Relevance of embodied energy on building retrofit assessment

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ABSTRACT: Many regulations and initiatives to promote the reduction of the energy consumption and carbon emissions have been implemented in the building sector. However, they are mostly targeted for new buildings. In order to have an effective impact and reach the goals that are being established, it is necessary to act in new but especially in the existing buildings, which correspond to the majority of the European building stock. Building renovation improves the buildings' energy performance, reducing the carbon emissions related to the operation of the building but the renovation involves adding new materials and technical systems. The production process of these new materials uses energy (embodied energy) and releases carbon emissions. In this sense, after a certain level of energy efficiency, the materials added to the building may have more embodied energy than the energy savings they will lead to. To evaluate the relevance of the embodied energy in building renovation, IEA EBC project Annex 56, developed a methodological framework to evaluate the cost-effectiveness of building renovation solutions which include a life-cycle impact assessment. In this context and using a particular case study, different renovation solutions are compared with and without considering the embodied energy. The results have shown that the embodied energy do not have a major impact on the evaluation of the cost-effectiveness of the renovation solutions, but as the renovation approach gets closer to zero non-renewable energy level, its relevance increases.

Keywords *LCA, Building renovation, energy efficiency and carbon emissions*

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1. GENERAL INSTRUCTIONS

In Europe, buildings are an important target for the reduction of energy consumption and related carbon emissions. They are responsible for 40% of the final energy consumption, which leads to 32% of carbon emissions sent to the atmosphere each year. These values are not stabilized, presenting an increasing trend (BPIE, 2011).

In an attempt to slow down the increase of these values, the European Commission has released and reviewed many regulations. A turning point was marked by the EPBD recast in 2010, where new concepts were introduced, namely the cost optimal and nZEB (European Parliament, 2010). Besides, to promote the energy efficiency in different sectors including the building sector, strategies like Europe 2020 and Europe 2030 were also defined (European Commission, 2016). Despite the effort, these legal means are mainly targeted for new buildings and the majority of the European building stock has more than 20 years. Given the low rates of replacement of existing buildings by new efficient ones (1% to 2% per year), the European Union will not achieve its targets unless there is a focus on the renovation of the existing buildings (European Commission, 2011).

Existing buildings have their own technical, functional and economic constraints, which may lead to expensive and complex renovation procedures, hardly accepted by the owners or promoters. This fact may contribute to missing opportunities of improving the buildings energy performance (IEA EBC, 2016). Building renovation may improve the energy performance, but it also increases the investment costs and presents environmental impacts due to new materials and building integrated technical systems (BITS) that will be added to the building (Almeida & Ferreira, 2015). In this sense, to try to address these trade-offs and adapt the new concepts to existing buildings, the IEA EBC launched a project, Annex 56 - Cost-effective energy and carbon emissions optimization in building renovation (Almeida & Ferreira, 2015).

The aim of the project is to develop a methodology for the cost-effective renovation of existing buildings combining energy efficiency measures and the use of energy from on-site renewable sources. The methodology intends to be used by private entities to help in the decision of renovating a building and also by governmental agencies that can use it for regulatory purposes. The methodology developed within Annex 56, balances the energy consumption and the global costs of each renovation scenario in order to compare them. It uses a life cycle approach instead of a payback period method, as established by the methodology for the cost optimal analysis presented by the Delegated Regulation nº244/2012 (European Commission, 2012). In addition to the life cycle costs, the Annex 56 methodology also considers a life-cycle impact assessment (LCIA) method, balancing not only the energy necessary for the operation phase but also the embodied energy and the carbon emissions related to the products manufacturing (IEA EBC, 2016). In existing buildings, the environmental performance is related to the materials added to the building, while in new buildings it is related to the building structure that involves bigger amounts of materials and consequently the impact is much more noticeable (IEA EBC, 2016).

Concerning the existing buildings, a question on whether the embodied energy of the renovation materials and related carbon emissions have a significant weight in the final primary energy use may arise. When the target is a building with a very high energy performance, a significant amount of materials is added in order to strongly decrease its energy needs and beyond a certain level, the additional savings in energy use might be lower than the embodied energy of the materials being used. When the target is a nearly zero energy building, where besides the very high energy performance there is a significant use of energy from renewable sources, the question is even more relevant once the non-renewable energy that is saved might be very low.

Within Annex 56 methodology and concerning the LCA, the participants in the project reached an agreement on restricting the number of indicators used in the analysis. Since the methodology consists in comparing different renovation scenarios, analysing many indicators could become very time-consuming and useless (IEA EBC, 2016). In this sense, only the GWP (global warming potential), the CED_{NRPE} (cumulative non-renewable primary energy demand) and CED_{TOTAL} (cumulative total primary energy demand) were assessed. The choice is related to the fact that these indicators have good correlation with the remaining environmental indicators considered in the LCA method, as concluded in other studies (Mateus et al, 2013).

Taking advantage of one of the several case studies of the project (Mørck et al, 2015), different renovation scenarios were analysed, with and without the embodied energy, in order to verify its relevance in a renovation process.

2. METHODOLOGY

In this paper, the Annex 56 methodology was applied to a Portuguese case-study. This methodology has five main steps: calculation of the energy use of the building in a reference case (building renovation to restore its functionality without improving the energy performance), the establishment of different renovation scenarios, calculation of the energy use for these alternative scenarios, calculation of the global costs associated with each renovation scenario and life-cycle impact assessment.

It starts with the calculation of the primary energy use in the reference scenario. The primary energy was calculated using the Portuguese thermal regulation (Ministério da Economia e do Emprego, 2013) which follows the ISO 13790 (ISO, 2008). The calculations are performed using a quasi-steady method, considering the indoor comfort temperatures of 18˚C during the winter and 25˚C during the summer. In these first stages of the analysis, the primary energy is related to the energy necessary for heating, cooling, domestic hot water (DHW) and lighting.

Regarding the contribution from on-site renewables, the electricity generation from the photovoltaic panels is calculated using PVGIS (Photovoltaic Geographical Information System (http://re.jrc.ec.europa.eu/pvgis/) and the solar thermal contributions is calculated using Solterm (http://www.lneg.pt/iedt/projectos/370/).

After this step, it is necessary to establish different renovation scenarios. These scenarios include renovation measures for the buildings envelope and for the BITS. For each of the established renovation scenarios it is calculated the primary energy use, as done for the reference situation.

Then, the global costs are calculated. The global costs calculations are performed using the net present value method or annuity values (IEA EBC, 2014). The global costs include

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investment costs, maintenance, replacement costs and energy costs. The investment costs, maintenance and replacement costs are calculated using CYPE® software that generates prices for construction works in Portugal (CYPE Ingenieros, 2014). The energy costs for the first year are retrieved from ERSE, the Portuguese entity that rules the energy prices (ERSE, 2012, 2013). The future costs of the energy are estimated using the European Commission's predictions (European Commission, 2012). The price of the pellets (solution foreseen in several renovation scenarios) is based on a research of the Portuguese market with an estimated increase of 3% per year. A discount rate of 6% is assumed and a lifetime period of 30 years is considered. The described methodology allows comparing the renovation scenarios balancing the energy during the operation phase and the related global costs.

To calculate the environmental performance, it is additionally necessary to quantify the amount of materials and BITS that are added to the building in each renovation scenario. The methodology used for the environmental life cycle analysis (LCA) is based on the EN 15978:2011 (CEN, 2011) and follows the steps of the EN ISO 14044:2006 (ISO, 2006). One of the most important stages of the LCA method is the inventory analysis. In the case of this study, the inventory analysis entails the quantification of the flows for and from each renovation scenario. There are several sources for the inventory data and in this study, the background data related to the considered process units was taken from the Ecoinvent 3.1 database (Weidema et al, 2013). To facilitate the quantification of the environmental indicators, a life cycle analysis software (SimaPro 8.0.5) was used to modulate the life cycle of the analysed renovation scenarios and to assess the abovementioned life cycle impact categories.

3. CASE STUDY

The case study consists of a building built in 1950 which belongs to a social neighbourhood located in Porto, in the north of Portugal. Most buildings in the neighbourhood presented signs of degradation and inadequacy to the current living standards, due to small living areas. These facts justified the decision of renovating the buildings. Figure 1 shows the building before and after the renovation.

a) b)

Figure 1 General aspect of the buildings a) before the intervention and b) after the intervention

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The selected case study has two floors and four apartments, two in each floor. It had no insulation on the envelope and there were no BITS for heating and cooling, apart from portable electric heaters and fan coils. The DHW (domestic hot water) is provided by an electric heater with a storage tank.

Table 1 Summary of the U-values before the renovation

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

Concerning the building solutions, the exterior walls consisted of single hollow brick walls with cement mortar on both sides, the roof was composed of a lightweight concrete slab and a structure that supports the fibre cement sheets. The floor consisted of a solid ground floor and the windows were wood framed with single glazing with external shutters. The U-values of these elements before the renovation process are presented in Table 1.

From the several renovation scenarios analysed, the implemented one included the increase of the living areas by joining in just one apartment the two apartments per floor and the improvement of the building's envelope. In this context, insulation was added to some of the elements of the envelope, the windows were changed and new BITS were installed. The implemented solution on the envelope included the application of ETICS (external thermal insulation composite system) with 6 cm of EPS (expanded polystyrene) on the external walls. For the roof, the solution consisted in removing the lightweight slab and introducing a suspended ceiling, introducing between the ceiling and fibre cement sheets, XPS (extruded polystyrene) with 5cm thickness. Besides the walls and the roof, the windows were also replaced introducing double glazing. It was decided not to make any intervention on the floor since the low floor to ceiling height did not allow increasing the thickness of the floor. These solutions represent the common building renovation scenario in Portugal.

In order to apply the Annex 56 methodology, two different solutions for the building envelope, which include different insulation materials, were analysed. One presents insulation materials that are usually applied in renovation works (expanded polystyrene and mineral wool) and the other uses cork that, despite being produced in Portugal, is applied less often due to its higher price. Table 2 shows the analysed solutions for the building envelope. In the table, EPS stands for expanded polystyrene, XPS is extruded polystyrene, MW is mineral wool and ICB is insulation cork boards. The analysis always included intervention in almost all elements. In cases where the energy performance was not improved, it was considered just maintenance work, such as painting, repairing cracks and smaller adjustments to solve further malfunction.

Table 2 Summary of the analysed renovation measures for the buildings envelope

Envelope	Wall	Roof	Floor	Windows
Reference	maintenance	maintenance	_	maintenance
A	EPS 10 cm	MW 14cm	MW 8cm	maintenance
B	ICB 8cm	ICB 8cm	ICB 8cm	wood U=2,4
Chosen/applied	EPS 6 cm	XPS 5cm	_	wood U=3,9

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Furthermore, these two envelope solutions were combined with four different combinations of BITS. Table 3 shows the above-mentioned combinations of the envelope solutions and the BITS. In total, 8 different combinations were analysed.

Table 3 Summary of the analysed renovation solutions

Combination	Envelope	Heating	Cooling	DHW	REN
Reference	Reference	Electric heater	Multi-split air conditioned	Electric heater w/ storage tank	–
1	A	Multi-split air conditioned	–	Electric heater w/ storage tank	Solar Thermal
2	A	Gas boiler	–	Gas Boiler	–
3	A	Air-source heat Pump	–	Air-source heat pump	Photovoltaic
4	A	Biomass boiler	–	Biomass boiler	Biomass
5	B	Multi-split air conditioned	–	Electric heater w/ storage tank	Solar Thermal
6	B	Gas boiler	–	Gas Boiler	–
7	B	Air-source heat Pump	–	Air-source heat pump	Photovoltaic
8	B	Biomass boiler	–	Biomass boiler	Biomass
Chosen/applied	Chosen	Multi-split air conditioned	–	Electric heater w/ storage tank	Solar Thermal

4. RESULTS OF LIFE CYCLE COSTS ANALYSIS

The life cycle costs analysis started with the calculation of the energy needs and primary energy use of the building for each of the renovation scenarios considered and the calculation of the related global costs.

The results of each renovation scenario are presented in figure 2.

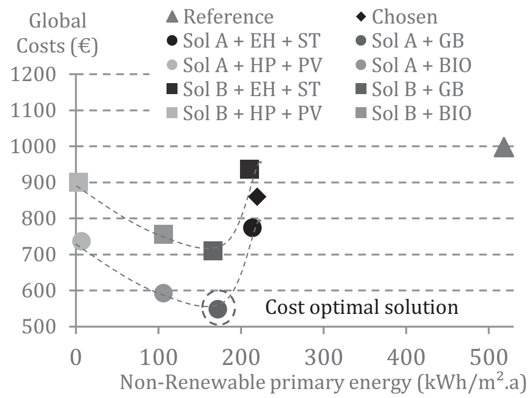

Figure 2 Results of the LCC analysis (non-renewable primary energy values without the embodied energy)

In Figure 2 there are two curves, each one related to a different solution for the building's envelope. The lower curve is related to the solution with current insulation materials and the higher curve considers the cork insulation boards (ICB). Observing Figure 2 it can be concluded that the solution with lower global costs includes current insulation materials, which results from the higher price of ICB. In this sense, the cost optimal solution is achieved with the solution A for the envelope (which consists of 10cm of EPS for the wall, 14cm MW for the roof and 8cm of MW for the floor) and a gas boiler for heating and DHW.

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The solutions that allow reducing significantly the primary energy use are the ones using a heat pump and photovoltaic panels, followed by the solutions that use a biomass boiler.

It is important to remind that these results do not yet include the embodied energy.

5. RESULTS OF LIFE CYCLE IMPACT ANALYSIS

After calculating the life cycle costs for the operation phase, it is necessary to calculate the impact of each renovation scenario in terms of GWP, CED_{NRPE} and CED_{TOTAL}. Table 4 presents for each material, BITS or energy vector, the potential unitary environmental impacts for a kilogram of material, one complete BITS system or for a kWh, in the case of the used materials, considered BITS and consumed energy, respectively. In order to have the full impact, those unitary values were multiplied by the total amount of material, BITS or energy.

Table 4 Summary of the SIMAPRO impacts

	Description	GWP [kg_{EP} $CO_2/(m^2y)$]	CED NRPE [$kWh/(m^2y)$]	CED TOTAL [$kWh/(m^2y)$]
Materials	Exterior walls painting	7,36E-04	4,01E-03	4,31E-03
	Repairing and painting windows wood frames	7,36E-04	4,01E-03	4,31E-03
	Black agglomerated cork	3,10E-04	1,86E-03	3,90E-03
	XPS	2,83E-03	7,44E-03	7,54E-03
	Rockwool	2,91E-04	1,42E-03	1,48E-03
	EPS	1,12E-03	7,87E-03	7,95E-03
	ETICS (without the insulation)	2,21E-05	1,16E-04	1,30E-04
	PVC window	6,99E-04	4,46E-03	4,64E-03
	Wood window	4,37E-04	2,16E-03	4,41E-03
	Aluminium window	2,54E-03	1,07E-02	1,22E-02
	Glass (single)	2,63E-04	9,31E-04	9,57E-04
	Glass (double)	3,80E-04	1,53E-03	1,60E-03
	Windows sills (aluminium)	2,25E-03	8,44E-03	1,02E-02
	PVC membrane under floor cork insulation	7,69E-04	6,98E-03	7,12E-03
BITS	Gas boiler	1,02E-01	4,74E-01	5,13E-01
	Air-source heat pump	4,26E-01	5,78E-01	6,10E-01
	Biomass boiler	7,87E-01	2,45E+00	2,60E+00
	Solar thermal	3,59E-01	1,57E+00	1,77E+00
	Photovoltaic	1,05E-01	4,79E-01	5,50E-01
Energy	Electricity (PT energy mix)	6,91E-01	2,74E+00	3,22E+00
	Natural gas	2,62E-01	1,24E+00	1,24E+00
	Biomass	4,50E-02	2,42E-01	1,34E+00

Figure 3 shows the results for the GWP analysis. In the figure, bars 1 to 4 are related to solution A for the building's envelope combined with four different BITS. Bars 5 to 8 include solution B for the envelope, combined with four different BITS.

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Observing the figure it is noticeable that the renovation solutions with lower GWP are number 3 and 7, which include the heat pump and photovoltaic panels, followed by the solutions 4 and 8 that include a biomass boiler. The chosen/applied solution is among the worse solutions in terms of GWP and the cost optimal solution (solution 2) also has a high GWP value.

Concerning the CED_{NRPE} the CED_{TOTAL} the results are presented in Figure 4.

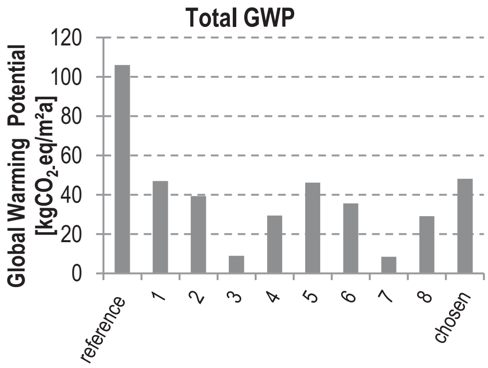
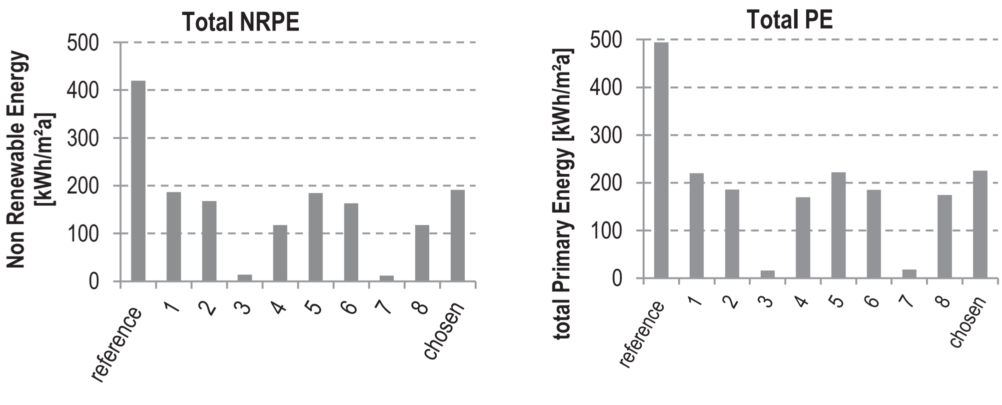


Figure 3 Results of the global warming indicator (GWP)

These indicators present the same trend as the GWP, where renovation solutions 3 and 7 (that include the heat pump and the PV) are the ones with lower CED_{NRPE} and lower CED_{TOTAL}, followed by solutions 4 and 8 (that include a biomass boiler). Both combinations use renewable energy sources, reducing significantly the non-renewable energy use.



a) b)

Figure 4 Results of a) the CDE_{NRPE} (Non-Renewable energy) indicator and b) CDE_{TOTAL}

The results of the comparison between the renovation solutions considering only the primary energy related with the operation of the building and the total primary energy (embodied and operation) are presented in Figure 5.

Observing Figure 5 it is possible to verify that generally there are no significant changes in the results. Solution A for the building envelope combined with a gas boiler is still the cost optimal solution. The inclusion of the embodied energy leads to a slight dislocation of the

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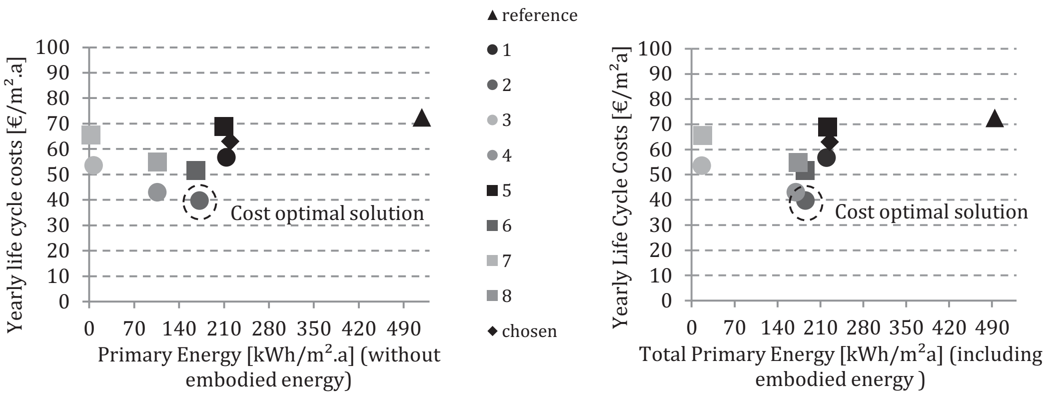
points. This is more noticeable in solutions 3 and 7 that without the embodied energy were almost over the vertical axis and with the inclusion of the embodied energy have moved slightly away from the origin.

Besides this, without the embodied energy, solution 7 presents a value of primary energy of 2.78 [kWh/m^2.y] and solution 3 a value of 6.72 [kWh/m^2.y]. Considering the embodied energy, the total primary energy reaches 18.01 [kWh/m^2.y] in solution 7 and 16.33 [kWh/m^2.y] in solution 3.



a) b)

Figure 5 Results of a) primary energy (not including embodied energy) and b) total primary energy (including embodied energy)

Thus, concerning the total energy value, there is a switch of positions between these two solutions. After the inclusion of the embodied energy, solution 3 is the one that leads to the best energy performance while without the embodied energy it was solution 7.

The reference situation presents a high value for the CED_{TOTAL} mostly related to the energy used during the operation phase. In solutions 3 and 7, and given the presence of the renewable energy sources, the CDE_{TOTAL} is mostly due to the impact of the embodied energy of the insulation materials and the BITS (especially the photovoltaic panels).

Unlike other solutions, and when compared to the primary energy (without the embodied energy), the reference solution presents a slight reduction of total primary energy, due to differences in the conversion factor used in the LCA and the grid factor used for the LCC calculations.

6. CONCLUSIONS

Results from the comparison of the life-cycle cost analysis considering only the operational energy and the operational and embodied energy show that the inclusion of the last does not change the cost-effective solutions or the cost optimal renovation packages. On the other hand, in terms of total primary energy, the best renovation package has changed due to differences in the environmental impact of insulation materials used in renovation packages with very low operational energy.

The results for the particular case of Portugal were similar to those achieved in the Annex 56 project for other five case-studies, each one in a different European country.

Embodied energy and embodied carbon emissions were not found very influential in the project's building renovation case studies when the focus is towards cost-effective renovation solutions. However, when the energy performance approaches nearly zero carbon emissions or nearly-zero energy renovation levels, the relative contribution of the embodied energy or embodied carbon emissions rises as far as the renovation becomes significant. In some cases, the renovation packages with the highest energy performance when considering only the energy use are not the ones with the best environmental performance.

These results indicate that when the target is nearly zero carbon emissions or nearly-zero energy renovation levels, the primary energy and carbon emissions optimization for both new and existing buildings should be done using a life-cycle perspective including the embodied impacts.

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