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A Portuguese study on building renovation towards a nearly zero energy building (nZEB)

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ABSTRACT: The social and environmental urgency of large-scale integrated retrofitting of the European residential building stock is widely acknowledged and supported by all Member States. However, the European building sector is currently still not able to offer an integral solution for deep renovation toward nearly Zero Energy Building (nZEB) for reasonable costs. MORE-CONNECT project aims to tackle this issue by developing cost optimal solutions to renovate buildings towards nZEB. In this project, the optimal solutions include the development of prefabricated, multifunctional renovation elements for the total building envelope (façade and roof) and installation/building services. This paper presents the first stage of the project, namely the analysis and comparison of three scenarios following the current national requirements in Portugal i) 80% reduction of the current primary energy consumption of the building, ii) cost optimal solution (nZEB) and iii) net zero energy (NZEB). The optimization of the building envelope will be the main driver for the three scenarios as well as the inclusion of renewable energy strategies. Overall, results suggest that it is possible to achieve cost-effective solutions for the renovation of Portuguese residential buildings. Moreover, the cost-optimal solution (scenario ii) matches approximately with the 80% reduction of energy scenario (scenario i).

Keywords *Building renovation, energy performance of buildings, cost optimal, nZEB, ZEB.*

1. INTRODUCTION

The building sector accounts for almost 40% of the total energy consumption in the European Union (World Business Council for Sustainable Development, 2008). This fact is widely acknowledged by the Member States and many regulations are now in force to tackle the reduction of energy consumption and greenhouse gas (GHG) emissions in new constructed buildings. However, since the replacement rate of existing buildings by the new-build is only around 1-3% per year (Ma et al., 2012), the highest potential for energy reductions lies in the existing building stock. The majority of the European building stock was constructed before 1960 (Buildings Performance Institute Europe, 2011), when there was no energy efficiency regulations, which makes of energy efficient retrofitting the fastest solution to strongly reduce energy consumption in the built environment. However, for this approach to be effective, European buildings have to be retrofitted to high energy performance levels in a cost-effective way. Buildings retrofitted today will still be in use 40 years from now. On the other hand, the rates of retrofitting across Europe are also very low and, in order to reach the goals of 2050 to reduce greenhouse gas (GHG) emissions in the building sector, it is necessary to quickly improve the volume of renovation. One of the reasons for the slow development of the European building renovation sector is its inability to offer an integral solution for deep renovation towards nZEB for reasonable costs. MORE-CONNECT project aims to tackle this issue by developing cost optimal solutions to renovate buildings towards nZEB. To develop these solutions, it is essential to conduct thorough energy, environmental and economic studies in the early design phase of a renovation. The present study focus on the first stage of the project, through the simulation of three different renovation scenarios for the Portuguese case study building and according to current national requirements. It analyses and compares the energy performance of the building on three levels: i) 80% reduction of the current primary energy consumption of the building, ii) cost optimal solution (nZEB) and iii) net zero energy (NZEB). The approach gives priority to the optimization of the building envelope, although solutions for the heating and cooling systems are also developed. Furthermore, renewable energy production is considered as a fundamental element to achieve highest levels of reduction of GHG emissions and the sustainability of the built environment. To achieve cost-effective solutions, cost-optimal method is used.

2. METHODOLOGY

The calculation for the energy performance of the building follows the Portuguese regulation for the energy performance of residential buildings (REH, Decree-Law 118/2013). In order to reach the different energy scenarios it is necessary to select renovation measures that are able to reduce the heat losses during winter, avoid excessive heat gains during summer and improve the efficiency of the heating/cooling systems. Additionally, renewable energy production must be considered in order to reduce GHG emissions. Following the priority of the MORE-CONNECT project, the main focus is to improve the energy performance of the building envelope, by improving the insulation levels of the walls, roof, floor and windows. The selected Portuguese case study building is representative of the national building stock of multifamily buildings built between 1991 and 2012.

Firstly, the current energy performance of a single apartment is calculated along with the impact of the maintenance measures that the building shall have in order to maintain its structural integrity (baseline scenario). Furthermore, the impact of the different packages of the proposed renovation measures (Section 2.1) is calculated to analyse the performance of the apartment in terms of non-renewable primary energy needs for heating, cooling and domestic hot water (DHW). Thus, the global costs for a 30 year period for the baseline scenario and for each renovation package is calculated. The global costs include the investment and the annual costs (running and maintenance costs). The cost-optimal analysis of the present study follows the methodology of the Commission Delegated Regulation Nº244/2012 in order to determine the cost optimal level. The analysis is focused on the private perspective which considers the discount rates and does not include the carbon dioxide emissions costs (European Commission, 2012). The discount rate considered in this study is 6%. The investment and maintenance costs are based on a price generator tool, the Cype® software. No incentives are included in the calculations. The evolution of energy prices for the period under study (2016-2046) follows the Energy Roadmap 2050 (European Commission, 2011).

The non-renewable primary energy and global cost for each package are then compared and analysed against the baseline scenario, and the cost-optimal (lowest cost) for each system solution to cover the heating, cooling and DHW needs is identified and further discussed.

2.1 Renovation packages

In order to optimize the building envelope, renovation measures with regards to the insulation of the exterior walls and roof, and the improvement of the energy performance of the windows are analysed. Five renovation packages, which consider different system solutions to cover the heating, cooling and DHW needs, are also analysed. Each of the five scenarios (A, B, C, D, E) presents different combinations of insulation levels for the exterior walls/roof and windows with higher performance than the current ones. Tables 1-5 present the description of each renovation package.

Table 1. Scenarios for renovation package 1

Renovation Package 1					
Building element	Scenarios				
	A	B	C	D	E
Exterior walls	EPS* 20	EPS 40	EPS 60	EPS 80	EPS 100
Roof	RW** 30	RW 40	RW 50	RW 60	RW 80
Windows	PVC frame 4:16:6; U=2.7 W/m².K; g=0.75				
Heating/cooling system	Multi-split				
DHW system	Gas heater				

*EPS - Expanded polystyrene

**RW – Rock Wool

Table 2. Scenarios for renovation package 2

Renovation Package 2					
Building element	Scenarios				
	A	B	C	D	E
Exterior walls	EPS 20	EPS 40	EPS 60	EPS 80	EPS 100
Roof	RW 30	RW 40	RW 50	RW 60	RW 80
Windows	PVC frame 4:16:6; U=2.7 W/m².K; g=0.75				
Cooling system	Multi-split				
Heating/DHW system	Biomass boiler				

Table 3. Scenarios for renovation package 3

Renovation Package 3					
Building element	Scenarios				
	A	B	C	D	E
Exterior walls	EPS 20	EPS 40	EPS 60	EPS 80	EPS 100
Roof	RW 30	RW 40	RW 50	RW 60	RW 80
Windows	PVC frame 4:16:6; U=2.7 W/m².K; g=0.75				
Cooling system	Multi-split				
Heating/DHW system	Gas boiler				

Table 4. Scenarios for renovation package 4

Renovation Package 4					
Building element	Scenarios				
	A	B	C	D	E
Exterior walls	EPS 20	EPS 40	EPS 60	EPS 80	EPS 100
Roof	RW 30	RW 40	RW 50	RW 60	RW 80
Windows	PVC frame 4:16:6; U=2.7 W/m².K; g=0.75				
Heating/cooling/DHW system	Heat pump				

Table 5. Scenarios for renovation package 5

Renovation Package 5					
Building element	Scenarios				
	A	B	C	D	E
Exterior walls	EPS 20	EPS 40	EPS 60	EPS 80	EPS 100
Roof	RW 30	RW 40	RW 50	RW 60	RW 80
Windows	PVC frame 4:16:6; U=2.7 W/m².K; g=0.75				
Heating/cooling system	Multi-split				
DHW system	Solar thermal + electric water heater				

3. PORTUGUESE CASE STUDY BUILDING

The Portuguese case study building is a social housing neighbourhood located in the municipality of Vila Nova de Gaia (North of Portugal). It is a multi-family building (1414 m^2), constructed in 1997. The building includes three separate blocks, each with three floors, corresponding to six apartments (a two-bedroom and a three-bedroom per floor). In total, the building includes eighteen apartments. The front view of the building and its floor plan are displayed in Figure 1 and Figure 2, respectively.

Figure 1 - Main façade of the building.

The building is facing west. It includes a pitched roof with ceramic tiles (3 cm of insulation), double pane masonry walls without thermal insulation and aluminium frames with double glazing without thermal break. The domestic hot water is provided through a gas heater for each apartment and there is no heating or cooling system installed in the building. Table 6 presents the thermal transmittances of the building envelope.

Table 6. Thermal transmittances of the building envelope

Building element	Thermal transmittance
	$W/m^2.K$
Exterior walls	0.96
Roof	0.91
Floor	0.78
Windows	3.60

In order to simplify the analysis, the calculations are undertaken for one two-bedroom apartment (59.96 m^2), which is located on the top floor of the building and for which the majority of the external walls are exposed to north (Fig. 2). This apartment is selected as it shows the worse thermal performances of the building, due to its location below the roof and the poor solar exposure.

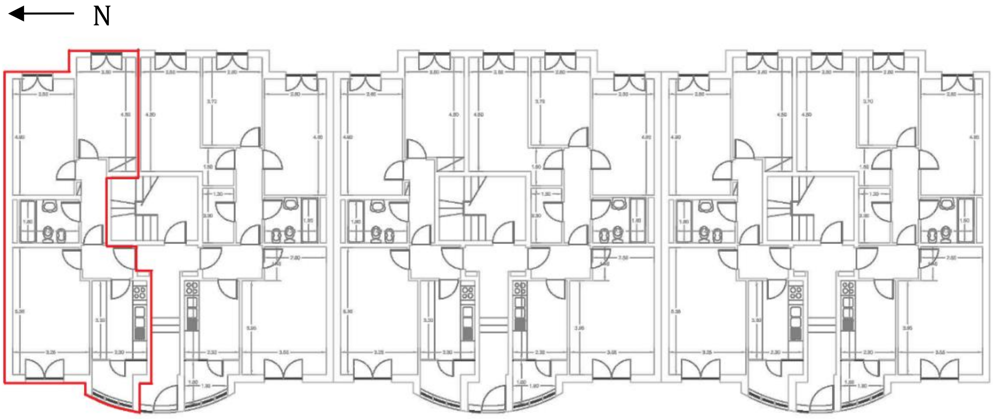

Figure 2 - Floor plan of the building with the selected apartment for the calculations of the scenarios

4. RESULTS

In this section, the results are presented for the simulation of the different renovation packages of the case study apartment. The results are compared with the baseline scenario which includes only the maintenance measures. Figure 3 shows the non-renewable primary energy consumption and the global costs for the baseline scenario and for the different renovation packages under analysis.

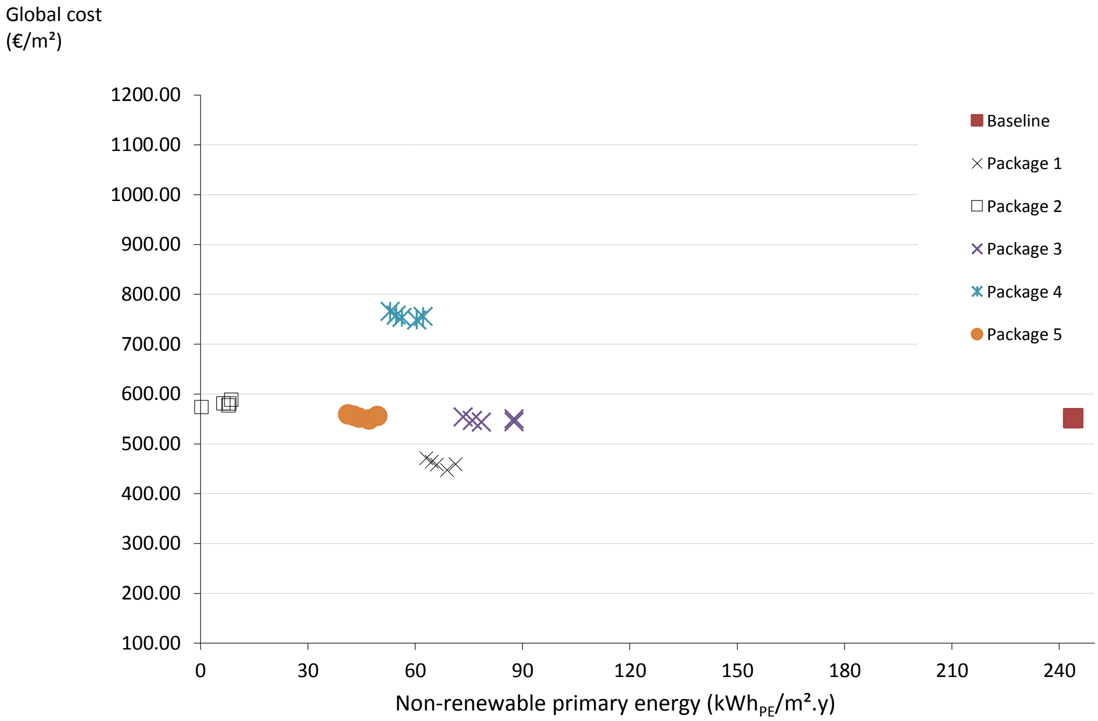

Figure 3. Non-renewable primary energy consumption and global cost of each renovation package

The results show that the renovation packages 3 and 5 present nearly the same global annual costs (544-559 €/m²) as the baseline (552 €/m²), however, present significantly lower energy performances: 73.4-87.6 kWh$_{PE}$/m².y (package 3) and 41.3-49.4 kWh$_{PE}$/m².y (package 5). These solutions represent a reduction on the non-renewable primary energy from 64-70% (package 3) and 79-83% (package 5). Package 4 presents the highest global costs of all packages, varying from 749 to 766 €/m², although it presents a non-renewable primary energy between 53 and 60.5 kWh$_{PE}$/m².y, with reductions of more than 70%. The higher cost of this package is explained by the high investment cost of the heat pump. The highest reduction in the non-renewable primary energy consumption (96.5-99.9%) is achieved with the renovation package 2, that includes the use of a biomass (pellets) boiler for heating and DHW, combined with the multi-split for cooling. It presents global costs between 574 and 589 €/m² and an expected non-renewable primary energy consumption between 0.3 and 8.6 kWh$_{PE}$/m².y. This was expected due to the use of renewable energy (biomass) and the high efficiency of the multi-split. The lowest global costs are achieved with renovation package 1, which combines a multi-split for heating and cooling and a gas heater for DHW. It presents global costs between 448 and 471 €/m² and reductions between 71 and 74% of the non-renewable primary energy (63-71 kWh$_{PE}$/m².y). The low global costs are explained by the low investments of both the gas heater and the multi-split, when compared to other technologies such as the heat pump. From these results, renovation package 1 can be regarded as the nZEB solution, due to its lowest global cost (investment and energy costs) and reduced non-renewable primary energy consumption. It also represents a reduction of 72% in the non-renewable primary energy consumption of the apartment, which can be regarded as close to the 80% reduction that is one of the More-Connect targets.

The cost optimal solution for the building envelope strongly depends on the efficiency of the system used for heating, cooling and DHW. The higher the system efficiency, the lower insulation thicknesses are needed to guarantee the same levels of comfort. Accordingly, for each simulated renovation package in this study, the cost optimal solution differed, being characterized by different insulation levels. Table 7 presents the characteristics of the cost optimal solution for each of the previously described renovation packages that differ in the systems used.

Table 7. Characteristics of the cost optimal solution for each system solution to cover the heating, cooling and DHW needs

	Building element					
	Exterior walls	U (W/m².K)	Roof	U (W/m².K)	Windows	U (W/m².K)
Renovation package 1	EPS 20 mm	0.64	RW 30 mm	0.50	PVC frame (g=0.75)	2.7
Renovation package 2	EPS 60 mm	0.38	RW 50 mm	0.39	PVC frame (g=0.75)	2.7
Renovation package 3	EPS 60 mm	0.38	RW 50 mm	0.39	PVC frame (g=0.75)	2.7
Renovation package 4	EPS 20 mm	0.64	RW 30 mm	0.50	PVC frame (g=0.75)	2.7
Renovation package 5	EPS 20 mm	0.64	RW 30 mm	0.50	PVC frame (g=0.75)	2.7

Table 8 presents the non-renewable primary energy consumption, the respective reduction compared to the baseline scenario and the global costs of the cost optimal solutions presented in Table 7.

Table 8. Cost optimal results for each system solution

	Non-renewable primary energy consumption	Reduction to the baseline consumption	Global cost
	kWh/m².y	%	€/m²
Renovation package 1	68.9	72	448
Renovation package 2	7.8	97	577
Renovation package 3	78.5	68	544
Renovation package 4	60.5	75	749
Renovation package 5	47.1	81	549

Following the aim of this study, one possible solution to achieve ZEB solution (third scenario) is the installation of a photovoltaic system in order to meet the remaining energy needs (68.9 kWh/m².y) of the cost optimal solution of renovation package 1. Thus, it would be necessary to install approximately 21 m² of photovoltaic modules to cover the annual energy needs (4132 kWh/y) which would have an investment cost of approximately 67.7 €/m².

5. CONCLUSIONS

The present study was conducted under the MORE-CONNECT project which aims to develop cost optimal solutions to renovate buildings towards nZEB. Several combinations of renovation measures were analysed for the Portuguese case study building in order to achieve three renovation scenarios: i) 80% reduction of the current non-renewable primary energy consumption of the building, ii) cost optimal solution (nZEB) and iii) net zero energy (NZEB). Results show that it is possible to achieve an nZEB solution by insulating the building envelope, using a multi-split to supply the heating and cooling needs and a gas heater to supply DHW needs. Cost optimal solution for the building envelope is achieved by insulating exterior walls with 20 mm of EPS, insulating the roof with 30 mm of RW and installing windows with higher energy performance (U=2.7 W/m^2.K; g=0.75). The non-renewable primary energy consumption of this solution corresponds to 68.9 kWh/m^2.y with a global cost of 448 €/m^2. Results also show that the nZEB scenario (ii) matches approximately (72%) with the 80% reduction of energy scenario (i). The NZEB scenario (iii) is possible to achieve by installing a photovoltaic system to cover the remaining non-renewable primary energy needs of nZEB scenario. For this last scenario the non-renewable primary energy needs would be zero and the global costs would be 487 €/m^2. The achievement of these scenarios shows that it is possible to achieve cost-effective solutions for this particular case study building.

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