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Solar powered net zero energy houses for southern Europe: Feasibility study

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Abstract

This study explores the feasibility of solar Net Zero Energy Building (NZEB) systems for a typical single family home in the mild southern European climate zone. Using dynamic thermal simulation of two representative detached house geometries, solar collector systems are sized in order to meet all annual energy needs. The impact of variations in building envelope, occupant behavior and domestic appliance efficiency on final energy demand and solar NZEB system size is analyzed. After sizing a set of solar thermal (ST) and photovoltaic (PV) solar systems, an analysis was performed to identify the best system configuration from a financial and environmental perspective. The cost and performance of the NZEB system shows low sensitivity to the size of the ST system, whenever solar hot water is used to its maximum. The introduction in the analysis of a micro-generation government incentive scheme shows great potential for financially attractive NZEB homes in this climate zone.

Keywords: NZEB; NZEH; Micro-generation; Building; Simulation

1. Introduction

Energy use in buildings represents about 40% of the European Union (Commission of the European Communities, 2006) final energy end-use, making building energy efficiency a top government priority (European Commission, 2003a). In response to this challenge the building design and research community is starting to develop efficient buildings that, on an annual basis, draw from outside sources an amount of energy that is equal to, or less than, the energy produced on site from renewable energy sources, i.e., a Zero Energy Building (ZEB).

A ZEB building can be dependent or independent of the electrical grid. As discussed by Voss (2008) and Marszal et al. (2011), with current technology, a grid disconnected ZEB is difficult to implement, both from an economical and technical viewpoint, due to the seasonal mismatch between energy demand and renewable energy supply. In the off-grid approach, the excess of renewable energy collected in the summer is wasted and cannot be used to balance energy needs during the winter period. A grid connected ZEB does not require on site electrical energy storage: any surplus in electricity production is injected into the grid, conversely, when production is insufficient, the building draws from the grid. This grid connected, energy exchange approach is called Net ZEB (NZEB): on a net annual base the building requires no energy input. In the case of houses, the most common denomination is Net Zero Energy Home (NZEH). In the future the net zero energy concept may be extended to a life cycle zero energy approach, as proposed by Hernandez and Kenny (2010).

An ideal NZEH should have the following features:

- Present low building related energy needs (adequate use of natural light and ventilation, optimal passive heating and cooling).

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- Have efficient building energy systems (including domestic appliances).
- Have adequately sized renewable energy systems.
- Be connected to a flexible energy infrastructure – the electrical grid must be able to exchange energy with the building.

The development of NZEH builds on research and experimental validation of Low Energy Homes (LEHs) that started in the 1940s and has been rising in the last two decades, with an increasing number of developments, mostly in the US and in Germany – Passivhaus (Passive House Institute, 2007). In a recent review paper Parker (2009) presents experimental results and a brief historic perspective on LEH in the US. The diversity of the North American climate results in different LEH approaches, including superinsulated solutions (in states with a colder climate) as well as more open houses incorporating renewable energy systems (in states with milder climates). The German Passivhaus approach is superinsulated and uses controlled mechanical ventilation (including heat recovery) and no mechanical cooling. A recently completed EU sponsored project, Passive-On (Passive-On Project, 2007), initiated the extension of the Passivhaus energy labeling method to southern Europe where summer overheating is often a problem. Warmer climates require climate control strategies that can ensure both winter and summer comfort with reduced energy demand. The model house proposed for Portugal, and used in this study, adopts moderate envelope insulation and air tightness, optimum use of passive and active solar gains, external shading, internally exposed thermal mass and natural ventilation (Carrilho da Graça et al., 2006; Paredes, 2006). This approach is similar to the LEH and NZEH that can be found in the warmer states of the US and in Australia (Miller and Buys, 2011). An early example of a solar based zero energy home is presented by Voss et al. (1996). In the Portuguese context, the only existing NZEB example is a small office building with building integrated PV and buried pipe ventilation system (Panao and Gonçalves, 2011). The study presented in this paper extends the passive house model introduced in 2006, and explores the feasibility of developing it into a solar powered NZEH.

There are several renewable energy systems that can be used in a NZEH: small wind (Iqbal, 2004) and hydro electrical generators, solar panels (thermal and electric), etc. The southern European climate has high solar irradiation, making the use of solar panels (both thermal and photovoltaic) an increasingly popular option. In this context this study will focus on solar as the renewable energy source. The proposed renewable energy system will be based on solar thermal panels (with a water tank for thermal inertia) and a grid connect PV array.

The typical size of a solar thermal system for single family homes depends on the demand, ranging from systems sized to meet only domestic hot water needs up to larger combisystems that also supply space heating (Lund, 2005). Water tank based inertia is the most common option, but there are alternatives, such as the seasonal heat storage system studied by Kroll and Ziegler (2011) that uses evacuated tube collectors (20–40 m^2 for a single family detached house) and a large soil based seasonal heat storage system (thermally insulated soil, with a total volume ranging between 36 and 132 m^3). For this system, the larger solar panel area is able to achieve a space heating solar fraction above 80%. Another alternative approach for thermal energy collection and storage is presented by Chen et al. (2010). In this system a geothermal heat pump is powered by integrated PV panels that also collect thermal energy (heating air that circulates in a closed loop in the back side of the panels). This system has the advantage of eliminating the need for a traditional solar thermal panels but is comparatively less efficient (approximately 20%) and, in its current form, uses air as the heat transport fluid, making thermal storage very difficult.

One of the goals of this work is to propose a system that is based on currently available technologies. For this reason we do not consider the capability to automatically optimizing the demand profile in order to maximize renewable energy use. The advantages of this future optimization, along with the main technological barriers that exist in the successful implementation of NZEB's, are discussed in detail by Kolokotsa et al. (2010).

There are several relevant previous examples of the use of thermal simulation in the design of NZEH. Bambrook et al.

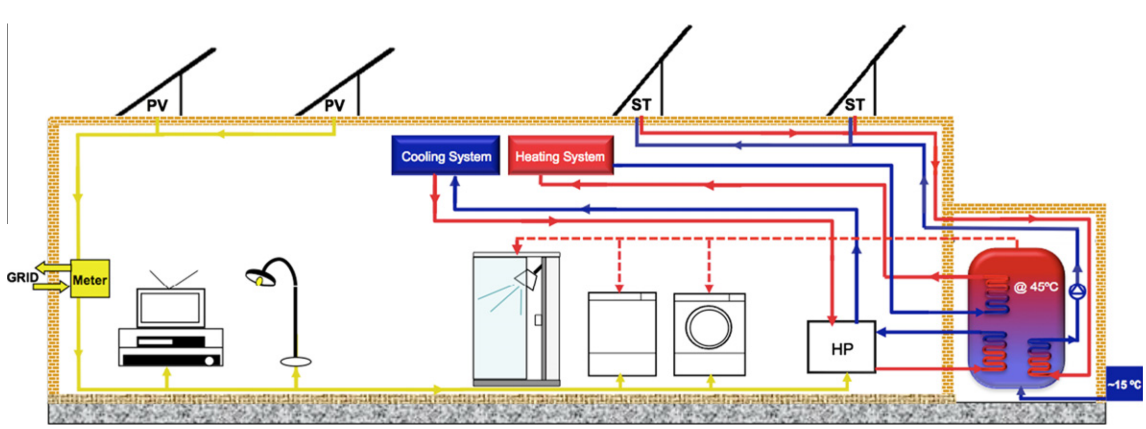

Fig. 1. Building energy systems used in this study.