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# Method for energetic and economic analysis of buildings

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ABSTRACT: Planet Earth is facing nowadays an environmental crisis without precedents. This is a matter of extreme importance and measures that allow reducing this problem have been discussed all over the world. One of the measures that have been appointed more often is the energy efficiency. In order to increase the energy efficiency, several technologies and legal documents have been developed. However, our society is facing, not only severe and unprecedented environmental crisis but also an economic crisis with similar magnitude. Therefore, it is of extreme importance to find methods that allow minimizing the environmental and economic impacts of the construction sector. The aim of this study is to find a method that allows the study of different measures relating their energy and economic performance.

## 1 INTRODUÇÃO

The emission of pollutants related with energy production is one of the most important causes of the current environmental crisis. The production and use of energy are responsible for 94% of $CO_2$ emissions (Isolani, 2008). This means that energy efficiency is a solution with an increasing importance in this matter (EC, 2010). The building sector is one of the biggest energy consumer and therefore one of the biggest contributors to the environmental crisis. The building sector was responsible for consuming approximately 40% (EU, 2010) of the final energy in Europe and it is expected that the dependence on the imported primary energy grows up to 70% by 2030 compared to 54% today (EEA, 2008).

However, despite of this scenario, it is also known that more than 50% of this consumption can be reduced through energy efficient measures (ADENE, 2009). This way, the building sector is one of the most influent concerning the energy efficiency matters not only because it is one of the biggest consumers but also because this consumption can be reduced through economic feasible measures (Almeida, 2009).

Aware of this situation, the European Commission has been promoting relevant measures to improve the energy performance of buildings. The European Directive nº2002/91/CE, Energy Performance Building Directive (EPBD), recently updated by 2010/31/EU (EPBD Recast), is an example of that. The EPBD was transposed into the Portuguese legislation through the review and subsequent adaptation of the thermal regulation constituted by three decrees-law (Decree-law no. 78/2006, Decree-law no. 79/2006 and Decree-law no. 80/2006).

The new thermal regulation has changed the building's design principles concerning the thermal comfort and energy efficiency. Nevertheless, it is very important that society understands what measures can improve the energy performance of their buildings and which are the best ones in an economically point of view.

This study presents a methodology that intends to compare different energy efficient measures in order to determine those having the best energy and economic performance. Thus, several parameters used by Decree-law no. 80/2006 (RCCTE - targeted to residential buildings) have been studied in order to select the most influent ones concerning the energy labelling calculation of residential buildings and in order to relate their energy performance with their economic performance.

## 2 METHODOLOGY

In order to fulfil the proposed objectives, a parametric and economic analysis has been developed. The parametric analysis was developed in order to study the influence of some parameters of the Portuguese legislation on energy performance of residential buildings, RCCTE (Decree-Law nº 80/2006), on the energy indexes (foreseen on the legislation) and on the final energy rating of the buildings. The goal of the economic analysis is to relate the energy and the economic performance of each solution.

### 2.1 *Case Study*

The study was carried out based on a case study building. This case study is a four room detached single family house with a heated area of 270 m$^2$. It is located in Ponte de Lima (Northwest of Portugal) at an altitude of 74m and about 25km away from the Atlantic Ocean coast. According to the Portuguese legislation, the climatic region of this building is I2/ V2 North (between the most severe, I3/V3, and the mildest one, I1/V1, climatic regions) and its thermal inertia is classified as strong (above 400 kg/m$^2$). The case study building, which will be referred as the reference solution, accomplishes all the legislative thermal requirements and its energy label is B- (low thermal quality since it is the minimum allowed for new buildings).

### 2.2 *Parametric Analysis*

The parameters analysed were the following: i) the heat transfer coefficient (U) of walls and slabs belonging to the exterior and interior (separating heated from non heated spaces) envelope, thermal bridges and windows; ii) the number of indoor air changes per hour; iii) the windows solar factor; iv) the shading factor (Fs) of vertical and horizontal windows; v) the external walls absorption factor ($\alpha$); vi) the efficiency of Domestic Hot Water (DHW) preparation systems ($\eta$a); vii) the contribution of solar systems to DHW preparation (Esolar); viii) the heating system efficiency ($\eta$i) and; ix) the cooling system efficiency ($\eta$v).

For each of the abovementioned parameters, alternative solutions to the conventional reference solutions were investigated. The selected alternative solutions include at least one high-performance solution, one low performance solution and two other different solutions. In any case, all the selected solutions are used and marketed in Portugal.

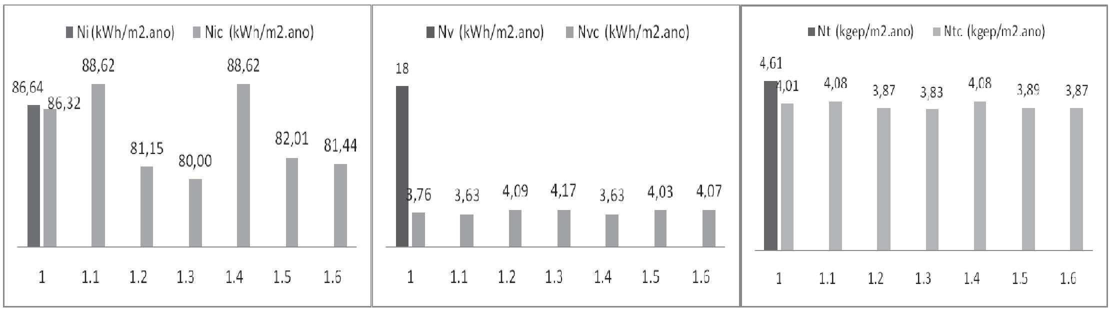
To each alternative solution, the four energy indexes foreseen in the Portuguese legislation (Ni – heating needs, Nv – cooling needs, Na – hot water needs and Nt – primary energy needs) were calculated and the results were compared to understand which are the best solutions regarding each one of these indexes.

As an example, the results for the analysis regarding the parameter “heat transfer coefficient of external walls” are presented in Table 1 and in Figure 1. The graph relative to Domestic Hot Water (DHW) energy needs (Na) is not presented since the parameter under evaluation has no influence in this index.

Table 1. Solutions under study to analyse the exterior walls heat transfer coefficient influence.

| Solution | U ($W/m^2 \cdot ºC$) |
|---|---|
| 1 – Reference Solution: Double masonry wall 15+11(cm) with 4cm of extruded polystyrene (XPS) | 0,50 |
| 1.1 - Double masonry wall 15+11(cm) with 3cm of XPS | 0,58 |
| 1.2 - Double masonry wall 15+11 (cm) with 8cm of XPS | 0,32 |
| 1.3 - Double masonry wall 22+22 (cm) with 8cm of XPS | 0,28 |
| 1.4 – ETICS (15 cm) with 4cm XPS | 0,58 |
| 1.5 - ETICS (15 cm) with 8cm XPS | 0,35 |
| 1.6 - ETICS (22 cm) with 8cm XPS | 0,33 |

In Figure 1, the dark grey bar represents the maximum regulatory values for heating needs (Ni), cooling needs (Nv) and primary energy needs (Nt). The light grey bars represent the heating needs (Nic), cooling needs (Nvc) and primary energy needs (Ntc) of each solution.



a) b) c)

Figure 1. Obtained results for the analysed exterior walls solutions. a) Buildind heating needs (Nic). b) Building cooling needs (Nvc). c) Annual primary energy needs (Ntc).

Through this study it is possible to select solutions that have the best performance to each parameter under analysis. In addition, the difference between the best and the worst solutions were determinate to each parameter. Through this difference, the influence of each parameter in final rating of the buildings can be discussed.

### 2.3 *Economic Analysis*

To perform the economic analysis, the study focused on the price difference of each alternative solution compared to the reference solution. This price variation was compared with the correspondent variation of global energy performance, obtained in the parametric analysis.

The global performance of each alternative solution was determined through the value of the correspondent annual primary energy needs (Ntc). The price of each alternative solution was obtained through a life cycle analysis. The determination of the initial costs was done through a search about the prices in the national market. The life cycle cost was assessed through the determination of the solution's maintenance costs and the associated energy costs through the building life cycle (life cycle adopted - 50 years).

The difference in energy consumption during life cycle is related to the difference in the annual primary energy needs of each alternative solution compared to the reference solution. Relating to heating, cooling, DHW systems and solar collectors it was accounted their service life and the number of replacements needed over the 50 years building life cycle.

To improve the visualization and comparison between different solutions, the economic analysis was carried out through a bi-dimensional graphic representation (Figure 2). The horizontal axis represents the costs variation and the vertical axis represents the energy performance variation. An alternative solution is always represented by a point in the graph. The cheaper solutions will appear leftmost in the graph and the solutions with better energy performance will appear above. The reference solution is always represented by point (0,0).

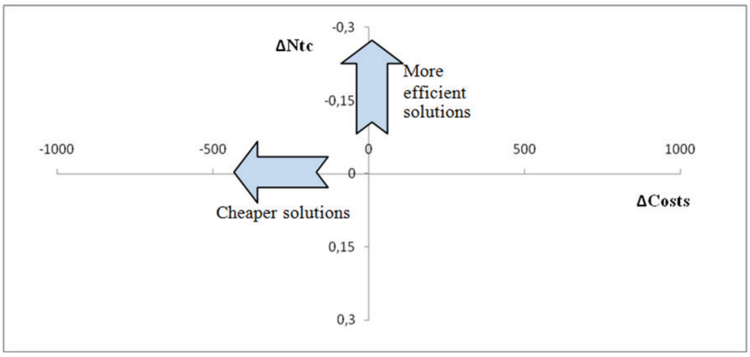


Figure 2. Graphic representation of economic analysis

This method has some important aspects regarding the comparison of solutions. When a solution is cheaper and has a better energy performance than other, it is easy to understand that it's better (in graph it appears on the upper left corner). However, compare alternatives when one of them is more expensive but also has a better energy performance may not be as obvious. To solve this problem it is necessary to find a comparison method that takes into account the value of money or the value of the improved energy performance. This comparison method will be useful to answer the question "To what extent is someone willing to pay for a certain improvement in energy performance of a building?". In numerical terms this will be the same as choosing an ideal cost-benefit ratio. To define this ratio it was used a payback time of 8 years (payback time considered as economically viable by Decree Law 79/2006). With this payback time it was possible to draw a line in the graph using equation 1, representing the value of money (Figure 3).

$$\Delta Cost = \Delta Ntc \times A \times PT \times Fpu \times Ec \qquad (1)$$

Where: ΔNtc – Primary Energy Needs Variance
A – Area
PT – Payback Time
Ec – Energy Cost
Fpu – Conversion factor of useful energy into primary energy

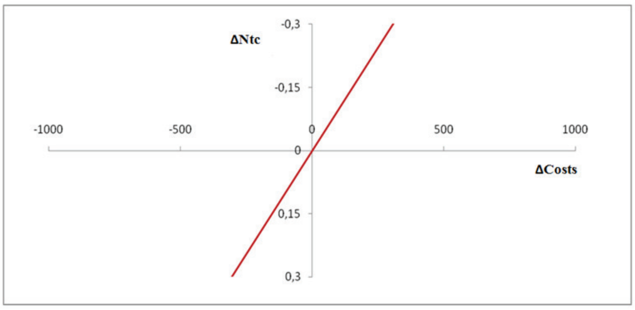


Figure 3. Graphic representation of the value of money reference line

Thus, it was possible to compare different solutions through the distance of each point to the line. The more up and left a point is located, the better is the correspondent solution (cheaper and more efficient).

## 3 PARAMETRIC ANALYSIS

To each parameter it was compared the differences in energy indexes between the alternatives solutions with best and worst energy performance. In Figure 4 it was presented those differences, in absolute and relative values, concerning the four energy indexes.

The relative values presented in Figure 4 correspond to the ratio between the difference between the best and the worst solution and the reference solution as presented in equation 1.

$$Relative\ difference = \frac{Best\ solution\ Value - Worst\ Solution\ Value}{Reference\ Solution\ Value} \tag{1}$$

It can be observed in Figure 4 that the most influent parameters concerning Nic value are the U-value of slabs, air change rate, U-value of external walls and U-value of windows. Although in a less significant way, the solar factor has also some influence on this index.

The influence of the heat transfer coefficient of slabs was very high. However, this parameter is not so influent on other types of buildings, like apartments, where the slab has no impact on their thermal performance.

It was observed in Figure 4 that concerning cooling needs, the solar factor has a significant influence on their determination. It was also observed that the modification of the solar protection has a greater influence than the modification of glass type. This was expected because the glass type accounts only for 30% for the solar factor value while the solar protection accounts for 70% (according to the methodology imposed by legislation). The air renovation rate and the obstruction factor have also a significant influence on this index.

| Parameter | Energy Indexes | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Nic | | Nvc | | Nac | | Ntc | |
| | kWh/m$^2$.ano | % | kWh/m$^2$.ano | % | kWh/m$^2$.ano | % | kgep/m$^2$.ano | % |
| Heat transfer coefficient of exterior walls | 8,6 | 10 | 0,5 | 14 | 0,0 | 0 | 0,2 | 6 |
| Heat transfer coefficient of interior walls | 0,0 | 0 | 0,0 | 0 | 0,0 | 0 | 0,0 | 0 |
| Heat transfer coefficient of slabs | 15,9 | 18 | 0,0 | 0 | 0,0 | 0 | 0,5 | 11 |
| Heat transfer coefficient of thermal bridges | 0,7 | 1 | 0,0 | 1 | 0,0 | 0 | 0,0 | 0 |
| Heat transfer coefficient of glazing | 8,4 | 10 | 1,0 | 27 | 0,0 | 0 | 0,2 | 6 |
| Number of indoor air changes per hour | 12,0 | 14 | 2,8 | 73 | 0,0 | 0 | 0,3 | 8 |
| Summer Solar Factor (Glazing analysis) | 3,2 | 4 | 1,5 | 39 | 0,0 | 0 | 0,1 | 3 |
| Summer Solar Factor (External protection analysis) | 0,0 | 0 | 4,2 | 113 | 0,0 | 0 | 0,0 | 1 |
| Winter Solar Factor | 6,5 | 8 | 0,0 | 0 | 0,0 | 0 | 0,2 | 4 |
| Shading factor (Horizontal shading) | 3,6 | 4 | 2,3 | 60 | 0,0 | 0 | 0,1 | 2 |
| Shading factor (Vertical shading) | 2,3 | 3 | 0,5 | 13 | 0,0 | 0 | 0,1 | 2 |
| Absorption coefficient (α) | 0,0 | 0 | 1,3 | 34 | 0,0 | 0 | 0,0 | 0 |
| DHW preparation systems efficiency (ηa) | 0,0 | 0 | 0,0 | 0 | 10,9 | 64 | 1,7 | 42 |
| Contribution of solar systems to DHW preparation | 0,0 | 0 | 0,0 | 0 | 9,9 | 58 | 0,9 | 21 |
| Heating system efficiency (ηi) | 0,0 | 0 | 0,0 | 0 | 0,0 | 0 | 1,9 | 48 |
| Cooling system efficiency (ηv) | 0,0 | 0 | 0,0 | 0 | 0,0 | 0 | 0,0 | 0 |

Figure 4. Differences between solutions with the highest and the lowest U-values

The obstruction factor has an important influence both on heating and cooling needs. However, the shading devices decreases the energy needs in summer but increases these needs in winter. It was difficult to find a solution that is both positive in summer and winter. The solution is the adoption of movable shading devices.

It was observed in Figure 4 that there are only two parameters that influence the DHW energy needs, the efficiency of DHW preparation systems and the contribution of solar systems to DHW preparation. Both of them have a great influence on this index.

It was observed in Figure 4 that the parameters that most influence the primary energy needs are the heating system efficiency, the efficiency of DHW preparation systems and the contribution of solar systems to DHW preparation.

Both heating and cooling systems efficiency are multiplicative factors of the correspondent needs. However, the heating needs are greater than the cooling needs. For this reason the heating system efficiency has a bigger influence than the cooling system efficiency. This situation occurs in buildings with a medium or strong thermal inertia (the most common in Portugal), in which the Nic index is much higher than the Nvc index.

The heat transfer coefficient of walls belonging to the exterior envelope has also some influence on primary energy needs as well as the air change rate.

Due mainly to political reasons, translated into the regulation calculations, the parameters related with DHW preparation have a huge influence on the primary energy needs in opposition to the cooling and heating needs caused by the envelope characteristics. For this reason, the importance of parameters related with the envelope performance is low.

## 4 ECONOMIC ANALYSIS

As an example, it is presented below the detailed economic analysis performed for the parameter U-value of external walls. The values used in this analysis are shown in Table 2. In the second and third columns are presented the cost and the Ntc index of each alternative solution (in a life cycle basis). In the fourth and fifth column are presented the price and Ntc variations of each solution in comparison with the reference solution. In the last column it is presented the distance between the point representative of each solution and the value of money reference line, following the methodology presented before.

Table 2. Economic analysis for the U-value of external walls

| Solution | Cost (€) | Ntc (kgep/m2.ano) | Δ Cost | Δ Ntc | d |
|---|---|---|---|---|---|
| Solution 1 | 5189 | 4,01 | 0 | 0 | 0,00 |
| Solution 1.1 | 5169 | 4,08 | -20 | 0,07 | 0,05 |
| Solution 1.2 | 5660 | 3,87 | 471 | -0,15 | 0,18 |
| Solution 1.3 | 6019 | 3,83 | 830 | -0,18 | 0,39 |
| Solution 1.4 | 6996 | 4,08 | 1807 | 0,07 | 1,30 |
| Solution 1.5 | 5181 | 3,89 | -8 | -0,12 | -0,13 |
| Solution 1.6 | 5543 | 3,87 | 353 | -0,14 | 0,10 |

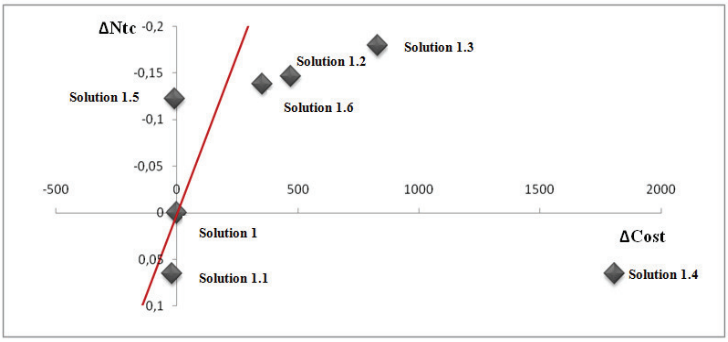


Figure 5. Graphic representation of economic analysis for the U-value of external walls

Figure 5 presents the economic analysis for the U-value of external walls. Like it was explained before, in this graph, the solutions that have a bigger negative distance from the reference line (that are above and to the left) are the best solutions. It was observed that the solutions 1.2 and 1.6 have a similar energy performance. However, the solution 1.6 is better because it carries lower costs. Concerning to solution 1.3, it presents a worse performance than solutions 1.2 and 1.6 since it is more expensive and its increase in energy performance is not rewarding.

### 4.1 *Economic analysis results*

In Figure 6 it is presented the distance between the best and the worst solutions for each parameter. This value indicates the economic performance variation that could be obtained through the choice of different alternatives solutions in each parameter. It can be observed in the figure that the parameters 11, 12 and 13 are those who should be studied in more detail in order to improve the building quality. The choice of one solution for these parameters can result in a higher energy/economic performance variation. It was verified that the solutions for parameters 7.2 and 8 require also a conscious evaluation.

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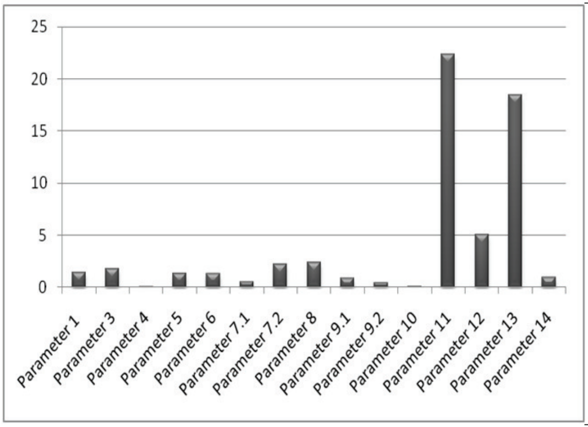

| | |
|---|---|
| **Parameter 1** | U (Walls belonging to the exterior envelope) |
| **Parameter 2** | U (Walls belonging to the interior envelope) |
| **Parameter 3** | U (Slabs) |
| **Parameter 4** | U (Thermal bridges) |
| **Parameter 5** | U (Glazing) |
| **Parameter 6** | Indoor air changes rate (Rph) |
| **Parameter 7.1** | Windows Solar factor (Summer - glass type analysis) |
| **Parameter 7.2** | Windows Solar factor (Summer - external protection analysis) |
| **Parameter 8** | Windows Solar factor (Winter) |
| **Parameter 9.1** | Shading factor (Horizontal shading) |
| **Parameter 9.2** | Shading factor (Vertical shading) |
| **Parameter 10** | External walls absorption coefficient (α) |
| **Parameter 11** | DHW preparation systems efficiency ($\eta$a) |
| **Parameter 12** | Contribution of solar systems to DHW preparation (Esolar) |
| **Parameter 13** | Heating system efficiency ($\eta$i) |
| **Parameter 14** | Cooling system efficiency ($\eta$v) |

Figure 6. Distance between the solutions with better and worst performance for each parameter

This economic analysis allows the comparison of different alternative solutions from different standpoints, taking into account the life cycle costs. Depending on the line's gradient, it is possible to perform the analysis from the point of view of the promoter, user or other stakeholder, through the use of different values of money.

However it was observed that sometimes, the cheaper solutions, even with a lower energy performance, prevailed compared with other that are more expensive and that have a better energy performance. This occurs because the money line that was used had a high slope, meaning that the value of money is higher than the value of a better energy performance. However, this gradient reflects the actual economic crisis and the importance that people attribute to money. Nevertheless, a great energy performance means also lower energy consumption and consequently a better economic performance (since life cycle costs are accounted).

## 5 CONCLUSIONS

Through this study it was possible to verify that the methodology developed allow to compare different solutions regarding their energy performance and life cycle costs enabling the selection of the best solutions.

The slope of the "values of money" reference line obtained through the payback time of 8 years gives more importance to the economic performance than the energy performance. This situation represents the reality marked by a big economic crisis. However, the methodology presented can be changed and adapted to other realities through the alteration of the reference line slope.

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