the residential buildings should be connected to a commercial office building, it shortens users' traveling time through places.

Figure 1: External Perspective of the Cultural Center

Figure 2: Internal Perspective of the Cultural Center

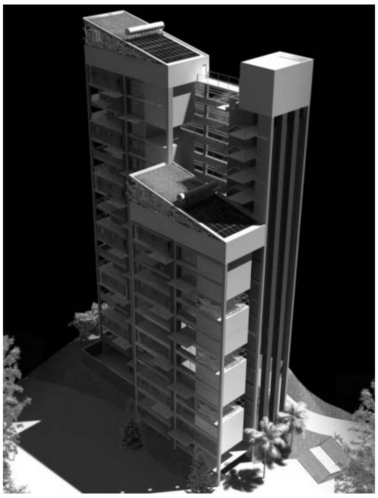


Figure 03: Residential Bulding

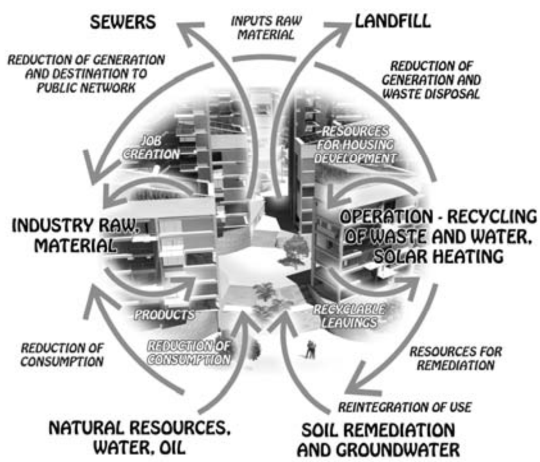


Figure 04: Resource Usage Diagram

3 DEVELOPMENT

Not only as a tendency, but also as a need, the global process of implementation of building standards concerning energy efficiency has gained more adepts. In Brazil, this project is yet incipient, and the studies looked towards an integration of bioclimatic strategies from its conception, in order to decrease the need of using energy operating systems.

3.1 *Standards*

The Brazilian electric energy sector has one of the biggest hydroelectric parks of the world, corresponding to 82.36% of all electric energy produced within the country. This is only possible because of its hydrographical basin which, besides its extension, has great capability as to generating electric energy. Until the mid 90's this system was able to attend the country's demand, however insufficient investments in the sector allied to political/economic issues, to a low rain rate and to an increasing energy consumption led the hydroelectric energy supply to give shortage signals. This process ended up in 2001 when the country was forced to implement energy rationing – a watershed in Brazilian electric sector –, which served as a route for new long term investments, thus extinguishing further rationing risks.

Later on, as seen on Europe and North America, measures concerning electric energy usage were adopted by the Brazilian government. The law 10295/2001 states that "the maximum level of energy consumption or minimum of energy efficiency, of energy consuming machines and equipment manufactured or commercialized in the country, as well as constructions shall be pursuant to technical indicators and specific regulations", which are defined in the decree. In order to implement these specifications, PROCEL – Electric Energy Conservation Program approved the RTQ-C – Technical Quality Standards for the Energy Efficiency of Commercial, Service and Public Buildings in 2009, while the Residential Building Standards shall be implemented in 2010.

RTQ-C building evaluation is divided into four unequally weighted sections, as follows: building envelope (30%), lighting (30%), air conditioning (40%) and the building as a whole; which are classified through rates from A – more efficient to E – less efficient. The evaluation is made either by a simplified prescriptive method or by building computer-aided simulation, enabling the evaluated building to receive an ENCE – National Energy Conservation Label, indicating the building's overall performance and also its performance on each section.

In opposition to other countries – where such measure was originally directed to the residential sector, the first set of parameters to be developed in Brazil was the RTQ-C. This is due to a growing range of diverging features among residential buildings in the country, where energy efficient strategies would also differ, as a result of the Brazilian climatic variety.

The original idea was to focus on developing commercial patterns, given the system standardization concerning energy expenditures, thus creating a smaller number of variants. Besides, artificial conditioning – preponderant in commercial buildings –, is seen as one of the main causes for the high energy consumption, along with inefficient equipment. In light of these topics, it is likely that both ventilation and lighting are to be held as the most important points as to bioclimatic projects.

3.1.1 *The brazilian and portuguese standards*

The Portuguese program, as in Brazil, follows similar patterns to those already adopted for household appliances, being currently extended to all new buildings. It differs, though, from the Brazilian model, by being mandatory for carrying building constructions and large refurbishments out. The most relevant step Portugal ever took was creating a regulation for the architects to effectively use energy simulation tools for building designing. We have strong reasons to believe a similar process will take place in Brazil as soon as its standards become mandatory.

3.2 *Bioclimatic studies*

The altitude tropical climate, prevailing over Formiga and Nova Lima, is relatively mild, with average mean temperature varying from 13° to 29ºC, being also characterized by rainy summers and dry winters. For both studies the climate of Belo Horizonte (lat.19º56’ S and long. 43º56’W) was used, as it’s the closest city with available data.

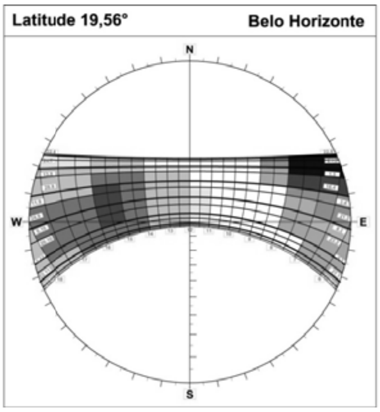


Figure 5: Solar Chart for Belo Horizonte

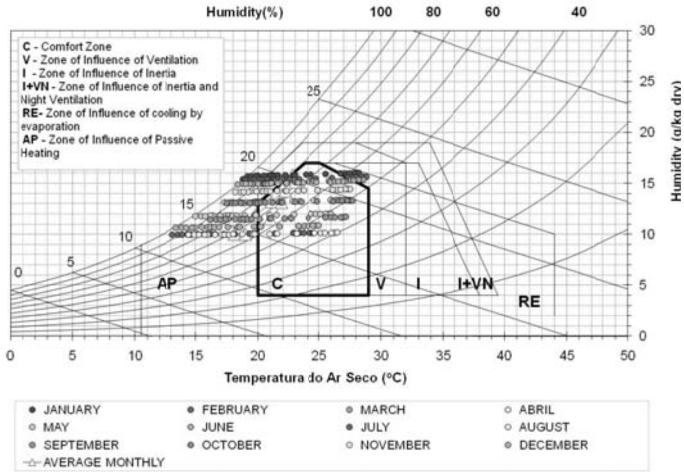


Figure 6: Givoni’s Diagram

Analyzing climatic data in light of Givoni’s Diagram, the following conclusions were reached: large areas between buildings should be built, thus allowing the wind to circulate – minding to prevent them, however, from recurrent cold winds; opening dimensions between 25 to 40% the wall surface; adequate opening protection against hard rains and excessive sun exposure; a minimum 8 hour thermal transmission time for walls and roof; well isolated roofing and proper rain drainage.

4 STRATEGIES APPLIED

4.1 *Cultural center*

The Cultural Center rating was made in account of the envelope structure (windows, walls and roof areas), as well as color specifications and component materials – besides lighting and conditioning systems, so the global heat transmission coefficient could be calculated. The items were evaluated according to prescriptive equations for bioclimatic zone three – as stated by the national standards (ABNT 15220-3/2005) –, which corresponds to both Formiga and Nova Lima.

Solutions for the final design came from a sustainable social/economic/environmental performance-oriented approach, from which some guiding topics were defined. Considering environmental performance, the following variants may be highlighted: adequate solar orientation; wind capturing and cross ventilation; natural light utilization; thermal performance of building materials; direct sunstroke prevention; use of low environmental impact materials.

$$PT=0{,}30.\left\{\left(EqNumEnv.\frac{AC}{AU}\right)+\left(\frac{APT}{AU}.5+\frac{ANC}{AU}.EqNumV\right)\right\}+0{,}30.\left(EqNumDPI\right)+ +0{,}40\left\{\left(EqNumCA.\frac{AC}{AU}\right)+\left(\frac{APT}{AU}.5+\frac{ANC}{AU}.EqNumV\right)\right\}+b_0^1$$

After defining building system specifications, the prescriptive method was applied to the building, using the above-mentioned equation in order to obtain the final performance of the building, where:

- EqNumEnv - equivalent number for the envelope; EqNumDPI - equivalent number for the lighting system;

- EqNumCA - equivalent number for the air conditioning;
- EqNumV – equivalent number for natural conditioning; APT – floor area of non-conditioned transitory spaces;
- ANC – floor area of non-conditioned permanent spaces;
- AC – floor area of conditioned spaces;
- AU ¬– used area;
- b – points obtained for bonuses varying from 0 to 1.

Figure7: Final Label for the Culture Center

4.2 *Housing development*

In order to obtain a proper implementation of the design, a climatic data survey was carried out, taking into account wind behavior, humidity condition and solar position. The same indicators were tested through low scale models and *in loco* measurements, aiming low rates concerning land movements, in order to preserve the natural surface of the land.

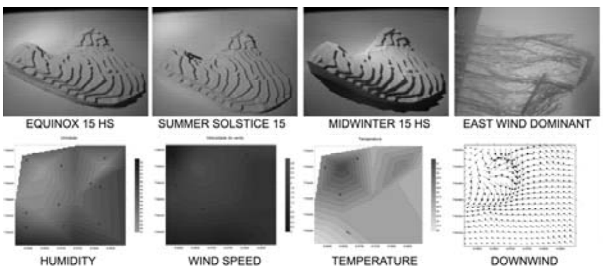
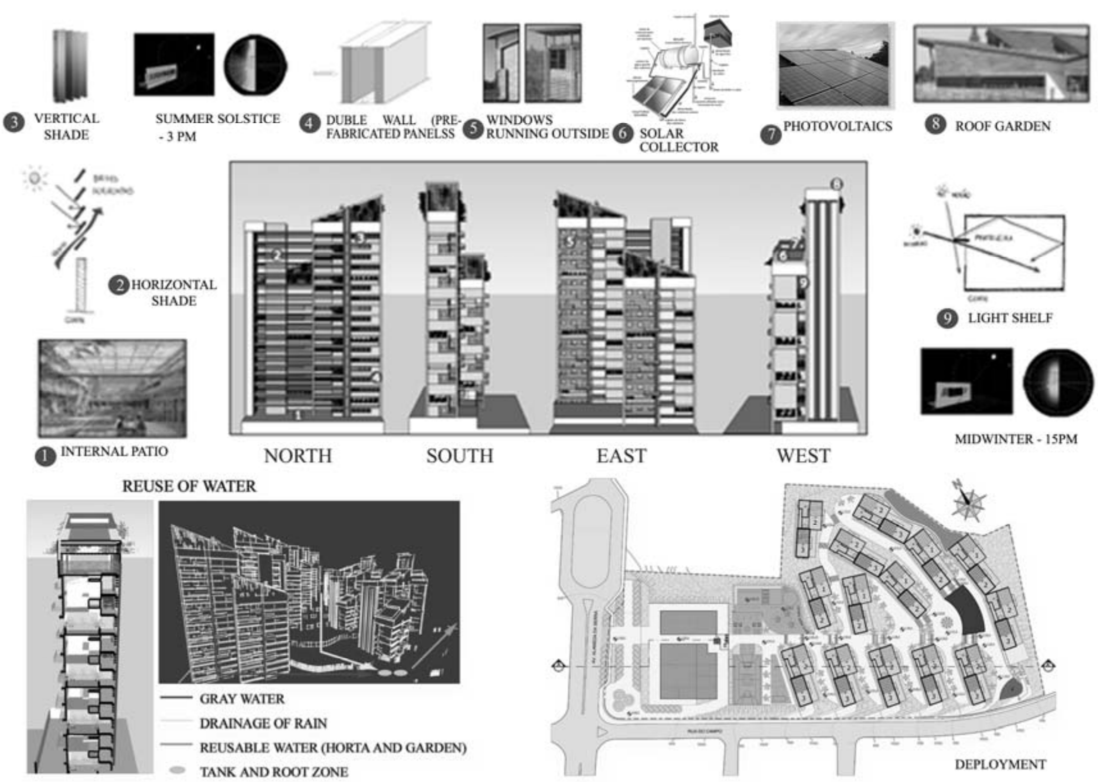


Figure 8: Study of climatic variables on the land

Figure 9: Cross Ventilation in apartment interior



PICTURE 10: Bioclimatic Measures adopted in Housing Development

Technology usage concerning the project may be linked to the utilization of an independent building structure that could be easily assembled; predominant using of local material and recycled wood; acoustic protection between apartments – as double walls (thus reducing air conditioning system usage); using of high performance envelopes and cross ventilation; suspended gardens and breathing zones for wind permeability, as well as abundant vegetation for shadowing and creation of microclimates; using of solar bulkheads for sunburn prevention; solar collectors and photovoltaic panels; visible piping and water pressure regulating valves for faucets, showers and toilets; rainwater harvesting for toilets; individual water meter sets for each residential unit; concentration of wet areas in west façade (leeward façade – air outlet); efficient lighting systems and presence sensors; PROCEL labelling in common use equipments, such as freezers and water pumps; selective waste collection areas; social integration areas; and a reduced number of parking spots and alternative proposals for public transportation, thus giving priority to pedestrians over vehicles.

5 CONCLUSION

As every new process, the brazilian energy efficiency labelling is still at trial and in improvement, as researches and application studies are being carried out. One can notice, though, how civil construction professionals get interested in obtaining the National Label of Energy Conservation.

Many of the technologies applied to efficient buildings imply on a more significant starting project investment, though their cost should not be overlooked, as energy expenses unbalance the figures. Anyhow, both studies showed that considering energy efficiency and bioclimatic aspects in early stages of building design process allows enhancing the building overall performance. For it to happen, however, several changes concerning the way buildings are developed in Brazil must take place. In order to prove the energy efficiency of adopted strategies, the architect must have proper technological knowledge of the systems' performance, and material specifications ought to be made in early stages, which doesn't actually happen in most building developments. Professionals must be integrated from the beginning so that energy alternatives can effectively be explored in their full range.

Although bioclimatic projects may present higher building costs over traditional ones, they have great appeal to the market and may as well contribute to brazilian's voluntary labelling.

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Traditional and passive house energy footprint calculation methods

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ABSTRACT: We build our houses according to current norms regarding energy consumption and economy. But how accurate are the calculations in the case of new technologies? Can they deal with super insulated structures? Do they take into account the entire energy consumption and generation that takes place inside the building? We propose a critical approach upon two methods of energy consumption calculation and two energy-wise different technologies of building the same house. First we will analyze the traditional calculation method (as per current Romanian standards), second we will analyze the passive house calculation method (as defined by the Passivhaus Institut in Darmstadt, Germany). Both methods will be applied first for a traditionally built house – as per current Romanian energy standards – and second for the same house built this time as a passive house – as defined by the Passivhaus Institut. The comparison aims to show the greater precision of the "passivhaus" method and also the lack of applicability of the traditional method in current passive house design.

1 INTRODUCTION

1.1 *General*

Passive houses vs. traditional building techniques is an ongoing debate since a few years. The issue becomes more and more obvious when we take into account the very volatile energy prices on the market today. We propose an approach that takes into account the characteristics of each method and tries to shed some light onto the passive-traditional debate.

2 TRADITIONAL – PASSIVE HOUSE PRINCIPLES IN COMPARISON

2.1 *General*

A passive house is defined as a building that has a very low energy consumption (max. 15 kWh/m^2/year for heating and cooling and a total energy footprint of less than 120 kWh/m^2/year). A dwelling which achieves passive house standards usually includes a few features that distinguish it from mainstream builds.

2.2 *Title, author and affiliation frame*

First of all passive houses will distinguish themselves through compact form (good A/V ratio) and good insulation. As such all components of the outer shell should achieve a U-value of at least 0.15 W/m^2K, all this while conventional housing takes less into account the A/V ratio and limits the U-values at about 0.3 – 0.7 W/m^2K.

Second, southern orientation and shading are taken into consideration as passive use of solar energy is a significant factor in pasive house design, whereas in traditional building planning consideration is given to a certain measure to north/south orientation but the improvements resulting from passive site design are often not taken into account.

Windows are a crucial part of passive house design as they usually provide the weakest part of the outer shell – energy-wise. As such the windows used in passive houses should have U-values not exceeding 0.80 W/m^{2}K (glazing and frames combined) with a solar heat-gain coefficient of around 50%. Typical U-values in traditional houses are in the range of 1.8 – 2.2 W/m^{2}K.

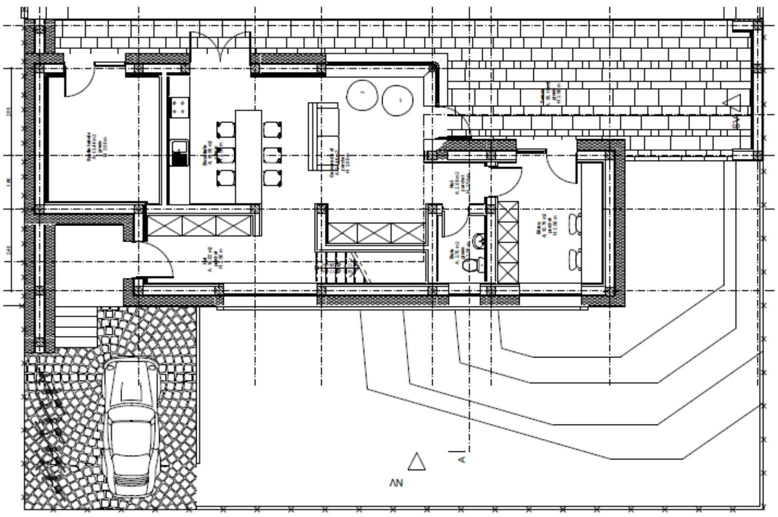


Figure 1 - Proposed ground floor plan of dwelling

The building envelope should be airtight in passive houses – insuring an air leakage rate of maximum 0.6 volumes per hour at a 50 Pa pressure difference between the interior and the exterior. Mainstream builds require only some airtightness, the norm actually takes into account a natural air change rate of at least 0.5 volumes per hour – achievable by opening the windows. Other standards require an airtightness at least 10 times poorer than passive house standards.

Other key points include a ventilation system with heat recovery running at an efficiency of at least 80% so that most of the heat is contained inside the house, preheating of the intake air for the ventilation system through underground heat exchangers (air-soil) so that the fresh air will be preheated to ca. 5°C even in wintertime. These measures have little significance for a traditional house with high air permeability where ventilation is usually achieved by opening the windows/doors or by using trickle vents or extract fans.

Energy-saving appliances are a must in a passive house as the requirement of a total energy footprint of less than 120 kWh/m^2/year imposes certain restrictions.

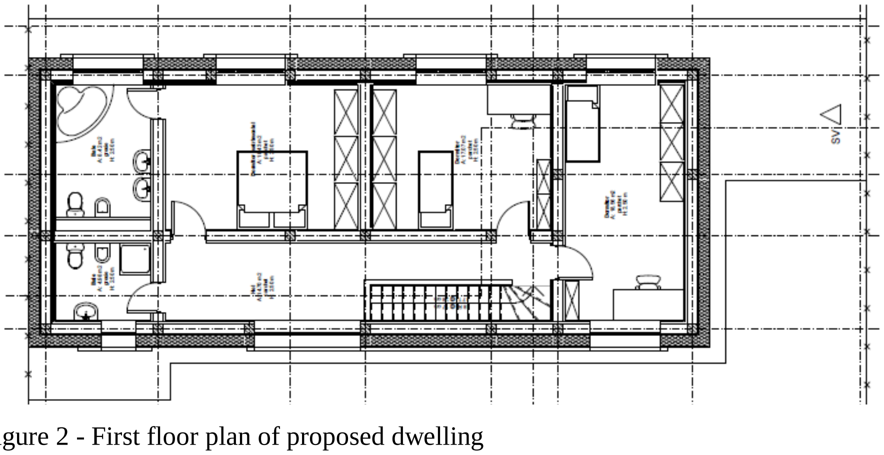


Figure 2 - First floor plan of proposed dwelling

2.3 *Insulation*

As previously stated the building components of a passive house should have superior insulating properties. The limiting U-value of 0.15 W/m^{2}K places the thickness of the insulation at around 30-40 cm (Fig. 3, 4) given the use of traditional materials like polystyrene foam or mineral wool. With such a highly insulating outer shell extraordinary care must be taken to avoid thermal bridges altogether, posing a series of technical difficulties.The continuity of the insulation in a passive house is an important matter since heat losses through even small thermal bridges have a very large impact on the global energy balance. The entire heated volume of the building should be wrapped in a continuous insulating shell, from below the foundations, running up the walls and over the roof.

Windows with U-values not exceeding 0.80 W/m^{2}K (glazing and frames combined) with a solar heat-gain coefficient of around 50% usually have triple glazing and provide in wintertime for most of the heat gain necessary to maintain a confortable indoor climate. Special care must be shown towards better quality frames for the windows as they constitute ca. 30-40% of the window surface and only contribute to the heat loss, exhibiting no solar gain. The superior insulating materials of a passive house also provide for a generally better indoor climate through higher inner surface temperatures in wintertime and lower in summertime, providing for a lack of cold surfaces – detrimental to confort – and a decreased chance of condensation as well as protection from the high summer temperatures.

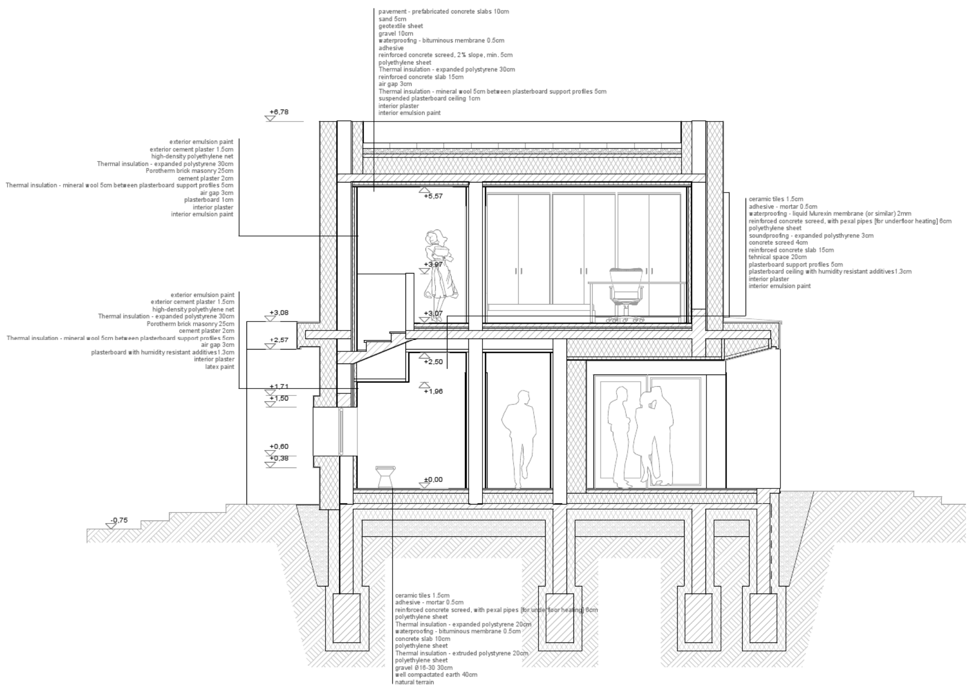
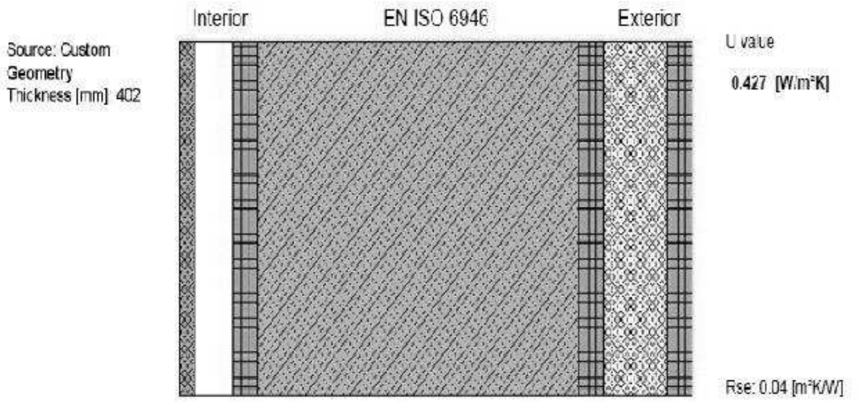


Figure 3 - Cross-section of proposed dwelling

2.4 *Mechanical*

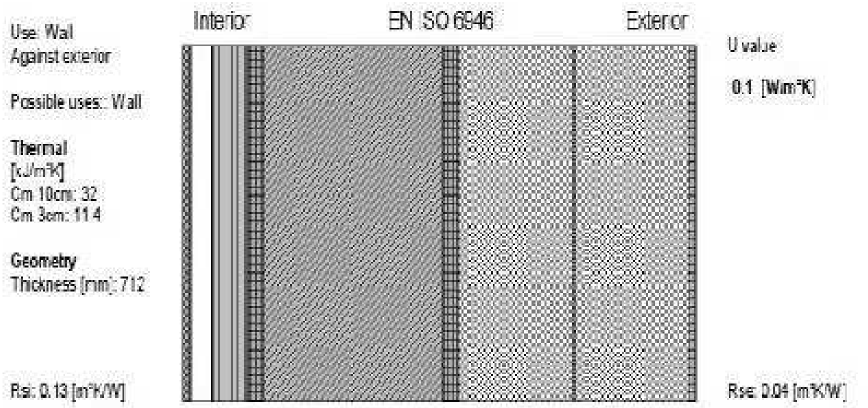
Passive houses must use, in order to take advantage of the great insulation otherwise and to insure a good quality of the inside air in an otherwise airtight house, a ventilation system with heat recovery. In order to make the most out of it the heat exchange efficiency should be higher than 80%, not difficult apparently, since commercial units achieve up to 92% efficiency.



Section 1 RT: 2.34 [m²K/W]

Material name:		Thickness [cm]	L	H	[W/mK]	[-]	[kg/m³]	c [wh/kgK]	R [m²K/W]
	Rsi								0.13
Gypsum plasterboard CEN		1.2	✓	✓	0.250	10	900	0.292	0.048
Air layer		3		✓	0.171	1	1.23	0.278	0.175
Cement mortar		2	✓	✓	1.400	15	2200	0.306	0.014
Standard clay brick BN 25		25	✓	✓	0.350	4	1100	0.250	0.714
Cement mortar		2	✓	✓	1.400	15	2200	0.306	0.014
Expanced polystyrene PS 15		5	✓	✓	0.042	20	15	0.389	1.190
Cement mortar		2	✓	✓	1.400	15	2200	0.306	0.014
	Rse								0.04

Figure 4 - Cross-section of traditional wall structure



Section 1 RT: 10.02 [m²K/W]

Material name:		Thickness [cm]	L	H	λ [W/mK]	μ [-]	ρ [kg/m³]	c [wh/kgK]	R [m²K/W]
	Rsi								0.13
Gypsum plasterboard CEN		1.2	✓	✓	0.250	10	900	0.292	0.048
Air layer		3		✓	0.134	1	1.23	0.278	0.183
Mineral wool 30 kg/m³ CEN		5	✓	✓	0.040	1	30	0.230	1.250
Cement mortar		2	✓	✓	1.400	15	2200	0.306	0.014
Standard clay brick BN 25		25	✓	✓	0.350	4	1100	0.250	0.714
Cement mortar		2	✓	✓	1.400	15	2200	0.306	0.014
Expanded polystyrene PS 15		16	✓	✓	0.042	20	15	0.389	3.810
Expanded polystyrene PS 15		16	✓	✓	0.042	20	15	0.389	3.810
Cement mortar		1	✓	✓	1.400	15	2200	0.306	0.007
	Rse								0.04

Figure 5 - Cross-section of passive house wall structure

2.5 *Building technique*

2.5.1 *Insulation*

The requirements for passive houses also mean that certain problems have to be solved in order to attain strict conditions. The high thickness of insulation poses certain problems as it must be continuous. Special types of insulation must be used under the foundations in order to insure stability of the building. Particular details have to be addressed in suspending the insulation on the exterior of the walls, in order not to create thermal bridges. These problems are usually dealt with less care in a traditional building because of the lesser influence they have on the overall result.

2.5.2 *Thermal bridges*

Thermal bridges become really relevant only in a highly insulated outer shell as an uninsulated building consists mostly of thermal bridges. Thermal bridge definition is somewhat different in a passive house compared to a traditional house. Generally passive houses are designed that the ψ factor of any thermal bridge is kept at a maximum of 0,010 W/(m²K) (Fig. 6). In these conditions any protrusion through the insulating shell must be carefully planned because otherwise the effect can be catastrophic on the energy balance.

2.5.3 *Airtightness*

Particular attention is paid to good airtightness of a passive house. If a passive house is built in a brick and mortar fashion, usually the inner render layer doubles as an airtight layer. If the building technology is in wood or steel, different measures have to be taken: usually an airtight layer of PE membrane or a similar material is applied on the interior of the building, beneath the final render layer.

2.5.4 *Windows*

Also important are the window details: windows should be mounted in such a manner that the fixing method does not allow for thermal bridges and provides for good airtightness (Fig. 7). Usually a separate PE or similar membrane is used to provide this level of airtightness.

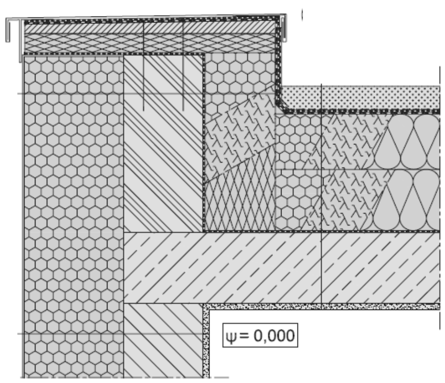


Figure 6 - Passive house roof to wall detail

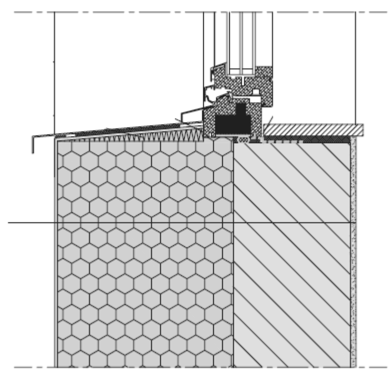


Figure 7 - Passive house window mounting detail

3 COMPARATIVE ENERGY CONSUMPTION EVALUATION

3.1 *Algorithms for estimating energy consumption*

The energy consumption assessment has been developed according to two methods of calculation: the traditional calculation method and the passivehouse calculation method. While the traditional method can be applied to passive houses the results do not correspond with the passive ouse calculation method results. Opposite, the passive house method can be applied to traditional houses results being closer to each other.

3.2 *Differences in assessment methods*

First and foremost we must point out that there are fundamental differences in the approach to energy consumption assessment according to each method.

The traditional energy consumption calculation method uses a global insulation coefficient for the entire building (G) – an average thermal transmittance value for the entire shell of the building. G is then used to determine the necessary energy per 1 m^2.

The passivehouse method involves a calculation of all the heat losses separately through all the surfaces comprising the building envelope, taking into account different U-values for different materials which eventually yields a total energy consumption for the entire house, which is then divided by the area of the building in order to obtain the necessary energy per 1 m^2.

Different factors also apply for shading, window to window connection heat loss, free heating energy as a result of building use resulting in a different result between the two methods.

3.3 *Solar heat gain / shading*

While the passivehouse calculation method provides for detailed analysis of solar heat gain according to precise (to the nearest degree) cardinal orientation, angle of the window around a horizontal axis, the traditional method only differentiates between 5 main cardinal directions and assumes all windows at an angle equal to or higher than 30 degrees as vertical. The latter method does not allow for a precise calculation of solar heat gain.

3.4 *Ventilation*

In the passivehouse calculation method there is provision for taking into account artificial ventilation with dehumidification factors while the traditional method applies a bulk coefficient for natural ventilation and assesses heat loss according to an estimated hourly ventilation rate.

3.5 *Internal heat gain*

Passive house method takes into account for a dwelling ca. 2.1 W/m^2 of heating energy while the traditional method allows for 7 kWh/m^3*year. The results are normalized in the table below.

Table 1- Internal heat gain comparison (kWh/m^2*year)

Traditional	Passivehouse
17.5	15.3

3.5.1 *Thermal bridges*

Both methods allow for thermal bridge loss calculation but the methods differ. This was not pursued here as both buildings were designed without thermal bridges.

4 CONCLUSIONS

4.1 *Calculation results*

The results are centralized in the following table:

Table 2- Internal heat gain comparison (kWh/m^2*year)

	Calculation method		Difference
Building method	Traditional	Passivehouse	
Traditional	90.6	103	13.69%
Passivehouse	33.54	21	-37.39%

4.2 *Interpretation*

The assessment presented here takes into account the energy consumption needed for heating a residential building with a net flor area of 142 m^2 in winter, calculated according to the two methods.

As the results show the difference in assessing a higly insulated dwelling are rather large. It is interesting to notice that the passivehouse method calculates a higher energy consumption for the traditional house while the traditional method assesses a larger energy need for the passive house, each one respective to the other calculation method.

Basically the traditional method is useless in assessing a passivehouse, mainly because it can not take correctly into account the solar heat gain and because it lacks provision for assessing the ventilation system heat loss.

The passivehouse calculation method shows results closer to the traditional method when applied to a traditional dwelling.

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Sustainable housing for all, respecting disabilities

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ABSTRACT: It is a well known fact that 6 – 8 % of the population is disabled. This ratio increases since the ratio of elderly people is increasing – parallel with the age the risk of disabilities and the cumulative effect of mobility, sensorial and cognitive impairments increase, too. The term "all" includes disabled and elderly people. One of the possible interpretation of "sustainability" means that the homes have to facilitate independent, safe and comfortable life of these people – in other terms the homes should become barrier free in case of need. Reviewing the concept of universal design it can be seen what is the cost of accessibility. It seems to be irrational to build all residential buildings as barrier free, however the possibility of converting them without high extra cost and destruction should be provided. The aim is to keep the affordable houses usable even if the abilities of the inhabitants change.

1 INTRODUCTION

Affordable housing is a well known term to describe dwelling units whose total housing cost are deemed to be "affordable" for those who have median income. (Wikipedia, 2009) Several elderly and disabled people belong to this sector. Their homes - however it is affordable - have to facilitate independent, safe and comfortable life. In other terms the houses should become barrier free in case of need.

Elderly or disabled people – either together, or without, a family of more generations – likely prefer to continue their life in their home rather than to move in an institute. In many cases the house they live in is the result of their efforts during decades – to leave it may become a psychological catastrophe. On the other hand from the point of the society it is more reasonable if elderly and disabled people are together with, and taken care by, family members instead of establishing and maintaining institutions. This is why the preconditions of the adaptation of houses to the needs of elderly and disabled people are of fundamental importance.

Emphasis is put on adaptability since it seems to be irrational to build all residential building according to the rules of universal design. Disregarding some inevitable preconditions, derived from the Universal Design concept the possibility to adapt the house to the special needs of the users - without high extra cost and destruction – is to be provided

People with special needs nowadays represent 6 – 8 % of the population – according to the statistical forecast this ratio will be higher in the future.

2 DEMOGRAFIC SITUATION

2.1 *Demographic situation related to disabled and elderly people*

The population structure changes continuously. According to the estimation of the WHO and the national statistical data – parallel with the higher life expectancy and the growing population - the ratio of elderly people is increasing too. By 2050, the age pyramid shows a significant difference in age structure of the EU-27's population. (Fig.1) Expectedly 30% of the total population will be aged over 65 years. (Fig.2)

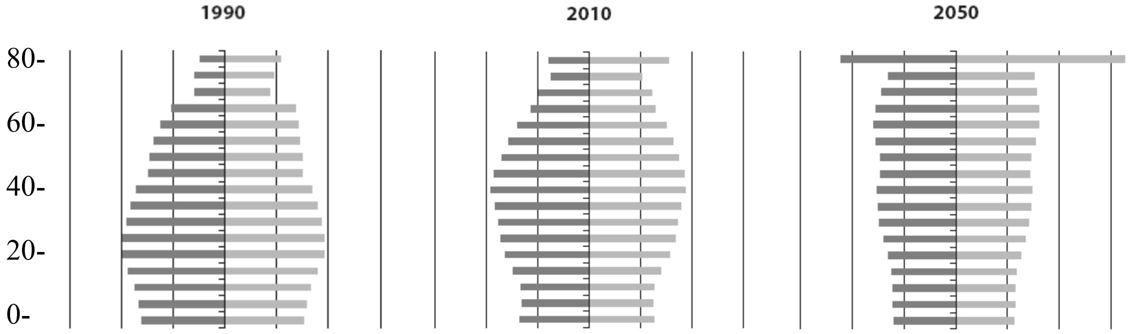

Figure 1. Proportion of age groups – past, present and forecast. On the vertical axis the age, on each chart on the left of the centre line: male, on the right: female. (Eurostat yearbook, 2009.)

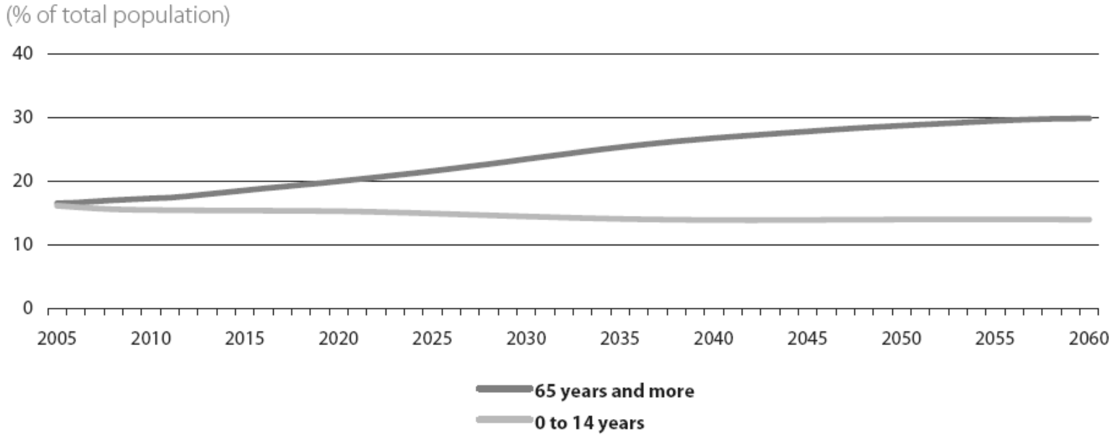

Figure 2. Proportion of the population aged 0-14 and 65 years and more, EU-27 (1). From 2008 onwards the data refer to projection (EUROPOP 2008 convergence scenario). (Eurostat yearbook, 2009.)

The ratio of disabled people increases since the ratio of elderly people is increasing – parallel with the age the risk of disabilities and the cumulative effect of mobility, sensorial and cognitive impairments increase, too. Elderly people without any kind of impairments could also have reduced skills and ability and prefer or may require barrier free environment.

3 DISABILITY TYPES

The reduced abilities of elderly and disabled people and the requirements of the built environment should be well-balanced. The gap between the reduced abilities and the requirements of the environment can be decreased or eliminated from both sides. The individual can be provided with assistive devices, such as prostheses, can, crutch, walking frame, wheelchair to facilitate his moving. The "response" of the house covers a wide range of conceptual design as well as constructional details. Some of them are self explanatory: non slippery floor covering, prevention of tripping, collision, easy to use doors and windows. Some of them mean the provision of space for the bulky assistive devices. People with balance problem can be supported by provision of grab bars and handrails. Limited force and manual ability can be expected from people with dexterity – adequate handles, taps, switches may make usable the home for them. Certainly in this case first of all the motor disabilities can be considered, however partial sighting and some cognitive problem can be responded, too.

4 PRECONDITIONS OF ACCESSIBILITY

Some of the generic elements must fulfil the basic requirements of the accessibility from the very beginning.

4.1 *Door*

Related to the door, 90 cm minimum width of free opening must be kept. This measure facilitates a wheelchair user to pass through and comfortable for those using other assistive devices (walking frame, crutch) for moving. It would be costly and would require some destruction to widen a narrow door later; however a longer bearer above the door as a minimum can make it easier.

It is also essential to have adequate area in front of the door for the manoeuvres to open, pass and close the door. Basically, 1,50x1,50 meter on either side of the door should be provided, but it can be refined in view of door-type and way of approach. Most frequently used door types are hinged and sliding doors, the minimum measures of usage are shown on Figures 3-4. This space should be provided either from the beginning or can be made free by removing for example a wardrobe. Narrow paths between heavy walls may prevent the adequate solution.

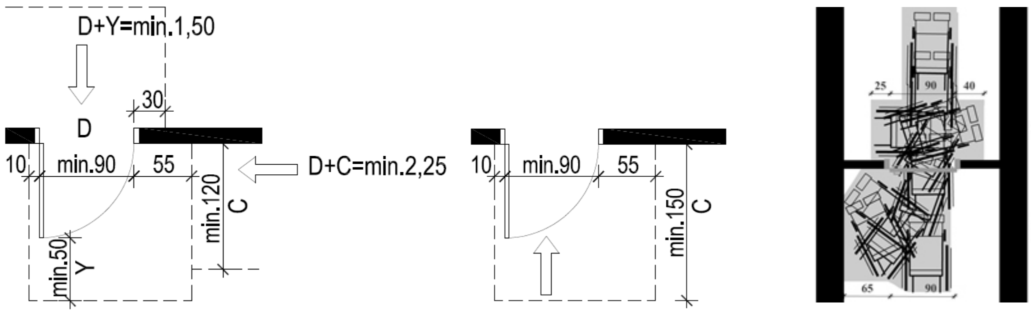

Figure 3. Area of approach and usage with wheelchair. Hinged door

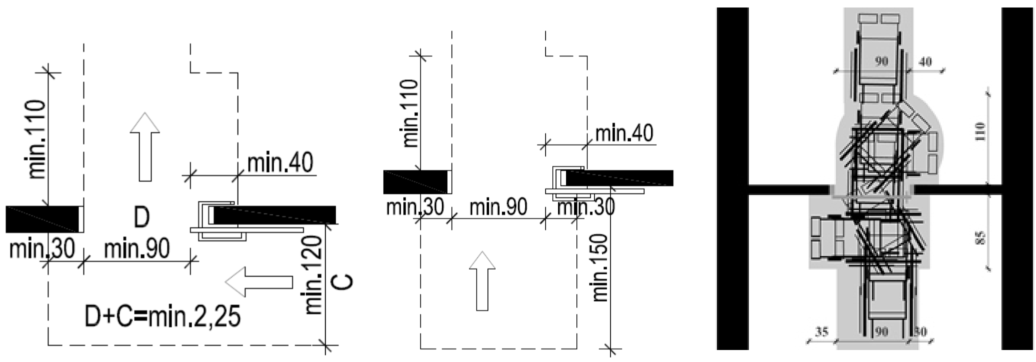

Figure 4. Area of approach and usage with wheelchair. Sliding door

4.2 *Floor slabs*

Bathtub is not usable for people with motor disabilities – they have to use shower in a corner of the bathroom. At the deepest point of the room a sinkhole must be provided - if it does not exist from the beginning the construction of the floor slab should facilitate its building in. The necessary slope of the floor, the diameter of the connecting tube and its slope may require about 12-15 cm free space above or between the loadbearing elements. (Fig. 5.)

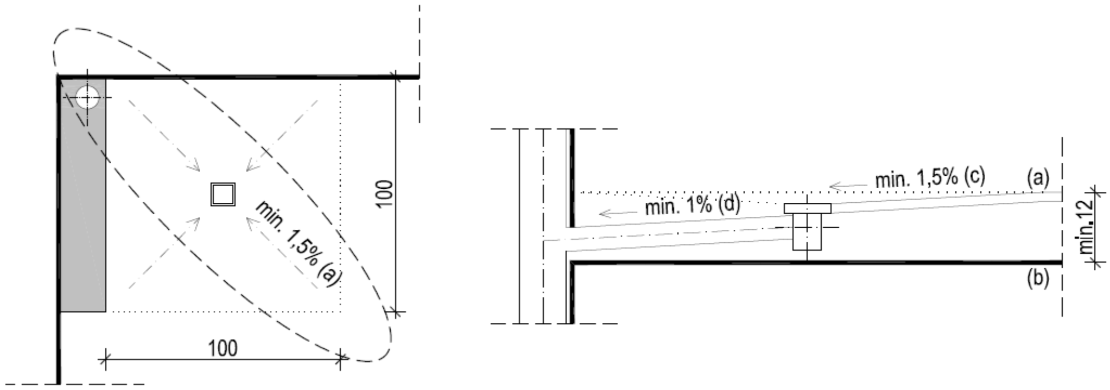

Figure 5. Shower place floor layout and section along the slope direction.
(a) floor level; (b) upper level of loadbearing construction; (c) slope of the floor; (d) slope of the connecting tube with diameter 50 mm

4.3 *Wall construction*

Fixation of accessories, like handrails and grab bars may become necessary in case of adaptation. If light-weight partition walls are used spots or strips with enough loadbearing capacity must be provided in advance between 80 and 130 cm above the floor, at both sides of the WC (Fig. 6.), at the shower or bathtub for people with motor disability. Further grab bars in more premises may become necessary for people with balance problems.

The loadbearing capacity for WC and shower seat must be about 400 kg, the same in case of grab bars should be about 200 kg.

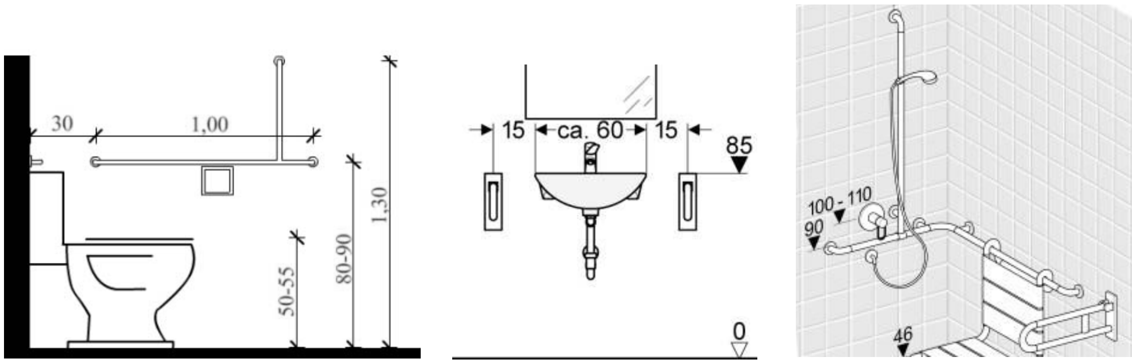

Figure 6. Fixation points of grab bars at the WC (AWARD, 2009), wash basin and shower (BME, 2009)

4.4 *Number of floors*

The number of stories is also worth of considering. In case of dwellings comprising two floors - typically semidetached or terrace houses – on the ground floor usually the kitchen, the dining and living rooms can be found – sometimes a single WC and a wardrobe. The bedrooms and the bathroom are on the upper floor. The two floors are linked by an inner staircase.

For people with reduced mobility the staircase can be used with less effort providing some basic rules are met and easy to grip continuous handrails are mounted.

Riser higher than 15 cm can cause difficulties for both elderly and disabled people. It is also essential not to have nosing and the edge of the step should be rounded (6 mm radius), otherwise the foot can stick easily. – Floating stairs - when the riser is completely missing - and curved stairs must be avoided, finishing must be non-slippery. (Fig.7)

For wheelchair users only a stairlift or a lifting platform would make the upper floor accessible, however it is beyond the “affordable” solution. Thus already in the stage of conceptual design the eventual need of a bathroom and the use of one room as bedroom on the ground floor should be pondered.

5 FREE CHOICE OF DETAILS

With respect of some details a barrier free solution does not require extra cost and difficult elements and facilitates to prevent the need of a future adaptation.

5.1 *Handrail*

Handrails provide safety and support as well, so they must be arranged along the flight of the steps, parallel with the pitch line at the height between 90 and 100 cm. In case of need additional handrail should be mounted between 70 and 80 cm. Diameter of a comfortable circular handrail is between 45-50 mm, fixation point should be at the lower level of it to let free moving of the palm. (Fig.7.)

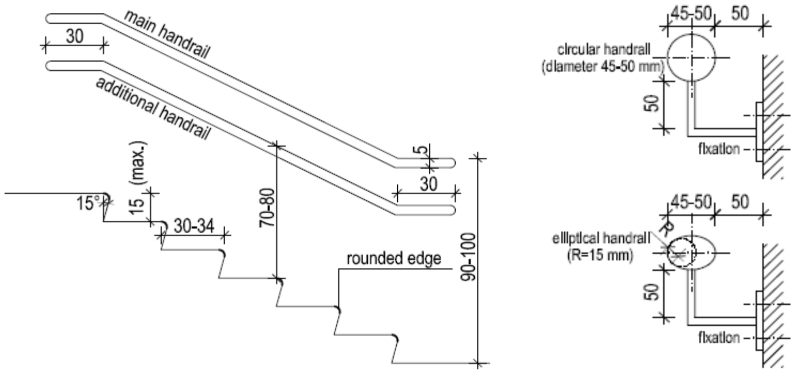

Figure 7. Stair and handrail constructed for low difficulty level

5.2 *Threshold*

Thresholds should be avoided, because they increase the risk of trip and above a certain height they can become a barrier for wheelchair user. Nevertheless entrance and terrace doors must be air-and watertight – here thresholds are necessary unless a tricky door with built-in threshold is applied. Traditional threshold lower than 2 cm is acceptable. In case of existing threshold higher than 2 cm the edges should be rounded and additional elements are to be provided according to Figure 8.

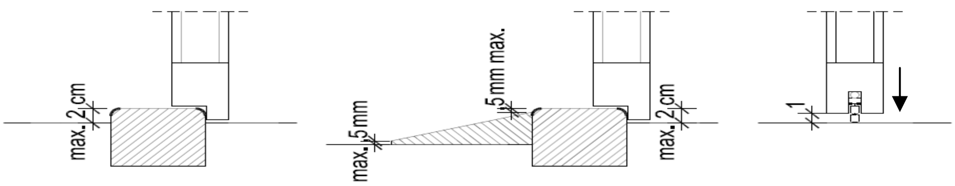

Figure 8. Thresholds from left to the right: threshold 2 cm or lower with rounded edges, conversion with additional element and built-in (automatic) threshold

5.3 *Siphons*

For wheelchair users it is essential to have free space for knees and feet. It is better to provide flat siphons for the wash-basin in advance than to change the traditional one.

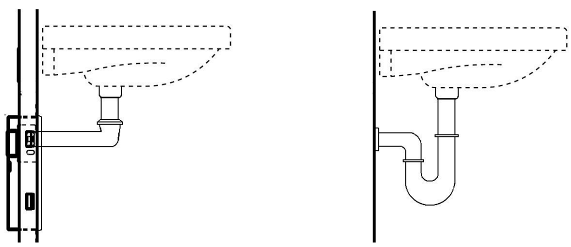

Figure 9. On the left there is a flat siphon under the wash-basin while the picture on the right side shows a traditional one.

5.4 *Built-in furniture*

The built-in furniture, first of all in the kitchen, should meet this requirement, as well. Certainly some of the usual pieces of furniture should be removed only in case of necessity, however if free space for feet and footrest in advance is provided then costly and dirty measures can be prevented.

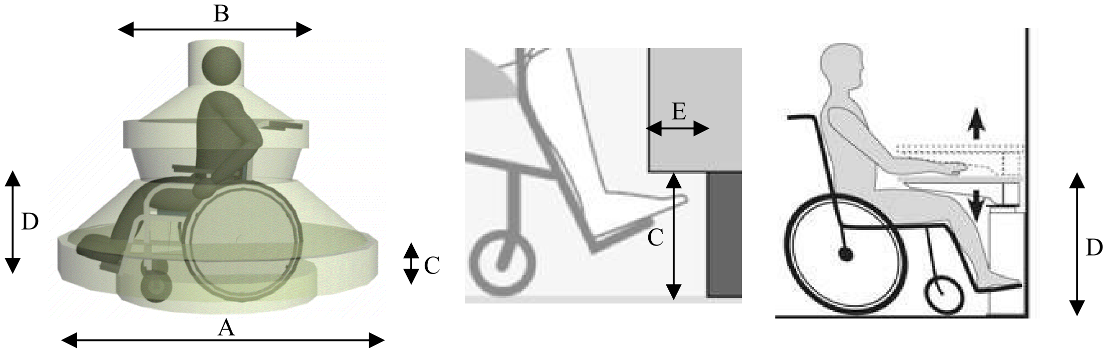

Figure 10. Basic extension of people seating in a wheelchair in case of turning 360 degree and the recessed foot of furniture (AWARD, 2009) A: Diameter of foot zone (150 cm); B: diameter of shoulder zone (85 cm); C: height of foot zone (30 cm); D: height of free space of knees (75 cm); E: depth of free space of feet and footrest (30 cm)

6 ADAPTABILITY

It seems to be irrational to build all residential buildings as barrier free, however the possibility of converting them without high extra cost and destruction should be provided. This conversion requires some flexibility in the layout.

Bathroom and kitchen are the most commonly affected premises to be adapted. Several times the adaptation needs the enlargement of the floor area – from this point of view it is reasonable to have light-weight partition wall at one or two edge(s) which can easily be removed. No less important is to have an area in the neighbouring room which can be sacrificed without serious consequences if the bathroom is to be extended. (Fig. 11.)

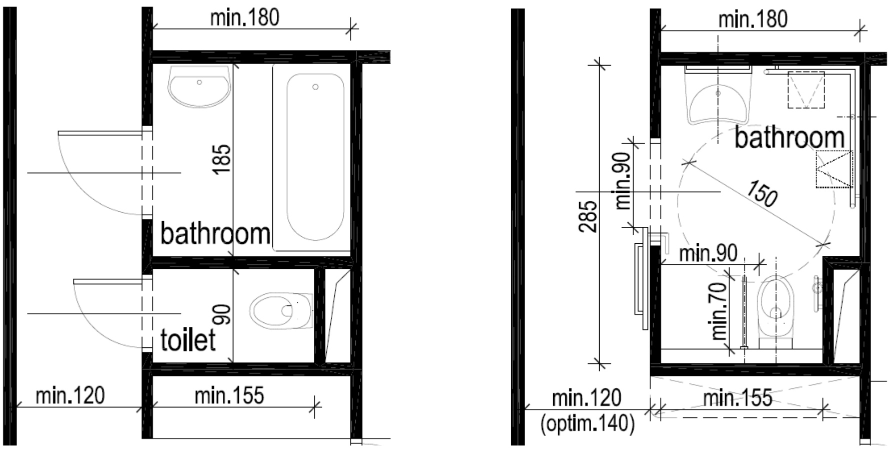

Figure 11. Increased area of bathroom by merging two rooms. The circle is the space requirement of a complete turn with a manual wheelchair. Many wheelchair users can seat to the WC and back only if the wheelchair is next to the WC. The same requirement should be met in the case of the shower seat which can be hinged on both of the rails, depending on the ability of the user. On the right figure sliding door is used instead of hinged door, thus - due to the side approach of the sliding door - 120 cm width of the existing corridor is sufficient. In case of 140 cm corridor width the hinged door can be kept.

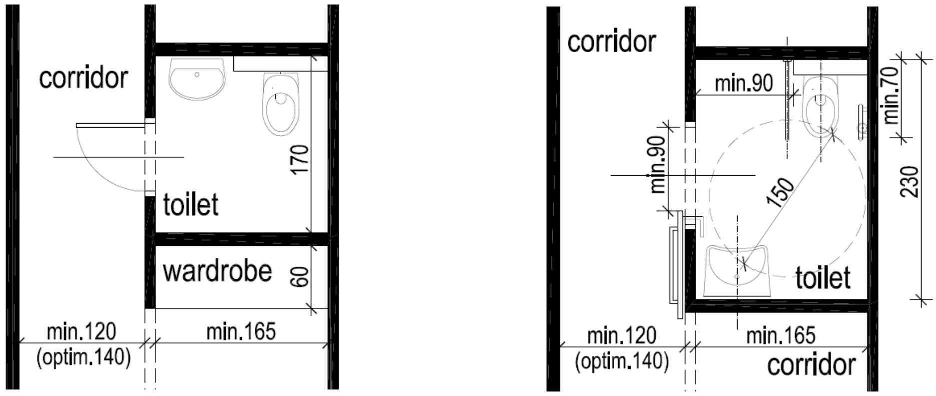

Figure 12. Increased area of WC by involving adjacent wardrobe. Many wheelchair users can seat to the WC and back only if the wheelchair is next to the WC. Certainly if the user is able to seat through from the front side, no extra space is necessary next to the WC, however even in this case the circle with a diameter of 150 cm must be provided for a complete turn of a manual wheelchair.

7 CONCLUSION AND RECOMMENDATION

The usability of the house for elderly and disabled people is of growing importance since a considerable and growing percentage of the population has to face the problem whether they can remain and live in their home, alone or with their families.

The rules of the Universal Design cover a wide range of potential disabilities and are to be applied in the case of public buildings. The application of the same rules in residential buildings from the very beginning would make questionable the affordability of the housing, however the homes must be adaptable to a given type of disability (or simply to the reduced abilities of elderly people) in case of necessity.

There are some preconditions of the adaptability. The entrance gate and the doors should be wide enough for a wheelchair, possibly without threshold or with a small one only. Space should be provided on both sides of the door for wheelchair manoeuvre. Providing the home is on two floors, the stair should not be steep, a bedroom and a bathroom should be provided on the ground floor. The construction of floor slab should facilitate the building in of sewage system.

Some details do not need explanation. Non slippery floor covering, easy to grip handles, less than 25 N force requirement to open the doors are important for elderly and disabled people - at the same time safe and comfortable for everybody. Having in mind these aspects, these conditions can be provided with no extra cost from the very beginning – these details meet the requirements of accessibility without any further change.

The most difficult measures of adaptation need the following considerations:

- light-weight partition walls on one or two sides of the bathroom and enough space to enlarge it at the cost of the demolition of a wardrobe or decreasing the floor area of the neighbouring room,
- change of bathtub to shower,
- load bearing lines or points in partition walls where the grab bars may be fixed,
- change of existing door to sliding door,
- provision of direct contact between a bedroom and the bathroom.

All of these aspects can be pondered in advance – the correct solutions make easier the adaptation in case of necessity, at the same time do not require many compromise in the original design.

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Can LiderA system promote affordable sustainable built environment to all?

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ABSTRACT: This paper present the LiderA system and its new approach (version 2.0). Special attention is given to the affordability question. In order to reach that goal it will be analyze some of the assessment systems, particularly LiderA system, highlighting the sustainable concept, conditions and cases where the applications of the system can lead to a sustainable approach and promote an affordable sustainable built environment to all.

1 LIDERA SYSTEM

1.1 *Voluntary assessment system*

Sustainable built environment is increasing and is been search in several countries. In order to precise and support what is sustainable built environment (or buildings), there is a offer of several sustainable building voluntary assessment systems.

The use of environmental and sustainable voluntary assessment systems are been increasing in different countries (Pinheiro, 2010), like BREEAM (United Kingdom), LEED (United States of America), DGNB (Germany), or LiderA (Portugal).

They are a manner to assess what is a good environmental performance and sustainable building or built environment and in some cases to support the design, search, or development of sustainable solutions. The shift from green building to sustainable building and the future requirements are a challenge for those building environmental assessment tools.

1.2 *LiderA Voluntary assessment system*

LiderA (Leadership for Environment) is a Portuguese voluntary assessment systems that has been in use since 2005 and in 2010 published a new version (version 2.0) that is based in environmental areas, but include also economic and social areas (Pinheiro, 2010).

The LiderA as other voluntary assessment systems, has a logic that is defined in the base of a detailed criterion set, the way defining the several classes or levels and the respective weights. The demand for sustainability in the built environment is based on principles, which cover the main aspects considered in six different categories, and they are:

- Enhance local dynamics and promote proper integration;
- Promote the efficient use of resources;
- Reduce loads' impact (both in value and in toxicity);
- Ensure environmental quality, focused on environmental comfort;
- Promote sustainable socio-economic experiences;
- Ensure the best use for built environments, through environmental management and innovation.

The six different categories were subdivided into twenty two areas, namely:

- Site and integration, with regard to Soil, to Natural Ecosystems, and to Landscape and Heritage
- Resources, including Energy, Water, Materials and Food Production;
- Environmental Loadings, involving Wastewater, Atmospheric Emissions, Waste, Noise Emissions and Thermal and Light Pollution;
- Environmental Comfort, in the areas of Air Quality, Thermal Comfort and the Lightning and Acoustic;
- Socio-economic experience, which includes the Access for All, Economic Diversity, Amenities and Social Interaction, Control and Participation and Life Cycle Costs;
- Support sustainable use, which includes Environmental Management and Innovation.

LiderA is based on the concept of re-positioning the environment in construction, under a sustainable perspective, assuming itself as a leading system for the environment. This system is organized into categories that include areas of intervention and are operated by criterion (43) which allows the guidance and evaluation of the level of demand for sustainability (Figure 1).

SITE AND INTEGRATION					
SOIL		NATURAL ECOSYSTEMS		LANDSCAPE AND	
Territorial Valorisation	Environmental Deployment Optimization	Ecological Valorisation	Habitats connection	Landscape Integration	Heritage Protection and Enhancement
C1	C2	C3	C4	C5	C6

CATEGORY
AREA
CRITERIA
Nº

RESOURCES								
ENERGY			WATER		MATERIALS			FOOD PRODUCTION
Energy Certification	Passive Design Performance	Carbon Intensity (equipment efficiency)	Potable water consumption	Local water management	Durability	Local materials	Low impact materials	Local food production
C7	C8	C9	C10	C11	C12	C13	C14	C15

ENVIRONMENTAL LOADINGS							
WASTEWATER		ATMOSPHERIC EMISSIONS	WASTE			NOISE EMISSIONS	THERMAL AND LIGHT POLUTION
Wastewater treatment	Wastewater use	Atmospheric emissions control	Waste control	Waste management	Waste Valorisation	Noise emissions control	Thermal and light pollution
C16	C17	C18	C19	C20	C21	C22	C23

ENVIRONMENTAL COMFORT			
AIR QUALITY	THERMAL COMFORT	LIGHTING AND ACOUSTIC	
Air Quality Levels	Thermal Comfort	Lighting levels	Acoustic insulation/noise levels
C24	C25	C26	C27

SOCIO-ECONOMIC EXPERIENCE							
ACCESS FOR ALL			ECONOMIC DIVERSITY			AMENITIES AND SOCIAL	
Public transportation access	Low impact mobility	Accessibility to disabled people	Flexibility / Adaptability	Local Economic dynamics	Local Work	Local Amenities	Community Interaction
C28	C29	C30	C31	C32	C33	C34	C35
AMENITIES AND SOCIAL INTERACTION		CONTROL AND PARTICIPATION				LIFE CYCLE COSTS	
Local Amenities	Community Interaction	Controllability	Participation and governance conditions	Natural risks Safety	Human Threats - Security	Life cycle costs	
C34	C35	C36	C37	C38	C39	C40	

SUSTAINABLE USE		
SUSTAINABLE USE		INNOVATION
Environmental Information	Environmental Management System	Innovation solutions
C41	C42	C43

Figure 1. LiderA (version 2.0) categories, areas and criterion

LiderA performance in each criterion has a scale that is defined from usual practice (Class E) to progressive incremental performance, like 12,5% (Class D), 25% (Class C), 37,5% (Class B), 50% or factor 2 (Class A) 75% or factor 4 (Class A+) and 90 % or factor 10 (class A++). The criteria depend of the phase, if it is prescriptive (in initial phase) or a performance base (in detail design or construction or operation).

So LiderA application in its very initial phase it is use to search for strategies. For example for first criteria, Territorial valorization, it must be asked if one can choose a better place to locate this construction? If you use a new area, occupying new soil without infrastructures in the local or nearby, it will be classified as class E; instead if you use a urban zone with infrastructures that can support the development, we've got a class A; if the project is developed in an urban contaminated land you are in a class A++, since you regenerate a zone.

In the sub sequential phases the criteria analysis will support the search for better performance, by ranking the possible performance levels (level of energy use, % of renewable energy, material durability, …) and the decision maker will assess what could be the better level, in order to be achieved in the accepted budget, what means that in most of the cases the economic dimension runs parallel to the assessment.

2 ECONOMIC DIMENSION AND AFFORDABILITY?

2.1 *Affordable is part of the economic dimension?*

Sustainability can be based in different perspectives; nevertheless, the most common includes social, environmental and economic dimensions. The economic base focuses in different aspects including costs.

Affordable is a term used relating to prices, meaning to have enough money to obtain something, so is a relative concept, usual applied to houses and to describe what total costs are possible to those that have a median income.

In that context, an important question is if sustainable have a relationship with affordable? The answer is positive since to be affordable is an important part of the economic dimension, which can be applied to a building, to a flat and to construction solution.

Affordable housing provides a useful context to consider the implications of conceptual and pragmatic challenges to sustainability (Arman *et al*., 2009). Affordable and sustainable housing adds a complicating factor, because sustainability parameters, including but not limited to intergenerational equality, economic feasibility, social acceptability, energy efficiency and minimization of waste must also be considered.

While it is a noble goal to ensure that households in affordable housing are also living in homes that minimize energy costs and are cost-effective to maintain over the building's lifecycle, the financial difficulty of how to incorporate costly features remains. In terms of affordable housing, Arman (*et. al*, 2009) demonstrated how many of the common challenges do not prevent a meaningful application of sustainability.

Concerning housing policy which traditionally addresses affordability, there has been a strong emphasis on social and economic sustainability objectives without the environmental component (Randolph *et al.*, 2008)

For housing to be considered truly affordable (Zerkin, 2006), it not only needs to be affordable concerningprice on the front end, but also concerning long-term operational costs. There are several barriers to this like ‘Split incentives’ for developers and the evaluation criteria for affordable housing projects.

Zerkin (2006) precises that in order to cut costs, developers of ‘affordable’ housing typically do not invest in high-efficiency appliances, which usually cost more. This is true whether the units are going to be for rent or sale. Thus the ‘split incentive’ problem - that the person making an investment decision is not the beneficiary of it- is particularly accurate in the arena of affordable housing.

3 ASSESSMENT SYSTEM – USE AFFORDABLE?

3.1 *Affordable explicitly or implicitly?*

Environmental issues and financial considerations should go hand in hand as parts of the evaluation framework. The 1999 Green Building Challenge (GBC) model already includes economic issues in the evaluation framework (Larsson, 1999) and that is also present at is new version of the SB Tool. This is particularly important at the feasibility stage, where alternative options for a development are assessed. Both environmental and financial aspects must be considered when assessing environmental concerns.

Some assessment tools, such as BREEAM and LEED, do not include financial aspects in the evaluation framework (Ding, 2008). This may contradict the ultimate principle of a development, as financial return is fundamental to all projects because a project may be environmentally sound but very expensive to build. Therefore the primary aim of a development, which is to have an economic return, may not be fulfilled if the project is financially less attractive to developers, even though it may be environment friendly.

If BREEAM and LEED does not include explicitly financial aspects other newer assessment systems explicitly include economic and financial aspects, like DGNB with the criteria (C16)

Building-related Life Cycle Costs (LCC) or LiderA with the criteria (C40) life cycle costs. So, in this system there have been explicitly included financial aspects, namely in the perspective of life cycle.

The economic aspect gain dimension, as you could see in LiderA, where areas like economic diversity involving Flexibility / Adaptability (C31), Local Economic dynamics (C32) or Local Work (C33) is present and used in the assessment and in the search of solutions.

Another analysis that can be carrying out is if implicitly the systems consider the cost or are interrelated with "low cost" or "affordable to all concepts". A global analysis of the four systems considered show that in most cases the lower level of performance and certification can be achieved with low investment in one condition, that is if include the sustainable approach in the beginning of the process and if the criteria is selected with lower cost implications.

As indicate by Castro-Lacouture (et al, 2009) the methodologies can guiding the planning and design processes. In these earlier stages of the construction process, planners can make decisions to improve building performance at very little or no cost, following the recommendations of the decision-making tool.

So assessment system give an option to low cost or affordable solutions at least in that context once they implicitly consider affordable as one question and it is possible that suck analysis is included in the earliest project phase.

4 LIDERA SYSTEM CAN SUPPORT AFFORDABLE APPROACHES?

4.1 *Performance and costs*

The differences in the systems are in some of the criterion where that could have an important economic cost and difference to achieve one credit or one point or one level in different criteria, special if they are cost-efficient.

In order to understand that question and if the system supports affordability, it is selected a set of the LiderA cases in where the cost is available. Part of the cases used the first LiderA version (V1.02), released in 2005, and they were mainly intended to evaluate, certify or recognize projects within the building scale and respective surroundings and the economic dimension is only implicit. The cases analyzed and selected and were:

1. Hotel Jardim Atlântico (Calheta, Madeira) was built in 1993, comprehending a touristic complex with 97 apartments. Type of use: touristic complex; gross area of construction: 7498 m^2. The project's environmental performance was emphasized by the combination of good performance solutions combined with an environmental management system, that contributed to a good level of service use in tourism and environmental performance. LiderA global assessment achieves class A.
2. Torre Verde - Green Tower (Lisbon) - Promoter: Cooperativa Viver a Luz; Project: Tirone Nunes SA; Type of use: housing; deployment area / land: 1225 m^2; gross area of construction: 7200 m^2. A very good balance between Bioclimatic solutions and a good performance in energy and comfort, characterizes this project, designed by Architect Livia Tirone. LiderA global assessment achieves class A.
3. Casa Oasis (Estoi, Faro) - Project: Engº Cândido de Sousa Santos, Engº António Santos and Arqtº António Cavaco (Landscape Designer); Type of use: tourism. Land: 2 400 m^2, Area of deployment: 160 m^2, gross area of building: 240 m^2 (ground floor - 160 m^2 and 1st floor - 80 m2). An isolated villa in a rural area of the Algarve region, this project includes a set of integrated sustainable solutions, assumed during the design and implementation phase. LiderA global assessment achieves class A.
4. Ponte da Pedra (Matosinhos) - Promoter: NORBICETA - Union of Housing Cooperatives, UCRL; Project: Carlos Coelho - Consultores, Lda; Type of use: housing; Deployment area: 3105 m^2, gross building area: 14852 m^2 (101 dwellings). Built in an urban area this project found solutions to enhance environmental performance in areas such as Energy, Water, and Controlled costs, in a combination with the ambition of the Norbiceta and project's responsible Arqº Coelho, of building a sustainable housing complex. LiderA global assessment achieves class A.

5. Parque Oriente (Lisboa) - planning phase - Project: TironeNunes Arqª Lda; Area of intervention: 20721 m^2; Area of deployment: 9536 m2, gross area of construction: 41441 m^2 (living area: 27912 m^2); No. of inhabitants: 720 (planned). A Plan for the conversion of an old industrial unit with an advanced approach to sustainability and good performance solutions in various areas is proposed by the Bureau of Architecture Tirone Nunes. LiderA global assessment achieves class A in design phase.
6. Estação de Campo da Peneda (Castro Laboreiro, Melgaço) - Designer: Arqtª Maria Inês Cabral. Deployment area: has 100 m^2; Lot area: 1000 m^2. Built in a natural area, the building has 2.5 floors adding up to 210 m^2. A careful approach to the buildings rehabilitation program, located in Peneda's National Park, in Gerês, has led to high levels of care, in the demand for a sustainable approach. LiderA global assessment achieves class A+
7. Casa dos Arcos (Óbidos) - project phase - Promoter: Monterg Construções SA. with the advice of Ecochoice; gross area of construction: 8 320 m^2. The demand for a high balance between costs and performance lead to a draft of forty two Villas with environmental concerns above average in Óbidos. LiderA global assessment achieves class B in design phase.
8. Centro Escolar Alcanede (Santarém) - project phase. – A school with a gross building area of 3118 m^2, sponsored by Santarém's municipality with several sustainable proposals, covering the areas of energy and comfort as well as several other areas. LiderA global assessment achieves class A.
9. Intituto Superior Técnico (IST) universitary residence - operation phase – Is a residence to IST students. 225 students, 6746 m^2. Possible refurbishment alternatives that could pass from global class C to B or A.

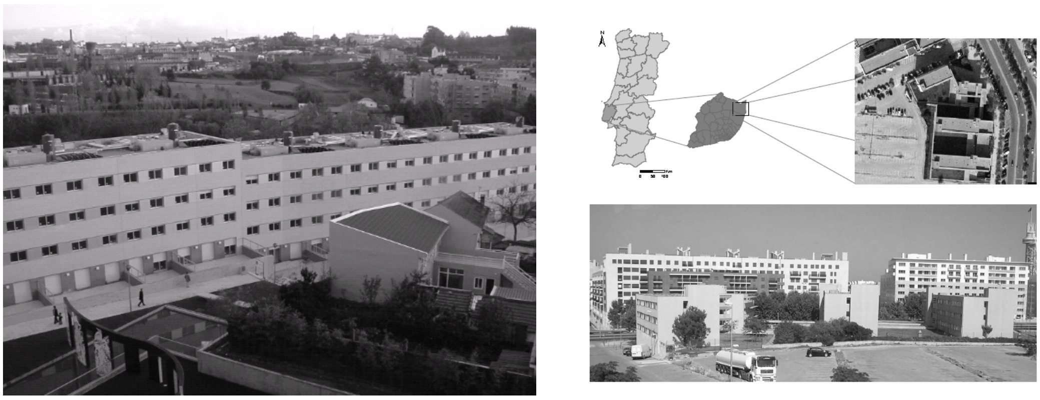

Figure 2. Perspectives: Ponte da Pedra (case 4) and IST universitary residence (case 9)

In this analyze were included other cases from the new LiderA version that has been developed to widening the system's borders, beyond the building scale, to the built environment, including a new demand for outdoor spaces, blocks, neighborhoods and sustainable communities. The cases selected are:

10. Touristic Resort of Falésia D'El Rey - Óbidos - project phase. Construction area of 124 000 m2. This project includes a set of hotels and townhouses, with a combined capacity of 3035 beds (construction area of 124000 m2). This project has demonstrated an excellent environmental performance in Water and Wastewater areas, a good performance in Soil, Energy, Air quality, Thermal comfort, and Lighting and Acoustic areas. LiderA global assessment achieves class A in design phase.
11. Vila Lago Monsaraz (Reguengos de Monsaraz) - Promoter: APRIGIUS, Companhia de Investimentos Imobiliários e Comerciais S.A; Type of use: hotel, golf, nautical resort, tourism. Set in a context marked by a landscape of hills and extensive cereal crops, punctuated by vineyards and olive groves, this project provides the underlying assumptions for a new tourist resort that not only assures the enjoyment of future users but also a new cultural and natural experience. The presence of water is considered as a structural presence of enormous value and scenic landscape. The strategies

related to it on site include water management, local materials, recycling strategies, buildings orientation, shading by vegetation and new footpaths, contributing to the project's good environmental performance. LiderA global assessment achieves class A in design phase.

12. Hotel Vila Galé Albacora (Tavira) - Promoter: Vila Gale; Type of use: hotel, tourism; Deployment area: 3 105 m2, gross building area: 6841 m². Being certified to Class A, the Vila Galé Hotel, achieves an environmental performance 50% superior to current practice, suggesting positive solutions from an environmental, economical and social point of view. Since it is located on a Natural Park and in a protected area, the project achieves good environmental performance in Local Integration, a result of careful planning, environmental deployment optimization, heritage, and the rehabilitation of buildings belonging to a former Tuna Fishing Company. LiderA global assessment achieves class A.
13. Centro Escolar de Jardim de Baixo (Santarém) - Promoter: Santarém Municipality; Type of use: school; Deployment area: 2685 m^2, gross building area: 3111 m². This project was certified as class A therefore, environmental performance is 50% higher than current practice, suggesting that implemented solutions that are positive in terms of local environment, economy and society. It includes both in its architecture and construction methods, sustainable parameters of safety, landscaping, adaptability and maintenance. The project calls for an integrated environmental performance during designing and building phases. The choice of native species, the level of energy and environmental comfort and the range of materials used are some of the strategic measures implemented. LiderA global assessment achieves class A.

When analyze this sample we found a wide range of global costs in construction that begin in new buildings in 620 €/m^2 (case 4) and in small refurbishment intervention (case 9) with minor changes that means 30€/m2 and allows the project goes from class C to B, and in the case of an investment of 98€/m2, it could pass from class C to A. With more structural investment, they can be implemented solutions that achieve class A++, but that will mean much higher cost.

In the students residence case, at a thesis co-oriented by the author, Limão (2007) indicate that in the process of building reconstruction/renewal (case 9), the reduction of energy and water consumption, ambient loads and the improvement of thermal and acoustic conditions constitute the main areas of intervention. From an economic point of view and for the solutions taken individually, with the exception of photovoltaic energy, the net present value (NPV) is positive (which means it is viable) and the payback time ranges from 1 to 17 years (at a discount rate of 5%) and from 1 to 13 years (at a discount rate of 2%) to achieve an A class.

Considering the total solutions Limão (2007) found that the payback time is 16 years at a discount rate of 5% and 13 years at a discount rate of 2%. The environmental performance classification of the residence according to LiderA, for the themes where the solutions are applied, is between the level C and A++. This contribution leads to an overall change from level C (reference situation) to level A++ (total solutions).

Overall, the implementation of the evaluated solutions leads to a reduction of 66% in the energy consumption and 32% in the water consumption, being possible to produce 100% of the electricity consumption of the Residence through wind and photovoltaic power.

A similar conclusion between performance and cost is found with the other LiderA cases, presented mainly in the first levels from class E to C or B and in some cases to A. The cost construction until class B and in some cases A is less than 1 to 2 %.

When considering higher classes like A+ and A++ the cost will have a strong increase, as well as local dependency and project typology. The LiderA results agree with most green buildings cost (Kats *et al.*, 2008), that is a premium of less than 2%, but yield 10 times as much over the entire life of the building.

When supplementary measures are introduced it is necessary to estimate cost and saving and compare it with the alternative. In that context the focus is more centered in ease assess measures; for example in energy is usual to analyze photovoltaic or other renewable energy than the benefits from bioclimatic approach. This resulting that equipments have a cost and will save a specific energy level, and to bioclimatic must be applied a simulation instrument (like Ecotec or Energy plus) and the specific contribution can de diluted.

4.2 *Could low cost and high cost be affordable?*

The stigma (Kats *et al.*, 2008) is between the knowledge of up-front cost vs. life-cycle cost. The savings in money come from more efficient use of utilities, which result in decreased energy bills. Also, higher worker or student productivity can be factored into savings and cost deductions. Studies have shown over a 20 year life period, some green buildings have yielded $53 to $71 per square foot back on investment (Langdon, 2007). It is projected that different sectors could save $130 Billion on energy bills (Fedrizzi, 2009).

The most criticized (Kats *et al.*, 2008) issue about constructing environmentally friendly buildings is the price of some active solutions, like photovoltaic, new appliances, and modern technologies that tend to cost more money.

Most of the times affordable are use in the sense of low cost. The concepts low cost and affordable are used in several cases with a similar meaning. However are they the same? and when is involving sustainable built houses or environment? Can high cost be affordable?

To be affordable must be low cost or can it be higher cost if the payment mode allow accessibility to lower incomes, that in some cases it is possible to include a percentage in the mortgage and in the rent, proportional of the payback time.

In LiderA life cycle cost criteria (C40) reveal a global reduce cost resulting in some cases from higher investment (e.g. better insulation measures) but lead to structural savings considering all the life cycle, even with a payback longer than ten years, but that is acceptable because it can be defined as structural, which means it will be affordable.

The resulting question is if it is possible to be payable by average income and the answer can be yes, if the private financial scheme to make the payment can be longer or if public entities give some support.

4.3 *Municipalities and other authorities contribution*

LiderA system was developed to support new demands for sustainable environments, helping public and private and public contractors and authorities to perspective new sustainable approaches in the build environment. It is important that public authorities like municipalities, who play a role in the provision of private licenses, plan and promote public local built environment, are involve and give signals to allow sustainable and affordable built environment.

In that context, LiderA was established several protocols, mainly with public municipal authorities, in order to support their sustainable development. The following protocols represent some of the initiatives that are currently underway:

In the 12th of June 2008, the Municipality of Santarem signed a protocol with the Certification System of Environmental Sustainable Construction - LiderA at Instituto Superior Técnico (IST). Due to this protocol the Municipality of Santarém is committed to conduct environmental practices applied to construction of buildings, in an integrated and interactive way.

Builders and planners who adhere to environmental certification will benefit from a reduction of 50% on the certification fee and also a reduction of 25% on the rates of urban operations in this municipality. Due to this factor, the Municipality has already build and certified two schools that were clearly recognized by LiderA for its good performance (Class A) and that have budgets similar to other schools. A new sport infrastructure is already under development and also a proposal for a new private development.

So the city of Santarem becomes a pioneer municipality in the application of environmental certification in the construction and give market signals that invest in sustainable is the way.

Such as the Municipality of Santarém, in the 18th of September 2009, the municipality of Torres Vedras signed a new protocol regarding the application of the LiderA system. As a result, the Municipality can promote the sustainable development of public or private enterprises/buildings within its borders and spectrum of action. The protocol provides a reduction of 25% on urban operations rates for new enterprises/buildings, in the city, that become certified by LiderA.

In the 12th of November 2009, the Municipality of Lisbon approved the reduction of 50% on Council Tax (IMI) for buildings that have the certification with higher classes according to LiderA system. As a result, annual council taxes will be reduced and as a consequence buildings' operation fees will diminish. These are positive examples that can promote not only sustainable built environment but also its affordability.

5 CONCLUSIONS - CREATING AN AFFORDABLE SUSTAINABLE BUILT ENVIRONMENT?

The main conclusions of this discussion paper are that the assessment systems like LiderA, DGNB, BREEAM and LEED (at least in the first certifying classes) can be use as a way to promote affordable and better built environment, at least implicitly in the way the first levels (thresholds or classes) are defined.

In that context they can promote affordable sustainable built. The degree of the affordability and the solutions adopted can give a strong or weak support, depend of the context of the building service and the building market.

An important aspect is that the life cost criteria is included, as in DGNB and LiderA, and can be well applied. In LiderA case it was difficult to get full detailled costs, and to more passive measures or new solutions it can be hard to estimate the benefits and savings and to understand the precise payback, resulting in strong limits to further life cycle cost approach.

This economic dimension and life cycle in assessment systems like LiderA is necessary but cannot be enough to assure affordability, because if in LiderA until class B the costs are in general affordable, in the sense of a low investment, even in some criterion that is not possible, so to higher classes, in some cases, to be affordable cannot be based only in low cost investment.

In that dimension a new financial approach and a role of public authorities can be decisive or another fundamental dimensions associate with the users' behavior that allows increasing the environment and sustainable performance.

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