Solar Energy
And Sustainable Development
Refereed, biannual scientific journal issued by
Center for Solar Energy Research and Studies

In–Situ Measurements of the Performance of Thermosyphon Solar Water Heating Systems in Libya[I]

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الملخص: تستعرض هذه الورقة مشروعا أنجز بمركز بحوث ودراسات الطاقة الشمسية للتعريف بمنظومات الطاقة الشمسية في ليبيا. حوالي 100 سخانة شمسية ركبت على أسطح المنازل بالقطاع المنزلي، واختير بعض من تلك السخانات وركبت عليها أجهزة قياس ومتابعة لتقييم الأداء الحراري للسخانات. أظهرت نتائج تحليل البيانات التي تم تجميعها لمدة عام كامل لمنظومة تم تركيبها لعائلة في قرية تبعد حوالي 90 كم جنوبي طرابلس، أن المشاركة الشمسية للمنظومة كانت 55.8 % لمتوسط كميات مياه مسحوبة تعادل 144 لتراً في اليوم عند متوسط درجة حرارة سحب حوالي 46.6 °م. وكانت الطاقة الكلية المسحوبة خلال عام كامل 1557 كيلو واط ساعة. ويستنتج من ذلك أن مثل هذه المنظومة ليست كافية من حيث فعالية التكلفة لمكان التركيب الحالي. فمن المستحسن أن تفوق المشاركة الشمسية السنوية لمنظومات تسخين المياه في القطاع المنزلي 70 % من أجل تحقيق الفعالية من حيث التكلفة وللمساعدة في الانتشار الموسع لهذه التقنية.

***Abstract*:** This paper reports on a project carried out by the Centre for Solar Energy Research and Studies (CSERS) to familiarise Libyan people with solar water heating technologies. Around 100 solar water heaters have been installed in the domestic sector and selected systems were equipped with monitoring instruments required to evaluate thermal performance. The paper presents the results of data collected over a one year period from a system installed in a family residence situated in a village located 90 km south of Tripoli (Libyan capital). The results showed that the system solar fraction was 55.8% of the average amount of daily hot water withdrawn (144 litres) at an average withdrawal temperature of 46.6 °C. The total energy withdrawn during the whole year was 1557 kWh. It is concluded that such a system is not adequate in terms of cost effectiveness for the current installed situation. It is recommended that the annual solar fraction for any solar water heating system should be over 70% in order to achieve cost-effectiveness and to help wide spread take-up of this technology.

I *Presented in "ICRE Proceedings, 2010, 5-8/4/2010, Syria"*

Keywords: field study, in-situ measurements, solar water heating, system performance.

1. INTRODUCTION

Despite the widespread use of solar water heaters in many places in the world that have less favourable climatic conditions for solar energy as compared with Libya, still there is no usage of such technologies in Libya except for only about 2000 thermosyphon solar water heaters that are spread in different parts in the country [1]. Most of these systems are located in Al Burayqah town, and they suffer from neglect and lack of maintenance.

The reason behind the lack of use of such systems in Libya goes back to many factors which may include: lack of clear policy and/or serious plans to establish such technology, cheap prices of conventional energy, and lack of environmental awareness.

However, more recently, new laws have been suggested to mandates the installation of solar water heating systems in new buildings supervised by the government wherever possible. Due to the huge number of new buildings being built every year, there is a risk that poorly performing, low-cost systems might enter the market and damage the image of solar water heating. Therefore, care should be taken to control the quality of systems on the market.

Since its first establishment in 1978, the Centre for Solar Energy Research and Studies (CSERS) has taken responsibility for the research and implementation of solar water heating technologies. The CSERS has participated in many projects aimed at introducing and improving the image of solar water heating systems among people. In 2000 the CSERS imported and installed about 100 systems of different types (forced circulation, natural circulation, heat pipe, integrated collector, and storage tank systems) from different manufacturers. Some of these systems were provided with full instruments to evaluate their thermal performance.

In a similar, but earlier, study [2] conducted on a system erected in a family house of 6 people living in Tripoli, a thermosyphonic system with collecting area (flat plate collector) of 3.54m^2 and a vertical storage tank (open loop) of 240 liters (better performance than the system currently under study) was tested. The results showed that the annual solar fraction was over 75% of the total energy consumed (which was about 3452 kWh), and the daily hot water consumption was 353 liters at an average withdrawal temperature of 49.6 °C.

Hawas and Muneer [3] have performed year round performance on thermosyphon systems erected in Benghazi. Measurements were taken by thermocouples for the inlet and outlet user temperature, flow rate and solar insolation were also measured. The study has shown that water is heated to a maximum temperature of 66°C while the minimum temperature during six months was as high as 50°C. The efficiency of the system ranges as high as 40 to 50%.

2. SOLAR WATER HEATER DETAILS

The current system under test is in a detached house located about 90 km south of the Libyan capital, Tripoli. The people in the house vary from 4 people during week days to 6 people during weekends.

The system installed is a thermosyphonic type with a horizontal tank of 210 liters, containing a shell and tube heat exchanger (closed loop). The system has two flat plate collectors with an effective area of 2.9 m^2. The tank is provided with an auxiliary electric heater with maximum rating power of 3.6 kW and is operated manually by the house holder. The detailed specification of the system is given in Table 1 in the Appendix.

3. TEST INSTRUMENTS AND MEASURED DATA

The thermosyphon system is equipped with instruments to measure selected parameters that are required to evaluate the thermal performance of such systems. The parameters measured are: inlet cold water temperature to the storage tank (T_i), outlet hot water temperature from the tank to the user (T_o), ambient temperature (T_a), incident solar radiation over the collector (G_{sol}), the flow rate (pattern) of the water to the user (W_{flow}), and the electric energy consumption from the supplementary electric heater provided in the storage tank (Q_{ele}). All the sensors relating to the above mentioned parameters were connected to a data acquisition system capable of scanning information from sensors every 10 seconds and storing it every minute as an accumulation or averaging of data, depending on the type of information.

In this study, the data are recorded every 30 minutes as average values for the temperature measurements (T_i, T_o, and T_a) and as an accumulation of values for hot water consumption, electric energy consumption and solar irradiance. A sample of daily recorded information is shown in Figure 1.

4. SYSTEM PERFORMANCE

The thermal performance of the system can be evaluated by using 'solar fraction' and 'thermal energy conversion efficiency'.

Solar fraction (SF) represents the ratio of the accumulated solar thermal energy (Q_{sol}) to the total thermal energy (Q_{tot}) contained in the hot water consumed in a certain period of time. Therefore:

The thermal energy conversion efficiency

$$SF = \frac{Q_{Sol}}{Q_{tot}} = 1 - \frac{Q_{Ele}}{Q_{tot}} \qquad (1)$$

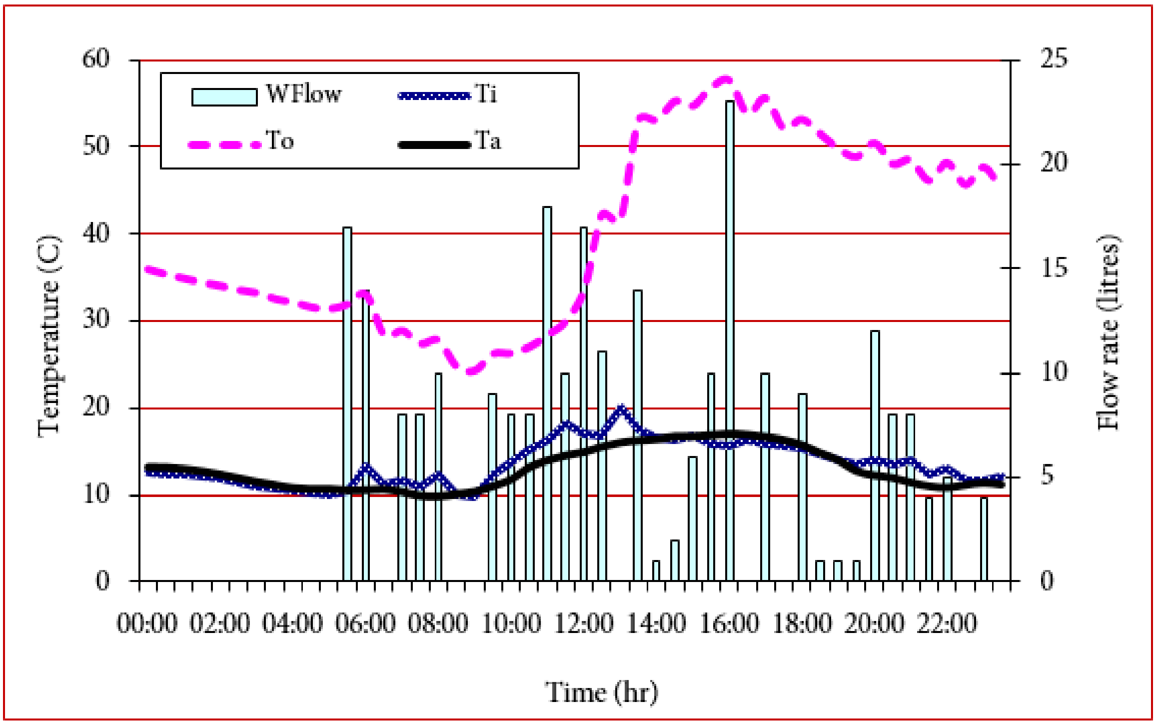
(η_{sol}) can be considered as the ratio between the thermal energy gained from the sun to the total incident radiation received over the collector total area for the same period of time.

Where A_c is the total area of the collectors.

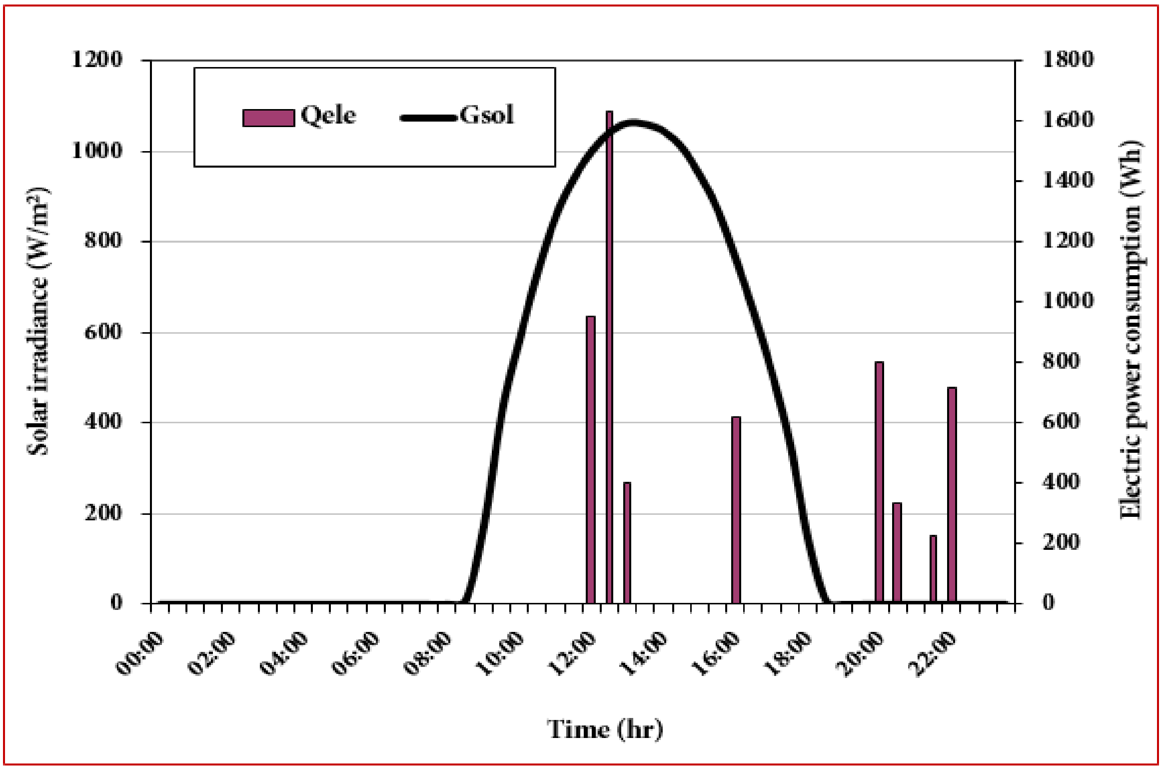
$$\eta_{Sol} = \frac{Q_{Sol}}{A_c G_{Sol}} \qquad (2)$$

5. RESULTS AND DISCUSSION

The data recorded from the system under study were for a whole year. This was logged as half hour periods and is processed and



(a)



(b)

Figure (1). Sample of daily recorded data

analyzed to give average daily, monthly and yearly values. The results obtained are presented in the following subsections.

a. Hot water load pattern

The results show that the average daily hot water consumption over a year was 144 litres per day with an average temperature of 46.6 °C. The largest amount of hot water consumed was in the winter season with 214 litres per day, and the lowest amount of hot water consumed was in summer with 73 litres per day. It has also been noticed that the average daily hot water drawn is almost always less than the tank capacity (210 litres). The normalized annual load pattern of the hot water is shown in Figure 2.

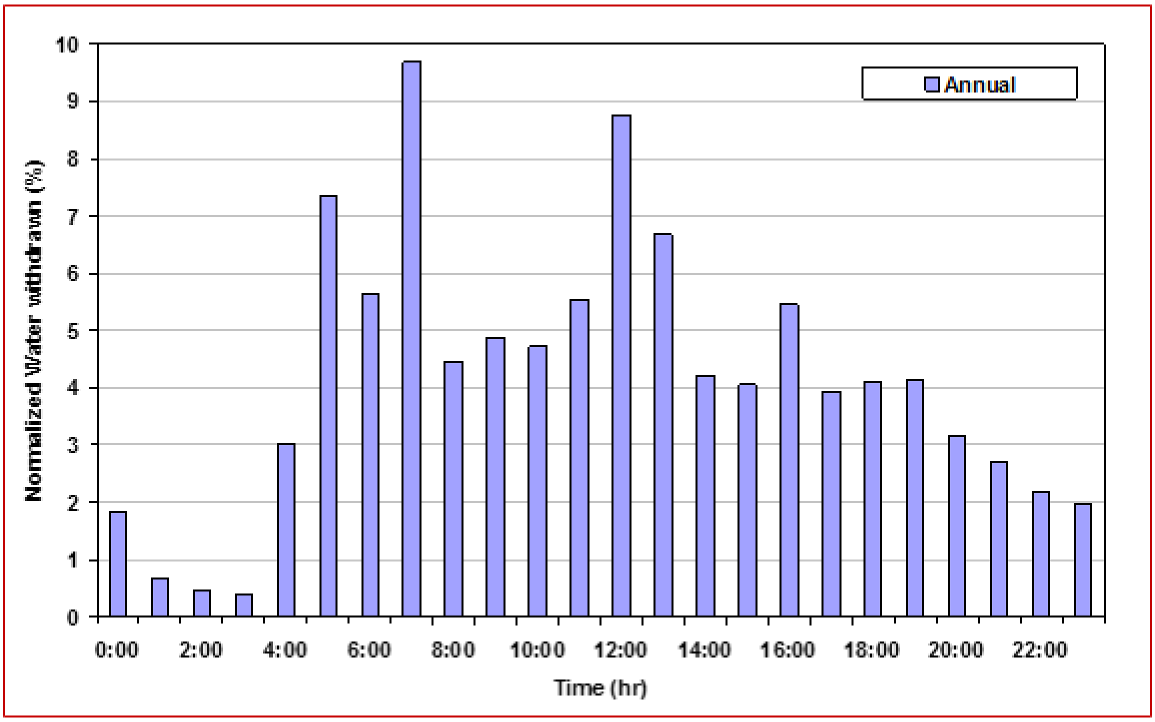


Figure (2). Annual normalized hot water consumption shown as daily average

b. Inlet, outlet and ambient temperatures

Figure 3 shows the monthly average values of inlet and outlet water temperatures as well as the ambient air temperature. It is clear from Figure 3 that the outlet water temperature is almost always constant at 49 °C in the relatively cold seasons, while in the hotter seasons the outlet temperature is lower than the yearly average value. In fact, this is due to the collector covers being painted with lime stone paint to minimize the solar irradiance absorbed by the collector (usually in summer people don't use hot water as the weather and the source water are relatively hot anyway). It can be also seen from Figure 3 that the source water is hotter than the ambient air temperature and has a similar trend to the ambient air temperature. This is due to the fact that the source water comes from the main tank which is fitted above the building, and the system is connected to the main tank through galvanized steel pipes exposed to the sun's rays. From the data recorded, the maximum outlet temperature was 80.1 °C at 1:30 pm on 03-10-2003 and the electric heater was disabled at that time.

Another conclusion can be deduced from Figure 4, that is that the inlet water temperature can be related to the ambient air temperature by a quadratic equation with a root mean square error of better than 0.988, the correlation being:

$$T_i = 4.5433 + 0.7405 T_a 0.006 T_a^2 \quad (3)$$

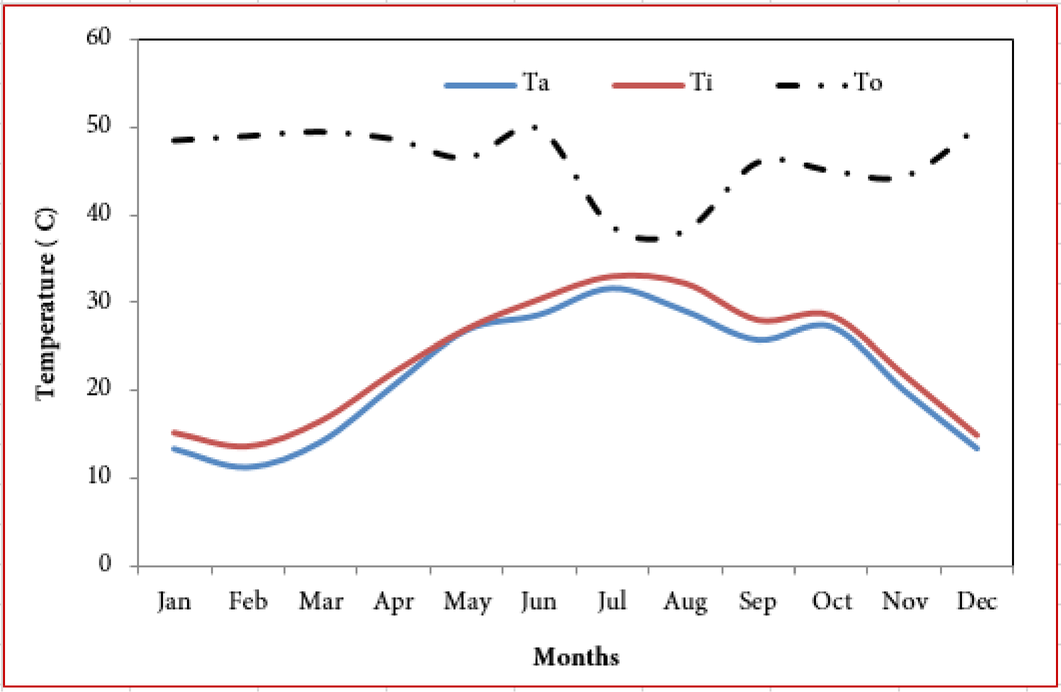


Figure (3). Mean monthly average values of inlet, outlet and ambient temperatures

c. Solar irradiance

Figure 4 shows the monthly average daily solar radiation received on the collector plan. It is clear from Figure 4 that the minimum amount of solar energy received was in November (5006 Wh/m²/day), while the highest amount of solar energy received was in May (6351 Wh/m²/day). The annual average solar energy was 5825 Wh/m²/day. This probably demonstrates the potential of the solar energy available in this region.

d. Solar system performance

Equations 1 and 2 are used to calculate the mean monthly solar fraction and thermal conversion efficiency of the system, and are respectively shown in Figure 6. The annual solar fraction was found to be 55.8% and in the winter season, where the hot water is in high demand, it was found to be only 31.6%. In the mean time, the thermal conversion efficiency reaches as high as 38.5% in March, which means the system has low performance compared to the data provided in reference [2] (where the maximum thermal conversion efficiency was 56.8% and the minimum value was 14.6%). The low performance of the system under study could be attributed to many reasons: relatively poor quality system in general, electric element sized incorrectly (oversized), closed loop system performance is always less than that of open loop systems, systems with vertical tanks perform better than systems with horizontal tanks, and poor operating conditions. In fact, irrespective of system quality, the operating condition strongly influences the thermal conversion efficiency; if the system is well-used (much hot water usage) then the efficiency of the system will be higher as compared with little hot water use.

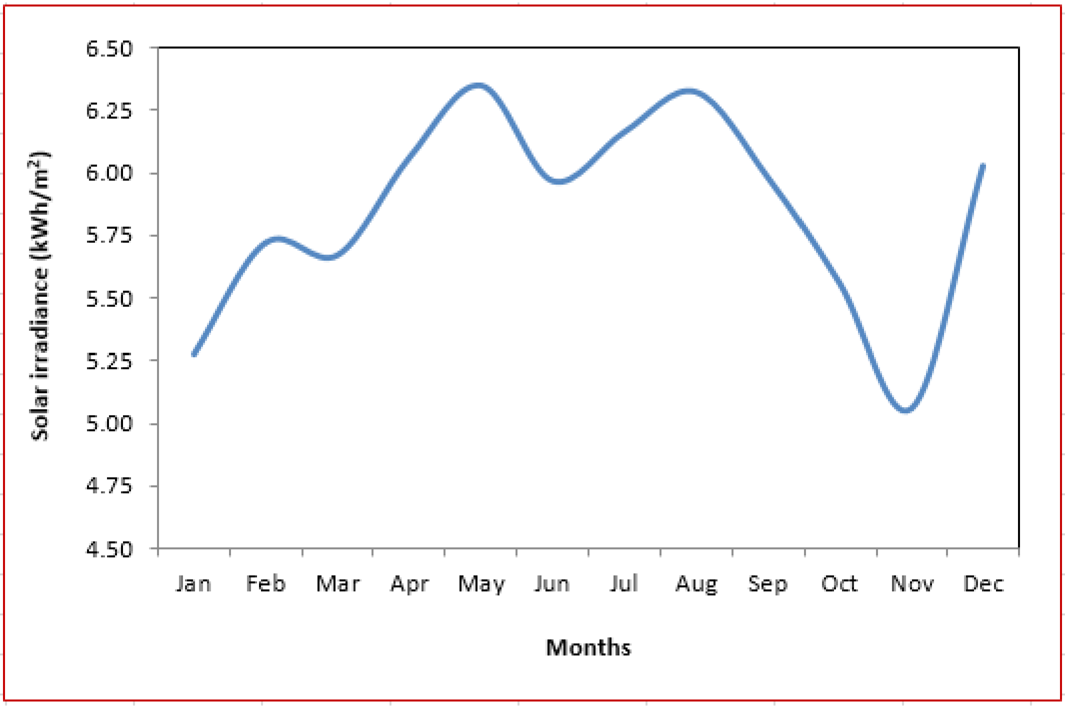


Figure (4). Monthly average daily radiation on collector plan

6. CONCLUSIONS AND RECOMMENDATIONS

The actual, in-situ measurements of the variables required to evaluate the thermal performance of the system are a good source of information for showing the interaction between the system designs, weather conditions and operating conditions. It is concluded from this study that the system under study performs relatively poorly if we consider that the system can provide only 55.8% of the hot water requirements in weather conditions such as those of Libya. One of the main reasons could be that the ratio of storage tank volume to the collector area of the system is 72.5 lit/m^2, which is higher than the recommended value (49-60) lit/m^2 depending on the quality of the system [4].

The following general recommendations should be considered for proper sizing of thermosyphon systems:

1. It is very important to conduct a field study to identify the hot water load pattern of Libyan families due to the fact that the load pattern has a strong influence on the system design and performance.

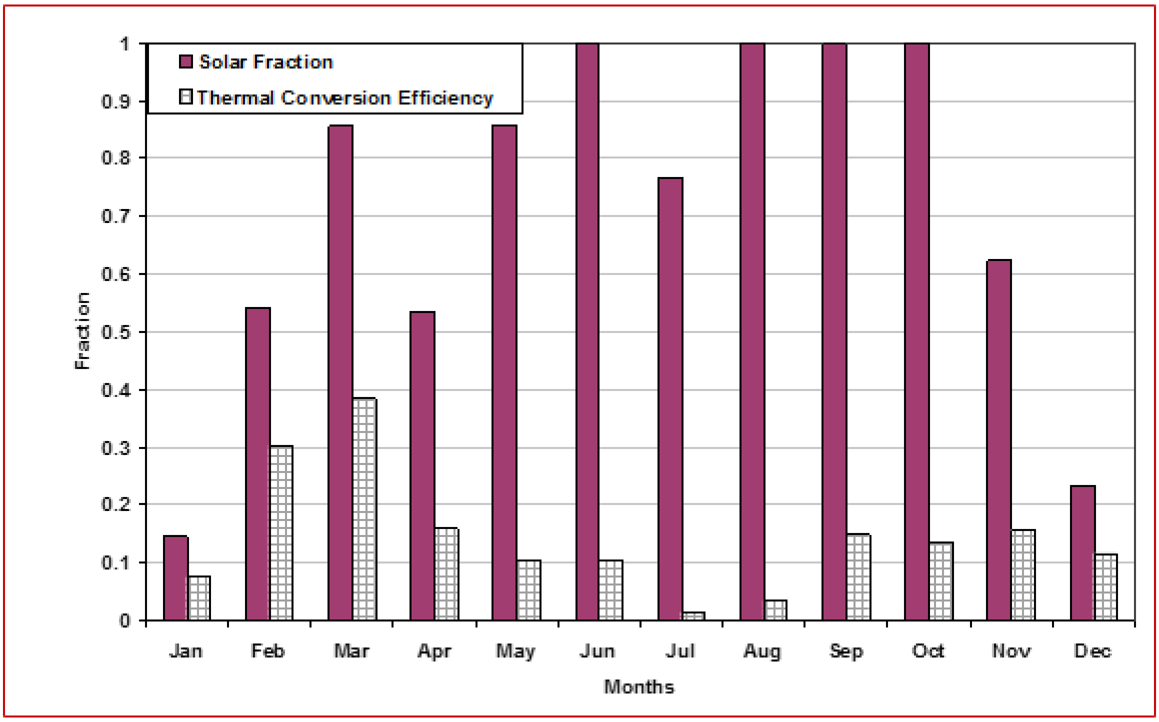


Figure (5). Monthly solar fraction of the tested system

2. In systems supplied with an in- tank auxiliary electric heater, the maximum power of the electric heater should be sized properly. Over-sizing will probably reduce the overall system efficiency.
3. From tests on different systems installed in the solar water heaters field implementation project, it is concluded that well-designed systems can easily provide over 70% of the required energy for hot water heating in Libya. Hence, in the Libyan environment, it is recommended that for any system the minimum solar fraction should be over 70% so as to increase the potential cost-effectiveness and to present a positive image of solar energy.

7. APPENDIX

Table 1. System detailed information

System type	Natural circulation Closed Loop (copper heat exchanger)
Collector area	2.9 m^2
Tank mode and size	Horizontal, 210 litres
Absorber	Copper, semi-selective coating
Glazing	Tempered glass, 4mm thickness
Back insulation	Polyurethane 25 mm Mineral wool 15 mm
Frame	Anodized Aluminium

8. ACKNOWLEDGMENT

Thanks are due to the Centre for Solar Energy Research and Studies for providing the facilities to carry out this work and for giving permission for its publication.

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