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Research Article

Experimental Study of a Prototype Solar Water Heater Used in Sahelian Homes

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Abstract

Environmentally-friendly, low-cost energy supplies are the backbone of sustainable development. Development must not only meet current needs, but must also look to the future and consider environmental issues as a challenge. Solar power as an environmentally-friendly energy source is a promising way of reducing greenhouse gas emissions. One of the most important applications of solar energy is the production of hot water using solar water heaters. These solar water heaters, which can provide between 100 and 200 l/d of hot water over a temperature range of 40-70 ℃., are of the separate-element and integrated-storage types. In the Saharan environment, hot water requirements are concentrated in winter. It is therefore necessary to develop efficient systems adapted to this reality. It is then necessary to develop effective systems adapted to this reality. There is a need to propose a new design to boost the solar irradiation absorbed by the collector-storage while reducing nighttime thermal losses. For greater user-friendliness and with the aim of adapting them to the Saharan environment, it is also necessary to offer solar water heaters integrated into the building and operating mainly in the winter period. The present work represents an experimental study of a solar water heater with separate elements and a simple design, in a Burkinabe climate. This is a separate element solar water heater with a capacity of 200 liters with an aluminum collector as absorber designed at the Research Institute of Applied Sciences and Technologies (IRSAT). The water in the tank forms a loop with the sensor. In the tank, donut a copper coil of a length equal to 15m with a diameter of 16mm. They use the principle of thermosyphon (cold water pressure) to circulate and store heat and are simpler and less expensive, but can only be installed in sunny countries and have limited efficiency. During the measurement period from 11:25 a.m. to 4:05 p.m., the maximum temperature of the hot water was around 57 ℃ at 11:45 a.m., and that of the cold water was around 27 ℃ at 12:15 p.m.. The experimental results showed acceptable thermal performance despite the simplicity of the sensor. Finally, an improvement can easily be made whether by perfecting the thermal insulation or using selective collection surfaces.

Keywords

Energy, Solar, Water Heater, Performance, Thermal

1. Introduction

In the current ecological crisis induced by the irrational consumption of fossil fuels producing greenhouse gases, solar water heaters seem the ideal solution to meet the hot water needs of households in rural areas. The most commonly used solar water heaters are made up of separate elements: the flat collector and the storage tank [1]. As a

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result, the cost of this type of system always remains high even if their performance reaches very appreciable levels. A simplification consists of creating rustic systems where the capture and storage functions are provided by the same element. They are called self-storing or sensor-storing and their performances are generally lower compared to those with separate elements [1]. In order to improve the performance of this type of system, a great deal of work has been carried out by a number of researchers [2], and recently [3] and then [4] have detailed the development of self-storage solar water heaters worldwide. The integrated storage system is simple to build, install and handle. It is compact, takes up less space and is aesthetically better than the system with separate elements, but it is less widely used than the latter because the hot water storage tank has high heat losses at night and during periods of low sunshine. This is because total protection of the storage tank is difficult, given that it also constitutes the absorbing surface for solar radiation, unlike the separate-element system where the storage tank is totally thermally insulated. The new designs aim to reduce front losses by integrating mechanisms to reduce these losses not only on the illuminated face but also inside the collector cavities or on the surfaces of the storage tank of the water heater with integrated storage. Baer, S. [5] provides an opaque and pivoting insulating cover, placed on the front face of the collector during the night and removed during the day. This device gives good results, only it requires manual interventions every day. The use of an automatic control of this cover solves the problem of operation and reliability of the system but it increases the cost of the installation and requires extensive maintenance and a supply of electrical energy to power the control system. Other techniques such as the use of selective covering [6], transparent insulation [7, 8] and multiple glazing [9] have been tried with varying degrees of success but these techniques have consequently the increase in installation costs and the reduction in the fraction of sunshine absorbed in certain cases. New techniques are also being used, one of which involves the use of a perforated envelope to limit heat loss from the inside of the tank to its outer walls [10], while the other involves partial insulation of the storage tank at the top, thereby reducing heat loss [11]. The geometry of the reflectors and the arrangement of the storage tank inside the cavity are also used to reduce heat loss by partially or completely insulating the absorbing surface of the tank exposed directly to solar radiation [12, 13]. This arrangement requires high reflectivity of the mirrors to maintain high optical efficiency, and the horizontal arrangement of the tank reduces the fraction of insolation absorbed compared with a vertical arrangement [11]. In the present work, we propose a new design of an integrated storage water heater with a compact parabolic concentrating system (CPC) with the aim of raising the water temperature level during the day and reducing the nocturnal thermal losses with a certain maneuver of the concentration system [14]. This is why we chose to study solar thermal systems through the theme: "Experimental study of a solar water heater" in order to fully understand how these systems work. Firstly we will carry out an experimental study of the solar water heater. Secondly, we will show the results from the experimental study.

2. Description of the Solar Water Heater

This is a 200-liter separate-element solar water heater with an aluminum collector absorber designed at the Research Institute of Applied Sciences and Technologies (IRSAT). The water in the tank forms a loop with the collector. A copper coil 15m long and 16mm in diameter is inserted into the tank. When the collector is exposed to the sun, the hot water it contains naturally seeks to rise, creating a natural circulation known as thermosiphon circulation. Over the course of the day, the water in the tank heats up. Heat loss is limited by glass wool insulation.

The hot water circuit intended for use passes through the coil. The residence time of the water in the coil allows sufficient heat exchange so that the water at the outlet acquires the temperature of that of the tank.

2.1. Materials

The capture system

Figure 1 shows us the photo of the sensor

Figure 1. *Photo of the sensor.*

It consists of an aluminum absorber with a surface area of approximately 2m2, a 4mm thick window, and glass wool as insulation.

To make it, we used:

1) heavy angles of 30 and 40 for the frame
2) a flat iron for installing the window,
3) an insulation which is glass wool
4) a rafter to position the absorber,
5) silicone for sealing,
6) the absorber is made of aluminum. Aluminum has a high thermal conductivity. In this case, it's a dark shade (black) to increase its absorption coefficient and thus increase

the energy absorbed.

7) the glass is 4mm thick. The level of the collector is lower than that of the reservoir, so that the thermosiphon effect is easily achieved. It should also be noted that the slope must be at least 15 degrees and must face due south.

The coil

Figure 2 shows a picture of the coil.

Figure 2. *Photo of the coil.*

With a length of 15m and an external diameter of 16mm, it offers an exchange surface of approximately $2\pi RL = 0.76\ m^2$; where

R=radius (0.008m) and L=length (15m)

Its entry and exit points are all located at the top of the tank. As such, this exchange cannot be described as either co-current or counter-current. The water intended for use passes through the coil. The coil is located in the upper 3/4 of the tank, while the lower part is cooler. With a length of 15 m, the water circulating in the coil has enough time to reach a temperature close to that of the water in which the coil ends.

The reservoir

With a capacity of around 200 liters, it is located at a higher level than that of the sensor. It is made from a black steel sheet. To limit heat loss it must be thermally insulated. For this we use glass wool to cover it completely. A final covering with corrugated metal allows the protection of the glass wool. The water contained in the tank, forming a loop with the absorber, is heated by the thermosyphon effect. It is essential to insulate hot water pipes. Figure 3 shows the image of the storage tank.

Figure 3. *The image of the storage tank.*

2.2. The Water Heater Thus Described is as Follows

Figure 4. *Photo du prototype du chauffe-eau solaire étudié de l'IRSAT.*

3. Experimental Study

3.1. Material Used

Eight (8) probes were placed on the water heater shown above. These probes are connected to a data logger unit called DATALOGGER GL220. To power the logger unit, we used National Electricity Company of Burkina (SONABEL)'s electrical power. Cold water was collected in a bucket and its temperature determined with a probe. Irradiance was measured using a solarimeter. Figure 5 shows the image of the GL220 Midi Datalogger.

Figure 5. *Digital data logger (Temperature).*

Figure 6*. Image of the solarimeter.*

3.2. Methodology

The water heater is put into operation (cold water inlet valve open). We then placed thermocouples and a solarimeter so as to be able to follow the evolution of the following temperatures with a variable time step and sunshine:

1) the ambient temperature of the site (Tamb),
2) the temperature of the cold water at the sensor inlet
3) the temperature of the window at three points (Tvitre1, Tvitre2, Tvitre3) from bottom to top
4) the temperature of the hot water leaving the tank (Hot)
5) the temperature of the metal plate below the sensor (Tfond)
6) irradiation

In this study, we limited ourselves to the results of 10/10/2023 and

11/10/2023. We consider the experience from the date of 10/11/2023 where the experiment was well carried out. The results obtained were represented on the curves below. We represented:

1) the variation of cold water temperature and that of hot water as a function of time,
2) the variation of the sensor temperature as a function of time,
3) the variation of irradiation as a function of time.

4. Results and Discussions

Figure 7 shows us the evolution of the temperature of hot and cold water over time. The time step used is ten (10) minutes.

The maximum temperature of hot water is approximately 57 ℃ at 11:45 a.m. and that of cold water is approximately 27 ℃ at 12:15 p.m. During the measurement period which begins at 11:25 a.m. until 4:05 p.m., we note a hot water temperature between 38 ℃ and 40 ℃. This hot water temperature is acceptable for direct use. Observation of the curve shows that the temperature of hot water is slightly linked to that of cold water. Figure 8 shows the evolution of solar radiation as a function of time.

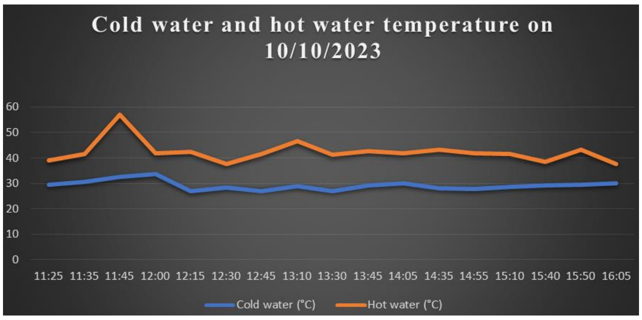

Figure 7*. Evolution of cold water and hot water temperatures as a function of the weather on 10/10/2023.*

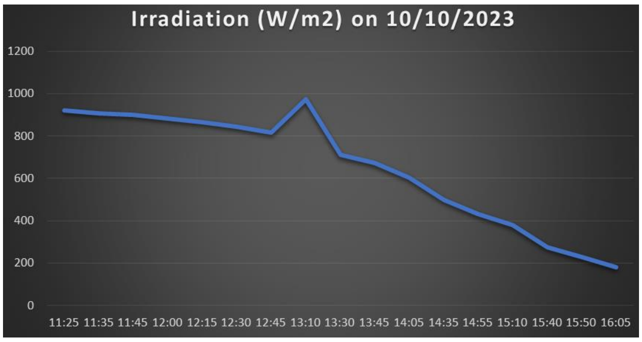

Figure 8*. Variation in solar radiation depending on the time of day on 10/10/2023.*

The irradiation figure does not look like a bell part as in the literature because of the late start of the measurements. The maximum value of 970W/m2 is obtained around 1 p.m., the curve decreases overall from 11:25 a.m. to 4:01 p.m. Figure 9 shows us the evolution of the temperature of hot water and that of cold water as a function of time during the day of 10/11/2023.

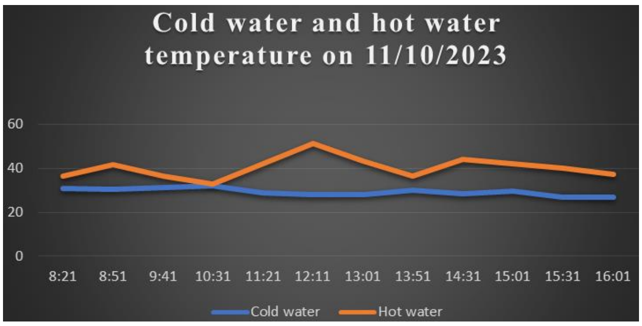

Figure 9*. Evolution of the temperature of cold water and that of hot water as a function of time during the day of 10/11/2023.*

The temperature of the cold water is practically constant while that of the hot water shows some small variations (51.5 ℃ maximum at 12:11 p.m. and 37 ℃ minimum at 4:01 p.m.). This is due to differences in the amount of energy stored during the day. Figure 10 shows the evolution of irradiation as a function of time

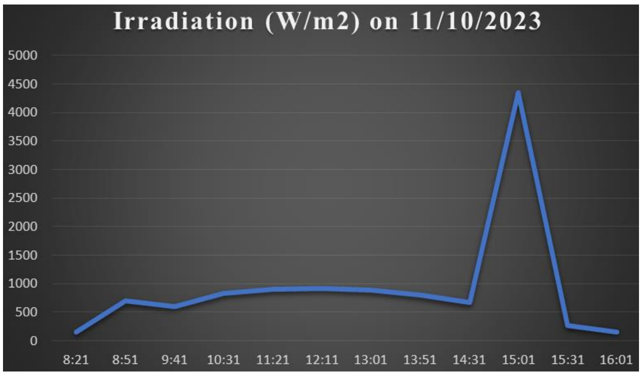

Figure 10. *Variation of irradiation as a function of time on 10/11/2023.*

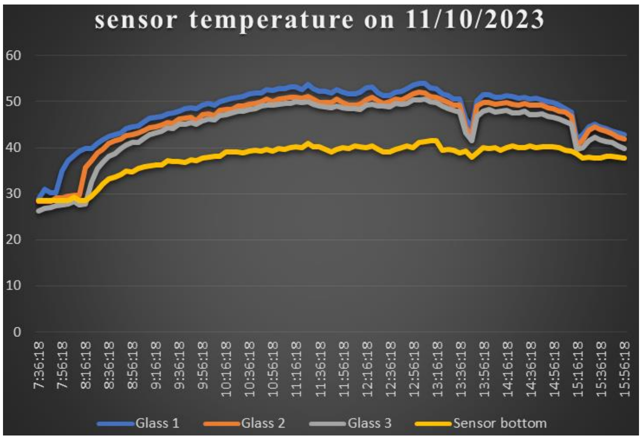

Figure 11. *Variation of sensor temperature as a function of time on 10/10/2023.*

We observe good sunshine with the maximum irradiation value reaching 900W/m2 at 12:11 p.m. It is also at this time that we have the highest hot water temperature. This confirms that the temperature of hot water is linked to solar radiation. Figure 11 shows the variations in sensor temperatures

We see that the temperature of the window increases from the bottom to the top of the sensor because of the thermosyphon effect. And that the temperature of the metal plate below the sensor (Tfond) is the lowest temperature. This is due to the quality of the orientation and tilt. We can explain this through the quality of the sensor insulation. The experimental study of the performance of this prototype solar water heater produced using simple means and available materials gave acceptable results. The performance of such a system is interesting for domestic water heating. Our results are in agreement with those obtained by [15] who show the thermal efficiency of solar water heater in thermal storage by designing a hot water storage tank spherically and using a phase change material (PCM). Their research aims to evaluate the performance of the spherical tank in terms of thermal energy storage capacity, thermal classification, mixability and thermal behavior of the (PCM). The optimal flow rate is determined in order to achieve maximum tank efficiency [15]. Jaber, M. W. K. et al. [16] validated that the proposed cone guidance improved the evolution of thermal stratification in the reservoir. An increase of 3.85 ℃ is obtained in the average tank temperature with the use of the conical guide after 3 h of charging. The approximate efficiency of the heat exchanger coil is approximately 90% while an increase of 7.6% is achieved through the use of the guide. Experimental research carried out by [17] made it possible to determine the quantity and temperature of Domestic Hot Water (DHW) at a constant mass flow rate of 0.1 kg/s. The prototype unit has shown that it can provide 99.1 l of hot water at 40 ℃ for 15 min and 39 s, while using lower temperature domestic hot water (up to 37 ° C) allows you to increase the quantity of hot water delivered up to 15 min and 39 s. at 156.2 liters [17]. Experimental results from the same researchers showed the viability of the prototype, areas for improvement, and further optimization possibilities. Overall, the results of the study are relevant for the development of latent thermal energy storage systems using fin-and-tube heat exchangers in tanks and for the feasibility of integrating such systems into DHW systems.

5. Conclusion

During this work, we studied a prototype of a solar water heater for the production of domestic hot water. This work allowed us to study the performance of the solar water heater through an experimental study. The results show that the hot water outlet temperature is related to the cold water temperature and irradiation. The performance of the water heater can be improved by adjusting these two parameters. In addition, good insulation of the storage tank will also increase the performance of the water heater over time. Maintenance of the water heater may be necessary for its proper operation. Once the installation is properly carried out, taking into account hot water consumption, the major maintenance is cleaning the sensors which allows good capture of solar rays. This water heating system, which uses renewable energy, namely solar, could contribute to sustainable development and preserve the environment.

Abbreviations

R	Radius (m)
L	Length (m)
Tamb	Ambient Temperature of the Site (℃)
Tvitre (1; 2 and 3)	Temperature of the Window at Three Points from Bottom to Top (℃)

Hot	Temperature of the Hot Water Leaving the Tank (℃)
Tfond	Temperature of the Metal Plate Below the Sensor (℃)
IRSAT	Research Institute of Applied Sciences and Technologies
CPC	Compact Parabolic Concentrating
SONABEL	National Electricity Company of Burkina
PCM	Phase Change Material
DHW	Domestic Hot Water

Author Contributions

Abdoul Aziz Ouiminga is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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