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Solar domestic heating water systems in Morocco: An energy analysis

A. Allouhi [a,*], A. Jamil [a], T. Kousksou [b], T. El Rhafiki [c], Y. Mourad [a], Y. Zeraouli [b]

[a] École Supérieure de Technologie de Fès, Université de Sidi Mohamed Ben Abdellah (U.S.M.B.A), Route d'Imouzzer, BP 242 Fez, Morocco
[b] Laboratoire des Sciences de l'Ingénieur Appliquées à la Mécanique et au Génie Electrique (SIAME), Université de Pau et des Pays de l'Adour, IFR, A. Jules Ferry, 64000 Pau, France
[c] Ecole Nationale Supérieure des Arts et Métiers, ENSAM Marjane II, BP 4024 Meknès Ismailia, Morocco

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ABSTRACT

The aim of this study is to assess the technical feasibility of solar water heaters (SWH) under Moroccan conditions. Annual simulations in six different regions for two technologies: flat plate and evacuated tube collectors were carried out using TRANSOL program. It is found that high values of solar fraction can be reached in almost the studied regions with the preference of using evacuated tube collectors. Furthermore, the study emphasizes that the location and the climate are determinant parameters on the overall performance of solar water heating systems.

1. Introduction

The rapid world population growth is accompanied by important technological changes promoting the improvement of living standards. Consequently, energy demand is exponentially increasing [1]. However, the current energy system is unsustainable because it is generally based on limited conventional energy sources and causes fearful environmental damages. This situation places the development of renewable energies at the top of political agendas around the world [2,3]. One of the most promising clean and abundant energy sources is solar energy. Accordingly, various technologies were developed in order to harness the sun's power [4–6].

Solar Water Heating (SWH) is a widespread and well-proven technology in the residential sector, allowing both fossil fuel savings and important reductions in CO_2 emissions [7,8]. The installed capacity worldwide capacity has increased from 160 GW_{th} by the beginning of 2010 to 185 GW_{th} at the start of 2011 [9].

SWH systems can be classified into two categories: active and passive according to the heat transfer fluid (HTF) circulation mode [10,11]. Passive systems use gravitational forces to circulate the HTF while active systems use a mechanical system (circulating pumps).

Currently, the major challenge facing the development of SWH systems is to ensure their adaptation to different climates with a better performance, to reduce the cost of the various components of the solar installation and to deal with the various problems related to corrosion, overheating and freezing during the winter months [12]. As a result, numerous works were conducted in order to make the solar heating option as a sustainable solution to fulfill the hot water requirements. For instance, in order to surmount the problem of freezing of the working fluid in SWH systems during cold climates, the drain-back/down technique was proposed; in which a differential controller integrated pump is utilized to control the system in phase with the hot water demand [9]. Moreover, many researchers focus on the corrosion issue that can affect the thermal collector. One of the main solutions to overcome this problem is the usage of polymer-based absorbers that can resist to a long exposure to solar radiation. According to the work of Martinopoulos et al. [13] in which they studied numerically and experimentally a novel polymer thermal collector, the integration of polymer, can withstand corrosion, can allow cost saving and can considerably reduce the weight of the thermal collector. Another important issue concerning the enhancement of SWH systems is the use of phase change materials as storage medium [14,15].

In many parts of the world, SWH systems with different configurations were tested and validated [16]. Economic and environmental aspects of their integration were discussed as well. Nikoofard et al. [17] presented a techno economic study with the aim of evaluating the energy saving potential and the greenhouse gas emissions reduction resulting from the retrofitting of solar water heating systems to Canadian houses. In Brazil, the assessment of the integration of low cost domestic solar water heaters was performed by Naspolini et al. [18]. The estimation of annual electricity savings averaged 38%, and peak-time electricity demand was reduced by 42%. Through a feasibility analysis according Greece, Kaldellis et al. [19] concluded that SWH systems for

* Corresponding author. Tel.: +212 670424928.
E-mail address: allouhiamine@gmail.com (A. Allouhi).

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Nomenclature

A	area (m^2)	*aux*	auxiliary
c_p	specific heat at constant pressure (J kg^{-1} $°C^{-1}$)	*g*	gain
G	solar radiation (W m^{-2})	*l*	load
Q	heat (J)	*loss*	losses
U	loss coefficient in the tank (W m^{-2} $°C^{-1}$)	*m*	mean
V	volume (m^3)	*s*	solar
Greek letters		*Abbreviations*	
ρ	density (kg m^{-3})	HTF	heat transfer fluid
η	collector efficiency (–)	HWC	hot water consumption
		SWH	Solar Water Heating
Subscripts			
a	ambient		

domestic purposes are more financially suitable than electric heaters but were not fully optimistic about the penetration SWH system in the national market due to the introduction of natural gas in the urban tertiary sector. Under the Chinese climate (Hong Kong) based on typical meteorological data, Chow et al. [20] evaluated the feasibility of a centralized solar water-heating system and found out that the annual efficiency and the solar fraction are 38.4% and 53.4% respectively. The authors reported that the payback period of this installation is 9.2 years.

In our country (Morocco), according to the best of our knowledge, there is until now no study treating the evaluation of SWH systems in the different Moroccan climates. As a result, the penetration of these systems into the national market cannot be guaranteed.

In this vision, this paper focuses on the prediction of the thermal performance of a forced circulation SWH system applied to residential buildings in different Morocco climates in order to evaluate the favorable collector technology for each climate region. The proposed analysis concerns two commercialized thermal collectors in Morocco, namely: Flat plate collectors (FPC) and evacuated tube collectors (ETC).

2. General considerations

Despite its strategic situation, Morocco imports more than 95% of its energy requirements with an energy demand that is expected to triple by 2030 [21]. In such a context, Moroccan decision makers have begun acknowledging the necessity to resort to renewable sources of energy, particularly solar energy [22–24]. Indeed, Morocco possesses a huge potential of solar energy with an intensive solar radiation (an average of 5.3 kWh m^{-2} and a mean annual sunshine duration of about 3000 h) [25]. For residential purposes, this potential can serve on the production a hot water whose consumption is expected to rise by 82% in 2030 compared to 2012. As a result, an ambitious program called Shemsi was initiated by the National Agency for the Development of Renewable Energy and Energy Efficiency (ADEREE) [26] with the aim of the installation of 1.7 million m^2 of SWH in 2020 against 350 000 m^2 currently.

Recently, the National Agency for the Development of Renewable Energy and Energy Efficiency (ADEREE) in partnership with the National Center of Meteorology has established a new climatic zoning map for Morocco in order to develop the thermal building regulation in the country. Actually, Morocco is segmented into six climatic zones. Each one is presented by "reference city" (Fig. 1). Table 1 summarizes the different cities of each climatic zone.

Hence, the current analysis will concern a same family house (of 5 occupants) supposed to be located in the representative cities of each one of the six climatic zones. The hot water is assumed to be delivered at a temperature of 45 °C.

Annual simulations concerning both configurations FPC and ETC are carried out using the TRANSOL 3.0 program [27].

3. Design aspects

3.1. System design

A schematic diagram of a forced-circulation SWH system is illustrated in Fig. 2. Compared to a gravitational system, this option offers a good freeze protection especially in extremely cold regions like zone 3 and zone 4. Furthermore, forced-circulation SWH systems are less sensitive to water quality. Generally, the quality of water in Morocco (hard/acid) is not suitable for gravitational systems because of scale deposits that can clog the absorber fluid passages. In the studied configuration, a pump is utilized to circulate the water from a storage tank to the thermal collector when the solar irradiance is available in order to increase its temperature. In cases of cloudy days or night hours, an electric appoint is used as an auxiliary heater. The thermostatic valve mixes hot and cold water to ensure a constant outlet temperature.

3.2. Weather data

As previously mentioned, ADEREE performed a new climatic zoning based on a network of 37 synoptic stations. Therefore, Morocco can be segmented into six climatic zones. The novelty of the current study is to take profit from this recent zoning in order to predict the thermal behavior and the evaluation of the contribution of the solar system. In what follows, each zone will be characterized by its representative city. The main characteristics of these representative cities are summarized in Table 2.

The ambient temperature and the incident solar radiation of the studied cities are generated by the Meteonorm database and are shown in Fig. 3.

3.3. Water heating load

During the design procedure of solar water heating systems, it is requisite to estimate the monthly average heating loads. The water heating load is influenced by various parameters like climatic conditions, occupant behavior and desired hot water set temperatures.