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Contribution of the solar systems to the nZEB and ZEB design concept in Portugal – Energy, economics and environmental life cycle analysis

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ABSTRACT

The recast of the Energy Performance of Buildings Directive settle that all new buildings should reach nearly zero energy levels by 2020 (2018 for buildings owned or occupied by public authorities). Therefore, technicians involved in building design, management and approval should be able to understand and apply nearly zero energy buildings (nZEB) concepts in both new buildings and renovation of existing ones. At European Union (EU) level there are large differences in commitment to the EU targets and the construction of nZEB between countries. It is thus urgent to develop studies to demonstrate the advantages of the nZEB and ZEB design process, increasing the awareness of both building clients and other stakeholders regarding this issue. In this context, the aim of this paper is to assess the energy and environmental life cycle performance of different renovation scenarios (Basic Renovation, nZEB and ZEB) for multifamily buildings in Portugal. This will be focused on the goals of the nZEB and ZEB design process and on the contribution of solar systems (solar thermal collectors, STCs, and photovoltaic panels, PVs) in the achievement of those goals. The results presented in this paper show that, in the Portuguese climate and for a typical multifamily building, it is possible to overcome 100% of the energy needs for acclimatization and domestic hot water (DHW) preparation with the integration of solar systems. From our results, it is also possible to conclude that a significant amount of energy and carbon emissions are avoided for every renovation scenario during the considered lifetime (30 years) and that the nZEB and ZEB scenarios are cost-effective with attractive payback times.

1. Introduction

The recast of the Energy Performance of Buildings Directive [1] establishes ambitious goals for reduction of energy use as well as carbon emissions in the building sector.

The decrease of energy consumption and carbon emissions are important goals for the European Union (EU) due to Europe's energy dependency, the increase of energy costs and climate change mitigation. The building sector is responsible for 40% of the total energy consumption and 32% of the carbon emissions in Europe [2]. Residential buildings represent 25% of the total energy consumption in Europe, being an important target for policies aiming to improve the energy efficiency and reduce carbon emissions [3].

The reduction of energy consumption and the use of energy from renewable sources in the buildings sector are essential measures needed to reduce EU energy dependency and carbon emissions. The potential of emissions mitigation in this sector is relevant since as much as 80% of the operational costs of standard new buildings can be saved through integrated design principles, often at no (or little) extra cost over the lifetime of the measure [2]. Utilizing the full potential for energy savings within the European building sector can bring significant benefits: boosting the ailing European economy and increasing EU energy security.

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 [1,4,5]. The targets defined for 2020 are 20% reduction in energy consumption, 20% reduction in carbon emissions and 20% increase in renewable energy use [1]. 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 [5]. 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 [4]. The Commission also proposes an objective of increasing the share of renewable energy to a minimum of 27% of the EU's energy consumption by 2030 [5].

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The EU legislative framework has been significantly strengthened by the recast of the Energy Performance of Buildings Directive (EPBD-recast, 2010/31/EU) and by the Renewable Energy Directive (RED, 2009/28/EC) [1,6], setting conditions for moving towards nearly zero energy buildings (nZEB) by 2020.

According to the EPBD-recast, all EU Member States shall ensure that by 31 December 2020 all new buildings are nearly Zero Energy Buildings (nZEB) and that after 31 December 2018 new buildings occupied and owned by public authorities are nearly zero energy buildings [1]. This Directive defines nZEB as a building that has a very high energy performance and requires the calculation of primary energy indicator. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

The EPBD-recast also requires that buildings have to be cost-effective during their life cycle and establishes a Cost-Optimal Methodology. This methodology is intended to guide member states in the process of setting minimum energy requirements for buildings and building components [2,3,7,8].

To achieve the settled targets, it is also mandatory to improve the performance of the existing building stock due to its representativeness in the overall building stock and poor energy efficiency. Additionally, due to the small rate of new building construction in Europe (1–2% per year) energy savings will be insignificant if the focus is only on new building construction [9]. Thus, Renovation towards nZEB is now an important goal in many European countries. The renovation of existing buildings is an opportunity to improve their energy performance that is frequently absent. The reasoning for this are the high investment costs and also to the lack of know-how and awareness (from owners, tenants and other stakeholders) regarding the cost-effectiveness of the energy renovation measures [10], especially if a life cycle cost approach is considered and ancillary benefits of energy renovation measures are taken into account. Ancillary benefits of renovation 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 [2].

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 roofs and therefore show a greater potential to be used as renewable energy systems than other systems [11].

Buildings require energy both in the form of heat (e.g. for the domestic hot water preparation, space heating and even space cooling) and electricity (e.g. for lighting, electric appliances, heating and cooling). Therefore, solar thermal (STC), photovoltaic (PV) and hybrid photovoltaic-thermal (PVT) systems are necessary technologies for building applications since they can be used as renewable heat, electricity and cooling energy sources to replace non-renewable energy systems.

The energy produced by an STC system can be transferred to a hot water storage tank, to a swimming pool, or can be used to heat air in the building. It can also be used for cooling the building when using an adsorption chiller (more common in office buildings that have higher cooling needs). Solar thermal energy can be stored for short periods (for DHW) or be used with thermal storage (for example phase change materials - PCM) for seasonal storage.

PV systems are more expensive and are less efficient than STC, being the initial costs the major barrier for installation of these systems in buildings [12–14]. However, the importance of these higher initial costs can be minimized if PVs partially or totally replace the facade or roof finishing materials, as in the case of building integrated photovoltaic products [15]. Among other factors, when installing this type of system, it is important to evaluate the resource potential (e.g. incident solar radiation and the number of hours of sun) and the cost of electricity (i.e. higher energy prices make solar PV technology more affordable) [13]. The availability of incentives (e.g. grants or rebates) and the possibility to sell renewable energy generated in excess on site to the public electricity network also influences the cost effectiveness of these systems. Solar electricity has to be used as it is produced or can be stored in batteries that are expensive.

Compared to other renewable energy systems, STC, PV and PVT systems are, in general, more easily assembled into buildings (e.g. both flat or pitched roofs or facades) [15], more reliable and have lower maintenance costs (e.g. most manufacturers give a 20–25 years lifetime warranty) [16]. As an example and compared with wind turbines, they are more easily integrated into the building aesthetics, do not produce noise and do not have impact on birds. These systems are also easier to install than ground source heat pumps, which require the use of buried ground pipes whose feasibility and efficiency depends on the space availability and geology of the site. The main disadvantages of solar energy are the initial cost of the systems, the intermittency and unpredictability, availability of sunlight during daytime only and the dependence on the local climate conditions [17]. Although solar energy can still be collected during cloudy and rainy days, the efficiency of the solar systems is reduced.

The installation of solar systems require a significant amount of space, and some roofs are not large enough to fit the number of solar panels needed to meet the building energy needs (thermal and electricity) and the installation on the facades can be limited due to shading produced by surrounding buildings. The use of PVT solar systems can simultaneously provide electricity and heat, needing less space and achieving a higher conversion rate of the absorbed solar radiation than standard PV modules [18].

In the feasibility studies regarding the benefits of using solar systems, it is also necessary to consider the potential environmental impacts related to their manufacture, transportation and maintenance and the environmental benefits related to the energy savings [16].

The challenge is thus to develop and select 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 to 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).

In building renovation, meeting nearly zero energy targets only by reducing the energy demand through an increase in the energy performance of the building envelope, can be a challenging process. For instance, taking costs into consideration, cost optimality is often achieved at levels far from nearly zero energy levels [2]. For further optimization, it is often more cost-effective to use renewable energy sources (if economically available) than to strive for reducing energy demand. At the same time, in many cases, the use of renewable energy sources is not only cost-effective but also leads to significant reductions in emissions and non-renewable energy consumption, even if the effects on total primary energy use are small.