Available online at www.sciencedirect.com
ScienceDirect
Solar Energy 115 (2015) 743–756
SOLAR ENERGY
www.elsevier.com/locate/solener

Solar energy systems potential for nearly net zero energy residential buildings

Georgios Tsalikis, Georgios Martinopoulos *

School of Science and Technology, International Hellenic University, EL 570 01, Thermi, Thessaloniki, Greece

Received 19 November 2014; received in revised form 19 February 2015; accepted 18 March 2015
Available online 8 April 2015

Communicated by: Associate Editor Mario Medina

Abstract

Solar energy systems are currently the most widely installed renewable energy systems in the building sector in an effort to reduce the energy consumption of buildings. This paper investigates solar potential regarding photovoltaic and solar thermal utilization in typical residential buildings in order to identify their impact towards nearly Net Zero Energy Buildings (NZEB). Different options regarding the installed capacity of photovoltaics and solar combi systems in various locations and climatic conditions are evaluated from a technical as well as from an economic point of view. The results indicate that in all cases, photovoltaics are able to cover the annual electricity demand of a residential building with a payback period of less than 7 years. In the case of solar combi systems, payback period ranges between 5.5 and 6.5 years when compared with a conventional fuel oil heating boiler and 9 years when compared with a natural gas boiler, providing at least 50% of the total heating demand of the buildings. In total, solar energy systems are able to cover at least 76% of the primary energy demand of residential buildings proving that they are a viable solution towards NZEB.

Keywords: Solar potential; Nearly net zero energy building; Solar heating systems; Photovoltaics

1. Introduction

The building sector represents one of the biggest energy consumers in the European Union (EU), accounting for more than 40% of final energy consumption (Environment Agency, 2010). To combat that, the EU implemented a series of directives that promote the use of energy alternatives for buildings, used primarily for electricity, heating, cooling and the provision of hot water, starting with Directive 2009/28/EC (2009/28/EC, 2009) which implied that all member states should increase the use of renewable energy sources along with energy efficiency and savings by 20% until 2020. Shortly after, EU passed Directive 2010/31/EC (2010/31/EC, 2010) defining minimum rules on the performance of buildings and introducing energy certificates, taking into account the external climatic conditions and defining the NZEB. To qualify as a NZEB, a building has to exhibit a very high energy performance and to cover the amount of energy required to a very significant extent from renewable sources that are produced on-site or nearby. Moreover, after 2018 all newly constructed buildings that were either occupied or owned by public authorities must qualify as NZEB, with all other new buildings following suit from 2020.

Of the various renewable energy systems that can be installed in the building sector in order to cover energy requirements (electrical and thermal loads), solar energy systems are currently the most widely used, mostly in the form of solar thermal and photovoltaic systems.

* Corresponding author. Tel.: +30 2310807533; fax: +30 2310474590.
E-mail address: g.martinopoulos@ihu.edu.gr (G. Martinopoulos).

http://dx.doi.org/10.1016/j.solener.2015.03.037
0038-092X/

Nomenclature

U_i	heat transfer coefficient (W m^{-2} K^{-1})	NPV	Net Present Value of the Investment (€)
A_i	building element area (m^2)	NZEB	Net Zero Energy Building
α	absorptivity	DPBP	Discounted Payback Period (a)
ε	emissivity	I_C	initial cost of investment (€)
DSHWS	Domestic Solar Hot Water System	n	expected lifetime of the project (a)
EPBD	Energy Performance of Buildings Directive	R_t	expected cash flows (revenues)
F_RU_L	Collector losses (W m^{-2} K^{-1})	i	energy inflation (%)
$F_R(\tau\alpha)_n$	Collector efficiency	r	real average interest rate (%)
NG	natural gas		

Especially for the southern countries of the EU, which typically have high annual solar radiation and temperatures, solar energy systems are already a viable alternative to fossil energy systems and are expected to become even more efficient and cost-competitive in the future (Ecofys, 2013). Most EU countries of the region enjoy high numbers of new installations annually both in the form of Domestic Solar Hot Water Systems (DSHWS) and of grid connected photovoltaic systems, while the biggest potential is expected for renewable combi systems that generate heat for space heating purposes in winter, cooling through air-conditioning systems in summer and domestic hot water throughout the year.

In Greece, solar energy systems present very high penetration rates both in the form of solar thermal systems as well as in the form of photovoltaics. DSHWS are a mature technology, boasting an installed capacity of 4.2 million m^2 (2900 MW_{th}) at the end of 2013, placing Greece third in the EU in per capita installed capacity (Solar Thermal Industry Federation, 2013). Photovoltaics, although a relatively new technology for the Greek residential market, have skyrocketed during the last five years as the installed capacity from 47 MW_p in 2007 reached 1536 MW_p in 2012 and climbed to 2579 MW_p in 2013. With more than 40,000 systems installed in residential buildings up to 2013, Greece is placed fourth, in the per capita installed capacity, in the world (Photovoltaics Industry Association, 2014; HELAPCO, 2014).

In the present work, a feasibility analysis is performed for a number of different sized solar combi and photovoltaic systems that are considered installed in a representative 120 m^2 reference house designed in accordance with the Greek regulation on the "Energy Performance of Buildings" (KENAK) YPEKA, 2010, which is in turn in accordance with Directive 2010/31/EC (2010/31/EC, 2010). The analysis was conducted for each of the four climatic zones designated in KENAK in order to identify the solar potential from photovoltaic and solar thermal utilization in typical residential buildings towards nearly NZEB.

For the energy calculation of the proposed solar thermal systems, the "f-chart" method was used; while for the heating and cooling loads of the buildings an EN 13790 (EN 13790, 2008) methodology based software (TEE-KENAK) was implemented. The RETScreen software (International, 2014) was used in order to calculate the electricity produced from the different photovoltaic systems examined. Furthermore, a financial analysis was performed and the Net Present Value (NPV) and Depreciated Pay Back Period (DPBP) as well as the corresponding total solar coverage (or solar fraction) were calculated for every case.

2. Building topology and solar energy systems description

The residential sector in Greece was responsible for 29.44% of the total final energy consumption in 2012 (YPEKA, 2014). According to a recent survey (Statistics Authority, 2011), every household in the country consumes, on average, 10.2 MWh of thermal energy, for space heating, hot water production and cooking and 3.75 MWh of electricity for the various electrical appliances. As Directive 2010/31/EC has been integrated in the Greek regulatory framework, energy demands for heating are expected to decline from more than 100 kWh/m^2,a to as low as 15 kWh/m^2,a (Asimakopoulos et al., June 2012).

According to the latest census, which was carried out in 2011, approximately 86% of all Greek residences have an area of up to 120 m^2 while the average household, not taking into account single member households, consists of 3.5 persons (Statistics Authority, 2011).

To qualify as a NZEB, a building has to exhibit a very high energy performance and requires the calculation of primary energy indicators (Mohamed et al., February 2014). Primary energy indicators (or primary energy rating) sum up in a single indicator all energy inputs and outputs, such as electricity, district heat/cooling, and fuels, of a building with the help of primary energy conversion factors (Kurnitski, 2013).

The 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 (Ecofys, 2013).