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# Effect of environmental assessment on primary energy of modular prefabricated panel for building renovation in Portugal

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# Effect of environmental assessment on primary energy of modular prefabricated panel for building renovation in Portugal

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**Abstract.** While facing increasingly strict regulations regarding energy efficiency, the construction sector should also adopt sustainable solutions in terms of new constructions and renovations of buildings. In particular, energy renovation of existing buildings has specific technical and economic constraints that are generally addressed through implementation of new materials and building integrated systems, whose environmental impact should be considered when assessing the most adequate solution. Within the context of the More-Connect Project, which aims to develop modular prefabricated solutions for energy renovation of buildings, several renovation scenarios for a pilot building in Portugal were assessed using a methodology to compare the cost-effectiveness of renovation measures. The article explores the use of lifecycle assessment to analyse the effect of considering embodied primary energy in cost-effectiveness calculations.

**Keywords:** Cost-effectiveness, energy efficiency, More-Connect, building renovation, Life Cycle Assessment.

## 1. Introduction

The urgency to act regarding climate change and its devastating consequences is increasingly recognized at a global scale. In this context, the European Union (EU) established goals to be achieved by the Member States in 2030 [1] and in 2050 [2] that will help them to be more competitive and, simultaneously, more sustainable. Cities, and in particular buildings, can have a significant contribution to help reaching these goals. European buildings are responsible for about 40% of the final EU energy consumption [3], which is strongly related with an important share of carbon emissions that are released into the atmosphere every year [4]. In order to deal with this issue, the European Commission promoted fundamental regulation and introduced important concepts aiming to reduce energy use and carbon emissions. The 2010 recast of the Energy Performance of Buildings Directive (EPBD recast) with its nearly Zero-Energy Buildings (nZEB) concept, is a significant example of the European initiative in this context [5]. However, despite the efforts to promote building renovation through European directives

[6], the main focus of regulations is still on new construction when, in fact, most of the European building stock is more than twenty years old [7] and is being replaced by new buildings at a very low rate of around 1% to 2% per year [8]. Being so, to achieve the 2030 and 2050 targets, it is necessary to promote a large-scale energy renovation in EU existing buildings. This can be facilitated by making available cost-effective technologies and solutions that also allow to reduce the time of intervention and to minimize the disturbance of the occupants. The More-Connect Project aims to develop cost-optimal solutions to deep renovations of existing buildings towards the nZEB level [9] with the above cited criteria. For this purpose, and in the project scope of an integrated renovation intervention, a modular prefabricated panel for the façade was developed. It comprises a wood frame with 100 mm, an internal/external cladding made of Coretech® sheets with 10 mm each, and a filling material of polyurethane foam with a 100 mm total thickness. Figure 1 shows a scheme of the prefabricated panel composition.

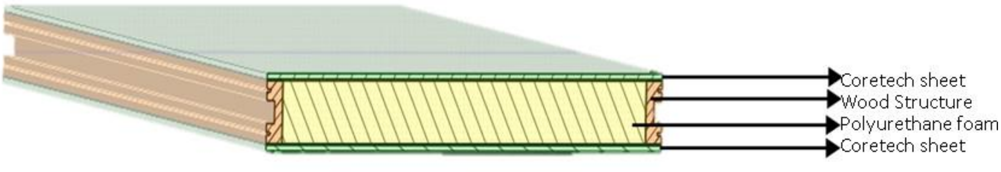


**Figure 1.** Modular prefabricated panel for façade renovation.

Although the modular prefabricated solutions for building renovation have been studied from other perspectives (e.g.[10]), the environmental aspects of such a solution are not widely explored. In this sense, this paper intends to contribute to this knowledge, investigating the effect of considering environmental assessment on primary energy for cost-effective calculations for an integrated building renovation taking into account a modular prefabricated panel in Portugal. For this purpose, this paper explores the use of the Cost-Optimal methodology and Life Cycle Assessment in order to compare several renovation measures in a case study building in Vila Nova de Gaia, Portugal.

## 2. Case study building

The case study building is a Portuguese multi-family building, built in 1997 in Vila Nova de Gaia (North of Portugal) in a social housing context. From the construction characteristics perspective, this case is representative of about 40% of the national building stock of multi-family buildings built between 1991 and 2012 in Portugal. Some building characteristics and energy parameters are compiled in Table 1.

**Table 1.** Characteristics of the case study building before renovation.

| Building Characteristics | Unit | Data | Energy Parameters | Unit | Data |
|---|---|---|---|---|---|
| Wall area (excl. windows) | $m^2$ | 2712.2 | U-value wall | W/($m^{2}$°C) | 0.96 |
| Roof area (pitched) | $m^2$ | 622.1 | U-value attic floor | W/($m^{2}$°C) | 0.91 |
| Area of ceiling of cellar | $m^2$ | 514.0 | U-value ceiling of cellar | W/($m^{2}$°C) | 0.78 |
| Area of windows to North | $m^2$ | 0 | U-value windows | W/($m^{2}$°C) | 3.60 |
| Area of windows to East | $m^2$ | 21.5 | g-value windows | Factor | 0.78 |
| Area of windows to South | $m^2$ | 0 | Energy needs for cooling | kWh/$m^2$ | 2.20 * |
| Area of windows to West | $m^2$ | 10.6 | Energy needs for heating | kWh/$m^2$ | 53.36* |
| | | | Energy needs for hot water | kWh/$m^2$ | 29.60* |

*Simulated values

The analysed building has 3 separate blocks and each block has 3 floors with 2 apartments per floor. In total there are 18 apartments with an average area of 70.25 $m^2$ and a 1265 $m^2$ heated area. From the construction perspective, the building is based on a concrete frame structure and is composed of a pitched roof with ceramic tiles, double pane masonry walls without insulation, windows with aluminium frames and double-glazing. Concrete slabs between floors have no insulation, including the one serving as the ceiling of the lower, semi-buried floor, designated as cellar. There are no centralized heating or cooling systems installed in the building, although it was verified that in some apartments small individual heaters are used. The building presents some deterioration and signs of lack of thermal insulation, such as reported thermal discomfort and condensation and mould problems. In general, the current renovation needs are related to the correction of thermal bridges, to the increase of the insulation level and to the installation of a centralized heating system.

## 3. Methodology

### *3.1 Cost-optimal methodology*

Calculations regarding cost-optimality were performed with an established methodology defined in the Commission Delegated Regulation 244/2012 [11], which complements the EPBD recast [5]. It is based on the comparison of various renovation scenarios with a reference case, known as "anyway renovation", where the energy performance of the building is not improved, dealing only with aesthetical, functional and structural issues. The reference case also establishes the threshold for the cost-effectiveness of renovation scenarios (composed by building envelope renovation packages and new building systems solutions) (Figure 2). If a renovation scenario leads to a lower energy demand and lower costs than the reference case, it is considered cost-effective. The comparison between the renovation scenarios requires the calculation of the energy use associated with each of them as well as the global costs, calculated with a life cycle cost perspective[12]. In this study, in order to calculate the building energy use, a simplified approach considered in the national legislation was used [13].

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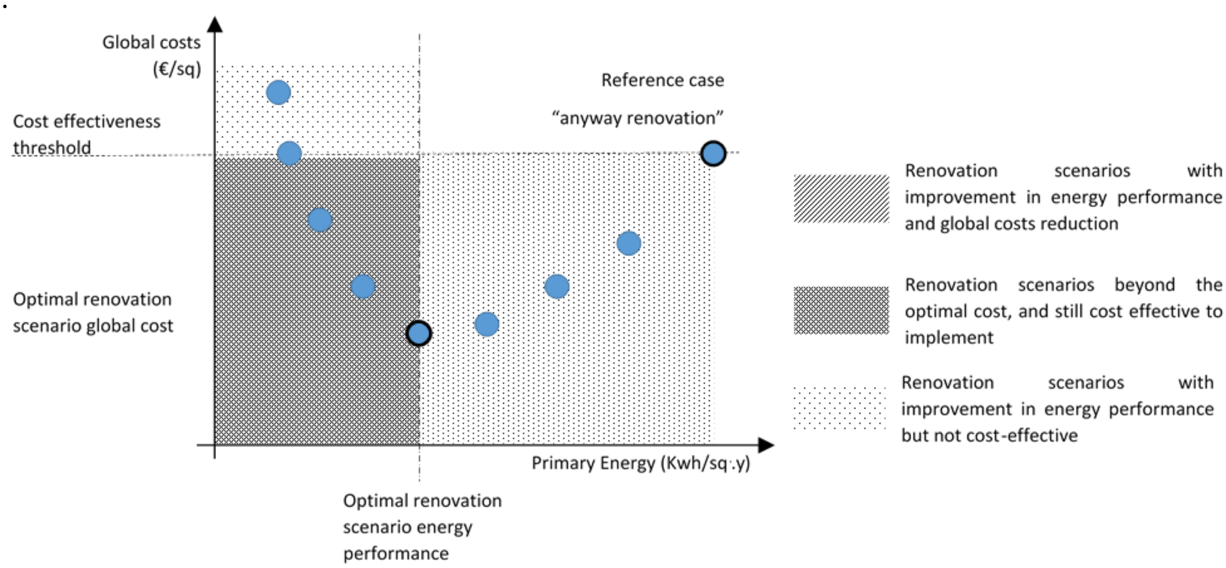


**Figure 2.** Identification of cost-optimal and cost-effective levels [12].

### *3.2 Life Cycle Assessment*

In order to understand the effect of the environmental assessment on primary energy, the embodied energy of the materials used in the renovation was also considered in the calculations. The Life Cycle Assessment (LCA) methodology used followed the one defined by Lasvaux et al. [14]. It takes into account the primary energy embodied in the construction materials and in the Building Integrated Technical Systems (BITS), as well as the operational primary energy use, according to Equation 1.

$$PE_{building} = PE_{materials} + PE_{BITS} + PE_{op\ energy\ use} \quad (1)$$

Where $PE_{building}$ is the primary energy associated to the building renovation, $PE_{materials}$ is the primary energy associated to all materials that were used in the building renovation, $PE_{BITS}$ is the primary energy associated to the BITS and $PE_{op\ energy\ use}$ is the calculated primary energy for the operational energy use.

### *3.3 Renovation packages and building system solutions*

The renovation scenarios were defined in order to assess the cost-effectiveness of the prefabricated panel in an integrated renovation of the building, as well as to compare this renovation solution with the most common measure used in Portugal – the application of the External Thermal Insulation Composite System (ETICS). In the case of the building envelope, nine renovation packages were proposed (Table 2). The packages include interventions in the walls, roof and cellar ceiling, as well as the replacement of the windows. To elucidate the impact that an optimized production line may have in the global costs, calculations for a renovation package considering cost production optimization (M9) were also performed considering a 73% reduction in terms of costs for the production of the prefabricated panel.
Regarding BITS for heating, cooling and Domestic Hot Water (DHW), five different systems were proposed. Furthermore, BITS were also combined with Renewable Energy Sources (RES), such as Photovoltaic (PV) and Solar Thermal (ST). Table 3 presents the combinations used in the calculations.

**Table 2.** Proposed building envelope renovation packages

| Renovation Packages | Characteristics |
|---|---|
| Reference | The walls are repaired and painted and the pitched roof is refurbished (with new tiles). These measures do not improve the energy performance of the building |
| M1 | The walls are insulated with ETICS: 8 cm EPS* |
| M2 | The walls are insulated with a prefabricated panel (12 cm) and a 6 cm MW** layer |
| M3 | The walls are insulated with a prefabricated panel (12 cm) and a 10 cm MW layer |
| M4 | M3 plus the refurbishment of the roof (including membrane), roof battens, shuttering, gutter and a 6 cm MW layer |
| M5 | M3 plus the roof refurbished (including membrane), roof battens, shuttering, gutter and a 14 cm MW layer |
| M6 | M5 plus the cellar ceiling insulated with a 6 cm MW layer |
| M7 | M6 plus new windows with (aluminium frame and U-value of 2.40 $W/m^{2o}C$) |
| M8 | M3 plus the refurbishment of roof with 6 cm of polyurethane (including membrane) roof battens, shuttering, and gutter. The cellar ceiling refurbished: 6 cm XPS*** |
| M9 | M8 with optimized costs for the production of the modular prefabricated panel |

*EPS – Expanded Polystyrene
**MW – Mineral Wool
***XPS – Extruded Polystyrene

**Table 3.** Proposed solutions for the building Systems.

| System solution | Heating | Cooling | DHW* | RES** |
|---|---|---|---|---|
| Conventional | Electric heater<br>η =1.0 | Multisplit<br>EER =3.0 | Gas heater<br>η =0.71 | |
| A | Multisplit<br>COP =4.1 | Multisplit<br>EER =3.5 | Gas heater<br>η =0.71 | |
| B | Gas boiler<br>η =0.93 | Multisplit<br>EER =3.5 | Gas boiler<br>η =0.93 | |
| C | Biomass boiler<br>η =0.92 | Multisplit<br>EER =3.5 | Biomass boiler<br>η =0.92 | |
| D | Multisplit<br>COP =4.1 | Multisplit<br>EER =3.5 | Electric boiler<br>COP =1.5 | PV (zero) ***<br>ST****for DHW |
| E | Heat Pump<br>COP=3.3 | Heat Pump<br>COP=2.68 | Heat Pump<br>COP=3.3 | |

*DHW – Domestic Hot Water
**RES- Renewable Energy Sources
***PV (zero) - Photovoltaic contribution consists of an installation with the necessary capacity to fully compensate the energy needs for heating and cooling
****ST – Solar Thermal contribution consists of an installation, sized according to the minimum requirements of the Portuguese legislation

## 4. Results and discussion

For a better understanding of the effect of the environmental assessment on primary energy, the results are shown in two different subsections. In the first one, the renovation measures (renovation scenarios + system solution) do not consider the embodied energy of the materials used in calculations, while in the second one, environmental impacts are added to the calculated primary energy.

### *4.1. Renovation measures without considering the embodied energy of the materials used*

Figure 3 presents the results of the cost-optimal calculations without considering the embodied energy of the materials used in the renovation.

In general, results indicate that the majority of the simulated renovation scenarios are cost effective to implement (with exception to the ones using System Solution E, M2 to M7 using System Solution C and M2 to M8 using System Solution B). The results of the calculations shown in Figure 3 suggest that M9 (which considers cost optimization of the prefabricated panel alongside roof and cellar insulation) represents the cost-optimal measure, independently of the system solution. In comparison, when cost optimization is not considered (M8), the use of the prefabricated panel in an integrated renovation intervention is still cost-effective in renovation scenarios using the Conventional System, System Solution A, C, D. In system solution B, this scenario is situated on the threshold line and cannot be considered cost effective. M1 is cost-effective with every system calculated (except system solution E), although when system solution C is used, the renovation scenario is very close to the cost-effectiveness threshold (611.33 €/m$^2$).

In terms of energy performance, the system solution C (biomass boiler and multisplit) is, clearly, the advantageous solution (values close to zero kWh$_{EP}$/(y.m$^2$)) while the conventional system is the worst one (values between 99.35 and 135.32 kWh$_{EP}$/(y.m$^2$)). The biomass boiler used in the system solution *C* plays an important role in this performance. Furthermore, the systems solutions that consider renewable energy, *C* (biomass boiler) and *D* (using Solar thermal and PV installations), show the more expressive improvement in the energy performance. With system solutions *A* and *D* as well as with the Conventional System, all renovation scenarios are under the limit of cost-effectiveness. However, the option *D* collectively presents the lowest values, between 405.47 and 559.61 €/m$^2$. System solution *E*, although indicated as providing significant energy reductions, is the one presenting higher global costs, mainly due to the high initial investment in the heat pump system.

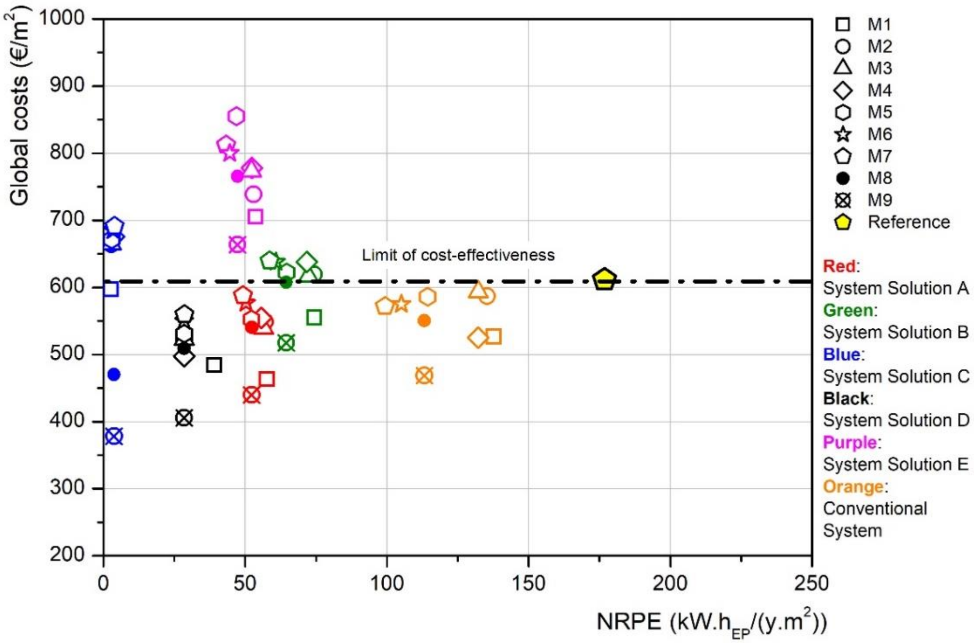


**Figure 3.** Results of the cost-optimal calculations without considering the embodied energy of the materials used in the renovation.

The results also show that all renovation measures present an improvement in energy performance compared with the reference case, or anyway renovation. It means that the modular prefabricated panel is a good choice regarding energy reduction. When directly compared with the most common renovation solution used in the Portuguese market, ETICS, the More-Connect panel presents a higher energy performance, although at a slightly higher cost. Cost optimization regarding mass production and optimization of production line is expected to improve the cost-effectiveness of the prefabricated modular panel, as seen in M9 renovation solution with system solution C, which is the cost-optimal solution and allows a reduction of 97.9% in primary energy in relation to the reference case.

### *4.2. Renovation measures considering the embodied energy of the materials used*

Figure 4 presents the results of the cost-optimal calculations considering the embodied energy of the materials used in the renovation.

When comparing Figure 4 with Figure 3, it is observed that when the embodied energy of the materials used in the building renovation is considered in calculations, there is an increase in the primary energy associated to each renovation scenario, regardless of the system solution considered. Despite this increase, the relation between system solutions and renovation scenarios, in most of the cases, remains the same. Concerning the global costs, the comparative position of the renovation scenarios in relation to the reference situation is the same, as well.

Considering the embodied energy, the cost-optimal option for the building envelope continues to be the renovation scenario M9 (which considers cost optimization of the prefabricated panel alongside roof and cellar insulation), independently of the system considered. Overall, the cost-optimal solution continues to be M9 together with the system solution C, allowing for an energy reduction of 49.3% when compared with the reference situation.

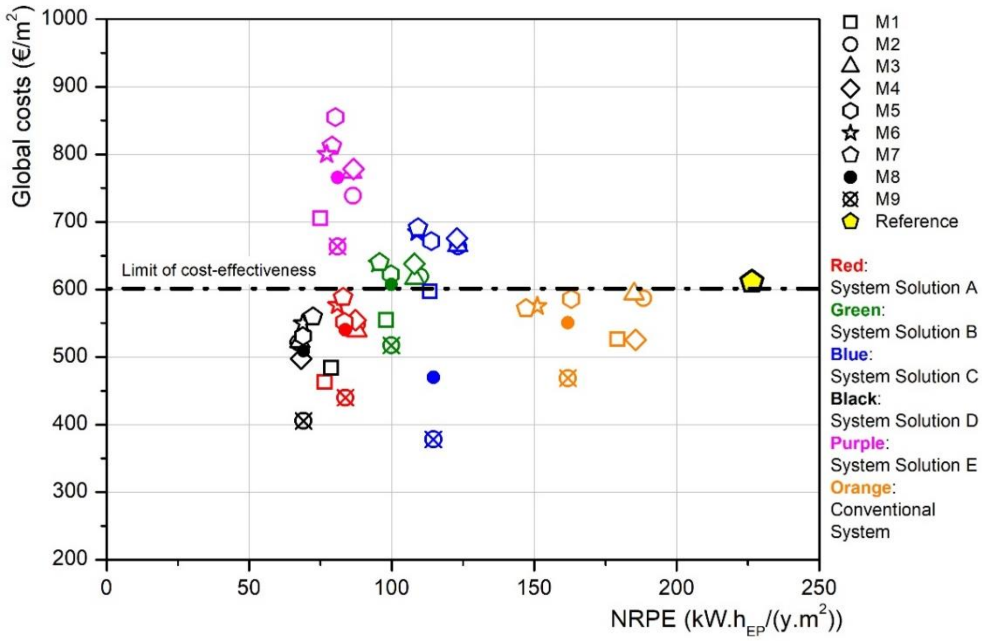


**Figure 4.** Results of the cost-optimal calculations considering the embodied energy of the materials used in the renovation.

Regarding the systems, the inclusion in the calculations of the embodied energy of the materials led to some changes and to a significant increase in the values of primary energy associated to the renovation solutions, particularly in solutions that include renewable energy sources as C and D. In these cases, the materials used to produce these renewable energy based systems may be the cause of this increase. The most important change is noticeable in the combination of system solution C (multisplit + biomass boiler) with the different renovation scenarios. In Figure 3, where embodied energy is not considered, the NRPE consumption of solution C is close to zero but as seen in Figure 4, when embodied energy is considered, the NRPE consumption is between 108.85 and 123.27 $kWh_{EP}/(y.m^2)$. So, it is possible to say that, in terms of energy performance, the system solution D (multisplit + electric boiler, assisted with ST and PV) is the best option (values around 70 $kWh_{EP}/(y.m^2)$) while the conventional system continues to be the worst one (values between 147.12 and 188.38 $kWh_{EP}/(y.m^2)$).

## 5. Conclusions

In general, the results suggest that in an environmental assessment, when the embodied energy of the materials is considered in the calculations, it is observed a noticeable increase in the Non-Renewable Primary Energy associated to the building. However, the relation between the renovation solutions and the system solutions and their relative positions remains essentially the same meaning that the cost-optimal solution is not affected by this consideration.

The results also suggest that the modular prefabricated panel, after the cost optimization of the production line, is the cost-optimal solution, regardless considering or not the embodied energy of the materials used in the building renovation. Calculations also highlight the competitiveness of the ETICS (M1*)* renovation solution in this context. However, in terms of global costs, the modular prefabricated panel presents an efficient answer to building renovation since most of the proposed renovation scenarios are under the limit of cost-effectiveness. The cost-optimal solution allows for a primary energy reduction of 97.9% without considering the embodied energy. When the embodied parcel is considered, the reduction is less significant but still relevant (49.3%).

## 6. References

[1] G. Secretariat of the Council 2014 “EUCO 169/14 - 2030 Climate and energy policy framework and economic issues” Brussels
[2] C. Comissão Europeia 2011 “Roteiro de transição para uma economia hipocarbónica competitiva em 2050” Bruxelas
[3] Gynther K, Lapillone L and Pollier B 2015 “Energy Efficiency Trends and Policies in the Household and Tertiary Sectors Energy Efficiency Trends and Policies in the Household and Tertiary Sectors An Analysis Based on the ODYSSEE and MURE Databases”
[4] Hsu D, Meng T, Han A and Suh D 2017 “Further Opportunities to Reduce the Energy Use and Greenhouse Gas Emissions of Buildings” *J. Plan. Educ. Res.*
[5] EU 2010 “Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)” *Off. J. Eur. Union* **EN L**
[6] EU 2018 “Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency” **2018 (May)** 75
[7] Almeida M, Bencresciuto A, Ferreira M and Rodrigues A 2015 “Cost-effective energy and carbon emission optimization in building renovation-A case-study in a low income neighbourhood,” *Energy Procedia* **78** 2403
[8] Artola I, Rademaekers K, Williams R and Yearwood J 2016 “Boosting Building Renovation: What potential and value for Europe? Study for the ITRE Committee” *European P.* **PE 587.326**
[9] Bolliger R and Ott W 2016 “Methodological framework and instructions for the selection of favourable concepts for the pilot projects (Task 6.1 part 1)”
[10] Silva P C P, Almeida M, Bragança L and Mesquita V 2013 “Development of prefabricated retrofit module towards nearly zero energy buildings,” *Energy Build.* **56** 115
[11] EU 2012 “No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements” *Off. J. Eur. Union* **L81** 18
[12] Almeida M and Ferreira M 2017 “Cost effective energy and carbon emissions optimization in building renovation ({Annex} 56),” *Energy Build.* **152 (Supplement C)** 718
[13] Ministério da Economia e Emprego 2013 “DL 118/2013 - Regulamento de Desempenho Energético dos Edifícios de Habitação (REH)” 4988
[14] Lasvaux S, Favre D, Périsset B, Mahroua S and Citherlet S 2017 “Life Cycle Assessment for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56)” International Energy Agency

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