Cost optimality and nZEB target in the renovation of Portuguese building stock

Rainha Dona Leonor neighborhood case study

Manuela Almeida
University of Minho, Department of Civil Engineering, Guimarães, Portugal
malmeida@civil.uminho.pt

Ana Rodrigues
University of Minho, Department of Civil Engineering, Guimarães, Portugal
anarocha32846@yahoo.co.uk

Marco Ferreira
University of Minho, Department of Civil Engineering, Guimarães, Portugal
marcoferreira@civil.uminho.pt

ABSTRACT: Improving energy efficiency in existing buildings is a great challenge. These buildings have their own limitations related with their design, location and function. To study the possibilities of cost-effectively improve the thermal performance of these buildings and increase the chances of reaching the nearly zero energy (nZEB) target, one building of Rainha Dona Leonor neighborhood has been analyzed. The purpose of the study was to find the most cost-effective renovation solution for this case study and assess in what way this solution contributes to reaching the nZEB target. With this work it was possible to understand that the energy performance of this kind of buildings can be firstly improved through renovation measures applied to the envelope but, above a certain level, changing the existing equipment and the energy source become more cost-effective.

1 INTRODUCTION

Buildings are responsible for 40% of total energy consumption and 36% of CO_2 emissions in Europe (BPIE, 2011).

In order to try to stop the increase of carbon emissions in the building sector, the EU Directive EPBD (European Parliament, 2010) introduced the nearly Zero Energy Buildings concept (nZEB) and established its mandatory implementation for new buildings after the end of 2020. These buildings present very high energy performances with very low energy needs that are to be satisfied with renewable energy sources harvested on-site (BPIE, 2011).

Besides the nZEB target, EPBD also requires that buildings are cost-effective during their life cycle and established a methodology for the cost-optimal calculations. The outcome of cost-optimal level shall include macroeconomic and financial calculations. The macroeconomic calculations take into account the carbon emissions costs, while the financial calculations only consider the investors costs (Diacon & Moring, 2013). Within this study, only the financial perspective is shown.

Apart from the type of energy source, the achievement of the nZEB target in buildings usually involves high levels of insulation, very efficient windows, good levels of air tightness and controlled ventilation (BPIE, 2011).

There are some renewable energy sources that can be used in buildings such as photovoltaic, solar thermal, wind, hydroelectricity and biofuels (Pless & Torcellini, 2010). However, some of these solutions cannot be applied to every building. Existing buildings face several barriers when it comes to refurbishment and even more when the target is nZEB. This gets even more difficult when the building is part of social housing. In Europe, social and public housing providers own and manage 12% of the housing stock (Diacon, 2013). Buildings belonging to social housing face severe economical, technical, legislative, social and organizational barriers. The lack of money, the split incentives and poverty are the main economic barriers to building renovation in social housing (Diacon, 2013). These buildings are usually rented to poor people and so, the rents should be kept at reasonable levels (Diacon, 2013).

Social buildings providers usually support the residents who are normally amongst the most vulnerable groups in society. Therefore it is important to build capacity and confidence amongst these providers towards the 2020 requirements for buildings, once they have an important role in the renovation processes (Diacon & Moring, 2013).

2 METHODOLOGY

To understand the potential of reaching the nZEB level in the renovation of Portuguese buildings, a case study was analyzed. This case study is part of a social housing neighborhood in Porto called Rainha Dona Leonor. This neighborhood has multifamily buildings and blocks of apartments. The renovation intervention started with the renovation of the multifamily buildings. Part of the neighborhood has already been submitted to renovation and based on the chosen renovation solution, the cost optimal levels were identified and it was analyzed in what way it is possible to reach a building with zero carbon emissions and net zero energy needs.

The first step was to analyze different renovation measures concerning the insulation of the buildings envelope and the buildings systems. For the chosen case study, different scenarios were tested, involving improvements in the building envelope and also the replacement of the heating/cooling and DHW systems. A life cycle of thirty years was considered, taking into account the replacement of the equipment after twenty years and considering its residual value in the end of this period. The alternatives considered for the equipment were HVAC for heating/cooling and an electric heater with storage tank and solar panels for DWH, gas boiler for heating/DHW and HVAC for cooling, heat pump for heating/cooling and DHW and HVAC for heating/cooling with a biomass boiler for DHW.

The base for the calculations was the cost-optimal methodology proposed by the European Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012, supplementing the Directive 2010/31/EU of the European Parliament and of the Council on the Energy Performance of Buildings as well as the Guidelines accompanying the Commissions Delegated Regulation No 244/2012 (European Commission, 2012 a) and b)).

The energy needs were calculated according to the Portuguese legislation that regulates the residential buildings thermal performance (RCCTE, Decree-Law 80/2006) in accordance with ISO – 13790 and primary energy was calculated in accordance with the proposed recast for the Portuguese thermal regulation considering total energy needed to deal with all the energy needs, and considering conversion factors of $2.5kWh_{PE}/m^2.a$ per $kWh/m^2.a$ for electricity and $1kWh_{PE}/m^2.a$ per $kWh/m^2.a$ for gas. The indoor comfort temperatures considered were 20ºC for winter and 25º for summer.

The costs were calculated with the Cype® software for generation of construction prices (http://www.geradordeprecos.info/). The energy costs used in the study were based on the Portuguese energy costs and it has been considered the scenario given by the European Commission (European Commission, 2012b)) for the estimation of the energy prices evolution in the near future.

After assessing the cost-optimal solutions for each one of the equipments considered, it was calculated the needed contribution of the photovoltaic panels for reaching the zero energy level. For this it was used the European Commission’s Photovoltaic Geographical Information System (PVGIS) (http://re.jrc.ec.europa.eu/pvgis/). The different renovation measures considered in the study are presented in Table 1. The renovation measures are separated by the systems used for heating, cooling and DHW preparation. For each system there are different combinations of measures to improve the building envelope that together form different renovation scenarios (Sn). In all, thirteen scenarios were analyzed. The base scenario (B) is the adopted renovation solution for this case study. Scenario 8 (S8) and 10 (S10) are similar but the windows have different U-values.

Table 1 Summary of the different renovation measures considered in the study

Heating/cooling/DHW	Scenario	Walls	Roof	Window	Glass
HVAC + electric heater with storage tank + Solar panels (except B)	B	EPS 6cm	XPS 5cm	wood	simple
	S1	EPS 8cm	XPS 8cm	PVC	double
	S2	EPS 10cm	XPS 10cm	PVC	double
	S3	EPS 12cm	XPS 12cm	PVC	double
Gas boiler	S4	EPS 5cm	XPS 5cm	wood	simple
	S5	EPS 8cm	XPS 10cm	PVC	double
	S6	EPS 12cm	XPS 12cm	PVC	double
Heat pump	S7	EPS 6cm	XPS 5cm	wood	simple
	S8	EPS 8cm	XPS 8cm	PVC	double
	S9	EPS 12cm	XPS 12cm	PVC	double
	S10	EPS 8cm	XPS 8cm	PVC	double
Biomass boiler + HVAC	S11	EPS 6cm	XPS 5cm	wood	simple
	S12	EPS 8cm	XPS 10cm	PVC	double
	S13	EPS 12cm	XPS 12cm	PVC	double

3 CASE-STUDY

The case study is a building from the social housing Rainha Dona Leonor neighborhood. It was built in the fifties and it is located in Porto, northwest of Portugal.

The renovation intervention took place on the smaller multifamily buildings of the neighborhood. These buildings have two floors and different indoor partitions, varying the number of rooms per apartment.

The buildings had very small areas and were already in decadent living conditions. Due to the small interior areas, users also added exterior compartments to support peoples' life style. These elements negatively changed the initial appearance of the neighborhood. So, the surrounding areas of the buildings were also improved to recover the initial identity of the neighborhood.

The building under analysis is a semi-detached house. It used to have four apartments with two rooms each. The envelope did not have any insulation and there were wooden window frames with simple glazing and external plastic shutters. The system for DHW production was an electric heater with storage tank and there were no heating/cooling systems apart from portable electric heaters or fan coils.

The renovation project aimed at increasing indoor living areas, improving thermal insulation and replacing systems.

Figure 1 shows the building before and after the renovation process. Table 2 shows the thermal characteristics of some of the building components before the renovation process, namely the U-values and the reference U-values in the Portuguese thermal regulation, as well as the efficiency of the systems for heating and DHW preparation. The initial heating needs of this building were 119,7kWh/m².y, the cooling needs 6,5kWh/m².y and DHW needs 37,1 kWh/m².y.

Figure 1 Building before and after renovation on Rainha Dona Leonor neighborhood

Table 2 Thermal characterization of the Building before renovation

Element	Area (m²)	U – Value before renovation (W/m².ºC)	U – Value reference values (W/m².ºC)	η (efficiency)
Exterior walls	141,00	1,38/1,69*	0,60	_
Windows	16,93	3,40	3,30	_
Roof	73,79	2,62	0,45	_
Floor	61,80	2,50	0,45	_
DHW	–	–	–	0,85
Heating	–	–	–	1

* The 1st value is for the first floor and the 2nd for the second floor

3.1 *Renovation process*

In this study, the base solution corresponds to the renovation solution really implemented in the building. This solution includes ETICS with a 6 cm thick layer of EPS in the exterior walls, XPS with 5 cm in the roof, wooden frames windows with double glazing and a new electrical water heater with storage tank. For heating and cooling the usable space, the renovation solution considered a HVAC system with multi-splits for the rooms and living room. It also includes solar panels for DWH preparation.
Table 3 shows the energy needs, the primary energy use and carbon emissions for the initial situation of the building (before renovation) and considering the above mentioned renovation solution (after renovation).

Table 3 Summary of energy needs and carbon emissions before and after renovation

	Heating needs (kWh/m².y)	Cooling needs (kWh/m².y)	DHW (kWh/m².y)	Primary energy use (kWh/m².y)	Emissions (Ton eq CO_2)
Before renovation	119,7	6,5	37,1	413,7	18,9
After renovation	68,5	7,9	27,1	127,2	5,8

Taking this renovation solution as base solution and analyzing the cost-optimal solution for the alternative renovation scenarios, the results for the financial calculations are presented in figure 2. This figure shows a graphical result with the primary energy for each scenario and its global cost. Each group of points represents different equipment and the lower point of each group is the cost-optimal solution for that equipment. The cost-optimal solutions are S2 for HVAC with electric heater and solar panels for DHW preparation, S5 for the gas boiler, S8 for the heat pump and S12 for biomass boiler.

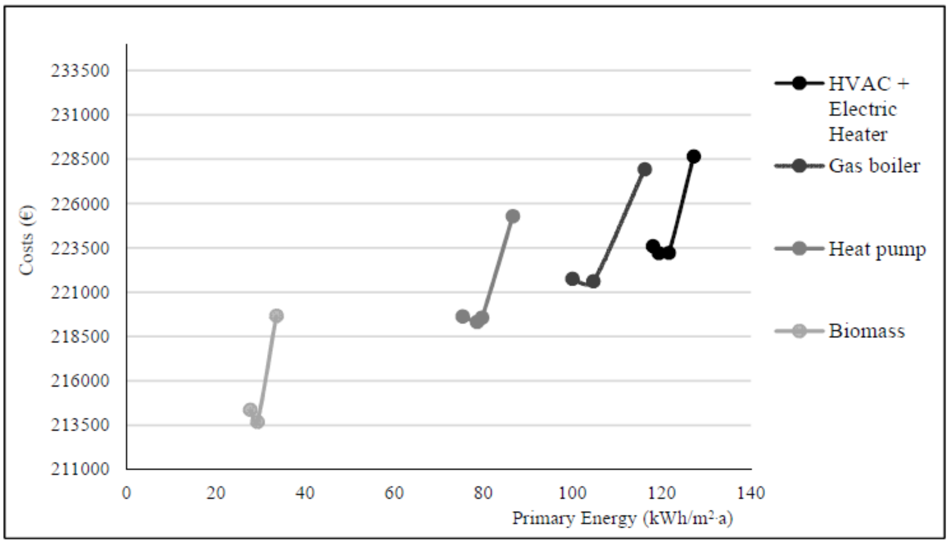

Figure 2 Global costs for each one of the alternative scenarios regarding primary energy use

Among all the scenarios, the cost-optimal solution is S12 corresponding to a biomass boiler for heating the living room and preparation of DHW and a HVAC system in the rooms. The U – value for the walls is 0,37/0,39 W/m².ºC, for the roof is 0,34 W/m².ºC and for the windows is 2,4 W/m².ºC. The boiler efficiency is 91%. This solution leads to primary energy needs of 29,3 kWh/m².y, which is 30% of the primary energy needs of the base solution (B). Table 4 shows the comparison between the U-values for the base solution, the cost-optimal solution and the Portuguese reference values.

Table 4 Comparison between the U-values for the base solution, the cost-optimal solution and the Portuguese reference values

Element	U – Value after renovation (W/m².ºC)	U – Value cost optimal solution (W/m².ºC)	U – Value Reference values (W/m².C)
Exterior walls	0,45/0,48*	0,37/0,39*	0,60
Roof	0,34	0,34	0,45
Windows	3,90	2,40	3,30

* The 1st value is for the first floor and the 2nd for the second floor

Figure 3 shows the costs disaggregation for each one of the analyzed solutions. On figure 3, the costs start above zero because the basic works necessary to the renovation process with the same value in every analyzed solution have been left out of the comparison. Based on the graphic, the most cost-effective equipment is the biomass boiler. Considering the other three equipments, the balance between the systems costs, renewable costs and energy costs result in a similar value and the maintenance cost are the ones responsible for the main differences between the solutions. Besides this and excluding the renewable costs, the systems costs and the energy costs are inversely related. The increase of the costs of the envelope, regardless the system used, does not exceed 1700 euros which corresponds to 16% of the base envelope solution costs.

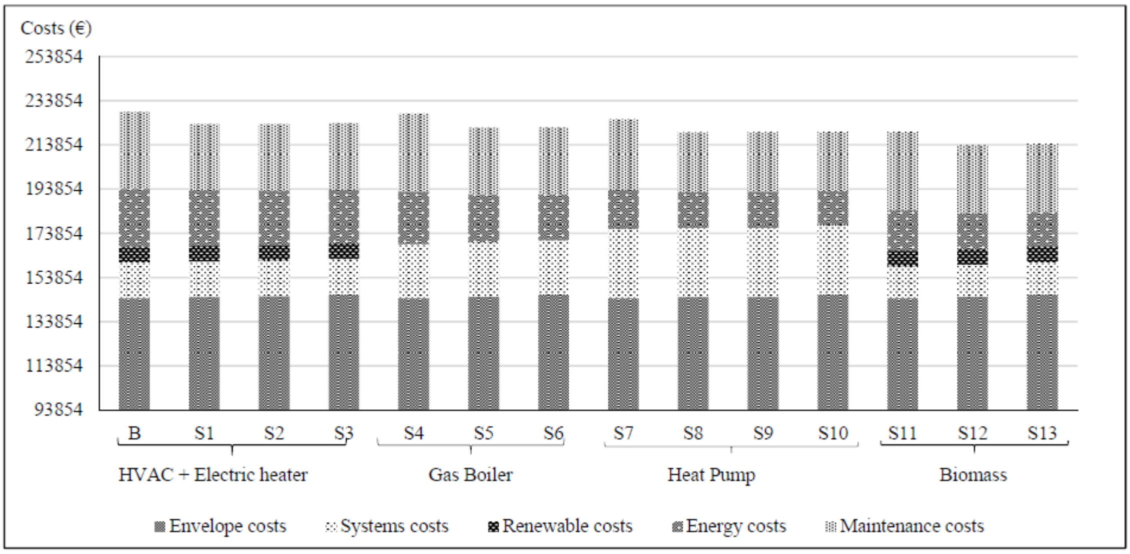

Figure 3 Disaggregated costs of the analyzed solutions

Figure 4 shows the carbon emissions, for each one of the alternative scenarios. This figure is similar to figure 2 because the primary energy is proportional to the carbon emissions, so the renovation solutions follow the same trend.

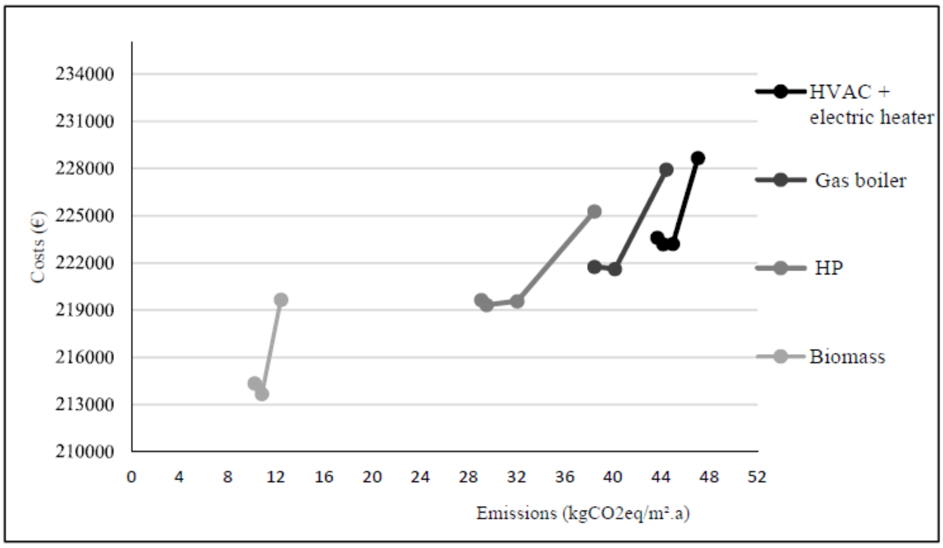

Figure 4 Global costs for each one of the alternative scenarios regarding carbon emissions

3.2 *Renovation process towards net zero energy level*

Another objective of this work consisted in assessing how the net zero energy level and the zero emissions level could be achieved. For this case-study, and taking into consideration the renovation scenarios mentioned before, the net zero energy level and the zero carbon emissions level were achieved considering the contribution of photovoltaic panels.

Figures 6 and 7 show the results obtained, in terms of energy, with the contributions of photovoltaic panels for each one of the analyzed measures. Each figure represents the results for each one of the combinations taken into account heating, cooling and DWH preparation, with and without photovoltaic panels. Each different marker on graphic represents one scenario, with and without photovoltaic panels to reach zero balance between the use of primary non-renewable energy and the on-site generation of energy from renewable sources. Analyzing the graphics it is possible to observe that most scenarios do not have significant changes with the addition of the photovoltaic panels in terms of cost-optimal level. But with the increase of the costs related to the photovoltaic panels, the cost-optimal solution for the gas boiler and biomass boiler gets closer to the other scenarios.

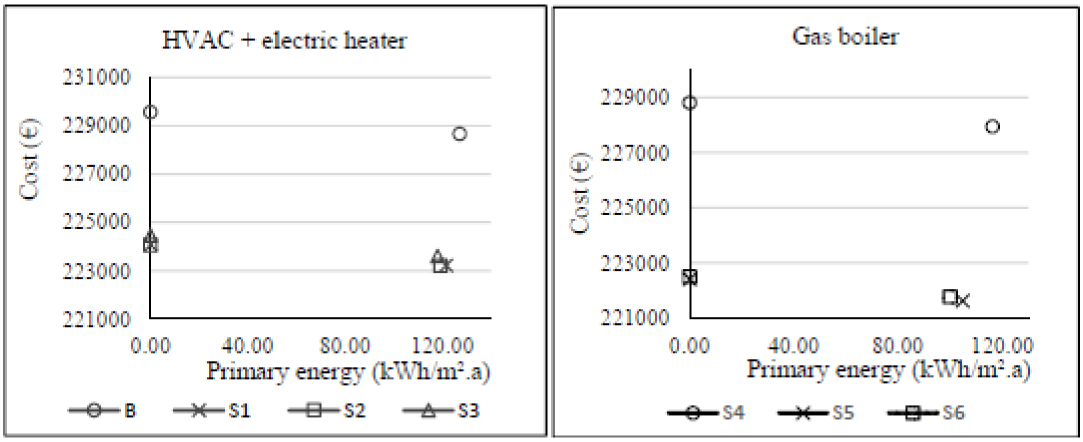

Figure 5 Results with photovoltaic panels for HVAC + Electric heater and for the Gas boiler

In Figure 5, the cost-optimal solution for HVAC with the electric heater for DHW preparation corresponds to the square marker and it corresponds to scenario 2 (S2). This solution has ETICS with 10 cm of EPS for the exterior walls, 10cm of XPS for the roof and PVC windows with double glazing. The U-values are 0.31/0.32 W/m². ºC for the exterior walls, 0.34 W/m².ºC for the roof and 2.4 W/m².ºC for the windows. For the gas boiler the cost-optimal solution is the X marker and it corresponds to scenario 5 (S5). It has ETICS with 8cm of EPS for the exterior walls, 10cm of XPS for the roof and PVC window frames with double glazing. The U-values are 0.37/0.39 W/m². ºC for the exterior walls, 0.34 W/m². ºC for the roof and 2.4 W/m². ºC for the windows. The inclusion of the photovoltaic panels does not change the cost-optimal solution for these two systems.

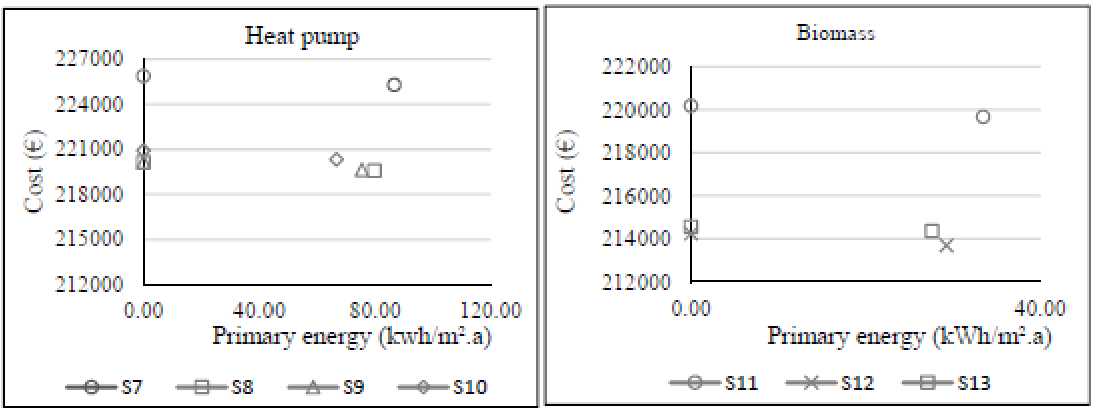

Figure 6 Results with photovoltaic panels and heat pump and biomass boiler

In Figure 6 the cost-optimal solution for the heat pump corresponds to scenario 8 (S8) and it is represented by the square marker. This solution included ETICS with 8 cm of EPS for the exterior walls, 10cm of XPS for the roof and PVC window frames with double glazing. The U-values are 0.37/0.39 W/m². ºC for the exterior walls, 0.42 W/m². ºC for the roof and 2.4 W/m². ºC for the windows. For the biomass boiler the cost-optimal solution is scenario 12 (S12) which corresponds to the cost-optimal solution for this building. The addition of photovoltaic panels does not have impact on the cost-optimal solution for these two systems.

4 CONCLUSIONS

Despite the specific restrictions of this building renovation process, it is already possible to take some conclusions on how the Portuguese building stock can cost-effectively move towards more energy efficient buildings. The calculation of the cost optimal levels in Portugal depends on the location, age of the building and on its construction techniques and materials, as well as on the buildings type.

The cost-optimal levels calculations show that the most cost-effective renovation solution includes a small biomass boiler for heating (partially) and DHW preparation and a multi-split HVAC system for cooling and to assure the remaining heating needs. The optimal levels for the building envelope are in accordance with the current reference values of the Portuguese legislation.

The evolution of this packages of measures towards the zero energy goal with the addition of photovoltaic panels for energy production, doesn't affect the optimal solution with the financial calculation remaining the same whatever the equipment considered. In some cases the global costs of the cost-optimal solutions with photovoltaic panels gets closer to solutions with higher level of insulation. Even though the cost optimal package hasn't change in the group of tested packages, this is an indicator that in these cases a slight increase of insulation beyond the cost optimal level should be analysed.

As so, the cost-optimal methodology for this building provides identical results for the analysis of renovation solution without energetic consumption restrictions and with renovation solutions using photovoltaic panels to reach a zero energy balance for heating, cooling and domestic hot water preparation.

Unlike initial expectations, considering the current prices of photovoltaic panels and the trade of electricity with the grid at equal prices, there were no relevant changes in the optimal solutions, when the main target is the zero energy balance.

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