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Parametric study of solar heating and cooling systems in different climates of Algeria – A comparison between conventional and high-energy-performance buildings

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A B S T R A C T

Parametric optimization using dynamic simulation of a solar thermal system for producing hot water, space heating and cooling was developed. The system layouts include a single-effect absorption chiller activated by heat generated by flat plate solar collectors and stored in a solar storage tank. Two construction types were compared; the first is the typical construction in Algeria (low thermal mass with U-values of 1.25 W/m^{2}K, single glazing), which represents the majority in the country, while the second is a High-Energy-Performance building (with U-values of 0.35 W/m^{2}K, double glazing), representing the pilot project called ECO-BAT. Three of Algeria's regions were considered to evaluate the climatic effect of solar systems integration. Algiers represents the coastal region; Djelfa, the highlands region; Tamanrasset, the Sahara region. In parametric study, two solar collectors' field parameters were analysed, including the surface area and the tilt angle. The results indicated that building loads are significantly reduced (12%, 44% and 22% for Algiers, Djelfa and Tamanrasset, respectively). The solar energy contribution is more than 60% for all cases, a significant contribution for an efficient building. In all cases, we observed that the solar fraction reaches more than 45% when the optimum parameters of the solar system are selected.

1. Introduction

A solar heating and cooling (SHC) system simultaneously produces thermal energy for heating during the winter season, cooling during the summer season and domestic hot water all year long. In the recent few years, many institutions and research have focused on the SHC system [1–5] to promote their diffusion and reduce their capital cost for residential and small commercial building applications.

In Algeria, the building sector is the biggest energy consumer, accounting for more than 41% of the overall energy consumption; this value has steadily increased in recent years (10.8% between 2012 and 2013) [6,7]. To optimize energy consumption related to residential buildings, a new program (called ECO-BAT) has been adopted, aiming to yield 600 apartments that comply with the high energy performance standard. The buildings of this pilot program are distributed over different climatic zones in the country of Algeria. Another pilot project attempts to realize and develop solar cooling systems based on adsorption and absorption process and examines what fits are the best, in the Algerian context, with respect to allowing for the reduction of fossil fuel consumption (electric and gas) and harmful emissions to the environment (CO_2). A part of the present study provides some first evaluations of these two pilot projects.

In the literature, several researchers have focused on the design and development of solar thermal systems [8–13], while an SHC system is rarely considered. Because the high cooling loads and solar gains occur in the same months, the application of solar energy for air conditioning is a logical option [14]. In particular, Gianpiero et [15] presented a thermal analysis of a new photovoltaic–thermal (PV–T) solar panel design; also, combinations of

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different water flow rates and different panel configurations were analysed to determine which one has the best performance in terms of optimal PV efficiency and available thermal energy. In another study [16], they tested experimentally a new type of nanofluid thermal solar collector; the experimental results showed an increase of thermal efficiency up to 11.7% [17,18] reviewed several solar collectors and thermal energy storage systems, including both non-concentrating collectors and concentrating collectors. The integrated collector storage solar water heaters were designed, constructed and experimentally studied by Souliotis et al. [19]. Colangelo et al. [20] conducted an overview of the innovations introduced with respect to the flat solar thermal collectors, taking into account new materials, geometries and heat transfer fluids. Colangelo et al. [21] experimentally analysed a new solution for a reduced sedimentation flat panel solar thermal collector using nanofluids as innovative heat transfer fluids for solar energy applications. In Ref. [22], recent advances in the design aspects of solar water heating systems in terms of both energy efficiency and cost effectiveness were presented.

The few studies of SHC systems in the literature differ with regard to the type of procedure. Some studies included a parametric study and cost analysis to determine the least cost systems [23,24], while others were based on the development of mathematical models [25]. More recent works used transient modelling [4,26,27]; most of these studies analysed only the case of European building types in their climates. In particular, some significant works were presented by Calise et al., who conducted dynamic simulation studies for different plant layouts of SHC systems, driven by different types of solar collectors (evacuated, PV–T and concentrating PV–T solar collectors) [4,14,28]. Buonomano et al. investigated a novel transient simulation model [29]; in another study, they presented different control strategies for thermal storage management in an SHC system [30].

In this study, a parametric optimization of the *SHC* system by using dynamic simulation is developed and two construction types are compared to evaluate the solar fraction of heating and cooling loads. The first construction ($U = 1.25\ W/m^2K$, single glazing) does not comply with energy regulations and reflects the majority of buildings in Algeria due to lower prices and faster delivery time. The second, a High-Energy-Performance (HEP) building ($U = 0.35\ W/m^2K$, double glazing), represents the building adopted by the ECO-BAT pilot-project [31], which has the same size and orientation.

Furthermore, this paper also includes a sensitivity analysis, performed to evaluate the climatic effect on the potential integration of SHC systems. Three of Algeria's regions are considered. Algiers represents the coastal region; Djelfa, the highlands region; Tamanrasset, the Sahara region.

In the parametric study, two solar collectors' field parameters are analysed, including the surface area and the tilt angle. In this study, the TRANSOL software, based on dynamic simulation, is used. This tool allows for sizing thermal solar systems using the transient simulation tool TRNSYS power [32].

2. Methodology

To simulate the SHC system, the dynamic simulation software TRANSOL has been used. This tool is based on dynamic simulation (calculation with 1-h time steps is adopted) and has been developed with the TRNSYS simulation tool [33], which is a well-known software diffusely adopted for both commercial and academic purposes. The software includes a large library of built-in components, often validated by experimental data [34].

The domestic hot water (DHW) loads are introduced, with the choice of a daily consumption profile (see Fig. 1) [33]. In all cases, a morning profile that represents high DHW consumption in the morning is selected as the input of our model. In Fig. 1, the hourly coefficients of the DHW consumption rate, which are summed over 24 h, must be equal to 24 [32].

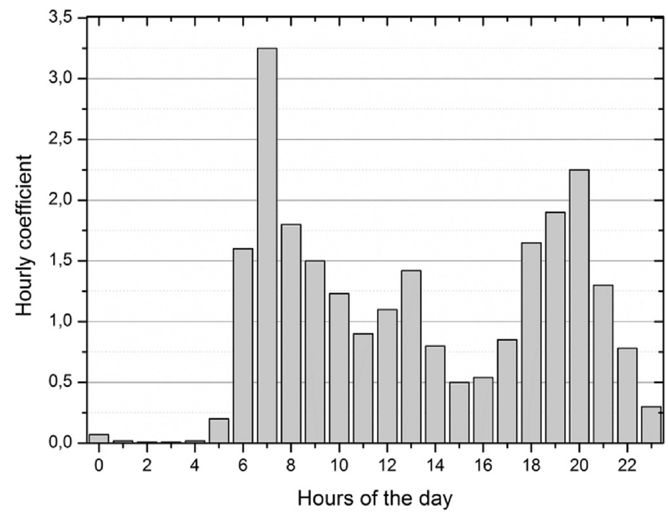

Fig. 1. Daily consumption profile of DHW.

The software has an integrated building model, which allows for the heating and cooling load calculation by introducing the building type parameters. The calculation is achieved by taking into account the weather data established for each region, studied by using the METEONORM software (TM2 file type).

The main model properties used in TRANSOL are [32]:

- One zone building model (the building is simulated as one thermal zone),
- Restricted walls' and windows' database (the roof and the floor are chosen automatically according to the wall types),
- Fixed shading devices inclusion: This step allows for defining fixed shading elements (overhangs and wing walls) for each of the four main orientations of the building [35],
- Internal gains computation,
- Automatic control of the gains due to artificial lighting systems: A simple lighting control strategy based on the total horizontal solar radiation is automatically defined (the lighting turns on when the total horizontal solar radiation is under 120 W/m^2 and turns off when it is above 200 W/m^2),
- Occupation rate and control profiles (heating, illumination, etc.), fixed for residential use.

2.1. Systems description

This system is simulated using a scheme for *DHW*, i.e., heating and cooling (SHC601) from the TRANSOL PRO 3.2 program [33], as shown in Fig. 2. The system comprises a solar collector field and solar and auxiliary tanks.

The solar collector field exchanges energy with the solar storage through an external heat exchanger. The solar and auxiliary storages are connected by an immersed heat exchanger at the bottom of the auxiliary tank. The auxiliary storage is also heated by a hydraulic auxiliary heater, which warms up through an immersed exchange in the top of the auxiliary tank. In the distribution loop, a recirculation flow can be defined to obtain the *DHW* consumption temperature.

The thermally driven chiller is directly connected to the solar storage and switches on when a cooling demand exists and the