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Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation
Annex 56 methodology and its application to a case study

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Abstract

Following the impact of the climate changes and their causes, buildings proved to be one of the main responsible for the greenhouse effect due to the carbon emissions related with their construction and use. The recent changes in the European regulations, in a tentative to improve buildings energy performance, are mostly suited to new buildings. However, the majority of the building stock has more than twenty years and renovating it, in accordance with the current standards, can lead to difficult and expensive procedures. Considering the main goals of reducing the use of fossil fuels and the related emissions, the use of renewable energy sources offers an alternative to these deep interventions in the buildings envelope.

In a search for the right balance between energy conservation and energy efficiency measures and technologies that require the use of renewable energy, IEA EBC launched Annex 56. The main purpose of the project is the development of a methodological framework that allows comparing renovation scenarios that deeply reduce energy and carbon emissions combining energy efficiency measures and the use of renewable energy. It takes into consideration not only the reduction of the energy use, carbon emissions reductions and costs, but also embodied energy and co-benefits that arise from the renovation procedure. The methodology was applied to a Portuguese case-study that has gone under renovation. The results allow comparing the chosen renovation scenario with other scenarios and justify the option of going beyond the cost optimal solutions in order to have more effective reduction of the carbon emission while still being cost effective.

Keywords: building renovation, cost effectiveness, energy, emissions, co-benefits

1. Introduction

In late years the climate changes are a major concern for most of the world leaders. Studies proved that the increase of greenhouse gases, such as carbon dioxide, is responsible for these changes. In this sense, different actions have been carried out to try to stabilize the concentrations of GHG, reducing them at long term [1] [2].

In Europe, buildings have been identified as major energy consumers due to their poor energy performance, which makes them responsible for a great share of the carbon emissions [3]. Most of the European building stock has more than twenty years and low energy performances. In this sense, building renovation plays an important role in the reduction of the energy use and carbon emissions. Existing buildings have a huge saving potential, but most times it is not totally exploited [3].

However, European regulations are still mainly targeted to new buildings, creating some problems in the application of these regulations into existing buildings. Existing buildings have their own constrains and barriers and the direct application of the requirements set for new buildings, may lead to expensive and complex procedures. In most cases this fact makes the renovation interventions unacceptable by users and promoters [4]. In existing buildings the renovation procedures should be analyzed in order to achieve the best energy performance with less effort and less user's disturbance [4].

In this context and in attempt to overcome these barriers, the IEA Energy in Buildings and Communities Programme (EBC) launched the project Annex 56 to study cost–effective optimization of energy and carbon emissions in building renovation [5].

The purpose of the project is to develop a methodological framework that allows evaluating packages of renovation measures to improve the energy performance of existing residential buildings, with the possibility of going beyond the cost optimal solution with measures that are still cost effective and that reduce more effectively the carbon emissions. [5].

This paper aims at presenting the application of Annex 56 methodology to a Portuguese case-study, comparing the reference renovation scenario that does not improve the energy performance of the building, with alternative scenarios to renovate the building, including the solution that has been chosen to be implemented in the field.

2. Annex 56 methodology

Annex 56 scope is residential buildings and office buildings without complex HVAC technologies and focuses on the measures with energy performance beyond the cost-optimal renovation scenarios (scenarios that lead to the lowest global cost considering investment and running costs), approaching the zero energy and zero carbon emissions levels. The goal is to start with the cost-optimal approach and go further, balancing energy efficiency measures and the use of renewable energy sources to reach the lowest energy use and carbon emissions level, lowest embodied energy in materials and the most achievable co-benefits.

The methodology uses a life cycle costs (LCC) approach, balancing the energy consumption and global costs for a life cycle of 30 to 60 years, for each analyzed renovation scenario. The comparison between the renovation scenarios is always related to a reference case, known as “anyway renovation”, which does not consider any energy related improvements.

To perform the assessment, different renovation scenarios improving the energy performance of the building envelope and using different combinations of building integrated technical systems (BITS) are created, and their energy use, related carbon emissions and global costs calculated.

In order to include the environmental impact of the solutions in the LCC, a simplified life cycle impact assessment (LCIA) may be performed allowing assessing the global warming potential (GWP) and embodied energy of each renovation scenario. With these results, not only the energy and emissions related to building use are considered in the assessment but also those related with materials used in the renovation process.

Besides, the methodology also includes a qualitative way of relating the energy renovation measures with co-benefits that potentially result from the application of those measures. The owner/user’s interests are considered by placing their willingness to pay for added benefits against the results from the LCC assessment.

3. Description of the case-study

The case study consists of a building built in 1950’s and it belongs to a social neighborhood located in Porto, in the north of Portugal. The building presented signs of significant degradation and also the living areas were not adjusted to current living standards. The building had two floors and four apartments, two in each floor. Figure 1 shows the general aspect of the building before and after the renovation.

Figure 1. General aspect of the building before and after the renovation

The building had no insulation on the envelope and there were no BITS for heating and cooling. The only systems available were portable electric systems such as electric heaters and fan coils. The domestic hot water (DHW) was provided by an electric heater with storage tank.

Concerning the building envelope, exterior walls consisted in single hollow brick walls with plaster on both sides and the roof was composed by a lightweight slab and a wooden structure that supports fiber cement plates.

The floor consists in a solid ground floor and the windows are wood framed with single glazing with exterior PVC shutters. Table 1 presents U-values for the building elements before renovation.

Table 1. Summary of the U-values before and after the renovation

Element	**U-values before**
Exterior walls	1.38/1.69
Roof	2.62
Windows	5.10

The building main problems were degradation and inadequacy of the living areas. In this sense, the renovation proposal chosen to apply on field includes the increase of the living areas by creating just one apartment per floor and the improvement of the building envelope. Taking advantage of this intervention, insulation was added to the elements of the envelope and new BITS were installed.

For heating and cooling, a multi-split air conditioner system with inverter technology has been introduced and for DHW the choice was a solar thermal panel with an electric water heater as backup system.

Concerning the external walls, the chosen solution was ETICS (external thermal insulation composite system) with 6cm of EPS (expanded polystyrene). For the roof, the solution was to remove the lightweight slab and the introduction of a suspended ceiling, attached to the wood structure that holds the covering plates. Between the ceiling and fiber cement plates, panels of XPS (extruded polystyrene) with 5cm of thickness were placed. The U-values after renovation are presented in the following table.

Table 2. U-values for the buildings elements with the chosen renovation

Element	**U-values after**
Exterior walls	0.45/0.48
Roof	0.64
Windows	2.90

It was decided not to make any intervention on the ground floor once the low height of the ceiling did not allowed to increase the thickness of the ground floor in order to include insulation. To do so it would require deeper intervention increasing the costs and the construction wastes.

The chosen renovation represents the typical renovation that is done in Portugal in current days, however, there may be other solutions that can lead to better energy performances or less costs, considering the building's life cycle. Thus, different renovation scenarios were analyzed using Annex 56 methodology. For that, different materials were chosen and different combinations of BITS were selected. Table 3 shows the combination of renovation measures that were analyzed for the building envelope.

Table 3. Summary of the analyzed renovation scenarios

Nº	**Wall**	**Roof**	**Floor**	**Window**
Reference	maintenance	maintenance	maintenance	maintenance
Chosen	6cm EPS	5 cm XPS	maintenance	Wood 2.9
1	maintenance	8cm MW	maintenance	maintenance
2	maintenance	14cm MW	4cm MW	maintenance
3	maintenance	14cm MW	8cm MW	maintenance
4	4cm EPS	14cm MW	8cm MW	maintenance
5	10cm EPS	14cm MW	8cm MW	maintenance
6	maintenance	14cm MW	8cm MW	PVC 2,4
7	maintenance	14cm MW	8cm MW	PVC 2,1
8	maintenance	14cm MW	8cm MW	PVC 2,0
9	maintenance	4cm ICB	maintenance	maintenance
10	maintenance	8cm ICB	maintenance	maintenance
11	maintenance	8cm ICB	4cm ICB	maintenance
12	maintenance	8cm ICB	8cm ICB	maintenance
13	4cm ICB	8cm ICB	8cm ICB	maintenance
14	8cm ICB	8cm ICB	8cm ICB	maintenance
15	8cm ICB	8cm ICB	8cm ICB	Wood 2,9
16	8cm ICB	8cm ICB	8cm ICB	Wood 2,5
17	8cm ICB	8cm ICB	8cm ICB	Wood 2,4

In Table 3, MW stands for mineral wool, ICB is expanded cork agglomerate, EPS is expanded polystyrene. Maintenance refers to the case where the energy performance of the element is not improved and the intervention is only to solve aesthetical, structural and functional problems.

Table 4. Summary of the analyzed combination of BITS

BITS	**Heating**	**Cooling**	**DHW**
1	Electric heater	Multi split AC	Electric heater + ST
2	Gas boiler	Multi split AC	Gas boiler
3	Heat pump	Heat pump	Heat pump
4	Heat pump + PV	Heat pump + PV	Heat pump + PV
5	Biomass	Multi split AC	Biomass
6	Multi split AC	Multi split AC	Electric heater

The renovation packages for the building’s envelope were combined with different combinations of BITS. The analyzed combinations of BITS for heating, cooling and domestic hot water are presented in Table 4.

4. Life cycle cost analysis

The first step to apply the Annex 56 methodology is to perform a LCC analysis. This step allows having an overview of the solutions that are still cost effective, which one is the cost optimal solution and the ones that lead to better energy performance when compared to the cost optimal level. In the presented case study, the calculation of the building energy performance was performed using the Portuguese regulation procedures, which follows the ISO 13790 [6]. The contributions from the photovoltaics were obtained with the Photovoltaic Geographical Information System (PVGIS) and the energy from solar thermal was calculated using the Portuguese software Solterm.

The costs are derived using the net present value or the annuity method [5]. The considered lifespan was 30 years, using a discount rate of 6%, which is considered an attractive value in comparison with alternative scenarios for the private investor. Energy costs for the first year were based on the values of ERSE, the Portuguese entity that rules the energy prices [8][9]. The price of the pellets was based on a research on the Portuguese energy market and the evolution of the prices during the calculation period is based on the predictions of the European Commission, presented in the Delegated Regulation nº244/2012 [7]. For pellets, the assumed increase of price was of 3% per year. The investment and maintenance costs were based on CYPE® software that estimates prices for construction works in Portugal [10].

This first LCC analysis didn't included embodied energy, allowing obtaining results only considering the primary energy use, and results are presented in Figure 2.

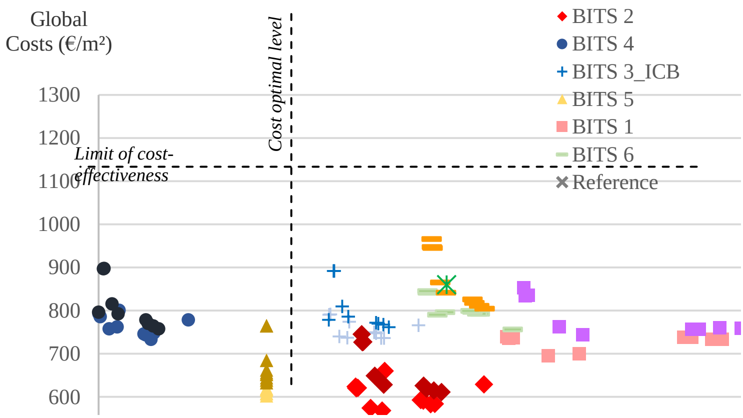

Figure 2. LCC analysis for all the renovation scenarios

Figure 2 is a typical graphic result of life cycle costs calculations for building renovation projects, where the cost optimal is the point with lowest global costs and the reference scenario does not improve the energy performance of the building. All the scenarios that present lower global costs than the reference scenario are considered cost effective.

In Figure 2 there are two curves for each BITS because there are different types of insulation materials which leads to different levels of costs. For each pair of curves, the darker marker represents the renovation packages with ICB and the lighter markers the solutions with EPS and MW.

The gas boiler (BITS 2) with current insulation materials leads to the cost optimal level. Concerning the envelope, combination nº 5 (10cm EPS on wall, 14cm MW on the roof, 8cm MW on the floor and maintaining existing windows) is the one that has the best relation between costs and energy and combination nº 17 leads to the lowest energy use. However, there are several measures that lead to better energy performances than the cost optimal solution and are still cost effective (costs below the reference scenario).

5. Life cycle cost analysis including life cycle impact assessment

The LCIA was developed with the calculation of the embodied energy and the related carbon emissions that result from the production of the construction materials using the Ecoinvent LCI database, version 2.2 [11]. These calculations allowed calculating the GWP of each renovation package of measures.

The number of renovation packages that has been tested was limited to the reference renovation scenario, the cost optimal scenario for the building envelope (combination nº 5) and the scenario that leads to the best energy performance (combination nº 17), which reduces more effectively the carbon emissions. These scenarios for the buildings envelope were combined with BITS 1, 2, 4 and 5. This selection is justified by the fact that these BITS lead to lower costs or better energy performances among the six analyzed BITS, given the presence of renewable energy sources.

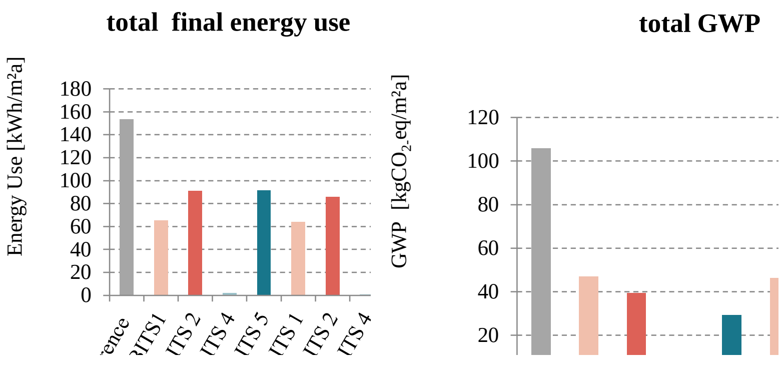

Figure 3. Results of the total final energy use and GWP calculations

In Figure 3 the results of the total final energy use, and the GWP of the selected scenarios are presented. Observing Figure 3 it is noticeable that both scenarios that are combined with BITS 4 (combination of heat pump with photovoltaic panels) are the ones with the lowest total final energy use and lowest GWP.

In general, the scenarios leading to better energy performances have slightly lower GWP than the cost optimal scenarios which means that, although more materials are used, the energy savings during the lifespan of the building outweigh the environmental impact of the materials production. The chosen solution is the second worst scenario right after the reference in what concerns the GWP indicator, although not that bad concerning the total final energy use.

The results for total Primary energy, including embodied energy, are shown in Figure 4. All the combinations including cost optimal solution for the building's envelope (combination nº 5) combined with the four selected BITS, have lower global costs than the scenario that leads to the best energy performance for the building's envelope (combination nº 17).

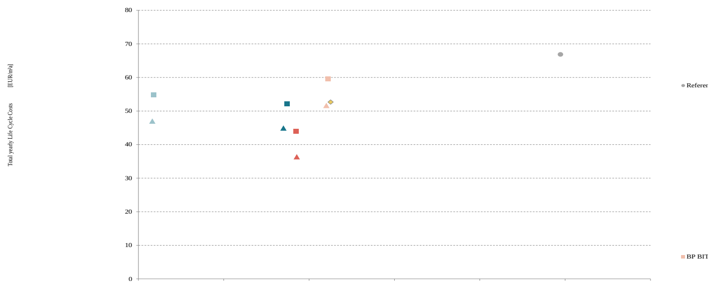

Figure 4. Results of the total primary energy per year

The cost optimal solution for the building's envelope (combination nº5) combined with BITS 2 is still the scenario which presents the lowest costs (red triangle). The chosen renovation is not far from the cost optimal solution in terms of primary energy, but has higher global costs.

The best energy performance and an effective carbon reduction is achieved with BITS 4 which includes an efficient heat pump and photovoltaic panels, combined with the cost optimal scenario (combination nº 5) for the building's envelope (blue triangle). The best energy performance scenario (combination nº17) considers an insulation material that has more embodied energy than the common insulations materials and for that reason, and despite reducing more effectively the energy use, the total primary energy is slightly higher.

6. Integration of the co-benefits

For the integration of the co-benefits, each renovation measure is evaluated based on a matrix developed in the project which relates each renovation measure with positive and negative co-benefits that typically result from their application.

In this case study, besides the analysis considering the matrix, a survey has been carried out. Table 5 presents the identifyed co-benefits for the reference, chosen, cost optimal (scenario nº 5 + BITS 2) and the best energy performance (scenario nº 17 + BITS 4) scenarios.

Table 5. Summary of the identified co-benefits and its impact

Co-benefits	**Reference**	**Chosen**	**Sce5 + B2**	**Sce17 + B4**
Aesthetics	▲	▲	▲	▲ ▼
Pride/prestige	▲ ▲	▲ ▲	▲ ▲	▲ ▲
Thermal comfort		▲ ▲ ▲	▲ ▲ ▲	▲ ▲ ▲
Building physics		▲ ▲	▲ ▲	▲ ▲
Internal noise		▼	▼	▼
Price fluctuation		▲ ▲	▲ ▲	▲ ▲ ▲
Air Quality		▲	▲	▲
External noise		▲		▲
Safety		▲		▲
Additional costs	33€/m^2	12€/m^2	-	13€/m^2

In the table, the triangles idenfity whether the co-benefit is positive or negative according to the positions. When it is upside-down it means it is a negative co-benefit. The last row presents the additional costs to implement that scenario, when compared to the cost optimal scenario.

The renovation scenarios that consider the windows replacement have more co-benefits than the cost optimal scenario regarding the improvement they cause in the protection against external noise and safety against intrusions. However, the best energy performance scenario presents one extra negative co-benefit related to the difficult architectural integration of photovoltaic panels in an existing building. On the other hand, it has greater positive impact when it comes to face energy price fluctuations. Nevertheless, in the survey to the users, external noise was considered as a minor issue, which means that the co-benefits associated to the windows replacement are not as relevant as expected but this is due to the specific building context that is inserted in a very quiet environment.

In this sense, the best choice, considering an effective reduction of emissions, would be the combination of the cost optimal scenario for the buildings envelope with BITS 4. The increase of global costs could be balanced by the co-benefits achieved due to the application of this BITS and the more effective reduction of emissions in the 30 years life cycle.

7. Conclusions

The analysis allowed comparing alternative scenarios for the renovation of the presented case study. Using Annex 56 methodology it was possible to confirm that the renovation that took place, although significantly improving the users' quality of life and reducing energy use, emissions and life cycle costs, could have been more profound. In fact, the cost optimal scenario is better than the chosen renovation scenario. But even this is still far from the zero energy use. The chosen renovation presents higher life cycle costs and worse energy performance than many of the tested alternative scenarios.

It was possible to conclude that major reductions on the energy use and carbon emissions are obtained more effectively with a switch of the BITS to renewable energy, mainly if the goal is to approach the zero energy and emissions level. Regarding the intervention on the building envelope, the combination of the cost optimal package of measures with the use of the renovation measures that maximize the positive co-benefits is a good strategy to limit the depth of the intervention. Beyond these points, global costs rise sharply and impacts on the energy and emissions become marginal. Investment costs for promoters and users annoyance by the works are also important arguments to this limit of intervention in the building envelope.

References

[1] NASA (2006). Available at: http://climate.nasa.gov/vital-signs/carbon-dioxide/
[2] European Commission (2016). Climate action. Available at: http://ec.europa.eu/clima/policies/strategies/index_en.htm
[3] BPIE (2011). Europe´s building under the microscope, A country-by-country review of the energy performance of buildings.
[4] European Commission. (2011). A Roadmap for moving to a competitive low carbon economy in 2050.
[5] IEA EBC, 2014 Methodology for Cost-Effective energy and Carbon Emissions Optimization in Building Renovation (Annex 56), Energy in Buildings and Communities Programme. ISBN: 978-989-95961-6-0. Available at: http://www.iea-annex56.org/index.aspx?MenuID=1
[6] Ministério da Economia e do Emprego (2013). Decreto-Lei nº 118/2013 de 20 de agosto. Diário da República. Portugal: Assembleia da República.
[7] European Commission (2013) Commission Delegated Regulation (EU) 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. Official Journal of the European Union L81/18.
[8] ERSE (2013) Tarifas de gás natural para o ano.
[9] ERSE (2012) Tarifas de venda a clientes finais dos comercializadores de último recurso em BTN em Portugal.
[10] CYPE Ingenieros, S.A. (2014). Gerador de preços. Portugal. Available at: http://www.geradordeprecos.info./
[11] Hischier, R. Weidema, B. et al, (2010) Implementation of Life cycle Impact Assessment Methods, ecoinvent centre