On the Night Heat Losses in Thermosyphon Solar Water Heaters

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Abstract

An experimental investigation of the effects of night heat losses on the performance of thermosyphon solar water heating systems has been carried out in this study. Based on the methodology suggested by the ISO 9459-2:95, three typical thermosyphon solar water heating systems, with different storage tanks have been tested. Analysis of the results served to quantify the night heat losses and examine the effect of these losses on the daily system performance. The results showed linearity between the heat losses and the night mean ambient temperature. The linearity correlation coefficients range from 0.93 to 0.95, while the losses reached almost 8000kJ at an ambient air temperature of 10°C. Examination of the results also revealed that for the local weather conditions in Cyprus and for the typical configuration of the thermosyphon solar water heaters used in the island, the thermosyphonic reverse flow is rather unimportant with minimal contribution to the night heat losses of the solar collector.

1. Introduction

Residential water heating is the most widespread solar application. Nowadays the systems for hot water production in single-family houses appear to be dominant, since they provide the most economically feasible and viable solution for water heating [1]. A number of studies on the performance of thermosyphon solar water heating systems have been conducted by several researchers [2-8]. In Cyprus, thermosyphonic solar heaters with flat plate solar collectors have been widely used in residential and commercial establishments to provide water heating. Both the thermal performance and cost effectiveness of such systems have been theoretically and experimentally studied. [9-11].

A typical domestic solar hot water heating system mainly consists of three major components: (a) the solar collector area; (b) the hot water storage tank and (c) the hot water circuitry through the house. Two basic configurations, based on the mode of circulation of water through the collector and storage subsystem, exist for solar domestic water heaters. These configurations are: (a) the thermosyphon system, where the water circulation is achieved by virtue of temperature difference and (b) the active system where a pump is used to provide the required water flow rate throughout the system. In the thermosyphon system, the storage tank needs to be positioned higher than the top of the solar collectors in order for the thermosyphon effect to operate. This however, under certain conditions, might initiate reverse water flow during night time and consequently increase the heat losses from the system.

The thermal behaviour of a solar water heating system is a complex phenomenon and it involves a number of interrelated parameters, such as the solar radiation, weather conditions, the water flow rate through the collector, the storage tank configuration, the effectiveness of the heat exchanger and the thermal load. According to Ogueke et al. [12], the high energy loss at night time, found in solar domestic hot water systems, serves as a major technical problem. The high energy losses at night are more evident in thermosyphon solar water heaters, mainly due to their specific configuration. During a 24 hour period, the temperature at night is the lowest and the solar collector acts as a thermal emitter, resulting in a reverse circulation of water from the top of the storage tank to the collectors. Consequently, a percentage of the collected energy during the day is lost. Morrison [7] performed a study to investigate this phenomenon for a thermosyphon solar water heater in Australia, which incorporated a vertical cylindrical storage tank. In the study performed by Faiman [6] it was suggested that a device to automatically decrease the heat loss coefficient of the system at night time is installed.

It is theoretically believed that for a given system under certain climatic conditions, as the water temperature in the storage tank increases, the thermosyphonic reverse flow also increases. Eventually, it is highly likely to have considerable heat losses due to the thermosyphonic reverse flow [8]. The phenomenon of thermosyphonic reverse flow is a complex issue and it is related to many factors such as the structure and thermal performance of the systems, the climatic conditions and the temperature in the storage tank. This study is aimed in gaining insights on the effects that night heat losses may have on the performance characteristics of thermosyphon solar water heaters in Cyprus. All the experiments mentioned herein were carried out in Nicosia. Three typical thermosyphon solar water heaters, each having a different storage tank, with horizontal cylindrical configuration, have been examined.

2. System Description

The schematic diagram of the system investigated is shown in Fig. 1. The system consists of two flat-plate solar collectors having a total surface area of approximately 3 m^2 and tilted at 45° from the horizontal. The insulated storage tank is equipped with a 3kW electric heater. The interconnecting piping is also shown in Fig. 1.

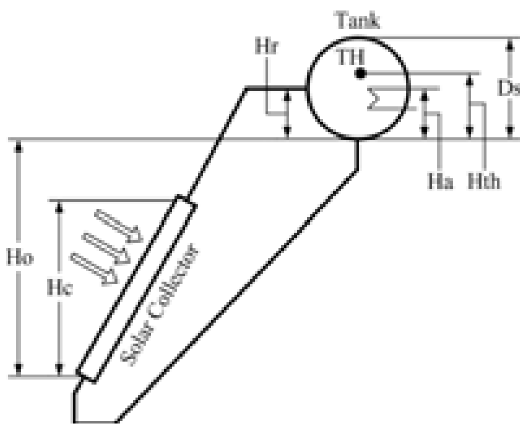

Fig. 1. Schematic diagram of a thermosyphon solar water heating system (TH: Thermostat).

Three storage tanks with different storage capacities of 150, 180 and 180 litres have been used in the experiments. The storage tanks are horizontal cylindrical, made of copper, and each tank incorporates a different insulation material. The collectors are connected in parallel through the supply headers. Each collector employs ten evenly spaced parallel copper pipes embossed by semi-circular grooves, formed in the flat-plat absorber. This particular system is rated to meet the hot water requirements of a family of four persons under the climatic conditions found in Cyprus.

The system parameters, as shown in Fig. 1 are provided in Table 1 for all three systems examined herein. The performance characteristics of the solar collectors and the heat loss coefficients of the storage tanks have been determined from tests carried out in Nicosia.

Table 1. Design parameters for the three systems under investigation.

Parameter	System 3	System 2	System 1
$H_c\ (mm)$	900	1320	1245
$H_o\ (mm)$	1140	1410	1270
$H_r\ (mm)$	390	300	290
$H_a\ (mm)$	285	290	285
$H_{th}\ (mm)$	285	290	285
$D_s\ (mm)$	580	580	590

2. Experimental Setup and Testing Methods

All the experiments mentioned herein were performed at the Applied Energy Centre testing facilities of the Ministry of Commerce, Industry and Tourism, during the period of August 2008 to February 2010. The testing facility conforms to the standard ISO 9459-2 [13] for outdoor testing methods for system performance characterisation and yearly performance prediction for solar-only systems, which establishes amongst others overnight heat loss test to determine the heat loss coefficient of the storage tank. The testing facility is designed to allow simultaneous testing of the three systems according to ISO 9459-2 [13]. Figure 2 shows a picture of the three systems under investigation.

All the tests were performed outdoors during night time with all the collectors exposed to clear sky. According to ISO 9459-2, the hot water in the storage tank is preconditioned since it is uniformly heated to a temperature above 60°C. In this study there was no need to heat the water in the storage tank since its temperature was higher than 60°C. In cases where the water temperature was below 60°C, heating was applied. Based on the standard ISO 9459-2, the water is mixed in the storage tank by using a pump to circulate water from the top to the bottom of the tank. The temperature of the water in the tank is assumed to be uniform if the temperature at the outlet of the store varies less than 1K for a time period of 15 minutes. The average temperature in this 15 minute time period is taken to be the initial temperature of the tank.

For the final condition, the tank is left to cool for a period of 12 hours. At the end of the test period, the water is recirculated in the storage tank in order to reach a uniform temperature. The average temperature over the 15 minute period is to be taken as the final temperature of the tank. Using a data acquisition system, the following measurements were recorded: (a) the ambient air temperature; (b) the surrounding air speed and (c) the inlet and outlet temperatures of the hot water storage tank.

The data acquisition hardware and software include features for controlling external devices, responding to events, processing data, creating report files and exchange information with other applications. These features enable continuous and remote data acquisition. The basic system consists of a personal computer, equipped with a high speed multiplexer coupled with sub-multiplexers, having cold junction compensation capabilities.

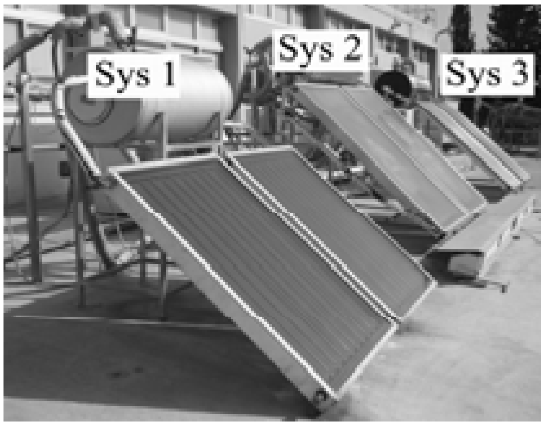

Fig. 2. Experimental testing layout of the three thermosyphon solar water heating systems.

3. Results and Discussion

The night energy losses represent the maximum heat losses in the storage tanks, as the tests were performed under no load conditions. The valve at the upper connecting pipe of the water heaters was left open (allowing water flow inside the collectors during night time) in an effort to better estimate the effects of reverse circulation.

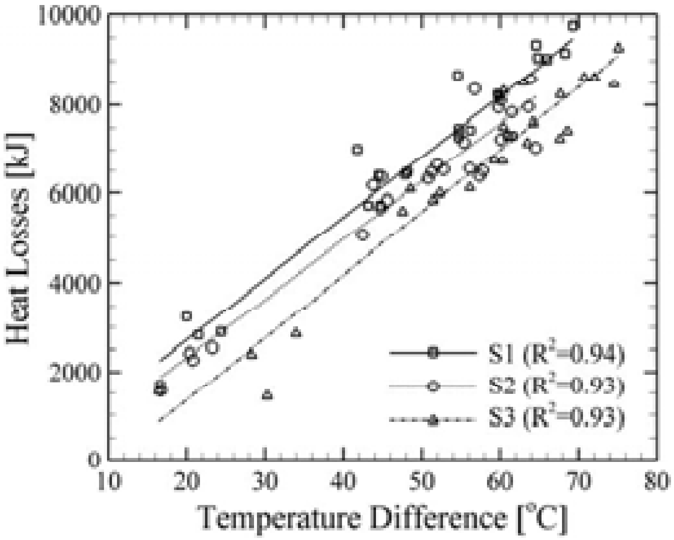

Fig. 3. Heat losses against temperature difference between the storage tank and the ambient.

The night heat losses as a function of the difference in average temperatures (hot water in tank and ambient) are presented in Fig. 3. It is noticed that as the temperature difference increases, the energy loss is also increased. The heat losses appear to have a relatively linear relationship with the average night temperature, with the correlation coefficients, ranging from 0.93 to 0.94, despite the presence of reverse flow in the collectors during night time. This indicates that the effect of reverse flow on the heat loss mechanism is rather unimportant. The results from this study show that under the weather conditions in Cyprus and for the collectors used nowadays, the thermosyphonic reverse flow is not a very important phenomenon to the losses. The flow reversals appear to have minimal impact/contributions to the night losses of the solar collector. This is in agreement with the work of Morrison [6] who showed that the heat losses associated with the reverse flow are very low, if the vertical separation between the storage tank and the collector is sufficient enough. On the other hand, very minimal reverse flow is encouraged, especially during winter, to provide freezing protection and avoid sub-zero temperatures. In Fig. 3 the deviating points from the linearity belong to data where the day was particularly cold with limited sunshine. Such data points can been seen in the lower portion of the temperature scale $(15 < °C < 35)$ where the energy losses have minimum values $(< 4000 kJ)$. If these data points are not accounted for then the correlation coefficient increases to 0.97, showing that the heat loss mechanism is mainly due to conduction losses.

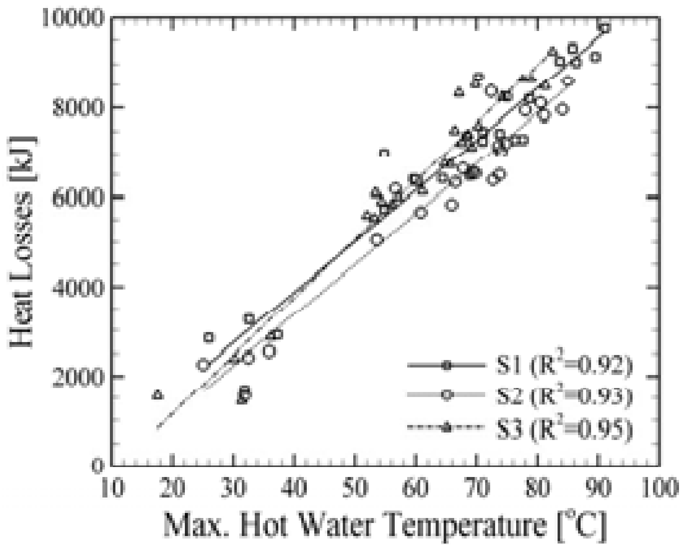

Fig. 4. Heat losses against maximum hot water temperature in the storage tank.

The variation of maximum hot water temperature against the heat losses is shown in Fig. 4. Similarly to Fig. 3., again the maximum hot water temperature shows a linearity with heat losses. The correlation coefficients vary between 0.92 and 0.95. Figure 5 can provide a very good estimation of the thermal losses by knowing only the hot water temperature in the tank. It is worth mentioning that the deviating points from the linearity belong to cold days with limited sunshine where very little energy was collected in the storage tank. If these data points are not accounted for, then the correlation coefficient jumps to a value of 0.98. This indicates that the heat losses can be well estimated by looking at the maximum water temperature in the storage tank.

To have a more clear understanding, from a statistical point of view, the heat losses were plotted as a function of the temperature difference in a scatter diagram as shown in Fig. 5. The scatter distributions show the amount of energy losses in typical solar collectors used in Cyprus. In Fig. 5 it can be seen that the average amount of energy loss at night time is around 7000 kJ. This value represents a total of 1.4 GJ of energy been lost per year.

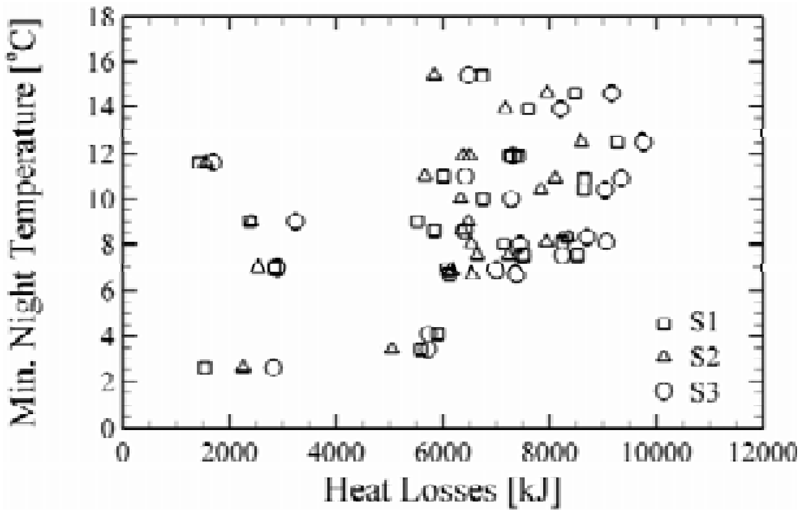

Fig. 5. Scatter diagram of heat losses against minimum night temperature.

4. Conclusion

An experimental investigation on the effects of night heat losses on the performance of thermosyphon solar water heaters has been carried out in this study. Three typical thermosyphon heating systems, with different storage tank capacities have been examined based on the ISO 9459-2.

Analysis of the results showed that the thermosyphonic reverse flow has no or limited impact on the night energy losses of the solar heater. This observation is in good agreement with the findings of Morrison [7]. It is thus evident that the energy losses of flat-plate collectors during night time are mainly due to conduction rather than due to the recirculation itself. The energy losses can be predicted with a high degree or accuracy as shown herein.

The results of this work bring about a revision to the estimated reduction in CO_2 emissions for the island of Cyprus. The estimated current area of solar collector in working order in Cyprus is around 600,000 square meters [14]. These solar collectors represent an annual solar thermal energy production of 336,000 MWh/year. With the extensive use of solar water heaters, 10% of total CO_2 emissions are avoided, which amounts to 285,600 tones CO_2/year. Following the same logic, a significant percentage of these emissions are not saved as the heat losses in hot water energy during the night amounts to a high percentage.

The correlation coefficients ranged from 0.93 to 0.95 while the heat losses reached almost 8,000 kJ at 10°C mean night ambient temperature. This amount of heat loss is a very significant proportion of the total daily collected energy. This the night losses is one of the most significant source of energy loss in thermosyphonic systems. The heat losses were reduced only when the daily collected energy was minimal with the hot water temperature barely reaching 35°C.

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