Solar Thermal Collector Education using Polysun Simulations Software

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Abstract—**There are a variety of solar thermal collectors available in the market today. These collectors are typically manufactured in diverse countries and have different performance characteristics. For homeowners and commercial solar solution providers, it is important to know how these collectors will perform to ensure maximum return on investment. Therefore, engineers and technicians need to be trained into how different collectors will perform in different locations. In this article, we demonstrate how a Swiss simulations software package called Polysun can be used to accurately determine the performance of a particular system under real operating conditions. To demonstrate the accuracy of the simulations tool, we show performance comparisons with experimental results for different types of flat plate and evacuated tube solar collectors. We also show examples of exercises that can be implemented in an undergraduate course in solar thermal systems. According to our investigations, the thermal performance predicted by Polysun was in close agreement with our experimental measurements. The outcomes of our investigations can help educators make informed decisions regarding teaching solar thermal systems to undergraduates using state-of-the art simulation and visualization tools.**

Keywords—Engineering Education, Technology Enhanced Education, Solar Thermal Energy.

I. Introduction

Solar energy is considered the most abundant and environmentally friendly source of energy for domestic and industrial applications [1, 2]. Absorbing materials have been implemented in solar thermal collectors to harvest the Sun's energy in the form of heat [3]. Moreover, several technologies have been developed for household applications, which include flat plate collectors (FPC) and evacuated tube collectors (ETC) [4]. Selecting an appropriate collector for a particular site or location is crucial to ensure an effective Return on Investment (ROI) for homeowners.

A variety of solar collectors are available in the market today. The environmental conditions as well as the operation parameters are the most important factors that determine the type of collector to be used for a certain application [5]. Factors such as the ambient temperature, irradiance, wind speed and accumulated dust affect the long-term performance of solar collectors [6]. Moreover, parameters such as flow rate and type of thermo-fluid have a direct impact on the thermal losses, which in turn, affect the maximum output temperature of the system [7, 8]. For instance, using a forced convection system instead of a thermosiphon system leads to improve overall daily efficiency by 22.5% in the performance of the FPCs [9, 10]. The efficiency of the collectors is usually enhanced by increasing the flow rate as it minimizes heat losses [8, 11]. However, high flow rate requires more pump power and larger pipe diameter, which renders them suboptimal for plant operation.

As previously mentioned, technology computer aided design (TCAD) can play an important role in understanding the complex nature of solar energy systems design [12]. Numerous commercial software packages have been developed to model and predict the performance of various solar collectors under different environmental and operational parameters. These packages include TRNSYS [13] and COMSOL [14], which are often used for studying the effect of different designs and components on the conversion efficiency [15]. Polysun provides great flexibility for sizing renewable energy systems with about 1,000 standard templates and catalogues for collector types produced by manufacturers around the world. The program is user-friendly, and the graphical user interface permits comfortable and clear input of all system parameters [16]. Furthermore, the software tool has been successfully integrated in a solar energy educational programme in Egypt [12, 17].

In this work, performance testing of various solar thermal collectors, subject to different environmental and operation conditions are shown. We demonstrate that Polysun is an easy to use, robust and reliable software tool that can be used to predict the performance of a variety of solar thermal collectors. This tool can be used to compliment or replace hands-on practical training in undergraduate teaching of solar thermal energy for students enrolled in physics or mechanical engineering degree programmes. Such practical training requires expensive equipment and well-maintained laboratories. This can be especially challenging during the current COVID19 pandemic. Consequently, educators can use this software programme to design laboratories and assessments that meet the intended learning outcomes of their courses [18].

Therefore, we show examples of detailed exercises that can be setup to help students understand these principles. Moreover, we provide comparisons between our experimental results with predicted data from Polysun. First, we describe the experiments that were developed to test different types of collectors. In section 3 we describe the results obtained from our experimental investigations and provide comparisons with our simulations. Finally, concluding remarks are provided in section 4.

II. METHODS

A. Experimental

Weather data was collected using DELTA T-GP2 advanced automatic weather station installed on the roof of the Faculty of Science in Fayoum University. Parameters such as global radiation, wind speed, wind direction, and ambient temperature were recorded and processed using Deltalink V3.1 software. The amount of global radiation incident on the collectors with different tilt angles was recorded using a Symmetric Multiprocessing (SMP) smart pyranometer by KIPP&ZONEN.

The thermal collectors used in this study were purchased from SOLE S. A. and were installed on the roof of Fayoum University's Faculty of Science. In this case, glazed FPC with selective absorber (SOLE Wasco 200), glazed FPC with non-selective absorber (SOLE NS 2.00) and U-pipe ETC (SOLE V15) were tested. The collectors were oriented towards the south and the tilt angle was adjusted to 30^o. Tap water was used as the heat transfer fluid. The inlet and outlet temperature of each collector were measured using type K thermocouples. The temperature sensors were calibrated (sensitivity ca. 0.1^o) and the values were recorded using an ARDUINO based system. In addition, the flow rate was measured using ARDUINO based YF-S201 Hall-Effect Water Flow Sensor (sensitivity ca. 0.1 L/minute).

To show the effectiveness and accuracy of Polysun for teaching purposes, we demonstrate a comparison between experimental results with predicted data from the Polysun simulation tool. First, the geographic coordinates of Fayoum University (latitude and longitude) were obtained using Google Maps, which are 29.3084°, 30.8428° respectively. Predicting each collector's performance was done using Polysun V 9.1 designer version. Climatic information for this particular location was obtained using Meteonorm [19]. In the software template projects, the solar collectors were chosen to be identical to the experimentally tested ones. Parameters such as tilt angle and flow rate were varied using the software options during the simulation.

Fig. 1 displays the images of the collectors during the measurements. Both selective (blue) and nonselective (black) FPC have the same insulation, dimension and aperture area (1.73 m^2). The only difference is the absorber material and coating. The aperture area of the ETC (Fig. 1c) is smaller (1.57 m^2). The three collectors were installed with the same tilt angle and direction. The data were recorded automatically and simultaneously to provide accurate and reliable comparison.

The exact values of the global radiation were obtained by fixing the pyranometer on one of the collectors as shown in Fig.1a.

Fig.1(d) and Fig.1(e) demonstrate the designs used for modeling the performance of the collectors using Polysun. The exact types of each collector were chosen from the software catalog to ensure that the technical specifications are the same. Furthermore, the operation parameters such as flow rate, tilt angle, azimuth angle and inlet water temperature were adjusted to match the real values during the experiments.

In the next section, we demonstrate examples of exercises that can be given to undergraduate physics of engineering students.

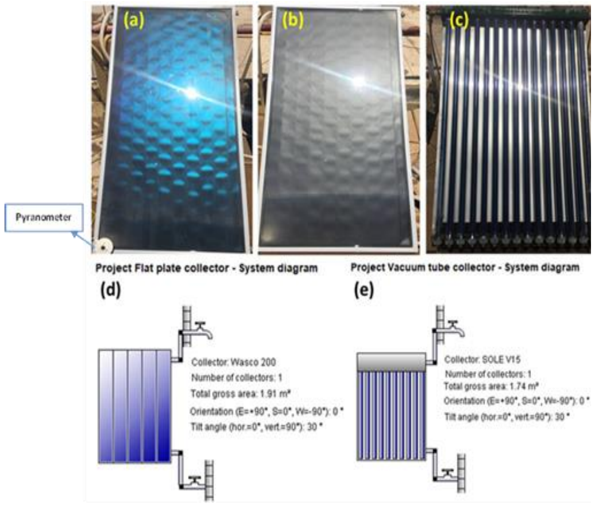

Figure 1. Images of the solar collectors. (a) Wasco 2.00 FPC (selective absorber), (b) NS 2.00 FPC (nonselective absorber, (c) SOLE V15 (ETC) and (d) Polysun projects used for modelling the experimental systems in (a) and (c)

III. RESULTS & DISCUSSIONS

A. Effect of Operation Conditions

In this experiment, students can observe the variation of solar radiation and temperature throughout the day. The exact weather data for our location during the experiments are shown in Fig. 2. Both the daily global irradiation and the ambient temperature are presented in Fig. 2a. Moreover, Fig. 2b shows the weather data predicted by Polysun on the same day. Our results clearly show good agreement between the expected and actual global irradiation values. The temperature profiles for the experimental and modeling results were also similar. However, the real values of the ambient temperature were higher than the simulation data by a fixed value of approximately 10 ̊C. Perhaps this could be attributed to outdated climatic data that has been averaged over the last 10 years and has not accounted for the effects of climatic change. Fig. 2c shows the predicted annual weather data of our location. Students can verify from the results that our location in Fayoum receives approximately 3,786.8 kWh of energy per year, with a peak value in August. The ambient temperature was in the range between 14.1-29.3 ̊C. The average wind speed was about 3.4 m/s, very close to the standard values.

B. Modelling Performance of Collectors

In this experiment, students can observe the influence of fluid flow rate on collector efficiency and outflow temperature. They can also compare their experimental and simulation results. Both types of FPC have the same profile of efficiency and outflow temperature (Fig. 3). As expected, the selective collector delivers higher values of temperature and efficiency compared to their nonselective counterparts. At low flow rate values of 10, 13 and 15 l/h, a large ΔT (i.e. 90, 80, 75°C respectively) yields higher collector heat losses, which leads to lower efficiency values.

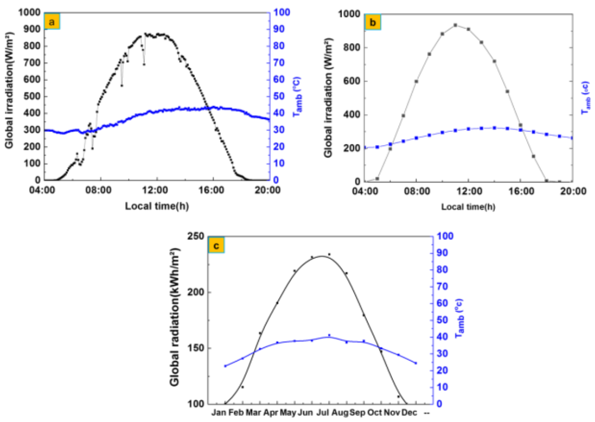

Figure 2. Weather data of Fayoum University over a day. (a) Global irradiation and ambient temperature collected by weather station, (b) Global irradiation and ambient temperature predicted by Polysun. (c) Annual weather data of the same location.

On the other hand, high flow rates (30 and 60 l/h) enable the ΔT to be smaller t (40, 35°C), which leads to relatively higher efficiency values. For ETC (Fig. 4), the variation of the efficiency with the flow rate is small. Unlike FPC, the thermal losses in case of ETC have insignificant influence on the performance of the collector. The thermal efficiency improved with different flow rate values. Thus, using a low flow rate with ETC is more energy efficient. In that case, we conclude that a flow rate of 60 l/h gives the highest possible efficiency of 70% for the selective FPC, 65% for the nonselective FPC and 60% for the ETC.

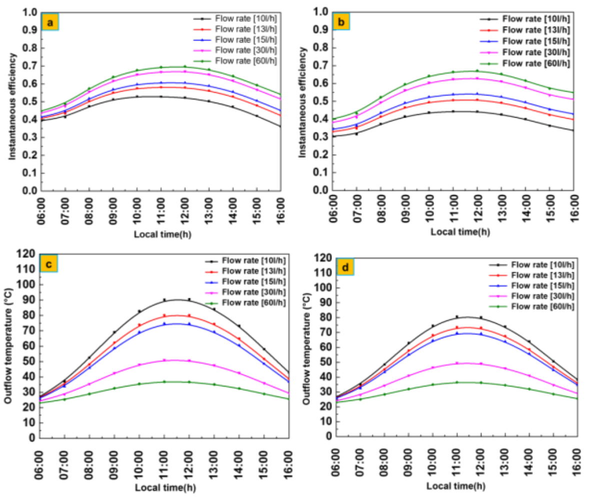

Figure 3. Instantaneous efficiency of FPC predicted by Polysun at different flow rates. (a) Wasco 200, (b) NS 2.00. (c) & (d) Outflow temperatures of Wasco 200 and NS 2.00 respectively.

C. Experimental Performance of Collectors

Based on the results mentioned in the previous section, students can observe that the optimum flow rate range is between 15-30 l/h for the flow rate was selected for the experimental measurements of the instantaneous thermal efficiency (Fig. 5). Both experimental and simulation results shown in figures 4 and 5 show very good agreement for both the efficiency and outflow temperature. The overall daily efficiency values were very close (+/-0.05 % for FPC and +/-0.03% for ETC at 30 l/h & +/-0.13% for FPC and +/-0.08 % for ETC at 15 l/h).

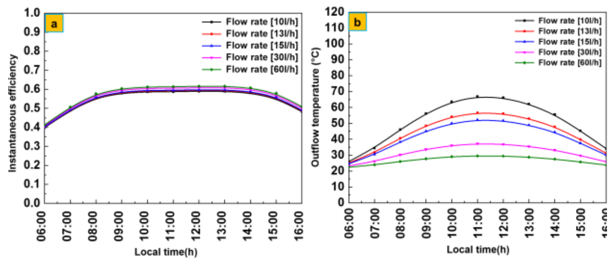

Figure 4. Instantaneous efficiency (a) and outflow temperature (b) of ETC (SOLE V15) predicted by Polysun.

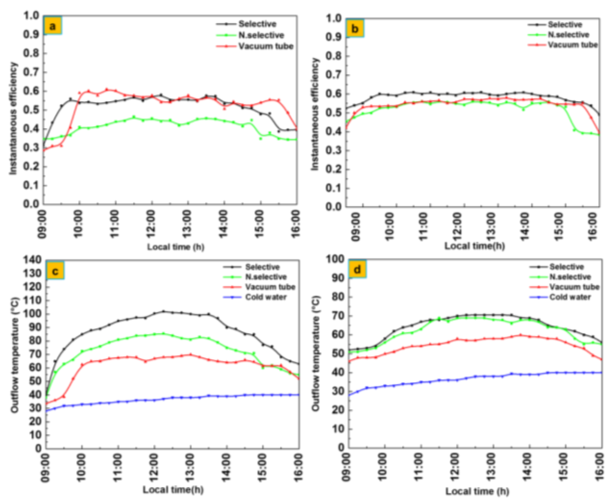

Figure 5. Instantaneous thermal efficiency of different solar collectors. (a) at 15 l/h, (b) at 30 l/h. (c), (d) Outflow temperature of each collector at 15 l/h and 30 l/h respectively.

IV. Conclusions

The purpose of this article is to demonstrate how Polysun can be used to compliment the teaching of an undergraduate course in solar thermal energy systems. This can be part of a Physics or Mechanical Engineering curriculum. We also showed examples of experiments that educators can implement in their teaching practice. We demonstrated the thermal performance of selective and nonselective FPC as well as ETC under different environmental and operating conditions. According to our experiments, students can deduce an optimum flow rate for the tested collectors to be 30 l/h. The predicted performance determined by Polysun showed excellent agreement with the experimental results for all the tested collectors. These results are a testament that Polysun is a reliable software tool, which can be used to effectively and accurately teach solar thermal systems design.

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