IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Sustainable Development and Planning
Vol. 16, No. 6, October, 2021, pp. 997-1003
Journal homepage: http://iieta.org/journals/ijsdp

Design, Construction and Experimental Testing of Solar Water Heaters under Saharan Weather Conditions

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https://doi.org/10.18280/ijsdp.160601

Received: 3 January 2021
Accepted: 12 April 2021

Keywords:
flat solar collector, thermal insulation, experimental test, daily yield, design, construction

ABSTRACT

In order to produce hot water, a solar energy collector is investigated experimentally in the current study. Various investigations are carried out in order to highlight the performance of the collector. Determining daily performance for different time periods is also under study. The collector was manufactured using inexpensive materials that are available on the local market. This study aims to encourage rural families to use solar energy to heat water by providing solar collectors. The results revealed that the hot-water temperature at the collector-outlet exceeded the temperature of 50°C, with an average daily yield of about 60%, under the Saharan climatic conditions of the city of Adrar.

1. INTRODUCTION

Solar water heaters are made up of two essential elements: the solar-energy converter and the energy-storage unit. A solar collector is an energy system for collecting and converting radiation energy. It is made up of flow tubes, heat-transfer surfaces, glass, and energy insulator to avoid leakage into the outer medium. The storage unit is thermally insulated integrated where to separate; which is sized in proportion to the collector-surface area. Recent studies have been carried out theoretically and experimentally with the aim of evaluating the performance of various solar systems based on heaters in the presence of different weather conditions [1, 2].

Chen et al. [3] highlighted an 18 percent increase in the performance of a water-heater based on the solar-energy conversion compared to the old systems. In Hong Kong, using two different models of heaters containing evacuated tubes, Chow et al. [4] conducted studies based on theoretical as well as experimental models in order to highlight their performance. The data indicated that the performance of the single-phase model decreased slightly if compared with the two-phase model.

Using a filled model evacuated tube with a U-shaped tube, the collector performance was evaluated theoretically and experimentally by Liang et al. [5]. The results showed the advantage of using this model of solar-collectors for their high performance. Chien and his colleagues [6] have achieved a high efficiency solar heating system, estimated to be approximately 82 percent in the case of a two-phase collector. The difference between the results of the results of this experimental study and the numerical ones was estimated at about 6 percent as an average value.

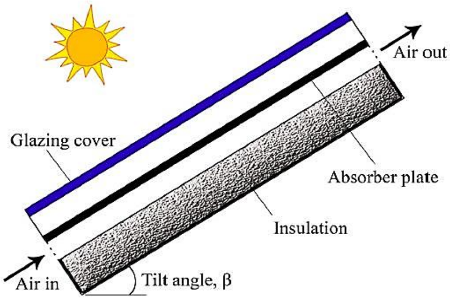
The performance of different systems of evacuated-tube water-fluid based heaters was evaluated numerically by Ayompe et al. [7]. The 1st case includes a flat plate, while a heat pipe is contained in the 2nd case. A 55% improvement in the efficiency of a water heating system based on solar radiation was highlighted in Baghdad and achieved by Joudi et al. [8] using the evacuated heat pipe model.

Depending on the annual data received from a field-trial-installation located in the country of Ireland, Ayompe et al. [9] conducted an analysis on the basis of experimental analyzes of the performance of a water-heater solar-system containing evacuated heat pipes, highlighting through it important values, which amounted to approximately 33.8, 63.2, and 52.0 percent in terms of solar-fraction, collector-efficiency, and system-efficiency, respectively.

Li [10] showed a distinctive design of an energy-system for a water-heater in the region of Shanghai, giving important energy values such as the winter-solar-fraction, which reached 38.6 percent, the summer-solar-fraction was estimated at about 68.7 percent, while the annual-solar-fraction was equivalent to 40.5 percent.

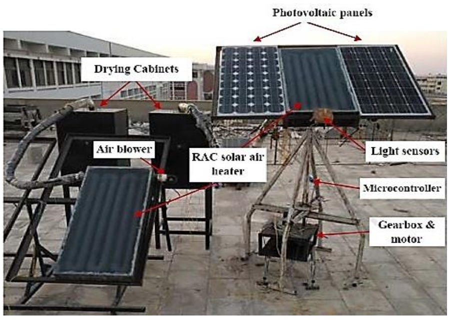
In studies based on experiments and numerical models, Huang et al. [11] improved the efficiency of a water-heater by 12.7 percent in the case of using a 2-phase, closed-loop system in the presence of a porous-wick. In the region of Gangcha, Liu et al. [12] conducted experimental and numerical studies of an energetic building containing solar heating. In the presence of the different loading patterns and the various weather conditions of Baghdad (in Iraq), Al-Joboory [13] conducted experimental investigations on two water heaters containing evacuated tubes. The first case is based on the convection of a natural-convection (thermosyphon-principle), while the second situation is containing biphasic tubes, closed and wickless.

Important studies were carried out in different conditions of flow and under various weather conditions from different regions of solar energy systems, such as those shown in Figure 1 for many researchers such as Qasem et al. [14], Arun et al. [15], El Gamal et al. [16], Vivekanandan et al. [17], Afshari et al. [18], Yu et al. [19], Khanlari et al. [20, 21], Abo-Elfadl et al. [22], and Li et al. [23].



(a) Flat-plate air SH [14]

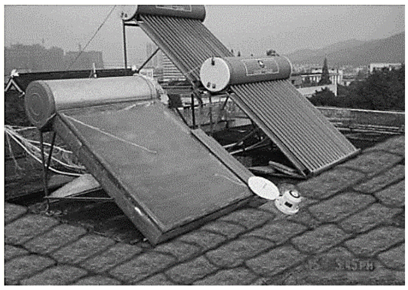
(b) Plain-and-dimples type tube water SH [15]



(c) Air SH (solar tracking) [16]


(d) Fully-developed air-flow SH [17]


(e) Tube-model air SH [18]


(f) Cellular-heat-pipe water SH [19]


(g) V-TP and V-QP air SHs [20]


(h) Tube-type air SH [21]


(i) Double-and-single pass air SH [22]


(j) Air SH with vs. surface forms [23]

Figure 1. Various solar heaters

Rectangular duct heat exchangers were recently studied [24, 25] in order to enhance heat transfer, which can be used in many fields of energy systems. Their technique for enhancing heat transfer is the use of vortex generators of various shapes [26, 27]. This technique has also been integrated with nanofluid technology [28, 29].

This paper presents a solar-water-heater (SWH) constituted with of a flat-type solar-energy collector manufactured locally by local materials, whose insulation is provided by the bark of the palm tree, this integration has shown that the stored water temperatures obtained from this system are becoming important [30], because this insulation have a 0.0475-0.0697 $W.mk^{-1}$ thermal-conductivity [31-34]. The present experimental study is reported to design, construct, and outdoor performance test of solar water heating systems under Saharan weather conditions in Adrar (27° 52' 50" N, 0° 17' 50" W) in the south of Algeria.

2. EXPERIMENTAL DOMAIN

As highlighted in Figure 2, the manufactured solar collector consists essentially of an absorber in two parts: an ordinary steel sheet and a copper exchanger to transport the heat transfer fluid.

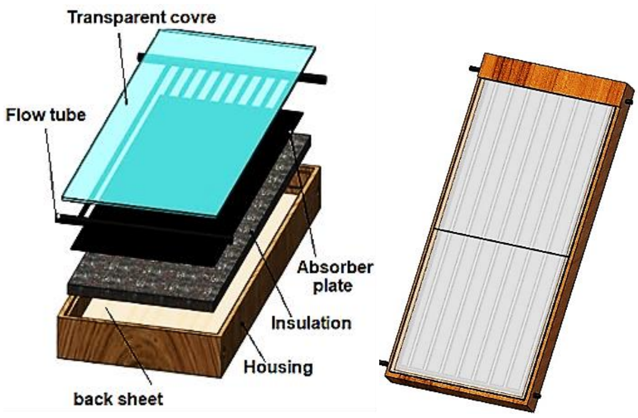


Figure 2. Schematic-domain

Thermal insulation is provided by arranged leaf pieces of the date palm called 'FDEM', placed inside a frame that forms the overall envelope maintained the rigidity of the collector.

The collector characteristics are given in Table 1.

Table 1. Collector elements and their characteristics

Component	Material	Dimensions
Collector bin	Wood	1710 × 800 × 110 mm
Open area		1504 × 700
Glazing	Plastic	Thickness = 0.5 mm.
Absorber	Steel	Thickness = 0.8 mm
Ladder-type	Copper	Length = 19 m Di/De = 20/22 Segments Number = 7 (1602 × 902)
Insulation	Fibrillum leaves	Rear thickness = 40 mm Lateral wood = 40 mm

The solar collector is made up of:

(i) Absorber:

It is one of the very important elements of the sensor, our absorber consists of two exchanger parts in parallel copper tubes with a diameter of Ø22 mm placed on a steel sheet 0.8mm thick, as highlighted in Figure 3.

Figure 3. Copper tubes solar-collector (Image)

(ii) Thermal insulation:

The material chosen for insulation must have a low coefficient of conductivity, because the material which has a low coefficient of conductivity is a good insulator.

As show in Figure 4, date palm fiber is an insulator extracted from date palm. These pieces of tissue in dry vegetable matter, locally known under the name of FDEM, are recovered from the trunk of the palm tree. It has a fibrous structure and forms a porous layer.

Figure 4. Palm fiber used as thermal insulation in the collector

(iii) Transparent cover:

In order to reduce the cost as much as possible and use the available materials, the transparent cover is provided by ordinary transparent glazing which is installed and glued with silicone sealant.

(iv) The box:

Is a wooden frame treated with linseed oil to provide mechanical and thermal protection, as shown in Figure 5.

Figure 5. Palm fiber used as thermal insulator in the collector

3. MEASURING INSTRUMENTS

During the system tests (Figure 6) the various parameters measured are:

- T_e: is the temperature of the cold-water at the section of the collector inlet (i.e. the initial temperature of the water);
- T_s: is the temperature of the hot-water at the section of the collector outlet;
- $T_{ambient}$: is the ambient temperature;
- Solar-energy irradiation on the inclusion-plane of the collector.

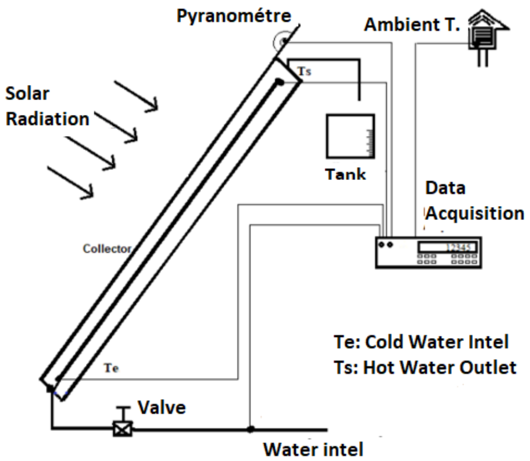


Figure 6. Experimental-setup (schematic diagram)

An analog water flow meter placed at the collector input to adjust the water flow in (l/m). The water supply was provided by a closed tank (350 liters) with a float. The prototype of the system was installed at URERMS (in Algeria), as highlighted in Figure 7.

Figure 7. Experimental-setup (Photograph)

4. RESULTS AND DISCUSSION

To study the performance of this collector, we did some validation tests under the climatic conditions of the Adrar region during the days of October 13, 14 and 16, 2019 and the experimental results obtained are presented, respectively, in Figures 8, 9, and 10.

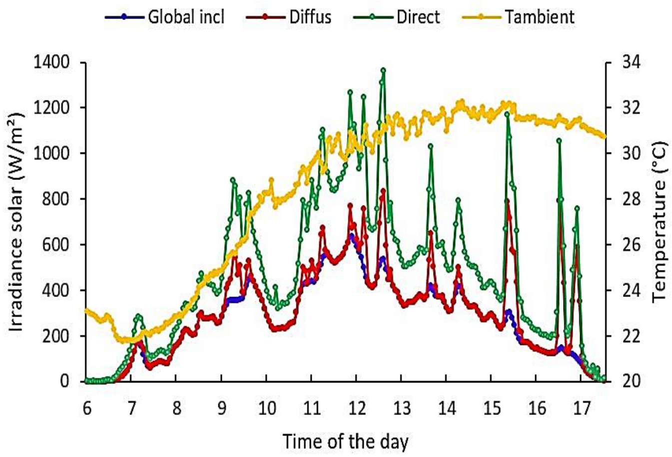


Figure 8. Solar-radiation (direct, diffuse, and global) and $T_{ambient}$ on October 13, 2019

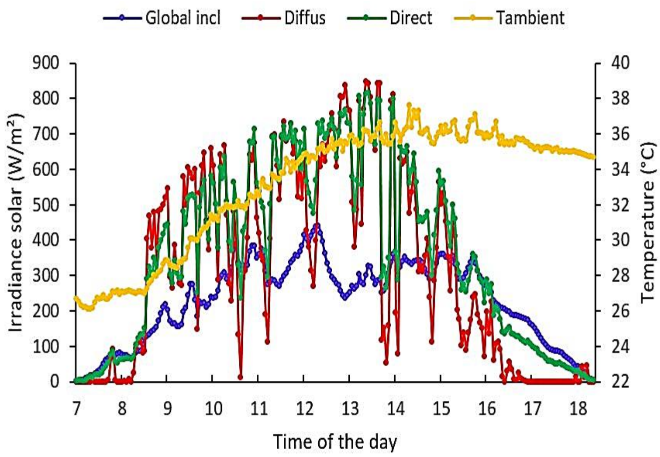


Figure 9. Solar-radiation (direct, diffuse, and global) and $T_{ambient}$ on October 14, 2019

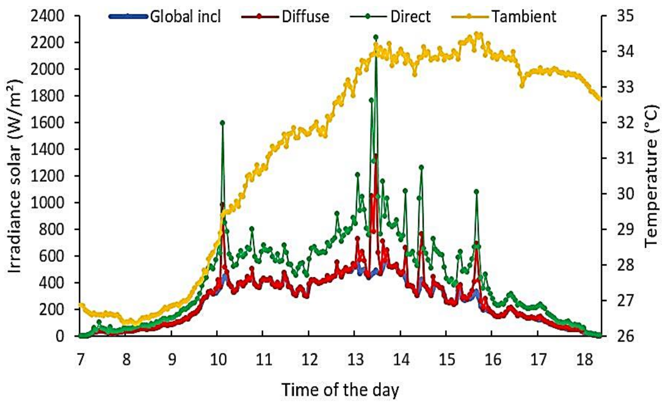


Figure 10. Solar-radiation (direct, diffuse, and global) and $T_{ambient}$ on October 16, 2019

The amount of energy extracted from the collector and recovered by the fluid can be expressed by the following relation:

$$Q_{ext} = q.\rho.Cp.(Ts - Te) \tag{1}$$

The average hourly yield is obtained by the following relation:

$$\eta = \frac{Q_{ext}}{A.H_{in}} \quad (2)$$

where,

- Q_{ext}: the energy delivered by SH;
- H_{in}: the incident-solar-energy on the area of the opening surface;
- A: the collector surface area (m²) that captures solar energy;
- C_p: the specific-heat (of water, J kg^{-1} °C^{-1});
- q: the water-flow expressed in liters per minute (L min^{-1});
- ρ: the water-density (Kg m^{-3});

The measured solar-radiation (direct, diffuse, and global) for the testing days are presented in Figures 8-10. We notice that this period characterized by fluctuations in radiation due to changes in weather conditions.

Curves of the temperature changes of the medium ($T_{ambient}$), as well as at the entrance (T_e) and exit (T_s) of the heater, in addition to the evolution of solar-energy during the previous dates (October 13, 14, and 16, 2019) are shown, respectively, in Figures 11, 12, and 13. The evolution of temperature change (ΔT between the inlet and the exit of the heater) during each period is also studied and shown oan the following plot (Figure 14).

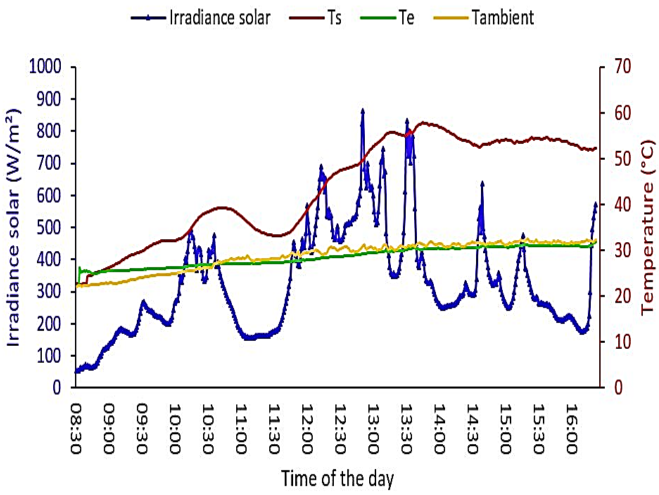


Figure 11. T_e and T_s evolution (October 13, 2019)

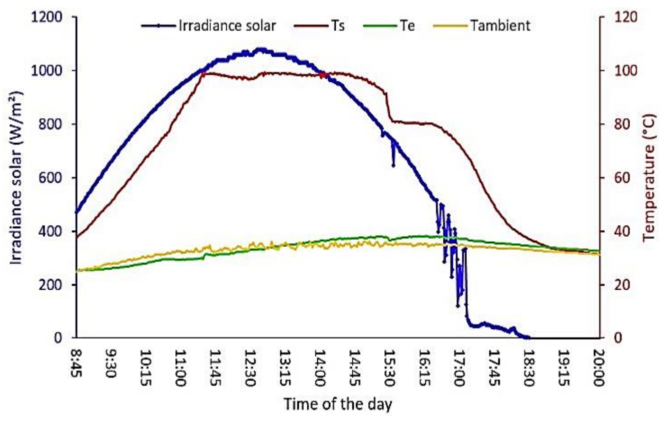


Figure 12. T_e and T_s evolution (October 14, 2019)

As can be seen from Figures 12 and 14, for the day (October 14, 2019) the collector provides a very attractive quantity of hot water with a ΔT reaching 33°C, with the ambient temperature below 35°C. During this day, it was also noticed that the temperature of the collector-inlet water remained near to $T_{ambient}$. This has made the yield more uniform and increases with sunlight.

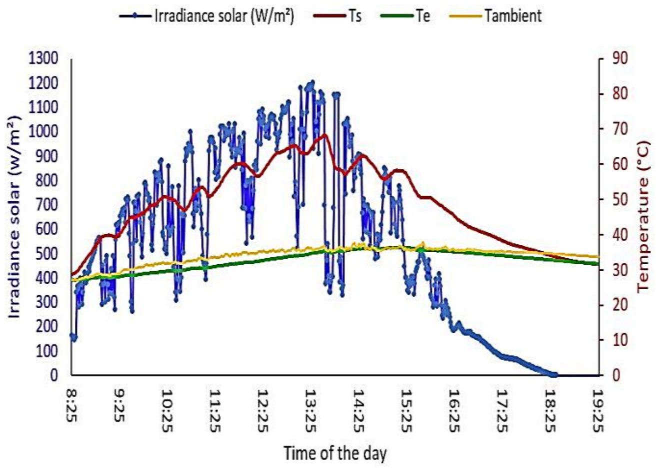


Figure 13. T_e and T_s evolution (October 16, 2019).

From the Figures 13 and 14 it can be seen that, the day (October 16, 2019) is characterized by a cloudy sky. However, the solar collector was able to produce significant temperatures when solar radiation was available, which confirms that the absorbent and the thermal insulation have positively interacted with the climatic fluctuations of that day.

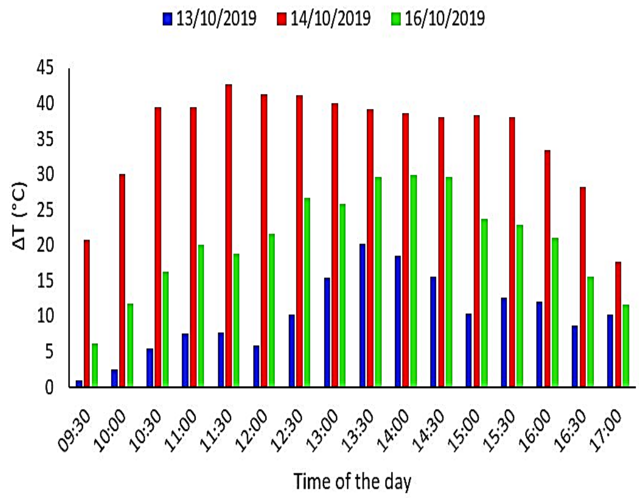


Figure 14. ΔT evolution

From Figures 14 and 15, the ΔT value is varied between 0.9°C and 42.66°C, while mean hourly yield is changed from 28.3% to 99.9% for the testing days. We noticed that the performance of the system is significant on the days October 13 and 14, 2019 compared to October 16, 2019.

Despite the disturbance observed in the intensity of the solar radiation, we notice that the system provides high temperatures during a cloudy day, where the water temperature at the input is lower than the $T_{ambient}$.

We noticed that the solar-water-heater performance is directly related to the collector ΔT. The insulation of the upper part of the absorber helps reduce heat loss at this level and increases the temperature of the drain water, this h remains trapped in the absorber and delay the drop in efficiency until 5 p.m.

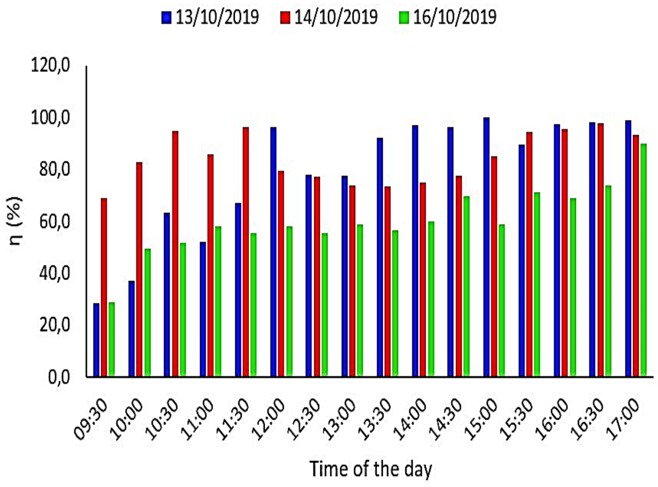


Figure 15. Mean hourly yield for the testing days

5. CONCLUSION

The study highlighted the testing results of the thermal performances of solar water heater under Sahara weather conditions.

The temperatures reached confirm our choice for the importance of the insulating material. The experimental results show that with an initial water temperature of 25℃; the maximum water temperature obtained varies from 55 to 75℃, with an average hourly output varies between 30 and 90%, solen the climatic conductions of operation.

Insulation with plant tissue extracted from the trunk of a date palm (FEDM) gave good thermal insulation at a lower cost. The obtained results confirm the feasibility of this type of system and encourage us to manufacture locally using local materials.

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