Cost optimal levels for envelope components in residential building renovation – Rainha Dona Leonor neighbourhood case study

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Short Summary

Energy Efficiency in Buildings has been gaining increasing relevance in the past decades due to the raise of the energy consumption in the building sector as a consequence of the modern way of living with higher comfort patterns. In Europe, buildings are responsible for 40% of the energy consumption, which turns them into an important target for carbon emissions' reduction [1]. Energy efficiency should be a main concern not only in new buildings, but also in the existing ones, which have poor energy performances. In Portugal most of the building stock was built before 1990, date of entrance into force of the first thermal regulation. Therefore, most of these buildings need intervention to improve not only the living environment, but also their energy performances. To evaluate the best measures, that fulfil the minimum requirements established for the energy needs with the lowest costs, the European Commission released the Commission Delegated Regulation (EU) Nº 244/2012 that establishes a comparative methodology framework for calculating the cost-optimal level for minimum energy performance. In order to verify the renovation potential of these buildings, based on the Delegated Regulation methodology and taking advantage of a renovation process in course, a social housing neighbourhood called Rainha Dona Leonor was analysed. This analysis allowed obtaining the optimal levels for different renovations measures. The results show that it is not possible to establish a direct connection between the optimal level for the building envelope and the building as a whole, without considering the influence of the building systems.

Keywords: Buildings renovation, cost-optimal, energy savings, renovation measures

1. Introduction

Changes in the comfort patterns required by the buildings occupants and the buildings poor energy performance, led to excessive energy consumption in this sector, especially electricity [2].
In order to stop the increase in energy consumption and help the member states to keep up with their commitment towards the 2020 targets, the European Commission released the Directive 2010/31/EU (EPBD recast) to replace the previous one, dating from 16 December 2002. The new Directive states that after 2020 every new EU building must be a nearly zero energy building (nZEB). Besides this, every member state should create a methodology to establish minimum recommended requirements for buildings and building components to be integrated into the national legislation.
The minimum recommended requirements should be established to the buildings cost-optimal levels and also to their components [3].The cost-optimal level is the balance between the best energy performance achieved with the lowest cost during the buildings life cycle [4]. The costs

include initial investment, maintenance costs and energy costs.
Based on primary energy consumption and on the investment in each renovation solution, this methodology allows analysing different solutions. Usually the analysis starts with a basic solution and evolves to more efficient ones. When the analysis includes packages, instead of individual measures, it is possible to observe not only one cost-optimal level but a group of similar packages that form a range of cost-optimal solutions [5].
The combination of several measures can create a synergy that leads to better results compared to individual ones. Therefore, it is possible that despite the increase of the initial investment, the global cost may decrease because there is less energy costs associated to a certain measure or package. However, after a certain point, the increase in the initial investment will not be compensated by the reduction in energy costs [5].
This is an iterative process and the biggest challenge is to assure that the analysis doesn't become unbearable due to the numerous possibilities. Therefore, the analysis should be targeted to the lowest energy consumptions and lowest carbon emissions [5].
The cost-optimal analysis can follow two different perspectives: private perspective (microeconomic) and social perspective (macroeconomic). The social perspective considers the cost of the carbon emissions and excludes investment rates and discounts. The private perspective considers the discount rates and excludes the carbon emissions costs [5].
The methodology also advices choosing a reference building that can be either real or virtual. This building must be representative of the major part of the national building stock in order to have results that do not depend much on the buildings specific characteristics. In countries where the building stock has not been renovated, the age criteria may be very useful [5].
In Portugal the building sector is the second biggest energy consumer [6] after transports.
Despite this fact, there aren't yet many studies in accordance with these recommendations, so it is important to develop knowledge by applying the methodology to case studies.
Therefore, the present work aimed at studying a real building in which this methodology has been applied. The chosen building is part of the social housing Rainha Dona Leonor neighbourhood and it is located in Oporto city, Norwest of Portugal.

2. Methodology

The analysis followed the recommendations of the Delegated Regulation and the selected building is representative of the Portuguese building stock and is currently under a renovation intervention.
The analysis started with the energy characterization of the building. The determination of the energy needs followed the Portuguese regulation for thermal behaviour of the buildings (RCCTE, Decree-Law 80/2006) in accordance with ISO – 13790 [7]. The comfort temperatures considered were 20ºC for winter and 25º for summer.
After this characterization it was necessary to establish renovation measures able to promote energy efficiency in the building. The measures should affect the elements of the building with higher losses in winter and excessive gains in summer.
For this case study, the renovation measures intended to improve the insulation level in walls, roof, floor and windows. There were also some calculations related to the heating/cooling systems. The analysed systems (one for heating and another for cooling) were divided into three groups: first, electric heater and electric cooler; second, gas boiler with radiators for heating and electric air conditioned for cooling, third, a heat pump for both heating and cooling.

To evaluate the impact of the renovation measures it is necessary to calculate the heating and cooling needs and then the energy needs for all other usages. After that it is necessary to calculate the primary energy usage.
After calculating the energy needs for each measure or package it is necessary to calculate the global cost. The solution with the lowest global cost is the cost optimal solution. This global cost depends on the initial investment and on all the costs related to the measure during the life cycle of the building that was considered of 30 years. The costs were calculated according to the private perspective, so the carbon emissions costs weren't considered. The discount rate applied was 6% and it was considered an increase of the energy cost of 3% per year. The initial investment and maintenance costs were based on the Cype® software for generating prices.
With the primary energy consumption and the global cost of each renovation measure, it was

possible to determine the cost optimal measure. For this case, the primary energy included only the heating and cooling needs.
For an easier reading, the results were presented in graphics with the primary energy consumption on the x-axis and the global cost in the y-axis, for every tested measure. This way of presentation usually allows drawing a curve where the lowest point shows the optimal level for the selected building.

3. Case study characterization

The analysed building is part of a social housing neighbourhood built in 1953. It has two apartments with three bedrooms each with a total area of 110.54m² (55.27m² each apartment), divided in two floors. The building no longer comply with the current living patterns, therefore it will be transformed in two apartments, one in each floor and, instead of three small bedrooms, there will be only one bedroom with a bigger area, in each apartment. Besides these changes, the project also includes improvements in the building envelope. Figure 1 shows the building final horizontal plan and figure 2 shows how it looks like after renovation.
The building has single brick walls, light weight slabs, a wooden roof structure covered with fibre cement tiles and wooden windows frames with single glass. There is no insulation and the domestic hot water (DHW) is provided by an electric heater with a storage tank. The building doesn't have any heating or cooling system installed.

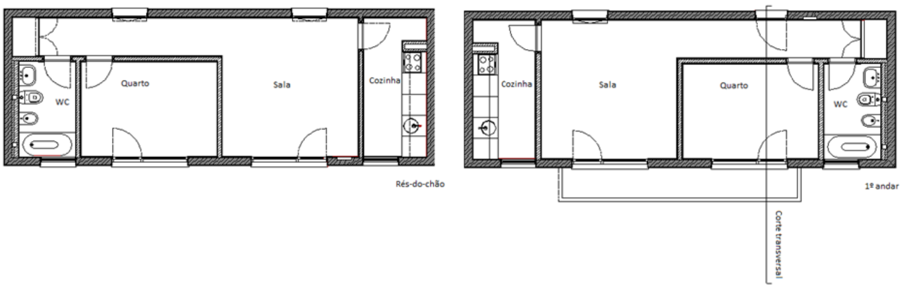

Fig. 1 Building horizontal plan after renovation

Fig. 2 Building front view, after renovation

3.1 Renovation measures

The intervention on the living space is a good opportunity to improve the energy performance of the building without increasing excessively the initial investment. However, it is important to study its impact before the final decision. Table 1 summarises the studied measures for this case study.

Table 1: Summary of the analysed renovation measures by building' component

Element	Renovation Measure	Analysed Insulation type
Wall	*ETICS	*RW (thicknesses of 80, 100,120 and 140mm)
	Ventilated Façade	*EPS, *XPS and *MW (thicknesses of 60 and 80mm)
	Insulation in the inside	*EPS and *RW (thicknesses of 40, 60, 80, 100, 120 and 150mm)
Roof	Insulation above the slab	*EPS, *XPS and *RW (thicknesses of 60, 80, 100, and 120mm)
	Insulation above the roof' wooden structure	Sandwich panel with MW or XPS (thicknesses of 60, 80 and 100mm)
	Insulation above the existing fibrocement sheets	*GW and *RW (thicknesses of 80, 100, 120 and 140mm)
	Insulation between the wooden beams	*MW (thicknesses of 50 and 60mm)
Floor	Insulation above the floor slab	*XPS (thicknesses of 40, 60, 80 and 100mm)
	Insulation above the regularization concrete layer	*RW (thickness of 20mm)
	Insulation under the slab	*RW and *XPS (thicknesses of 40, 60, 80 and 100mm)
Window	New windows with PVC, Wood or Metal frames	Glass: 4+6+6 Low ε; 100% árgon
		Glass: 4+10+6 Low ε; 100% árgon
		Glass: 4+12+6 Low ε; 100% árgon
		Glass: 4+16+6 Low ε; 100% árgon
		Glass: 4+18+6 Low ε; 100% árgon
Heating and cooling Systems	Electric heater and cooler	
	Gas boiler	
	Heat pump	

*ETICS – External Thermal Insulation Composite System; XPS – Extruded polystyrene; EPS – Expanded polystyrene; MW – Mineral wool

4. Results

This section presents the cost optimal results obtained for the walls, roof, floor and windows considering the referred three heating and cooling systems for the analysed renovation measures. The purpose of the analysis was to find the cost-optimal solutions for each one of the building elements. Building renovation packages were not analysed. The reference solution (the starting point) included 60mm of EPS on the walls, 60mm of XPS on the roof and windows with wooden frames and double glass.

4.1 Wall

For the walls, the best solution consists in placing the insulation on the inside. This is due to the low investment needed to implement this solution. Figure 3 shows the results for different thicknesses of wall insulation and for the three heating/cooling systems analysed. The lowest point in each cloud of points is the cost optimal solution for that specific system.
Table 2 shows a summary of the best solutions per each one of the systems analysed. The best performance corresponds to 80mm of insulation on the wall when using heat pump for heating and cooling. This equipment may have a high initial cost but the energy savings along the building life cycle compensate the initial investment resulting in a lower global cost. For the other equipments the cost optimal solution was obtained with higher insulation thicknesses.

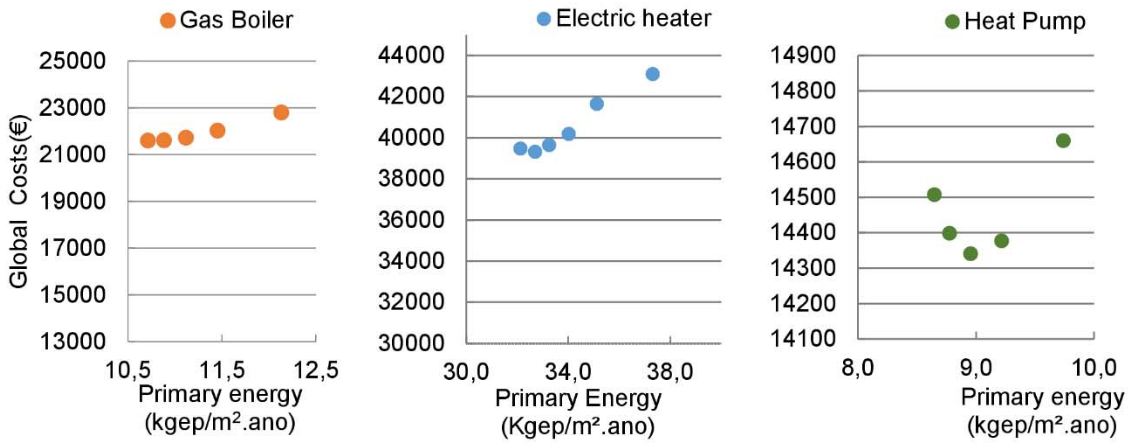

Fig. 3 Cost Optimal curves for the external walls for each of the three tested systems

Table 2: Cost optimal solutions for exterior walls per type of heating/cooling system

Equipment	Cost optimal	U-value (W/m².˚C)	Primary energy (kgep/m^2.year)	Costs (€)		
				Investment	Energy	Global
Electric heater and cooler	120mm *EPS	0,27	32,70	5593	33726	39320
Gas boiler	120mm *EPS	0,27	10,71	5593	16012	21605
Heat Pump	80mm *EPS	0,36	8,95	5108	9234	14342

*EPS – Expanded polystyrene

4.2 Roof

Among the measures analysed for the roof, the best solution corresponds to keeping the existing roof solution and applying insulation above it, placing asphalt shingle on top. Figure 4 shows the results for different thicknesses of roof insulation and for the three heating/cooling systems analysed. Per each system, the lowest point represents the optimal solution, which corresponds to placing rock wool with 80 to 120mm, depending on the heating/cooling system adopted, above the existing roof and cover it with shingle.

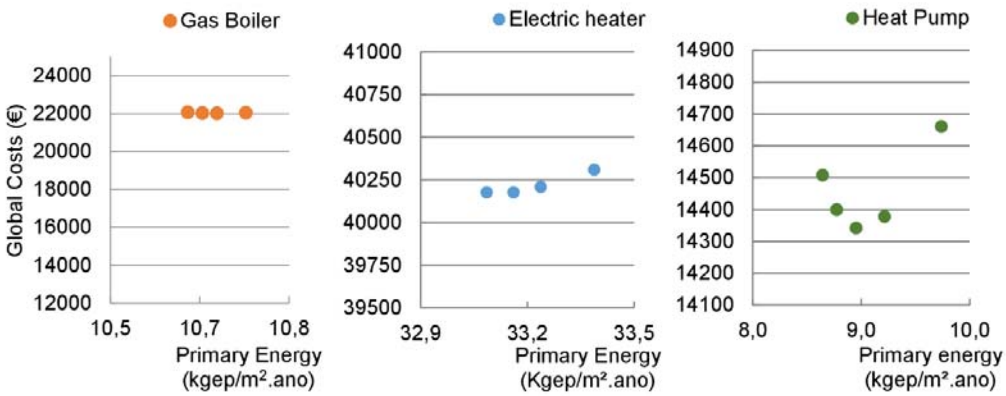

Fig. 4 Cost optimal solutions for the renovation measures in the roof per each of the tested systems

Table 3 summarises the results for the cost-optimal solutions with different heating/cooling systems. The heat pump is the equipment that combined with this solution requires the lowest roof insulation level.

Table 3: Cost optimal solutions for the Roof per type of heating/cooling system

Equipment	Cost optimal	U-value (W/m².°C)	Ntc (kgep/m^2.year)	Costs (€)		
				Investment	Energy	Global
Electric heater and cooler	120mm *RW	0,17	33,16	5974	34205	40178
Gas boiler	100mm *RW	0,18	10,68	5927	16107	22034
Heat pump	80mm *GW	0,20	8,55	5871	8816	14687

* RW – Rock wool; GW – Glass wool

4.3 Windows

For the window frame type, PVC is the most cost effective. The changes come especially from the glass type. Figure 5 shows the results for the windows with PVC frames with different glass types. The best glass type is the 4+16+6 with argon or air inside the air gap.Table 4 summarises the cost-optimal solution for the windows with PVC frames, for the three systems analysed.

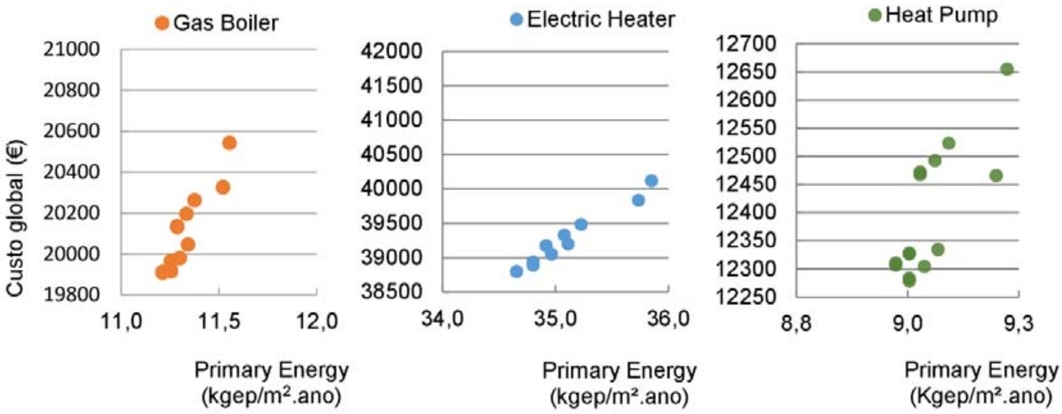

Fig. 5 Cost optimal solutions for the window renovation measures, for each one of the three analysed systems

Table 4: Cost optimal solutions for Windows with PVC frames with different systems

Equipment	Cost optimal	U_{glass}-$U_{frame.}$ (W/m².˚C)	Primary energy (kgep/m^2.year)	Costs (€)		
				Investment	Energy	Global
Electric heater	PVC + 4+16+6 100% Árgon	2,60-1,70	34,65	3052	35746	38798
Gas boiler	PVC + 4+16+6 100% Árgon	2,60-1,70	11,21	3052	16856	19908
Heat pump	PVC + 4+16+6	2,70-1,70	9,00	2993	9287	12280

4.4 Floor

For the floor, every solution was tested considering the creation of an air space underneath the floor slab. Taking this into account, the best solution was the application of rock wool under the slab. Figure 6 shows the results of different thicknesses combined with each one of the analysed systems. Table 5 has the compilation of the cost optimal results. The best result comes with the heat pump and with 40mm of rock wool insulation under the slab.

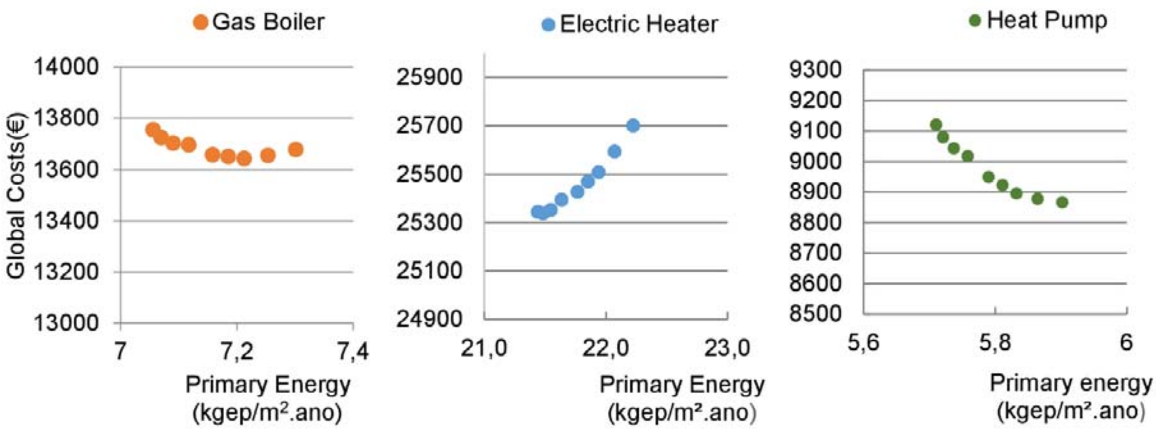

Fig. 6 Cost optimal solutions for the floor renovation measures, for each one of the three analysed systems

Table 5: Cost Optimal solution for the Floor per type of heating/cooling system

Equipment	Cost Optimal	U-value (W/m².˚C)	Primary energy (kgep/m^2.year)	Costs (€)		
				Investment	Energy	Global
Electric heater and cooler	140mm *RW	0,21	21,48	3180	22158	25338
Gas boiler	60mm *RW	0,42	7,21	2880	10764	13643
Heat pump	40mm *RW	0,55	5,90	2780	6087	8867

*RW – Rock wool

5. Conclusions

For each building component, the cost optimal solution depends on the efficiency of the heating/cooling equipment used. The more efficient the system the lower the level of insulation of the envelope needed. In this case, the heat pump allowed using a thinner layer of insulation to maintain the same comfort levels as the other systems.

In this particular case, the reference solution was already a good solution, considering the Portuguese patterns, unless for the floor. Therefore, the only renovation measures with significant impact on the building energy performance were those related to this building element. However, this conclusion cannot be generalized since this is not the common situation of the Portuguese existing buildings.

6. References

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