High Energy Efficiency Retrofit Module Development

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ABSTRACT: One of the main key sectors where it is vital 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 Directive on Energy Performance of Buildings where important measures to limit the buildings primary energy consumption are foreseen. Within this context, it was initiated a new project focusing the development of a new retrofit solution – a prefabricated façade retrofit module. This solution is, to some extent, a by-product of the authors' participation on the International Energy Agency project IEA ECBCS Annex50 and on the FCT funded project PTDC/ECM/67373/2006. In order to achieve a better support for the design of the solution and for the module thermal optimization, there were applied some computational tools like Google SketchUp® for 3D modelling to test the design options and eQuest® tool for energy performance prediction of several construction options and to assure their accordance with the applicable regulations. At the moment, a prototype is being developed and built in the Test Cells of University of Minho in order to carry out several "in-situ" thermal performance measurements.

1 INTRODUCTION

Taking into 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 use. There are also some predictions (Zimmerman, 2006) pointing out that if a significant change of practice does not take place, in 2050 the buildings stock will represent 80% of the total energy consumption. Thus, in order to avoid this situation, the building stock behaviour must progress without any doubt as represented in Figure 1.

With the growing awareness of the European Union for this problematic, a regulative EU intervention was made with the entrance into force of the *Energy Performance of Buildings Directive* (EPBD, 2002) whose objectives are to promote the sustainable development of the building sector reducing its excessive energy consumption. This directive has been recently reinforced with the EPBD-Recast (EPBD, 2009) whose main goal is the so called 20/20/20, i.e., to reduce the greenhouse gases emissions 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.

The transposition of the EPBD to National Law was compulsory in all EU countries. In Portugal this was carried out with the revision of the existing buildings thermal regulations RCCTE (2006) and RSECE (2006), and the implementation of the new buildings energy certification system SCE (2006). The RCCTE objective is to improve the residential buildings thermal behaviour, while the RSECE aims to control the energy consumption and indoor air quality of office buildings. SCE sets the application fields of all the thermal regulations, defines the buildings energy labelling system and establishes the required qualifications for those who will apply RCCTE and RSECE.

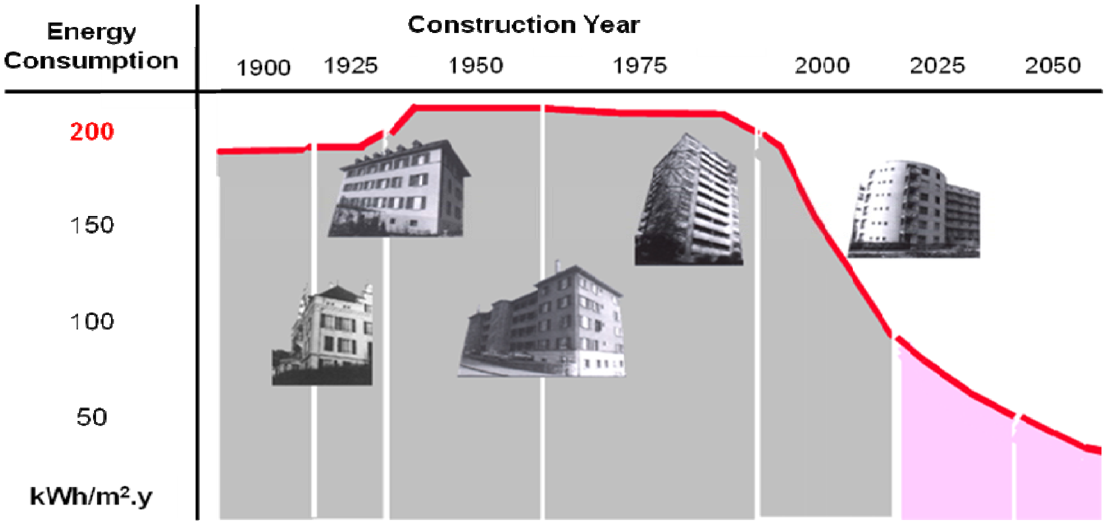

Figure 1. European Building Stock energy consumption through the years (Zimmerman, 2006)

In Portugal, the excessive energy consumption scenario is even worse since 77% of the building stock was built before 1990, year of the publication of the first building thermal regulation. This means that the majority of the existing buildings was built without any thermal concerns and shows very high energy consumptions even when minimal comfort conditions are required (CENSUS, 2001). Also, the investment made in conservation and rehabilitation of the building stock is very low – only 23% of the total investment in the construction sector, while in EU the average investment is 45% (Euroconstruct, 2005), since, mainly by cultural reasons, building retrofit in general, and thermal retrofit in particularly, are not considered good alternatives when compared with the option of new construction. However, construction companies are becoming more aware of this problematic and recognizing a market opportunity, since 41% of the building stock has retrofit needs (CENSUS, 2001) which could represent, according to Paes (2009), a business 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 efficient energy retrofit strategies for residential buildings by gathering world specialist in this area and support their exchange of knowledge. In the scope of this project and also supported by the Portuguese project funded by FCT (PTDC/ECM/67373/2006), the LFTC – UMinho is developing an optimized prefabricated façade retrofit module for Portuguese residential buildings.

The evaluation of the potential of the developed system, in terms of design, structural and thermo-acoustic behaviour, etc., will be made with the help of 3D modelling tools, dynamic energy simulations 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. Nowadays, it is possible to find in the market several tools specifically developed for the construction sector aiming at optimizing the design and predict functional and structural behaviour of different solutions. During the development of the proposed retrofit solution, the applied tools were the 3D Modelling Google SketchUp® (2008) to verify how the solution can be applied and its aesthetic characteristics, and the energy simulation tool eQuest® (Hirsh, 2003) to predict its energy efficiency.

2 RETROFIT MODULE DEVELOPMENT METHODOLOGY

2.1 *Initial Premises*

The main objective of the facade retrofit module is the development of a solution that can result in a swift rehabilitation process, by the application of the module over the existing façade walls, causing the least possible inconvenience to the buildings occupants and with less economical investment when compared with the traditional systems.

The guidelines for the module development are: i) the application of an optimized thermal insulation thickness, in order to increase the energy efficiency; ii) the application, as much as possible, of recycled materials with low embodied energy (energy necessary for production, transportation and application of the materials); iii) the integration of ducts inside the module to lodge sanitary hot water and heating/cooling systems since, further than improving the final solution aesthetically, it can also provide ducts insulation.

2.2 *Solution Description*

The system under development is based on traditional discontinuous prefabricated insulating finishing, although with integrated ducts and optimized insulation thickness.

Several design alternatives were executed and tested, as shown in Figures 2 and 3 and the final module composition is (from the outside till the inside): aluminium composite exterior finishing (6mm); agglomerated cork insulation (20mm); extruded polystyrene insulation (XPS – 120mm); plastic box for the ducts filled with injected polyurethane insulation (120mm); agglomerated cork insulation (30mm); air vapour barrier; aluminium composite interior 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 $m^{2o}K/W$, considering the average between the thermal resistance on the regular zone and on the ducts zone. 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 3D models of buildings for a conceptual phase of the projects. Two design alternatives of the solution under development were applied to a single-family house with retrofit needs in Braga, Portugal and their results visualized with Google SketchUp®. This study was carried out in order to optimize the solution design and also to test its in situ application. Therefore, the building was modelled and the application of the retrofit system was studied. The overall retrofit strategy of the building consisted not only on the module application, but also on the general improvement of the building envelope, i.e., roof slab insulation (application of 8cm of XPS), ground slab insulation (XPS - 2cm) and replacement of the existent single glazing and aluminium frame windows (U_{wdn} = 4.1 $W/m^2.°K$) by double glazing and aluminium frame with thermal break windows (U_{wdn} = 2.5 $W/m^2.°K$).

The following figures illustrate some of the 3D models that were executed in Google SketchUp® during the study and development of the retrofit module:

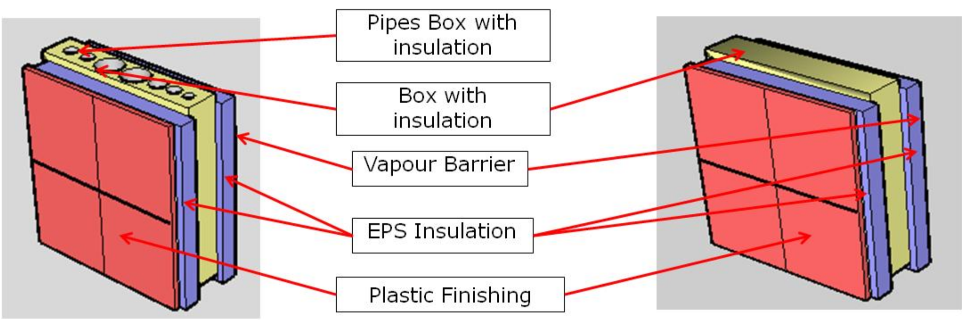

Figure 2. First design of the prefabricated retrofit module - 3D model

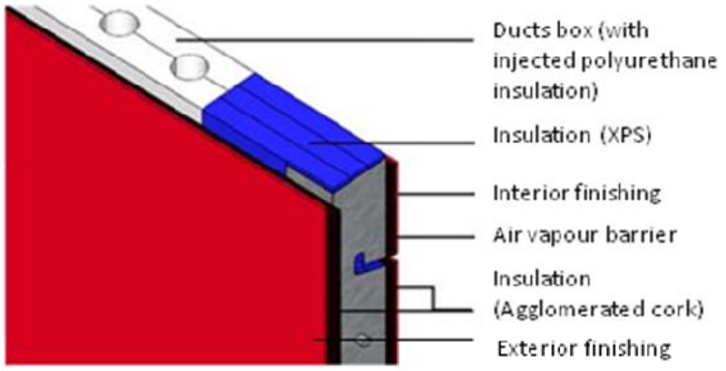

Figure 3. Final design of the prefabricated retrofit module - 3D model

Figure 4. Case study with retrofit needs: a) photograph; b) exterior 3D model; c) interior 3D model; d) 3D model cross-section;

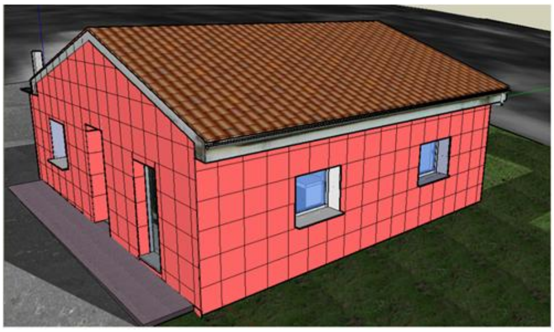

Figure 5. Application of the retrofit module first design alternative to the case study

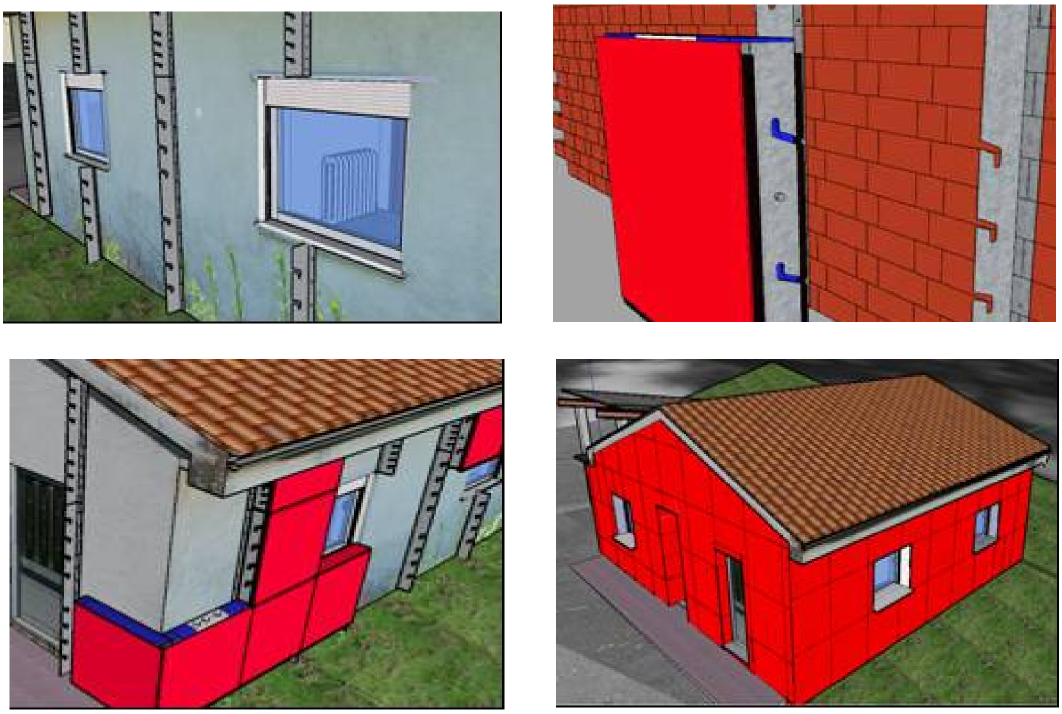

Figure 6. Necessary steps to apply the retrofit module to the case study

By the previous figures it is possible to confirm the large potentialities of the 3D modelling in this type of product development, since it allows not only its design optimization, but also the simulation of the application of the product in reality, making possible the study of the necessary support structures and how to apply it in order to be as fast as possible, while guarantying the maximum quality of the building retrofit process.

2.4 *Dynamic energy simulation*

The energy simulations were done with eQuest®, which is a free simulation tool developed by the Department of Energy of USA to calculate the energy performance of buildings. This tool is in the state of California the mandatory tool in the energy certification system. It is a GUI (Graphical User Interface) of the renowned tool DOE-2.2, which introduced new energetic systems and a faster thermal loads calculation engine. Its new 3D graphical engine makes easier the editing of the exterior and interior envelope of buildings.

In order to optimize the energy performance of the prefabricated retrofit module under development, two design alternatives were simulated with this tool, applied to the case study previously presented (single-family house in Braga). To simplify the process, the Google SketchUp® models shown earlier were exported to a CAD format and imported to eQuest®. Subsequently, the envelope characteristics, equipments, occupation and illumination profiles were defined for the original and for the retrofitted building with the application of the module under development and several scenarios were simulated.

The original building presented an U-value for the exterior walls of 1.9 $W/m^{2o}K$. With the application of the first design alternative of the retrofit module it was possible to reduce this U-Value to 0.4 $W/m^{2o}K$. With the application of the final design alternative solution it was possible to reduce this value to 0.2 $W/m^{2o}K$.

The results obtained with the simulations showed a significant reduction of the energy needs, particularly with the application of the final version of the retrofit module, as presented in Table 1. It is also possible to observe a slight increase in the cooling needs, since the increase in the insulation level of the building requires a longer time for the building to cool. This problem is aggravated when many consecutive hot days occurs. However, the cooling needs are insignificant when compared with the total needs, so this is not a real problem.

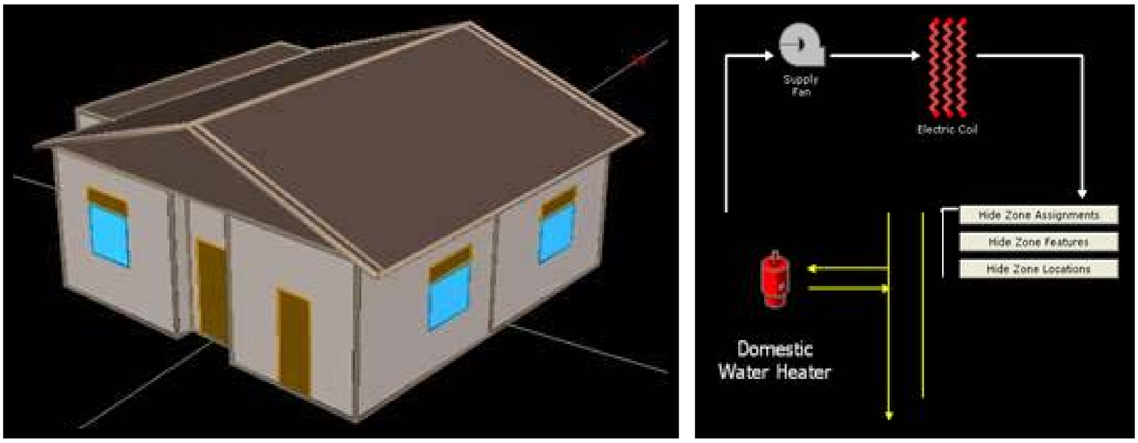

Figure 7. Model of the heating and domestic hot water systems.

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**

Simulations with eQuest® allowed the optimization, in terms of thermal performance, of the retrofit module under development. Several options were considered in what concerns insulation level and thermal bridges treatment. The application of the retrofit module allowed reducing significantly the U-value of the exterior walls and this, in conjunction with an overall increase of the envelope insulation level, allowed the reduction of the energy needs of the initial building in about 73%.

2.5 *Future Prototype*

After the retrofit module optimization, in terms of thermal performance, industrialization, quality assurance and cost-effectiveness, it was recognized that, in order to further improve the module, it was necessary to build several prototypes.

At this time, the prototypes are under construction and two types of assessments are schedule:

- Mechanical performance evaluation – for these tests it will be assessed the module mechanical resistance (torsion, tension, service fatigue, etc.), in order to guarantee the absence 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 the detection of thermal bridges 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 real scale cells with 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 level in the entire envelope except in the south façade where it is possible to test different façade solutions.

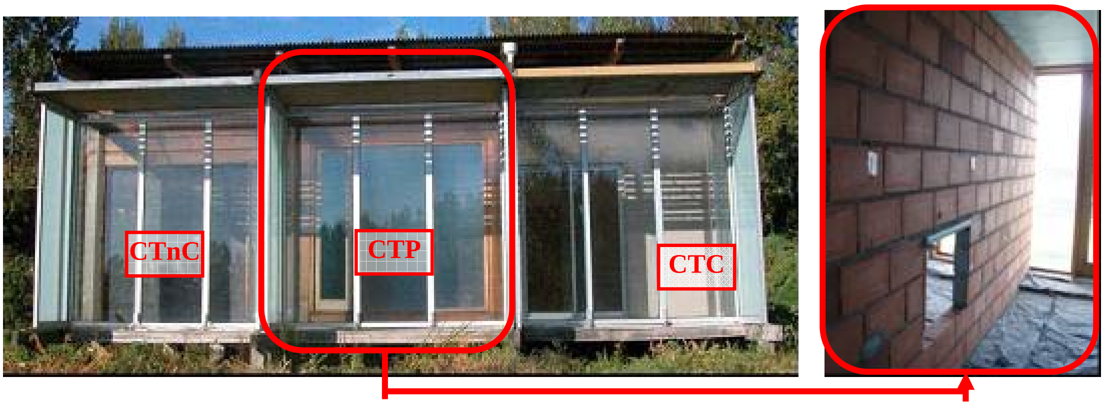

Figure 8. South façade of the Test Cells and interior partition where the retrofit modules will be applied

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 8. 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 cells 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 building stock is one of the main responsible for this excessive consumption, representing 40% of the global final energy consumption, LFCT-UMinho believed essential the development of new retrofit solutions aiming the reduction of the energy needs, the increase on thermal and acoustic comfort conditions and indoor air quality, without overlooking the aesthetics.

Thus, the development of a new prefabricated facade retrofit module for residential buildings 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 it can be obtained an overall reduction of the energy needs of about 70%, if the application of the module will be complemented with a systematic improvement of the building envelope – slabs insulation and windows replacement.

For the final validation of the retrofit module under development it was initiated the construction of several prototypes that will be instrumented with monitoring equipment and their mechanical and thermal performance certified.

Throughout this paper it was shown the development of a prefabricated façade retrofit solution that, besides contributing to the reduction of the energy needs of the buildings, can also improve their aesthetics with faster, higher quality assurance and less expensive interventions that can also reduce the occupant's disturbance, usual in this type of works. Thus, this is a solution with a very high potential of application in the fast growing Portuguese market of building rehabilitation.

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