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ScienceDirect

Procedia Environmental Sciences 38 (2017) 405 – 412

Procedia Environmental Sciences

International Conference on Sustainable Synergies from Buildings to the Urban Scale, SBE16

Simulation of Solar Thermal Systems with Seasonal Storage Operation for Residential Scale Applications

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Abstract

Buildings worldwide constitute one of the biggest energy consumers with 32% of the total final energy consumption, while in terms of primary energy consumption they represent around 40% in most countries according to the International Energy Agency. 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. Especially for locations with 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. One of the problems associated with the use of solar thermal systems for space heating applications is the fact that solar potential is low during the heating period. To solve this problem solar systems that utilize Seasonal Thermal Energy Storage (STES) have been developed and are investigated for residential scale applications in the current work. STES implementation concerns the storage of heat in large facilities during the summer period for later use during autumn and winter, when heating load is in high demand.

To that end the TRNSYS modelling software is used to simulate a typical Solar Thermal System with STES. The model calculates the space heating and domestic hot water needs of a typical 120 m² single-family detached home in the city of Thessaloniki, Greece that has been built according to the latest building code. The contribution of the solar system, as well as the thermal load covered by the auxiliary conventional system is determined and the seasonal solar fraction is calculated.

Peer-review under responsibility of the organizing committee of SBE16.

*Keywords:*Seasonal Thermal Energy Storage; TRNSYS; Solar Energy

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Peer-review under responsibility of the organizing committee of SBE16.
doi:10.1016/j.proenv.2017.03.124

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[1]. 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[2] 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[3] defining minimum rules on the performance of buildings and introducing energy certificates, taking into account the external climatic conditions and defining the Net Zero Energy Building (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. Especially for the southern countries of the EU, with their 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[4]. 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 times, cooling through air-conditioning systems in summer and domestic hot water throughout the year. The vast majority of the installed capacity worldwide, almost 90%, is used to cover hot water for sanitary uses, in the form of (non-pumped) thermosiphon systems with less than a quarter being of forced circulation. Water heating for pool use, is the second most used application (around 6%) mainly in the form of unglazed liquid collectors, while less than 5% of the total installed capacity is used for supplying heat for sanitary uses, space heating, industrial processes or thermally driven solar cooling technologies[5].

In Greece, solar energy systems enjoy 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 4.3 million m² (3,000 MW_{th}) at the end of 2014, placing Greece third in the per capita installed capacity in the EU[6]. One of the problems associated with the use of solar thermal systems for space heating applications is the fact that solar potential is low during the heating period. There are actually three different mechanisms for energy storage, which can therefore be considered for seasonal storage of solar thermal energy as well. These concepts include sensible heat storage, latent heat storage and chemical reaction/thermo-chemical heat storage. With regard to residential scale thermal storage applications, and particularly those currently used in practice, most of them store energy in the form of sensible heat, while latent and chemical methods are considered promising but not mature enough yet. The sensible heat storage method concerns the storage of heat as internal energy in the temperature increase of a selected material, generally a liquid or solid, which is used as the storage medium. The specific heat of the medium used, as well as its temperature increase determines the amount of sensible heat that is stored.

High specific heat and density are two major desired characteristics for a storage medium concerning its thermal capacity evaluation. Since space availability is an important factor, especially for residential applications, limitations of this kind nominate liquids and solids as the only choices. The rate of absorbing or releasing heat is another important requirement, depending each time on the specific application where heat storage is utilized. In addition, the temperature range over which the system operates can also influence the medium choice. Finally apart from good thermal capabilities, the low cost is another issue under consideration, especially for seasonal storage where the systems are large enough. For all the above reasons water, rock materials (gravel, pebbles) and soil/ground have been typically used as storage media for solar seasonal storage systems in residential applications. Depending on the mediums used, different system configurations are considered. The choice of the suitable sensible heat storage concept should take into account the temperature range of the store, the available site size as well as local geological conditions and probable legal issues linked with them such as drilling permission issues.

In the present work, TRNSYS modelling software is used to simulate a typical Solar Thermal System with STES. The model calculates the space heating and domestic hot water (DHW) needs of a typical 120 m² single-family