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Experimental study on the performance of built-in storage tank solar water heater in Benghazi climate

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ABSTRACT

This paper presents an experimental investigation on a built-in solar water heater in Benghazi climate. The heater was a rectangular in shape (1440 × 720 × 6 mm) and manufactured locally from galvanize iron sheets with capacity of 60 L. The top surface of the heater was painted with black paint to perform the dual function of absorbing the solar energy and storing the heated water. A glass sheet of 2 mm thickness was used to cover the top surface. The sides and bottom of the heater were insulated with fiber glass wool to reduce the heat loses. Experiments have been carried out to test the performance of the heater: end-day, hourly and night cooling effect measurements. The results showed that the heater works efficiently under Benghazi climate. The maximum water temperature of the heater was 76°C, obtained on bright days. Night cooling effect on the heater was reduced by using a wooden cover or well-insulated drum.

Keywords: Isolation, insulation, collector, efficiency, cooling effect, latitude angle.

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INTRODUCTION

At the present time, the solar energy is more attractive than ever as an alternate energy source, which can provide heating and cooling, water distillation and electric power generation at economically competitive costs and without environmental degradation. It has been known that Libya has an ideal location for use of solar energy, since many hours of bright sunshine are reported in many locations (Saied and Shuaeib, 2007; El bagdadi and Garsho, 2007). Solar water heating for domestic use is at present the most attractive way of utilizing solar energy. This is largely due to regular daily demand of hot water at moderate temperature resulting in an efficient collection of the incident solar radiation without the necessity of large storage. Solar water heaters can be classified into two types: collection and storage in separate units and collector - storage in a single unit. The collection - storage in separate units consists of a grid of water carrying tubes bonded to the absorber plate. It has been observed that a large temperature difference between the collector plate and tubes is a drawback, resulting in lower collection efficiency. Moreover, the collection efficiency depends highly on the bond between the plate and the tubes. The usual bond method is either soft soldering or gas welding. Both are expensive. Also, the soldered or gas welding bond may develop crakes due to thermal stresses associated with heating and cooling. These cracks cause leakage and corrosion problems. Increased cost due to separate storage tank and absorber unit as well as slightly lower efficiency is the demerits of such solar water heater.

The built-in storage tank solar water heater (Integrated collector storage solar water heater) is one attractive to tradition the solar water heating system. Since the built-in storage tank solar water heater is a compact unit (collector and storage tank are one unit), the cost of the heater is remarkably reduced. Such unit is widely used in many countries such as India, South Africa, Japan, Palestine and China (Smyth et al., 2001; Chavrasia and Twidell, 2001; Souge et al., 2014). The heater has been studied by many researchers. For example, Faiman et al. (2001) investigated the night cooling effect of built–in storage tank solar water heaters and they devolved a device that automatically lowers the heat loss coefficient of the system during the night. Madhlopa et al. (2006) studied, experimentally, the effect of tank-interconnection geometry on temperature stratification in an integrated

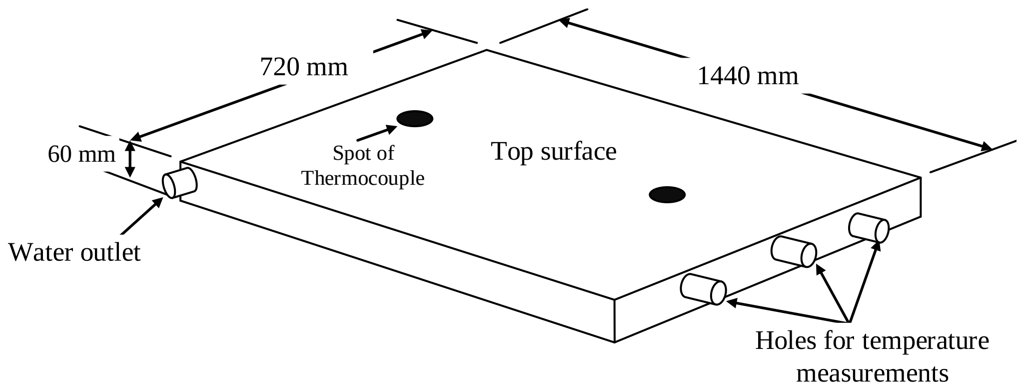


Figure 1. A schematic view the storage tank of the solar heater.

collector–storage solar water heater with two horizontal cylindrical tanks. Reddy (2007) carried out thermal modeling and analytical studies on solar integrated collector storage water heating systems. Two insulation materials were used to cover the top surface of the storage tank. The top layer, which made from transparent insulation materials, works as a glass cover and the bottom layer which made from paraffin wax works as an absorbing plate. He found that the two insulation layers increased the latent heat storage and reduced the heat losses of the heater. Bozkurt and Karakicik (2012) studied, experimentally and theoretically, the thermal efficiency of a solar pond integrated with solar collectors. Good agreement between theoretical and experimental efficiencies was found. Al-Kayiem and Lin (2014) used the paraffin wax and nanodditives as an energy storage medium at different inclination angles. Recently, Chaabane et al. (2014) proposed a new method to reduce the night cooling effect, in which the storage tank is covered with an outer glass tube. Also they conducted a parametric study in order to evaluate the optimam air spacing gap between the water tank and the covering glass tube.

In brief, it can be observed that the night cooling effect is the major problem of built–in storage tank solar water heaters and the most studies attempt to overcome this problem using different ideas and methods. This paper aims to present an experimental study on the performance of such heaters in Benghazi climate and proposes two methods to minimize its night cooling effect.

EXPERIMENTAL

Manufacturing of the built-in storage tank solar water heater

The built-in storage tank solar water heater was manufactured locally, in the workshop of the University of Benghazi - Libya, using galvanized sheet metals, 6mm steel angles and fiber glass wools. A rectangular box storage tank was manufactured from 2 mm rectangular metal sheets, which welded together with dimensions of 1440 × 720 × 60 mm by arc welding (Figure 1). The capacity of the tank was 60 L. The outer top surface of the tank was painted by matt black paint to work as a plate collector to the heater. Inlet, outlet and drain steel pipes were welded on the sides of the tank. Three holes at the top sides were made for measuring the water temperature inside the tank. Two thermocouples were fixed at the top and bottom of the outer surface of the tank for measuring collector plate temperatures.

Assembly of the heater

The collector-storage tank was rested in a box whose skeleton was made of steel angles and covered by galvanized metal sheet 2 mm thickness. The bulging of the tank under water pressure was reduced by using a steel plate bolted on the sides of the box. The top surface of the tank was covered with a single glass window cover of 3 mm thickness. The air space gap between the outer top surface of the tank and the glass cover was 20 mm. The whole assembly was carried by a steel angle stand which inclined at 32° from the horizontal (according to the latitude of Benghazi city) and was oriented due to south to collect maximum solar radiation. Inlet, outlet and drain pipes were welded to the storage tank. The storage tank was insulated with fiber glass wool, 100 mm at the bottom surface and 50 mm at the sides. All the connection pipes were insulated with 50 mm of fiber glass wool as shown in Figures 2 and 3.

Measuring technique

Water temperature, inside the storage tank, was measured at nine places by a thermocouple according to the grid of the points as shown in Figure 4. The thermocouple was fixed at the front of long movable wooden stick that can be inserted inside the storage tank to the required depth through three pipes in the upper side of the tank. The solar radiation (insolation W/m^2) was measured by a pyranometer which inclined at the same angle as the collector plate. The ambient temperature was read by a glass thermometer.

Night cover and insulated drum

In order to study the effect of night cooling of the heater, two methods were suggested. The first method is to cover the outer surface of the collector by a wooden cover to reduce the heat loses during the night. The cover was a wooden frame with damnations of 960 × 1700 × 150 mm, insulated from inside by a 100 mm layer of

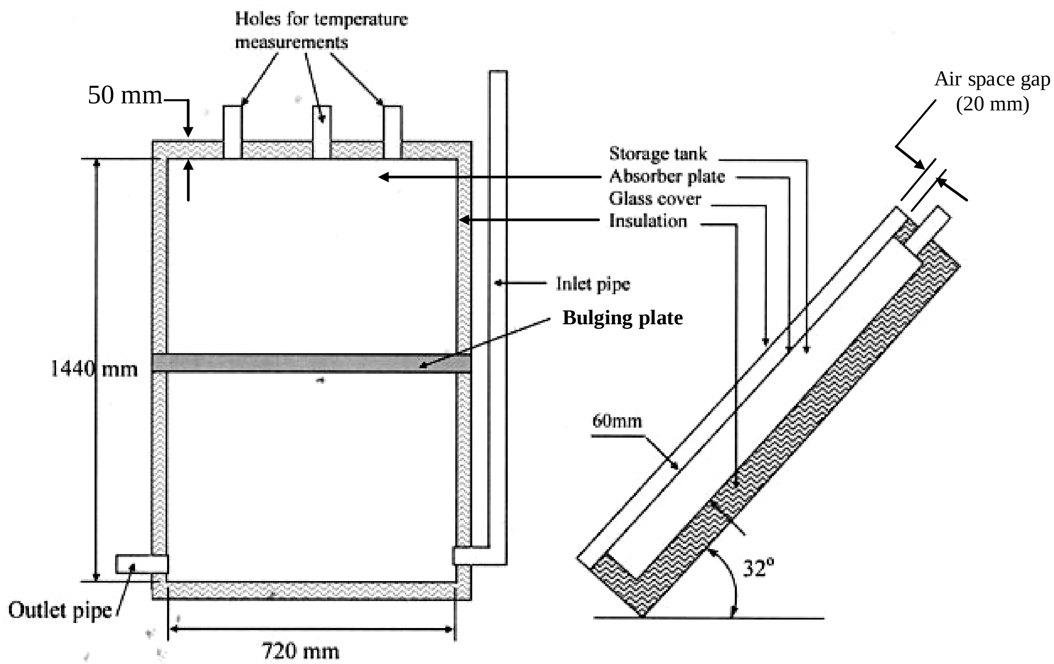


Figure 2. A schematic view of the built-in storage tank solar water heater.

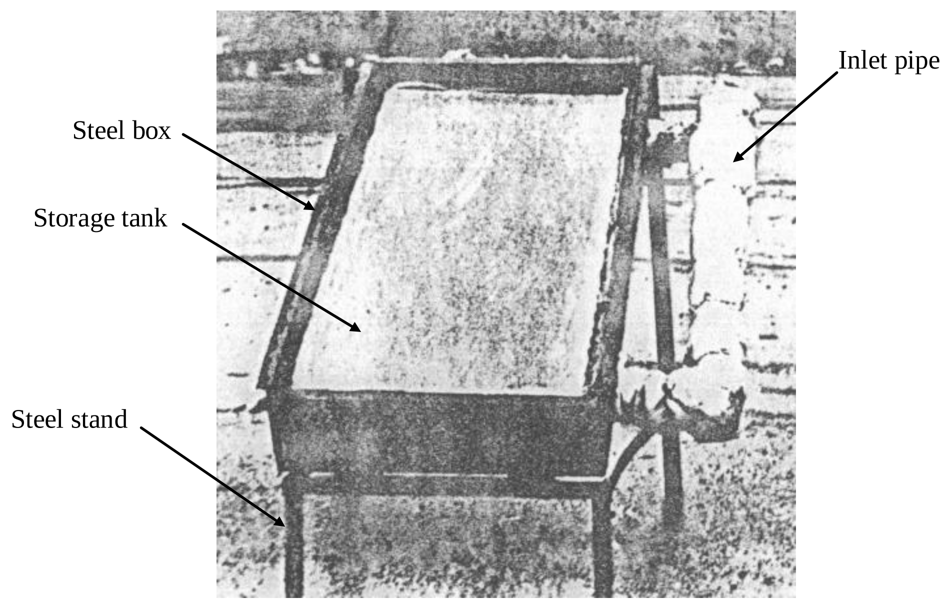


Figure 3. A photograph of the built-in storage tank solar water heater.

fiber glass wool. Figure 5a shows a photograph of the heater covered with the night wooden cover and Figure 5b shows a cross-section view of the wooden cover.

The second method is to transfer the hot water from the heater to an insulated drum at the end of day. The insulated drum was made from galvanized metal sheet of 2 mm thickness and has a capacity of 66 L. The drum has three holes; two of them were in the top surface, one for measuring water temperature and the other for water inlet. The third hole was made on the side of the drum for outlet pipe. The drum was insulated with 20 mm thick fiber glass wool (Figure 6).

Measuring schemes

In order to evaluate the performance of the heater, several measurement schemes were carried out. In the daily scheme, the storage tank of the heater was filed daily at 8:00 am with fresh water. Initial water and ambient air temperatures are noted with a glass thermometer. The heater was left through the day without

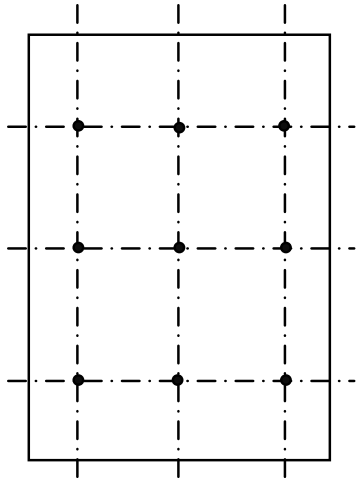
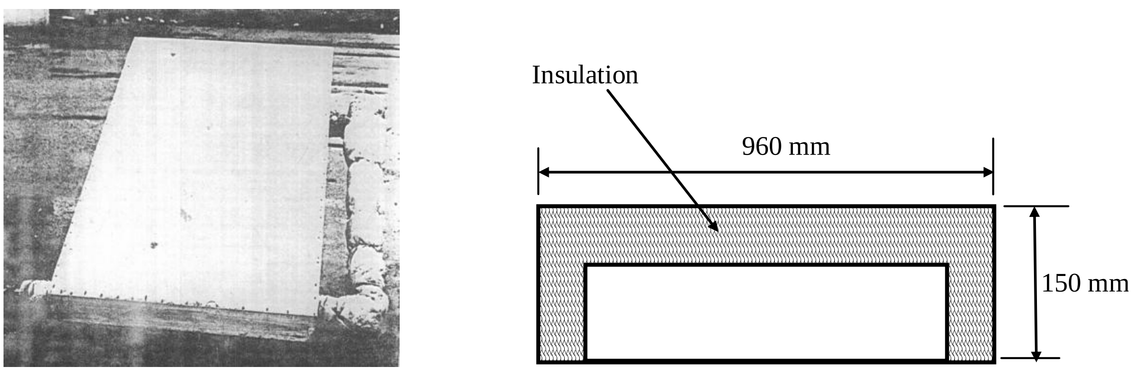


Figure 4. Grid of points for temperature measurements inside the storage tank.



(a) (b)

Figure 5. (a) A photograph of the heater with night wooden cover. (b) A cross-section view of the night wooden cover.

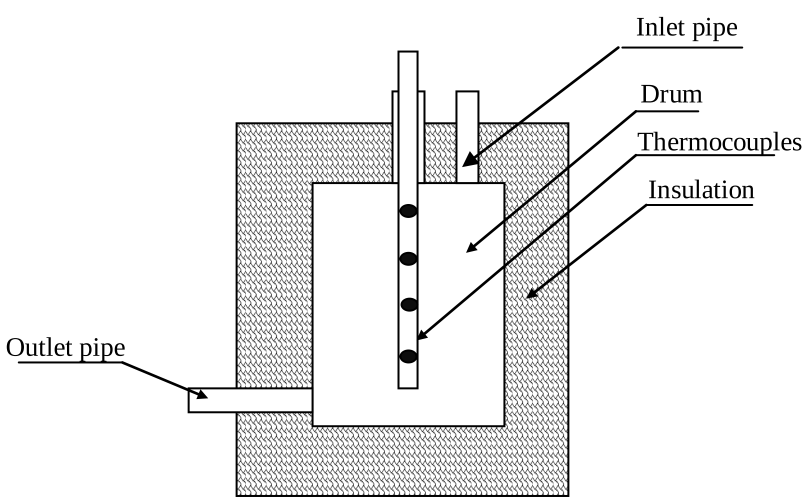
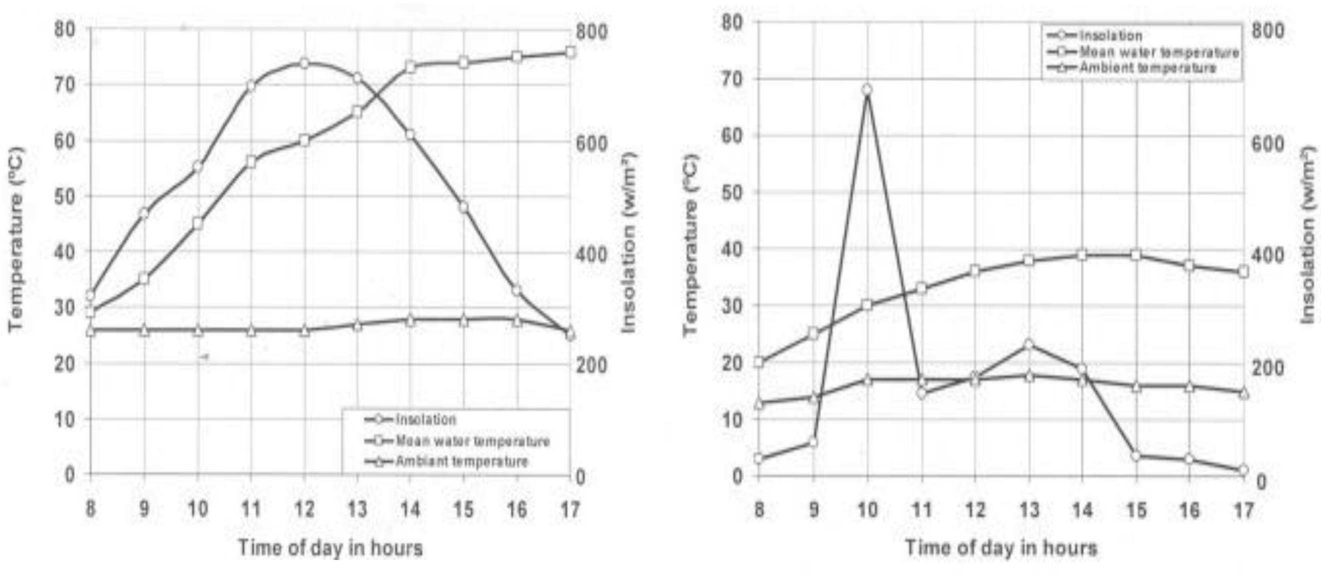


Figure 6. The insulated drum.



(a) (b)

Figure 7. Hourly variation of solar radiation intensity, ambient and mean water temperature. (a) sunny day (b) cloudy day.

drawn off. At 17:00 pm, the water was discharged after recording the storage water and ambient temperatures. In the hourly scheme, the storage tank was filled in the usual manner and the ambient temperature, storage water temperature and solar radiation were measured hourly. The water temperature inside the storage tank was measured at 9 points through the area of the tank and mean value was calculated.

In the night cover scheme, the water was allowed to heat up during the day without draw off. At 17:00 pm, the heater was covered with night cover after recording the water and ambient temperatures and then left it over the night. In the next morning, it was removed and water temperature of the storage tank and air were again recorded. In the insulated drum scheme, at the end of the day, the hot water was drained off into the insulated drum. The drum was then left overnight and in the next morning the water is drained off after recording its temperature.

RESULTS AND DISCUSSION

The heater was tested experimentally for seven months (from August 1st, 2006 to March 7th, 2007). The measurements included solar radiation, ambient temperature and mean water temperature in the storage tank.

Performance curves

Figure 7a and b shows a typical examples of hourly measurement for a sunny summer day on September 9th, 2006 and cloudy winter day on January 5th, 2007, respectively. It is clear from the Fig. (7.a) that the solar radiation increases rapidly from early morning to reach its maximum value (755 w/m^2) at 12:00 am and then decreases to reach it its minimum value (300 w/m^2) at 17:00 pm. The main water temperature of the storage tank always increases during the day time to reach its maximum value (78°C) at 17:00 pm. The ambient temperature appears to be approximately constant during the day time with main value about 30°C. This manner of the curve has been observed for all the bright days. In Figure 7b, the solar radiation fluctuates during the day time with maximum value of 700 w/m^2 at 10:00 am where as the mean water temperature inside the storage tank increases slowly during the day time to reach its maximum value of 40°C at 3:00 pm. The ambient temperature was about 18°C for all day time.

Day-end mean water temperatures

Figure 8 shows the variation of day-end mean water temperatures of the heater during the period of August 1st, 2006 to March 7th, 2007. It can be observed that the temperature fluctuations round its mean value because the heater is directly affected by climatic conditions. Also, it is clear that the fluctuation is more pronounced during the winter season and minimal in summer season. During the summer the maximum water temperature reached was 78°C on August 22th, 2006 while the minimum was in 32°C on January 5th, 2007.

Daily thermal efficiency

The daily thermal efficiency of the heater is defined as the ratio of total energy gained by water to the solar energy incident on the absorber plate during the day. Mathematically it can be expressed by the following

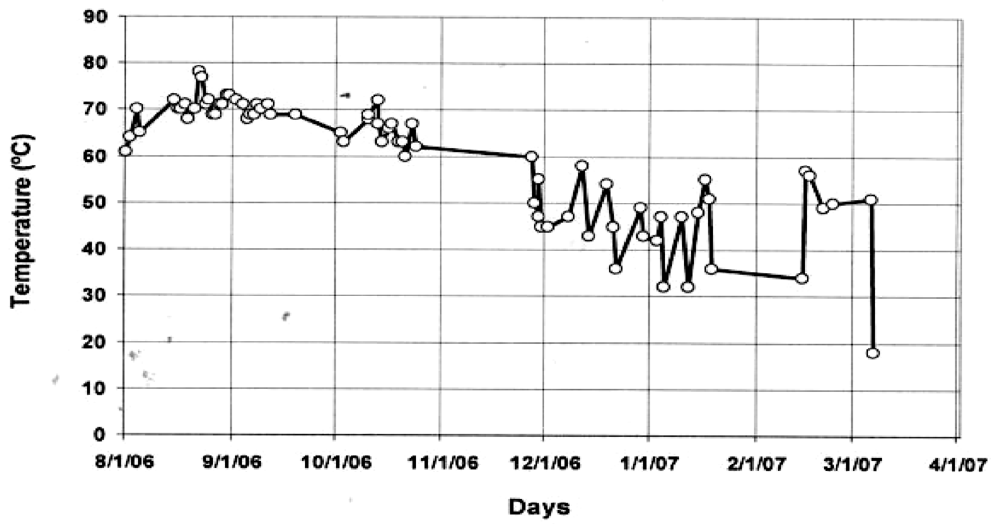


Figure 8. Variation of day-end mean water temperatures for the period from August 1st, 2006 to March 7th, 2007.

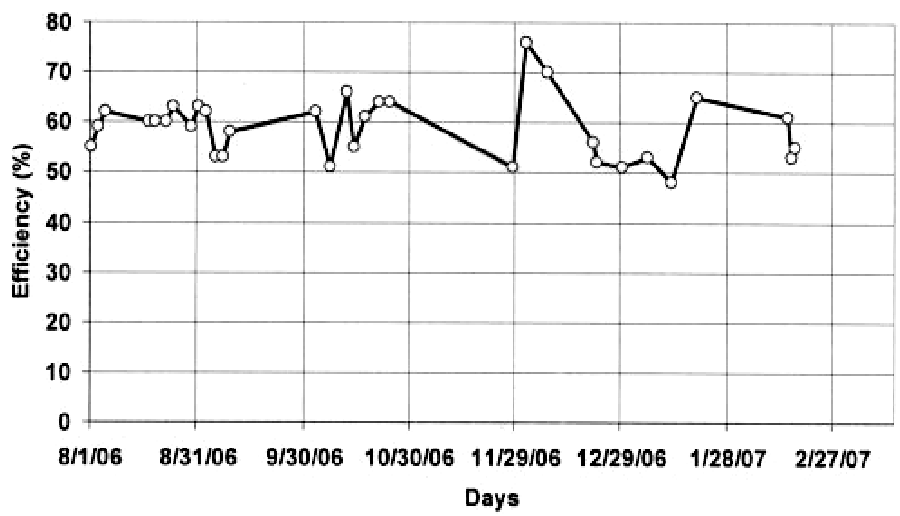


Figure 9. The daily thermal efficiency versus days.

equation:

$$\eta = \frac{m C_P \Delta T}{3600 \sum I} \quad (1)$$

Where: m is the mass of the water (kg), Cp is water specific heat (J/kg-°C), ΔT is increase in water temperature (°C) and ∑I is the Insolation (solar radiation w/m^2).

Figure 9 shows the variation of daily thermal efficiency of the heater during the period from. August 1st, 2006 to February 16th, 2007. It can be seen that the efficiency fluctuates around its mean value (about 58%). The maximum efficiency was 76% and the minimum was about 48%.

Effect of night cooling

The main drawback of the built-in solar water heater is the heat loss during the night hours. This is clear from the Figure 10, which shows night cooling effect. The temperature drop overnight was 14°C.

As a result of this drop, the heater can not be used for providing hot water in the early morning. As mentioned previously, to overcome this drawback, two methods were used. The first method is to cover the glass with an

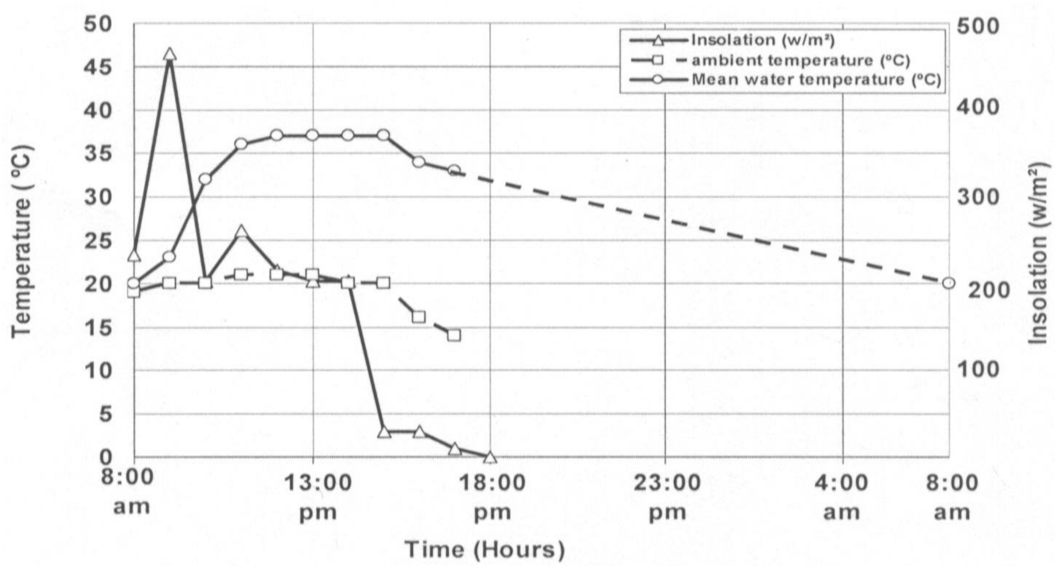


Figure 10. Night cooling effect on the performance of the built-in solar water heater.

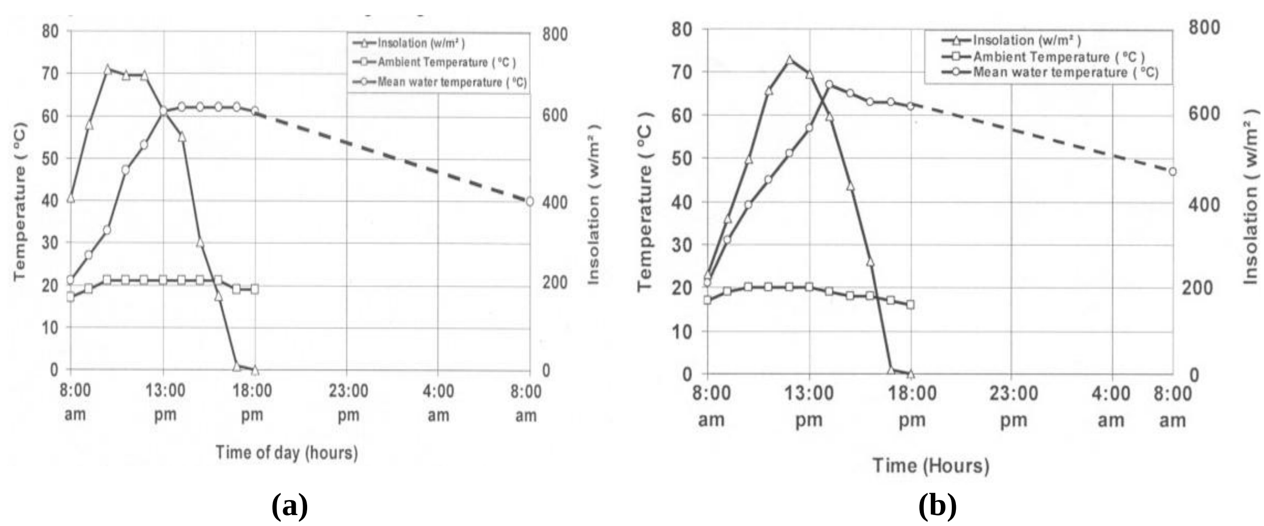


Figure 11. The effect of night cooling on the performance of the heater using (a): wooden cover and (b): well insulated drum.

insulated cover. Figure 11a shows the night cooling effect on the performance of the heater with night wooden cover. It can be seen that the water temperature inside the storage tank raises up to 63°C at 17:00 pm. This temperature falls to 40°C in the next morning when the heater was lifted covered during the night. The second method is by storing the hot water in an insulation drum overnight. Figure 11b shows the night cooling effect for the heater with well insulated drum. It can be observed that the temperature drop overnight was 9°C. In the morning temperature overnight 47°C was recorded.

From these two methods, it can be observed that both methods improved the performance of the heater significantly. However, using well insulated drum showed better results than the night wooden cover.

CONCLUSIONS

1. Performance study made for a built-in solar water heater during the period from, August 1st, 2006 to March 7th, 2007 showed that the heater works efficiently under Benghazi climate with maximum temperature of 78°C in bright days and 45°C in cloudy days. The maximum daily efficiency was 76%.
2. Night cooling effect on the built-in solar water heater can be reduced, hence improve the performance of the heater, by using a wooden cover or well-insulated drum.

3. The well insulated drum showed better results then the night wooden cover.

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