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Dynamic simulation and thermal investigation of a PTC for building integration under the climatic conditions of South eastern MOROCCO

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Abstract. This paper aims to report a detailed study of a Parabolic Trough Collector (PTC) prototype's thermal system that requires a sizing and dimensioning investigation of its main parts. This PTC system possesses a field-type evacuated tube solar collector with U-shaped. Furthermore, a simulation study developed with TRNSYS is carried out to evaluate the validity and the feasibility of this system, in particular, for the low-temperature range. The solar collector is oriented to the south and follows the sun from east to west through a single-axis tracking system under real weather conditions. From the simulation results we noticed that for the operating configuration considered in this study, the solar fraction is significantly large throughout the year. During the summer, needs are covered almost 100 %. Whereas, it is necessary to integrate an auxiliary system for the winter period. The tank temperature reached a maximum of around 90 °C during the summer period. The system constantly ensures a heated floor temperature of around 28 °C. This reported simulation and analysis may enable to design and estimate of the region potential and the system productivity over the year, for different applications such as heating domestic water and underfloor systems.

1 Introduction

Solar Water Heating (SWH) and Air Heating Systems (SAH) present a significant part of building's energy bill, which can be reduced through the use of solar energy. Indeed, several works have focused on the study of SWHs and SAH to improve its performance and efficiencies, which vary according to the type, geometry, climatic conditions, internal and external parameters of the solar collector. In this context, M. S. Mohsen et al. [1] carried out a thermal analysis of a compact solar water heater under local climatic conditions of Jordan, to evaluate the performance of the heater and determine the optimal depth of the storage tank. A. Sakhrieh and A. Al-Ghandoor. [2] carried out an experimental investigation of overall performance, efficiency and reliability of five types of solar collectors (blue, black coating-selective copper, copper, aluminum collectors and evacuated tubes collectors). Y. Taheri et al. [3] have realized a novel design, construction, outdoor testing of a passive, simple and low-cost compact solar water heater (CSWH) system. Chafie et al. [4] presented a detailed experimental study to evaluate the performance of a designed and manufactured solar parabolic trough collector under Tunisia climatic conditions, which the final cost of the experimental device has also been estimated. A. Mostafaeipour et al. [5] identified and prioritized the factors associated with the use of SWH systems for dry arid regions.

Many studies have been reported on the analysis, design and estimate of the Moroccan regions potential to implant different solar technologies for various applications [6-10]. A. Allouhi et al. [11] estimated the technical feasibility of solar water heaters (SWH) under Moroccan conditions in six different regions for two technologies: flat plate and evacuated tube collector. B. El Ghazzani et al. [12] conducted a dynamic simulation of a small sized parabolic trough collector plant for generating heated air for an industrial factory. In order to analyze the configuration proposed for this plant, the selected case study is a food industry, which requires heated air at 150 °C. I. Outana et al. [13] presented a detailed experimental and numerical study to evaluate the performance of a designed and manufactured solar parabolic trough collector under weather conditions of Errachidia region, located at the Southeast of MOROCCO. Thus, the modeling of the considered collector is developed using a TRNSYS simulation program to improve that the region is a suitable location to install concentrated solar power systems.

In this present study, we report the simulation results of thermal performances of a solar PTC to investigate the effectiveness and the validity of this solar system. Our solar system can be designed for combined production namely heating domestic water and underfloor.

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2 Prototype description and dynamic modeling under TRNSYS environment

The prototype can be designed for a combined production, namely domestic water heating and radiant Heat Flooring. Fig. 1 and 2 present the schematic and photographic view of the experimental setup that is developed at the renewable energies laboratory of the Faculty of Science and Technology of Errachidia. The system is consisting of different elements: 1- Mixer; 2- Tank; 3- Electrical Heater; 4-Solar reflector; 5- U-shaped vacuum tube; 6- Heat exchanger device; 7- Circulation pump; 8- Expansion vessel; 9- Diverter; 10- Underfloor heating system.

Fig. 1. Photographic view of the experimental setup.

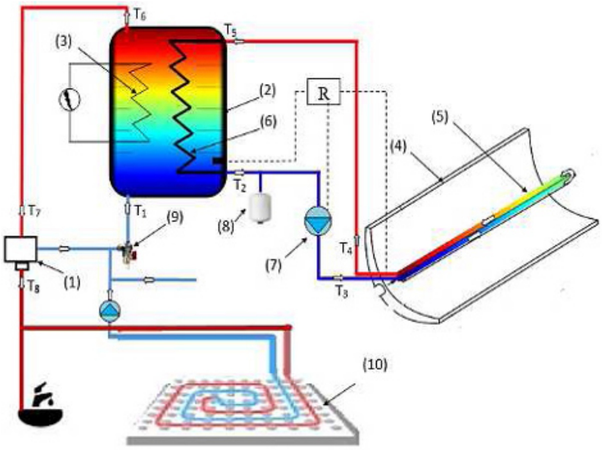

Fig. 2. Schematic view of the experimental setup.

The studied system is made up of two essential circuits. Namely, a primary for heat transfer fluid between the storage tank and the solar collector, and a secondary connects the storage tank and the load (hot water domestic using and the floor heating). The total system was developed using a TRNSYS simulation program to simulate the prototype production under real conditions. This software offers a wide variety of standard components and other libraries that are available to expand the software's ability, such as the TESS (Thermal Energy System Specialists) library. The circuit parameters set were introduced in the TRNSYS model shown in Fig. 3. The circuit consists of a component for the treatment and injection of actual weather data from our meteorological station (Type 109-MY2), linked to the Type (536) for the PTC collector (Concentrator area = 5 m^2) based on the Duffie-Beckman equations model. The collector is exposed on the horizontal surface and follows the sun from east to west.

Thus, the concentrator circuit is connected with a circulator pump (Type 3d) (Flow rate = 100 [l / h]) and a storage tank (Type 4c) (Tank volume = 0.3 m^3), specific heat of the fluid = 4.19 (kJ/kg.K)). The start and stop of the pump are provided by the differential control element which monitors the tank temperature compared to the collector temperature (Type 2b).Mixers and diverters which are subject to external control are often necessary for thermal systems. The flow temperature mixing is provided by mixers, in which two liquid inlets are mixed into a single liquid outlet flow (Type 11h). Flow dividers that divide a mass flow rate of entering liquid into two liquid outlet streams. Thus, an input stream can be divided into as many individual streams (Type 11b). The consumption model of domestic hot water is established by a set of discrete data points indicating the value of the function at various times throughout a cycle (Type 14b). The heating of a shower is provided by floor heating incorporated into the soil (Type 706). Several points in the models are connected to tracers (Type 65), to visualize different parameters (inlet and outlet temperatures, useful energy, irradiation, etc.).

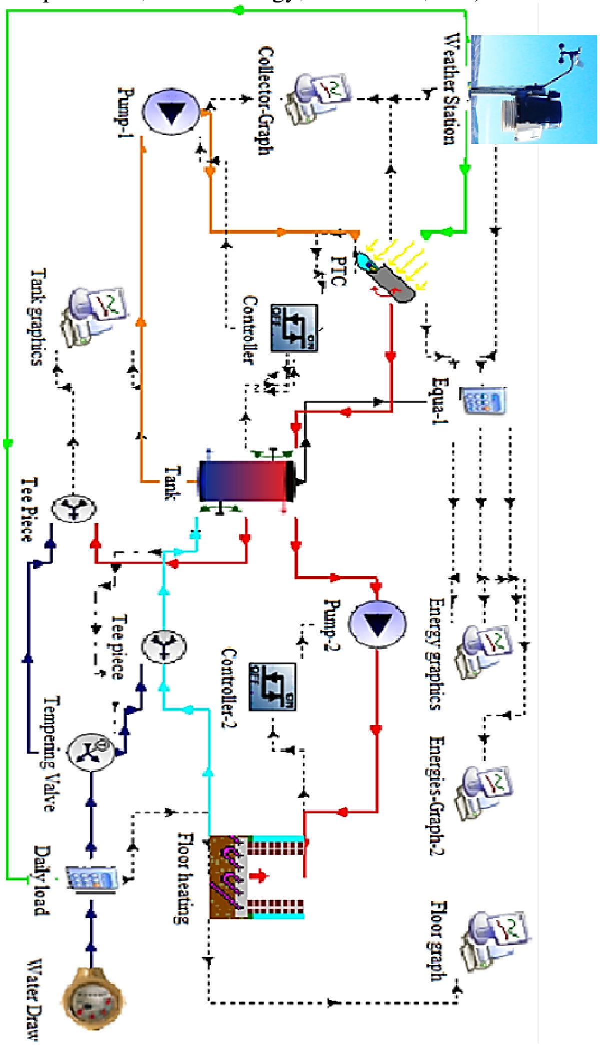

Fig. 3. Functional diagram under TRNSYS-simulation studio environment.

2.1 Experimental validation

The model is validated experimentally in our previous work by comparing the experimental and simulation results. The experimental analysis of the parameters is realized under similar real climatic conditions. As illustrated in Fig. 4, the measurements are carried out for the inlet temperature of about 25 °C. The outlet experimental temperature reached a maximum of 82 °C, 87.6 °C and 77.3 °C for period 1, period 2 and period 3 respectively, and a maximum temperature of 85.8 °C (period 1), 78.47 °C (period 2) and 80.2 °C (period 3) for the simulation. The maximums absolutes errors are about 9.95 °C, 9.13 °C and 8.7 °C for period 1, period 2 and period 3, respectively. The absolute percentage error (APE) is of about 9.93 %, 10 % and 8.4 % for period 1, period 2 and period 3, respectively. In period (1), the absolute percentage error (APE) is 9.93 %. Thus, the maximum absolute error occurs after 30 min of the test, which is about 9.95 °C [13, 14].

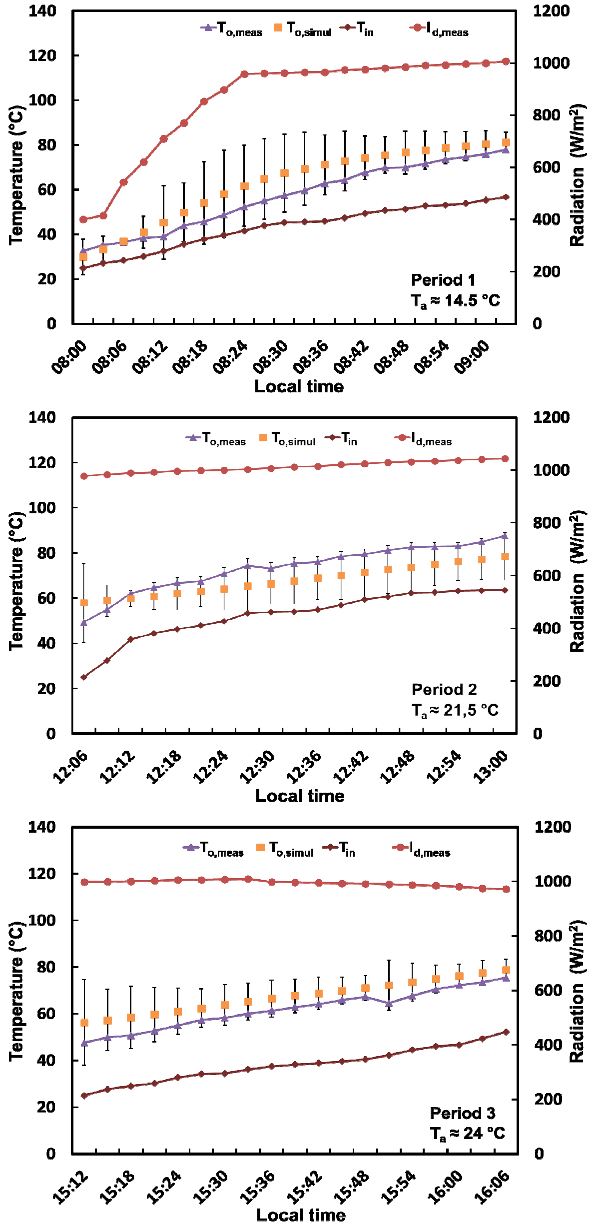

Fig. 4. Evolution of measured and simulated temperatures for different periods: period 1, period 2 and period 3.

2.2 Needs treatment methodology

This studied model can provide daily or annual results per hour. Moreover, when the requirements and calculate assumptions are clearly defined, it is easier to design a suitable and effective DHW production solution. For this reason, the simulations are carried out on a dynamic basis; require a specific methodology for processing the various instantaneous parameters. Indeed, the temperature of the supply network is variable seasonally as well as daily. For this reason, we have assumed that the inlet temperature of the system is that of room temperature.

The domestic hot water demand or the thermal load varies greatly from one consumer to another. However, it is not practical to use a repetitive load profile. During the summer period, the consumption model is a bit higher. During this period, the temperature required for hot water is not as high as in winter. For the present study, the profile of daily domestic hot water consumption is considered to be identical for all days of the year with a total daily load of 200 l/day, the required hot water temperature is about 45 °C. The variable profile of daily consumption is presented in Fig. 5. The control system adjusts the heated floor surface temperature to around 28 °C.

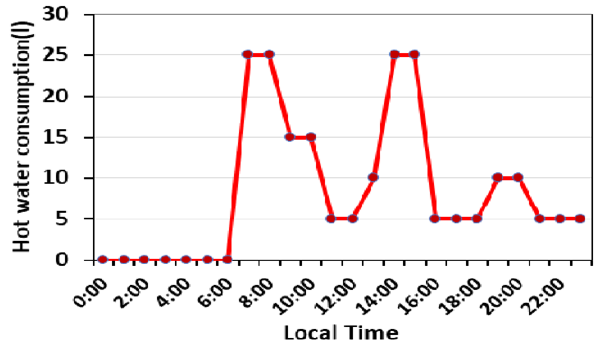

Fig. 5. Proposed profile of the daily domestic hot water consumption.

3 Results and discussion

This study consists of analyzing the evolution and the scenarios of the different thermal performances at the different parts of the system, the tank and the underfloor heating dynamically for a sequence of analyzes that is spread over one year per hour. The results of this simulation are illustrated in Figures 6, 7, 8, 9 and 10 using representative graphs in 2D (Fig. 6) and 3D (Figs. 7, 8, 9 and 10), to determine the variations and the evolution of the various parameters hour by hour.

Fig. 6 shows the variation of direct solar irradiation per unit collector area over the year. In this figure, zones 1 and 2 represent days and/or periods of low sunshine. From the results presented in Fig. 6b and Fig. 8, we can conclude that the outlet temperature of the PTC is very important during the midday and its duration has become longer during the summer, while the value maximum at the outlet is around 120 °C and the maximum difference between the inlet and outlet temperature is around 30 °C (Fig. 6b).

The increase in the outlet temperature is due to the considerable increase in direct radiation, which directly led to an increase in the useful power (Fig. 7); the latter reaching a maximum of around 3900 W in summer. Regarding the storage tank (Fig. 9), it can be seen that during typical summer days the temperature of the tank increases from around 45 °C to a maximum of around 90 °C. Auxiliary heating is used when the water temperature in the storage tank is below 45 °C. Fig. 6c shows the durations of use of auxiliary energy.

As shown in this figure, the system can reach the desired temperature (higher or equal to 45 °C) for most of the time; in summer, it has been noticed that needs are covered almost 100 % by relying solely on solar energy, without the intervention of the auxiliary system energy. On the other hand, in winter during periods of low sunshine or in nocturnal cases, it is necessary to add auxiliary heating energy. This auxiliary heating system requires reliable electrical power, corresponding to a maximum of 1700 W for short periods. From the visualization of the behavior of the surface temperature of the heated floor (Fig. 10), we can see that there is a significant difference between winter and summertime. Indeed, during the winter period, the system constantly ensures a temperature around 28 °C. For the summer period, the floor temperature is increased to maximum margins around 39 °C; this increase is due to ambient temperature growth.

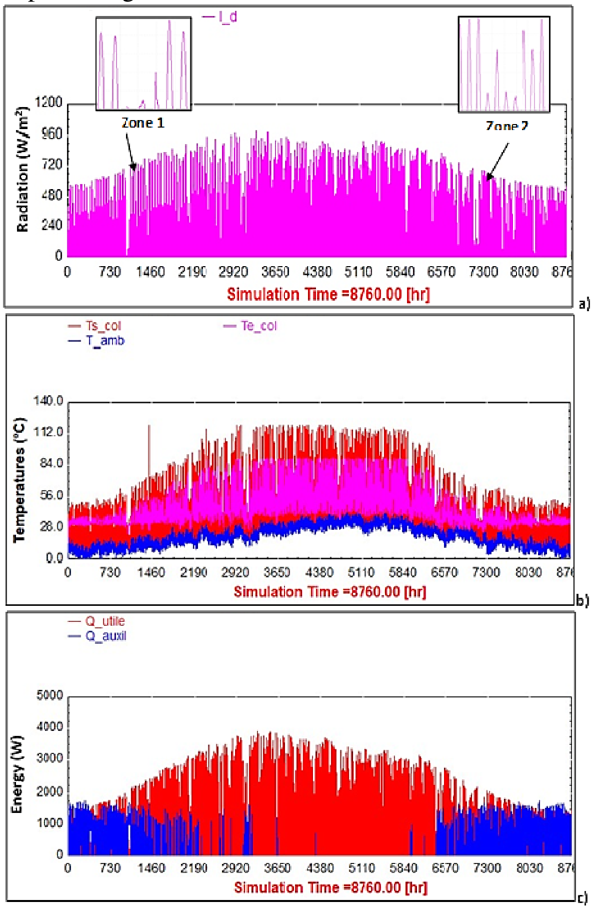

Fig. 6. Annual variation of (a) Solar radiation on the opening, (b) PTC inlet, outlet and ambient temperature, (c) Tank and mixing valve temperature.

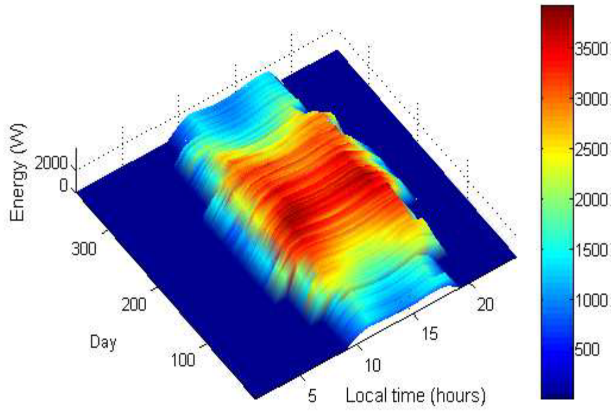

Fig. 7. Useful energy supplied by the PTC to the load.

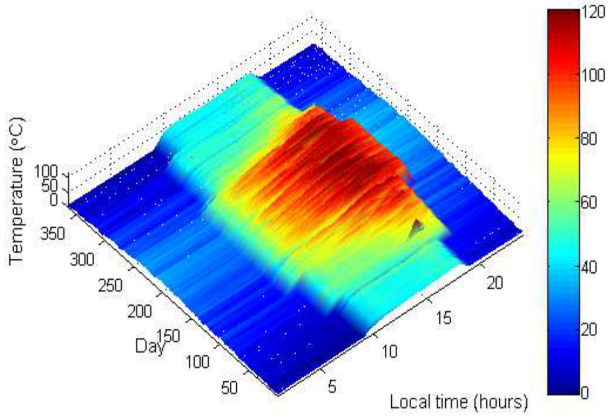

Fig. 8. Outlet temperature of the PTC.

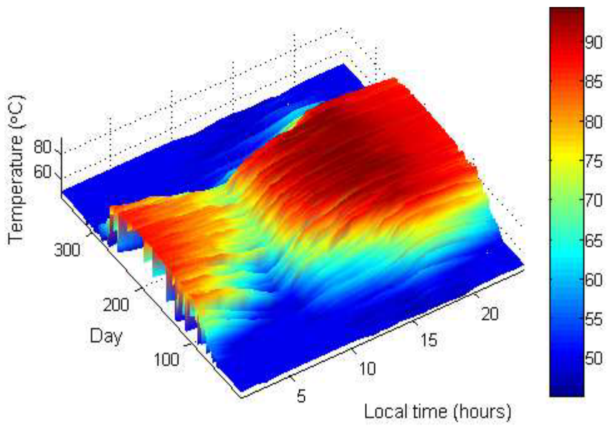

Fig. 9. Tank temperature with the auxiliary system.

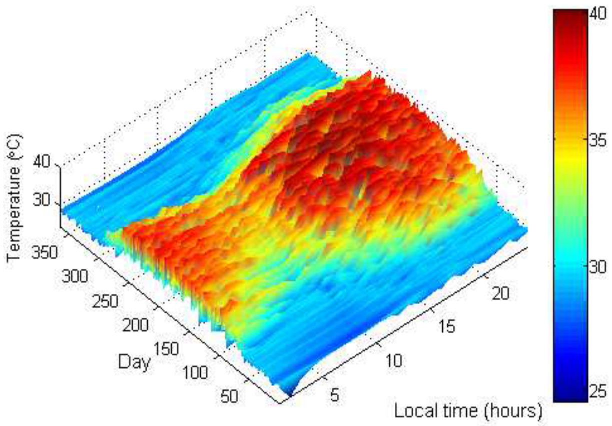

Fig. 10. Surface temperature of the floor heating.

4 Conclusion

In this present work, we investigated a solar PTC provided with an evacuated tube collector with U-shaped. A dynamic simulation for a full-time operation under real conditions climatic was carried out. The comparison between the tests and the simulation results of the outlet fluid temperature showed a good agreement for different test conditions. Indeed, we opted for a perspective of domestic applications of our PTC system, based on a complete simulation under the TRNSYS environment, intended to produce domestic hot water and air conditioning by a heated floor. The results of this analysis can be summarized as follows:

- For the operating configuration considered in this study, the solar fraction was significantly large throughout the year.
- During the summer, needs are covered almost 100 %. Whereas, for the winter period, it was necessary to integrate an auxiliary system.
- The tank temperature reached a maximum of around 90 °C during the summer period.
- The system constantly ensures a heated floor temperature of around 28 °C.

The global objective of this dynamic simulation was to carry out a general investigation and analysis of the optical and thermal performances of a PTC with a U-shaped absorber tube, in order to demonstrate the conformity of this system in the low-temperature range, for the production of domestic hot water in south-eastern Morocco.

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