The importance of the solar systems to achieve the nZEB level in the energy renovation of southern Europe's buildings

Ricardo Mateus[a], Sandra Monteiro Silva[a] and Manuela Almeida[a]

[a]Centre for Territory, Environment and Construction (CTAC), University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal.

Abstract: Nowadays, in the European Union the construction rate of new buildings is very low and therefore achieving the EU targets at the energy consumption level of the building sector is only possible through nearly zero energy renovation of the existing building stock. Reducing energy consumption through passive measures is a priority but this is not enough to achieve the nearly Zero Energy Building (nZEB) level. Therefore, the active systems, namely those that allow harvesting the solar energy to partially replace the use of non-renewable energy, are one of the best solutions to consider. At this level, solar thermal and photovoltaic panels play an important role, mainly in countries with high levels of solar radiation, as in the Southern European countries. Nevertheless, there are still some barriers to overcome for the broader dissemination of the implementation of these systems. One of the most important is that building owners are not fully aware of the life-cycle benefits that systems have at the economic level. As in every new different design approach, the best way to arise awareness is through the analysis of case studies, highlighting the reduced life-cycle costs and potential environmental impacts and other long-term benefits resulting from the integration of these active solutions. Thus, this paper is aimed at assessing the contribution of the solar systems to achieve three levels of energy performance (Basic Renovation, nearly Zero Energy Buildings - nZEB and Zero Energy Buildings - ZEB) in the energy renovation of a multifamily building located in Portugal. From the results, it is possible to conclude that, on an annual basis, and for the Portuguese climate, it is possible to overcome, a large amount of the energy needs for acclimatization and domestic hot water preparation with the integration of these systems. The study also shows attractive cost and carbon payback times resulting from their use.

1. Introduction

Improving the buildings' energy performance is an important part of the EU 2020 and 2030 energy targets as well as of the roadmap for moving towards a competitive low carbon economy in 2050 (EPBD recast 2010; EC 2014a; EC 2014b). The targets defined for 2020 are 20% reduction in energy consumption, 20% reduction in carbon emissions and 20% increase in renewable energy use (EPBD recast 2010). The EU framework on climate and energy for 2030 is committed to reducing, until 2030, EU domestic carbon emissions by 40% when compared with the 1990 level and 25% reduction in energy consumption (EC 2014b). This target will ensure that EU is on the cost-effective track towards meeting its objective of cutting emissions by at least 80% by 2050 (EC 2014a). The Commission also proposes an objective of increasing the share of renewable energy to at least 27% of the EU's energy consumption by 2030 (EC 2014b). Based on these new targets, renovation towards nZEB is now a goal of the European countries.

The nZEB performance is achieved by: reducing the buildings' energy needs, through passive approaches (e.g. improving insulation levels, optimizing solar gains and using external shading systems and night cooling); selecting efficient appliances and systems (e.g. lighting, heating, cooling and ventilation systems); and on-site production of renewable energy to reduce the remaining non-renewable energy use. Solar thermal and photovoltaic systems together with biomass and geothermal energy sources are the most common energy sources used in buildings. In buildings, especially in building renovation, solar thermal and photovoltaic systems can be easily added or integrated into facades and/or roofs and therefore show a greater potential to be used as renewable energy systems than other systems (Gorgolis & Karamanis 2016).

To achieve the defined targets, it is necessary to improve the performance of the existing building stock due to its representativeness in the overall building stock and poor energy performance. Additionally, the small rate of new building construction in Europe (1–2% per year) makes energy savings insignificant if the focus is only on new building construction (EC 2011). The renovation of existing buildings is an opportunity to improve their energy performance that is many times missed. The two main barriers for the dissemination of energy renovation of buildings are the high initial costs and the lack of know-how and awareness regarding the cost-effectiveness of the energy retrofit measures (Bartiaux et al. 2014), especially if a life cycle cost approach is not considered and ancillary benefits of energy retrofit measures are ignored. Ancillary benefits of retrofit measures beyond energy savings include lower noise levels and improved comfort from insulation and glazing, better indoor air quality and temperature control from new HVAC systems, less operational maintenance or increased energy security against energy price fluctuations by the deployment of renewable energy resources (Boermans et al. 2011). After reducing the energy losses and controlling the unwanted heat gains it is necessary to use renewable energy systems to supply the remaining energy needs of the building.

Buildings require energy both in the form of heat (e.g. for the domestic hot water preparation, space heating and space cooling) and electricity (e.g. for lighting, electric appliances, heating and cooling). This energy can be supplied using solar thermal (STC), photovoltaic (PV) and hybrid photovoltaic-thermal (PVT) systems.

Supported by the conclusions of other studies (e.g. Lamnatou et al., 2015a), solar systems show to be effective in reducing the whole buildings life-cycle impacts and therefore this is an aspect that should be taken into account in the feasibility studies regarding the benefits of using solar systems. Therefore it is necessary to implement cost-effective strategies for increased efficiency and deployment of renewable energy to achieve the best building performance (e.g. less energy use, fewer carbon emissions and higher co-benefits related with indoor environmental quality) at the lowest possible effort (e.g. initial costs, life cycle costs and occupant's disturbance in the case of building renovation). Based on this context, this paper is aimed at assessing the contribution of the solar systems to achieve three levels of energy performance (Basic Renovation, nZEB and Zero Energy Buildings - ZEB) in the energy renovation of a multifamily building located in Portugal.

2. Case study and Methodology

In this study a typical Portuguese multifamily building is analysed. Its main facades are oriented to the northeast and southwest and this building represents the Portuguese multifamily housing stock built between 1990 and 2000. This case study is equivalent to 41% of the total Portuguese multifamily housing stock (LNEC 2013). It has three floors, a half buried basement used as a garage, 18 apartments (nine two-bedroom dwelling and nine three-bedroom dwellings). The building implantation area is 600 m^2 and has 1279 m^2 of net area.

The building has a reinforced concrete structure and beam and pot slabs. There is no insulation in the building envelope, as it was the common practice at the time. The exterior walls are cavity wall construction (two masonry panes with an air gap, without thermal insulation) with render on the inside and outside surface; the windows are double glazed with aluminium frames; the floors are lightweight slabs; and the roof is pitched with ceramic roof tiles. The roof has 2 cm of mineral wool placed over the last slab and there is a 2 cm thick expanded polystyrene (EPS) insulation in the slab between the common garage (non-heated area) and the first floor. Each apartment has a gas heater for domestic hot water (DHW) production (efficiency of 0.87) and there are no central heating or cooling systems, just portable electric heaters and fan coils, which is the common situation in this type of dwelling (LNEC 2013).

The properties of the building before and after each one of the studied renovation scenarios are shown in Table 1. Portuguese regulations define that the nZEB solution corresponds to the cost-optimal renovation solution of the envelope.

Table 1. Properties of the building before and after each of the renovation scenarios

Properties of building	Before renovation (only maintenance)	Basic renovation (fulfils minimum legal requirements)	nZEB renovation	ZEB renovation
Thermal transmittance, W/(m^2·K)				
U_{wall}	0.96	0.54	0.47	0.47
U_{roof}	1.01	0.45	0.31	0.31
U_{floor}	0.86	0.60	0.29	0.29
$U_{window\ (glass/\ frame)}$	3.10	2.70	2.40	2.40
U_{door}	3.10	3.10	2.40	2.40
Linear thermal transmittance, W/(m·K)				
$\Psi_{wall/wall}$	0.55	0.50	0.50	0.50
$\Psi_{roof/wall}$	1.00	1.00	1.00	1.00
$\Psi_{floor/wall}$	0.75	0.50	0.50	0.50
$\Psi_{window/wall}$	0.25	0.25	0.25	0.25
$\Psi_{window/shutter\ box}$	0.30	0.30	0.30	0.30
$\Psi_{door/wall}$	0.25	0.25	0.25	0.25
$\Psi_{balcony/wall}$	-	-	-	-
Internal heat gains (heat from inhabitants, appliances, equipment and lighting)	4.0 W/m^2			
Ventilation (air change rate)	0.94 ach	0.79 ach	Winter: 0.55 ach Summer: 0.6 ach	Winter: 0.55 ach Summer: 0.6 ach
Heating system type and efficiency	Radiator (1.0)	Radiator (1.0)	HVAC (4.1)	HVAC (4.1)
Cooling system type and efficiency	HVAC system (3.5)	HVAC system (3.5)	HVAC system (3.5)	HVAC system (3.5)
DHW preparation system type and efficiency	Natural gas heater (0.75)	Solar thermal collectors and natural gas heater (0.75)	Solar thermal collectors and new natural gas heater (0.87)	Solar thermal collectors and new natural gas heater (0.87)
Renewable energy sources		-		
Solar collectors for DHW, m^2	-	40	80	80
Solar panels for electricity production, m^2	-	-	0	135

This analysis is aimed at presenting, at the building scale, together with the cost and energy analysis, the potential environment life-cycle impacts resulting from different renovation scenarios. To archive this goal, the methodology is based on the analysis of the: i) life-cycle impacts resulting from each scenario, using a standardized LCA method (EN 15978 (CEN 2012)); ii) economic payback time (EPBT); and carbon emissions payback time (GPBT). For the calculation of the energy needs the methodology of the Portuguese regulation for the thermal performance of residential buildings was followed (Portugal 2013), which is based on the quasi-steady state method presented in ISO 13790 (ISO 2008).

The costs of the renovation scenarios and the related maintenance costs were estimated based on market surveys. The energy costs are based on Portuguese energy prices and the estimation of the evolution of the energy prices for the calculation period follows the scenario given by EC (EC 2012/C 115/01 2012). The average prices of energy (VAT included) considered were 0.22 €/kWh for the electricity and 0.08 €/kWh for natural gas. The global costs of each of the retrofit scenarios defined earlier refer to the net present value (NPV) of the capital costs for the initial retrofit works and replacements during the considered period of 30 years, the maintenance costs and the energy costs, with a discount rate of 3%.In all the renovation scenarios, materials, workmanship and maintenance costs were considered. The life span and the annual preventive maintenance including operation, repair and servicing costs in % of the initial investment of the systems defined in the EN 15459 standard were considered. The radiators, fan coils, gas heater, HVAC systems and solar thermal systems were replaced after 20 years and the PV system after 25 years (in accordance with manufacturers' warranties).

The costs considered in the maintenance scenario are the reparation of cracks and the cleaning and painting of the facade and the replacement of the roof tiles (removal of the tiles and transport to landfill and installation of the new roof tiles). Additionally, the radiators and fan coils and the gas heater were also replaced for equivalent ones. In the basic renovation, the costs considered are the cost of the materials and workmanship of the renovation works (repair of cracks, cleaning the facade, application of the ETICS on the façade, application of the insulation on the roof and garage's ceiling, replacement of the roof tiles and of the windows) and the systems and fittings (radiators, cooling system, gas heater, storage tank and solar thermal collectors). In the nZEB and ZEB renovation, the costs considered are the cost of the materials and workmanship of the renovation works (repair of cracks, cleaning the facade, application of the ETICS on the façade, application the insulation on the roof and garage's ceiling, replacement of the windows and roof tiles) and the systems and fittings (gas heater, HVAC systems for heating and for cooling, storage tank and solar thermal collectors). Additionally, the ZEB scenario includes the costs of the PV system.

3. <u>Presentation and Analysis of Results</u>

3.1. <u>Energy performance</u>

The results of the energy simulations carried out for the four different scenarios are presented in Table 2. From the analysis of Table 2 it is possible to verify that compared to existing building the reduction in the primary energy consumption is around 32%, 74% and 100% respectively for the basic, nZEB and ZEB renovation. The reduction in the primary energy consumption of the nZEB renovation compared to the basic renovation scenario is around 61%. In the ZEB scenario the building has a positive balance of 0.4 kWh/(m^2·year) in the delivered energy.

3.2. <u>Life-cycle costs</u>

The investment costs of the renovation (envelope and systems) and of the replacement of the systems at the end of their lifetime (20 for all the systems but the PV system that is 25 years) are high. Therefore, it is important to analyse, for each renovation scenario, the evolution of the lifetime cumulative costs of each renovation scenario (Figure 1). As Figure 1 shows, the Basic renovation has the shorter payback time, about 13.5 years. nZEB and ZEB renovation scenarios payback time is around 14 years, approximately half of the lifetime of the systems installed. Analysing Figure 1 it is also possible to understand that the contribution of renovation works and systems acquisition (year 0) in the overall lifetime impacts is considerable, as well as the replacement of the systems (years 20 and 25), especially in nZEB and ZEB renovation scenarios. It is also possible to see the reduced effect of the PV system cost in the ZEB renovation scenario when compared with the nZEB scenario.

Table 2. Results of energy simulations for the different scenarios

Properties of building	Before renovation (only maintenance)	Basic renovation (fulfils minimum legal requirements)	nZEB renovation	ZEB renovation
Building's energy needs (net energy, without system losses), kWh/(m^2·year)				
Space heating	57.3	37.1	27.2	27.2
Space cooling	2.2	2.8	3.7	3.7
Domestic hot water	29.3	29.3	29.3	29.3
Delivered energy (energy use of technical systems with systems losses) net energy, kWh/(m^2·year)				
Space heating	57.3	37.1	6.6	6.6
Space cooling	0.6	0.8	1.1	1.1
Domestic hot water	39.1	33.7	33.7	33.7
Produced energy on site, kWh/(m^2·year)				
Solar collectors (heat)	0	19.4	27.5	27.5
PV panels (electricity)	0	0	0	14.3
Primary energy use, kWh$_{PE}$/(m^2·year)				
Energy performance value, kWh$_{PE}$/(m^2·year)	184.0	125.4	48.4	0.0

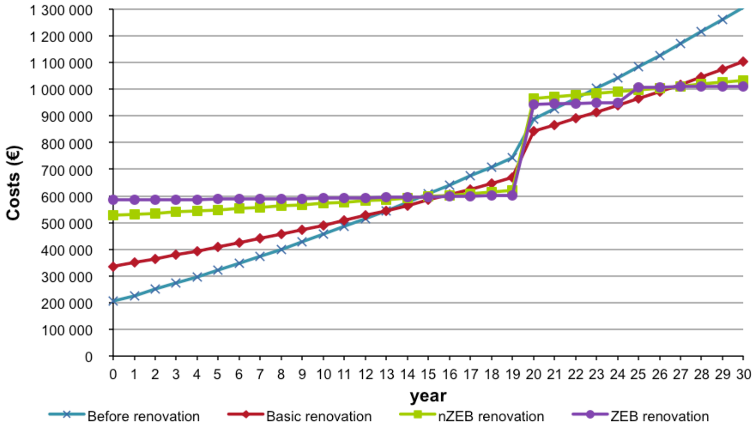

Fig. 1. Lifetime cumulative energy costs of each renovation scenario

These results show that considering the lifetime costs, the nZEB and ZEB renovations are cost effective and that the acquisition and the replacement of the HVAC systems, STC and PV systems and gas heater are both amortized before the end of the renovation lifetime (30 years).

3.3. Environmental performance

Table 3 presents, for each renovation scenario, the building products inputs related with the construction works of each renovation scenario.

Table 4 presents, for each renovation scenario, the annual equivalent lifecycle impacts and the potential improvements compared to the performance of the existing building. In the assessment of the performance of the existing building only the maintenance related impacts are considered. As recommend by the EN 15978 (CEN 2011), for the ZEB scenario, Table 9 presents separately the benefits resulting from the electricity produced in the PV panels as "benefits outside the system boundary". Reasoning for this is that PV panels are connected with the public electricity network and 100% of the produced renewable electricity is exported to this network. Nevertheless, these benefits are deducted from the lifetime inside boundary's impacts in order to allow comparisons with the other scenarios.

Table 3. Inventory of used building products

Inventory item	Before renovation (only maintenance)	Basic renovation (fulfils minimum legal requirements)	nZEB renovation	ZEB renovation
Lifetime material input (kg)				
Water-based paint	1278.20	1278.20	1278.20	1278.20
Synthetic mortar		7101.10	7101.10	7101.10
Expanded polystyrene (EPS)		757.80	1486.34	1486.34
Mineral wool (MW)		852.00	1533.60	1533.60
Aluminium window sills		260.70	287.70	287.70
Lifetime windows renovation (m^2)				
Aluminium windows with double glazed glass		96.03		
PVC windows with double glazed glass			96.03	96.03

Table 4. Annual equivalent life-cycle impacts per net floor area and potential improvements resulting from each renovation scenario

Environmental indicator	Before renovation (only maintenance)	Basic renovation (fulfils minimum legal requirements)		nZEB renovation		ZEB renovation			
	Impacts (/m².year)	Impacts (/m².year)	Improvement (%)	Impacts (/m².year)	Improvement (%)	Impacts of the physical boundaries (/m².year)	Benefits outside the system boundary	Overall impacts (/m².year)	Improvement (%)
ADP_elements	4,75E-05	6,20E-05	-30%	1,05E-04	-121%	2,13E-04	1,08E-05	2,02E-04	-326%
ADP_FF	5,80E+02	3,70E+02	36%	1,01E+02	83%	1,32E+02	1,11E+02	2,05E+01	96%
GWP100a	4,25E+01	2,80E+01	34%	7,38E+00	83%	9,88E+00	8,49E+00	1,86E+00	96%
ODP	2,95E-06	2,01E-06	32%	6,07E-07	79%	1,14E-06	6,10E-07	5,25E-07	82%
POCP	1,29E-02	9,23E-03	28%	2,71E-03	79%	3,71E-03	2,72E-03	9,82E-04	92%
AP	3,01E-01	2,13E-01	29%	5,93E-02	80%	7,92E-02	6,72E-02	1,20E-02	96%
EP	7,11E-02	5,35E-02	25%	1,88E-02	74%	2,90E-02	1,69E-02	1,20E-02	83%
CED_NRE	6,18E+02	3,98E+02	36%	1,11E+02	82%	1,46E+02	1,20E+02	2,55E+01	96%
CED_TOT	7,19E+02	4,67E+02	35%	1,27E+02	82%	1,69E+02	1,45E+02	3,22E+01	96%

From the analysis of Tables 2 and 4 it is possible to conclude that the lower the energy consumption of a renovation scenario is the better is the environmental performance. Since the goal of the nZEB scenario was to reduce in 80% the primary energy needs of the existing building (before renovation), results show good correlation between the reduction of energy needs and the reduction of the overall potential environmental impacts. These results also highlight that he contribution of the energy related impacts in the overall potential environmental life-cycle impacts is much higher when compared with the contribution of the building integrated energy systems and embodied impacts of building products. This means that the thermal retrofitting of building envelopes together with the integration of solar systems (STC and PV) is a good principle to significantly reduce the life-cycle impacts of a building.

According to several authors (e.g (Mateus & Bragança 2011; Mateus et al. 2013; EPA Science Advisory Board 2000) the environmental impact category that most influences the overall environmental performance is the Global Warming Potential (GWP). Therefore, it is relevant to analyse, for each renovation scenario, the evolution of this impact category along the considered lifetime (Figure 2). From the analysis of Figure 2 it is possible to understand that the contribution of renovation works (Year 0) in the overall lifecycle impacts is very low. It is also possible to see the reduced effect of replacing the STC systems in the three renovation scenarios (year 20) and the effect of replacing the PV system in the ZEB scenario (year 25). Due to the avoided CO_2 emissions related to the production of renewable electricity in the PV panels integrated in the ZEB scenario, it is possible to see the slightly decrease of the accumulated GWP along the considered lifetime. Compared with the before renovation scenario, the emissions saved in the lifetime are 549 ton.CO_2eq., 1340 ton.CO_2eq. and 1560 ton.CO_2eq. for the Basic, nZEB and ZEB scenario, respectively. Additionally, it is possible to conclude that the Greenhouse Emissions Payback Time (GPBT) of each scenario is around 5 years, 1.5 years and 2 years for the Basic, nZEB and ZEB scenario, respectively.

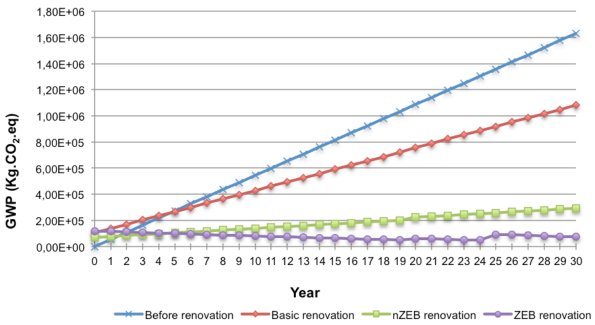

Fig. 2. Lifetime Cumulative Global Warming Potential (GWP) of each renovation scenario

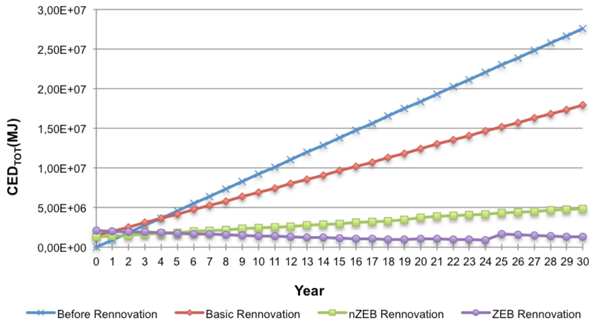

Fig. 3. Lifetime Cumulative Energy Demand (CED_{TOT}) of each renovation scenario

Figure 3 shows the lifetime Cumulative Energy Demand (total) – CED_{TOT} - of the four renovation scenarios. The CED_{TOT} considers both the renewable and non-renewable embodied energy in the building products and energy systems used and the delivered energy consumed during the building operation phase and in the operation. It also includes maintenance and replacement of the building energy systems. Comparing Figure 2 with Figure 3, the results show good correlation with the CO_2 cumulative emissions, showing the importance of the energy consumption in the potential environmental impacts. Compared with the before renovation scenario, the lifetime saved CED_{TOT} is 9 670 GJ (2 686 111 kWh), 22 700 GJ (6 305 556 kWh) and 26 300 GJ (7 305 556 kWh), for the Basic, nZEB and ZEB scenarios respectively. Additionally, it is possible to conclude that the energy payback time (EPBT) of each renovation scenario is around 4 years, 1.5 years and 2 years for the Basic, nZEB and ZEB scenario, respectively.

4. Conclusions

This paper studied four renovation scenarios (maintenance, basic, nZEB and ZEB) for a multifamily building located in the suburbs of Porto, Portugal. The building is representative of 41% of the Portuguese residential building stock and represents the buildings built between 1990 and 2000. For each renovation scenario the economic payback time and greenhouse emissions payback time for the materials and systems used were assessed. To study the efficiency of each renovation scenario this paper calculated the lifetime costs and energy consumption using the Portuguese thermal regulation methodology. Additionally, the payback time of the renewable energy systems was also estimated. In conclusion, this study shows that the considered scenarios for the implementation of the nZEB and ZEB energy levels in Portuguese multifamily buildings are cost effective while providing important potential environmental benefits during the lifetime of a renovation scenario (30 years). The energy prices variation and the discount rate might change the results of the analysis and in some situations the use of solar thermal and PV systems might not be adequate due to the shading of the surrounding buildings or an insufficient area to install the solar thermal and PV panels. In this situation an alternative renewable energy source should be considered, depending on the location of the building.

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