An investigation into the performance of a thermosyphon solar water heater

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ABSTRACT

This paper is concerned with the investigation of the performance characteristics of a thermosyphon solar water heating system using a computer simulation model.

The instantaneous collector efficiency was determined as a function of flow rate of water and the water temperature difference between the collector inlet and outlet.

The model was also used to predict the monthly and yearly solar contribution of the system for two different load profiles. The results of simulation indicate that the yearly solar contribution of the system for a low consumption profile is about 94% as compared to 63% for a **high consumption pattern.**

1. INTRODUCTION

Thermosyphon solar water heaters are widely used for domestic water heating due to their simplicity in construction, installation and maintenance and their cost effectiveness as compared to conventional methods of water heating.

In Cyprus, for example, it is estimated that there are more than 130,000 units in operation, which means one solar water heater for five people in the island. According to Construction and Housing Statistics for 1987 [1], about 87% of new dwellings built in 1987 have been equipped with solar water heaters as compared to 69% in 1982.

There has been, extensive work on the analysis of the performance of thermosyphon solar water heaters, both experimentally and analytically, by numerous researchers [1-9]. Most of these studies correlated the system performance with the thermosyphonic flow_, the temperature difference and the solar insolation, and a good agreement between simulation results and experimental data was reported by a number of researchers [8, 9].

The present study aims to investigate the performance characteristics of a typical Cypriot Thermosyphon Solar Water Heater for the conditions of Nicosia, through simulation, using the model of TRNSYS [10] Simulation Program. Such an investigation will provide a detailed understanding of the phenomena involved in the system operation which will help in further improvements in the system performance.

2. SYSTEM DESCRIPTION

A schematic diagram of the system under investigation is shown in Figure 1.

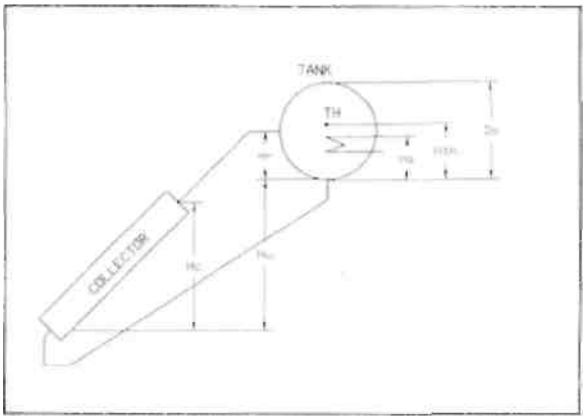

Figure 1 Thermosyphon System Schematic

It consists of two flat plate solar collectors having a total surface area of 3 m^2 tilted at 42 degrees from horizontal, an insulated horizontal storage tank of capacity 180 litres equipped with a 3 kw electric heater and interconnecting piping. The collectors are connected in parallel through the supply headers, both employing ten evenly spaced parallel copper pipes embossed by semicircular grooves formed in the flat plate absorber.

The above system is supposed to meet the hot water requirements of a family of four.

The system parameters are shown in Table 1.

3. SYSTEM MODELLING AND SIMULATION

The performance of a thermosyphon solar water heater depends on the weather; both the energy collected and the load are functions of solar radiation, ambient air temperature, wind velocity and other meteorological variables which may be viewed as a set of time dependent forcing functions acting on the system.

Experimental investigations are essential and useful in determining the performance characteristics of a system but they are not repeatable. The alternative solution is the modelling and simulation of a system which can provide much of the same thermal performance information as the experiments with less time and cost.

TABLE 1. System Design Parameters	
A_c	3m2
F»n	0.77
F U „ L	24.4 kJ/h m^2 «C
G_{test}	54 kg/h m?
0	42 degrees from horizontal
N_B	20
^dR	12 mm
d „	26 mm
L „	1900 mm
d_I, d_0	20 mm
H_c	1000 mm
H_0	1150 mm
H_r	250 mm
H_a	300 mm
H ,h	370 mm
L_1, L_0	2000 mm, 520 mm
<UA>„. <UA>po	1.6 KJ/hoc, 0.5 KJ/h°C
V_s	180 litres
D_s	500 mm
$(UA)_s$	4.65 KJ/h oc
P_{aux}	3Kw

The simulation of a thermosyphon system can provide a mean of analysing the dynamic performance of the system in response to selected meteorological data and load profiles and can be used to generate design methods.

Like most solar energy systems, the thermosyphon solar water heater is modular and the simulation model for the system can be formulated by connecting models of each of the system components. This modular approach is used in TRNSYS [10], where system components are described by individual FORTRAN subroutines which are based on models. The simulation of the system requires hourly weather data which must be representative of the location under investigation and this is the difficulty. For design, "long-term" performance refers to a period equivalent to or representative of the expected life of the system, which may be 10-20 years. Klein et al [11] have constructed the "average year for a number of simulations by selecting for each month of the year, that month of data from the 8-year period which most closely corresponded to the average monthly insolation and ambient temperature.

For the present investigation, monthly average values for the years 1984-1987, of the daily solar radiation and air temperatures, taken from the Cyprus Meteorological Service [12, 13], have been used in the simulation, as shown in Table 2, where:

T - ambient air temperature, °C

I = monthly average of the daily total radiation incident on a horizontal surface, kJ/m^2

v wind velocity, m/s

TABLE 2. Monthly average values of weather data for Nicosia.			
Month	**(°C)**	(kJ/m^2 day)	V (m/s)
January	10.3	8,568	3.09
February	10.9	11,948	4.12
March	13.2	15,836	3.61
April	17.1	20,624	4.12
May	21.9	23,267	4.64
June	26.3	25,304	5.15
July	29.0	25,758	5.15
August	28.8	22,835	4.64
September	25.8	18,846	4.12
October	21.5	13,892	3.61
November	16.4	9,896	3.09
December	12.0	8,269	3.09

4. ANALYSIS OF SIMULATION RESULTS

Two different scenarios of daily load profiles have been used: a high load profile corresponding to a consumption of 160 litres of hot water at 50 °C daily as shown in figure 2, and a low load profile corresponding to a daily consumption of 120 litres of hot water at 45 °C.

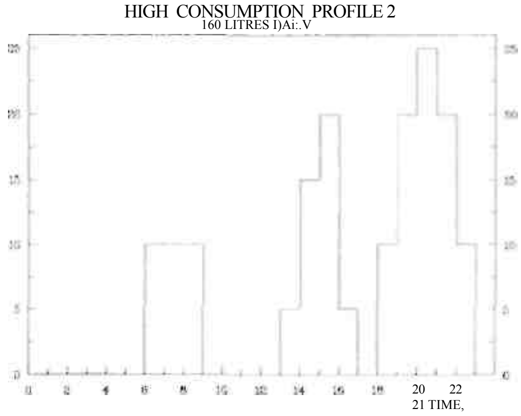

Figure 2 High consumption profile (2)

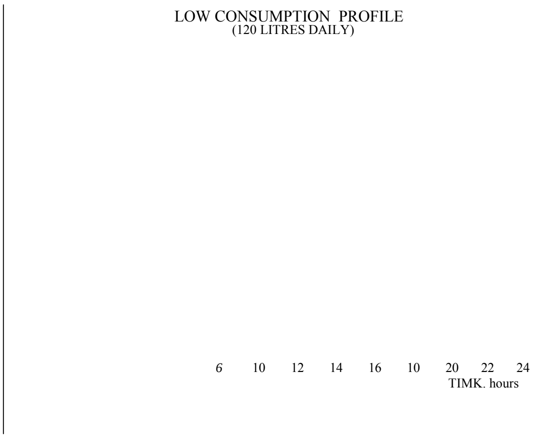

Figure 3 Low consumption profile (3)

Daily simulations have been ran for a number of days and the results of 1 st May were used to plot a number of graphs to correlate the various parameters of the system, i.e. the flow rate, the efficiency, the temperatures and the solar fraction with time, and the efficiency with the thermosyphonic flow rate of water.

The system was also simulated to investigate its behaviour without any load. Figure 4 shows the variation of thermosyphonic flow and incident solar radiation with time for a high consumption pattern (profile 2). Water flow rate in the system was found to follow the pattern of variation of the solar insolation as expected. The flow rate increases during the morning hours to reach a maximum of about 86 kg/h at solar noon, corresponding to approximately 28.7 kg/h per m^2 of collector, and then starts to decline in the afternoon hours as the solar radiation does. The same pattern of variation was also observed for the other two cases studied i.e. without load and with the low load profile 3.

The above values seem to be high as compared to experimental data reported by Shitzer et al [14] for a similar system tested in Israel and Pafiliaset al [15] for a similar system tested in Greece. However, no concrete conclusions can be made before the system simulated is tested experimentally in Nicosia.

Figures 5,6,7 illustrate the variation of the system efficiency with time for the three different scenarios under investigation, with the graph of flow rate variation superimposed. The system efficiency follows a pattern which is slightly different from that of flow rate. It increases rapidly during the morning hours to reach a maximum of about 60% at around 9.00 a.m. solar time in all three scenarios. There is however a remarkable difference in the afternoon hours where the best efficiency pattern is obtained in the case of high consumption. Thus, at 4.00 p.m. the efficiency of the system without load becomes zero while in the case of load profile 2 (high consuption) the system collects energy at an efficiency of about 25%. This can be attributed to the fact that the temperature of water entering the collector in the system without load is higher than that with load and therefore the collector is operating at high (Ti-Ta) corresponding to low efficiency. Another interesting piece of information which is provided by the above figures, is that the peak of efficiency does not coincide with that of thermosyphonic flow.

In correlating the efficiency with the thermosyphonic flow, it appears that the pattern of variation is more or less the same in all three cases, with slight differences in the case without load.

From figures 8 and 9, it appears that in the morning hours the efficiency rises slowly as the flow rate increases, and it reaches a maximum of 60% when the flow is 55 kg/h, that is 18 3 kg/h per $m^?$ of collector. As the flow rate increases further, the efficiency declines very slowly to drop down to 58% at 83 kg/h with high consumption and down to 57% at the same flow without load.

The variation of collector inlet and outlet temperatures and their difference, with time is shown in figures 10 and 11 for the systems with and without water consumption repsectively.

The first interesting piece of information in these graphs is that the collector temperatures start rising in the morning hours following the variation pattern of the solar radiation, but they reach their peak values at around 2.00 p.m. in the cases of water consumption (profiles 2 and 3) and at 4.00 p.m. in the system without load and reached 72 deg C at the collector outlet, at 4.00 p.m. In the case of consumption profile 2 the maximum temperature attained at the collector outlet was 69 deg C at 2.00 p.m.

Another interesting piece of information is that the temperature difference between the collector inlet and outlet starts rising in the morning to reach a maximum of about 18 deg C in all cases, at 9 am and drops down in a slow rate afterwards. It is interesting to note that the variation of the temperature difference follows the pattern of the variation efficiency.

In the absense of experimental results, no comparison can be made to validate the simulation results.

The variation of the annual solar contribution for the high and low consumption profiles are shown in figures 12 and 13 respectively. In these figures, *f, the solar fraction,* is defined as the ratio of the useful solar energy supplied to the system and the energy needed to heat the water if no solar is used. As a matter of fact this represents fractional energy savings relative to conventional system. It must be noted here that these results assume the same daily load profile throughout the year. This is not quite true when it comes to summer, where the consumption pattern is somehow different. However, during the same period, the hot water

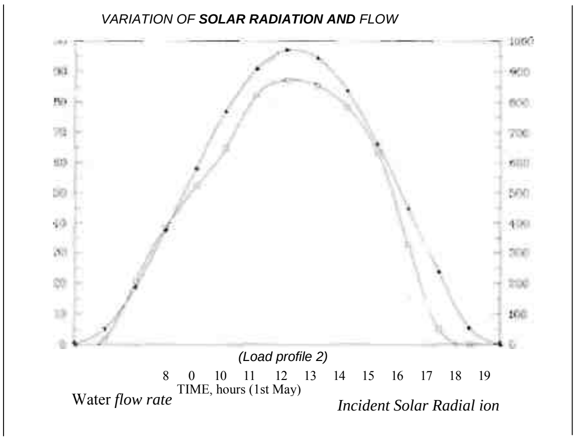

Fig 4

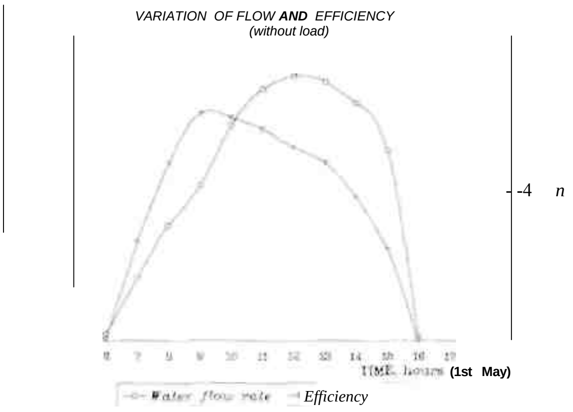

Fig 5

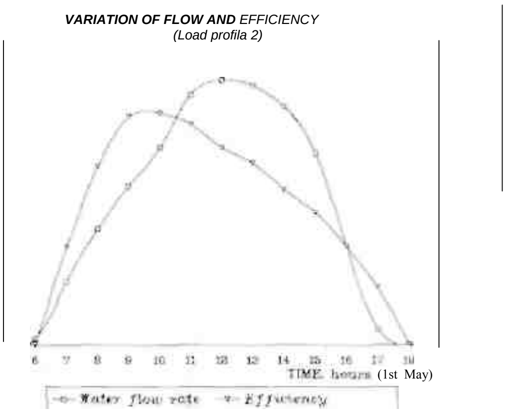

Fig 6

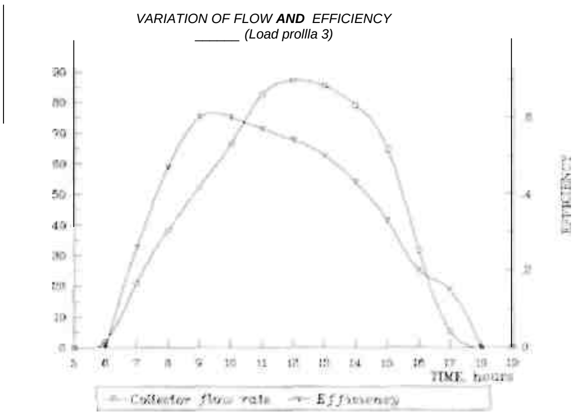

Fig 7

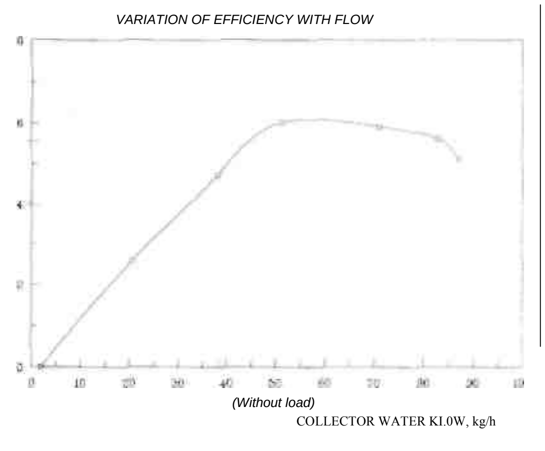

Fig 8

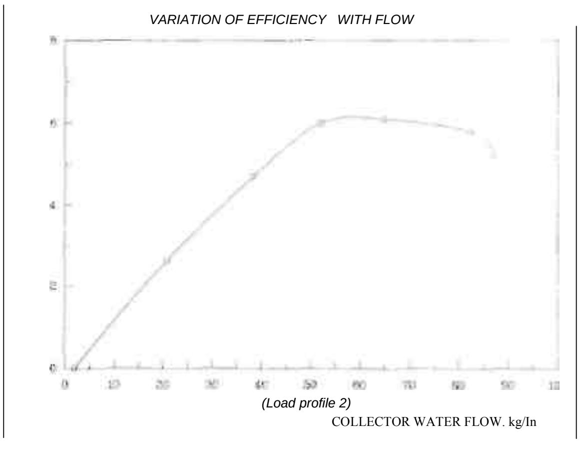

Fig 9

temperature requirements are not as high as in the case of winter. Consequently, from the point of view of thermal energy requirements the difference cannot be much. With the high profile consumption the yearly solar fraction is 66% as compared to as high as 89% with the low profile consumption and lower water temperature.

With reference to figure 13, it must be noted that the useful energy collected during the seven months of the year, namely April to October included, is greater than the load; in these cases the solar fraction is taken as 1.

The validity of the simulation results cannot be checked unless monitoring of the system under actual operating conditions is carried out.

5. CONCLUSIONS

A thermosyphon solar water heating system, representative of systems commonly used in Cyprus, was simulated using TRNSYS Simulation Program. The simulated results lead to the following observations:

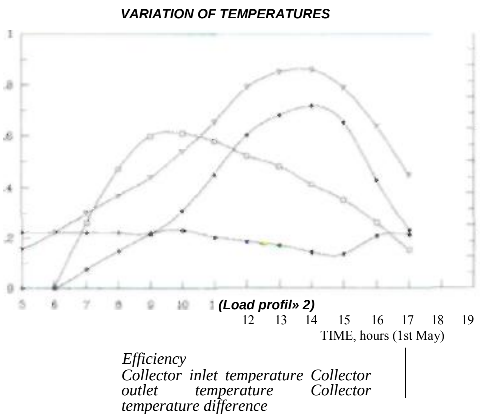

Fig 10

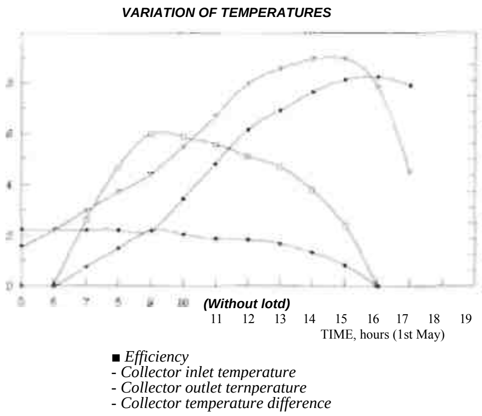

Fig 11

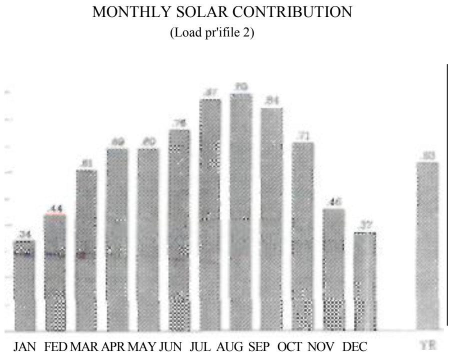

Fig 12

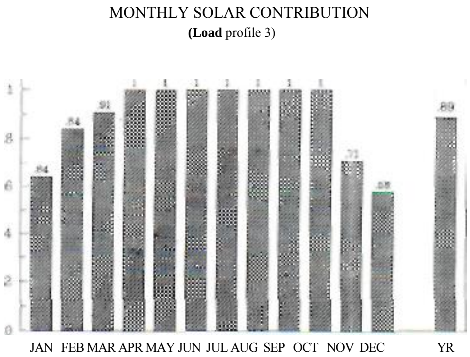

Fig 13

1. Thermosyphonic flow of water in the system generally follows the pattern of variation of the incident solar radiation. The flow rate increases during the morning hours, reaches a maximum of about 86 lt/h and then starts declilning in the afternoon hours.

2. The variation of the system efficiency does not follow the pattern of flow rate. It reaches its peak value in the morning hours and it drops down slowly in the afternoon hours. The efficiency pattern is better in the case of high load profile.

3. The efficiency rises as the water flow rate increases, and reaches a maximum value of 60% when the flow rate is 55 kg/h.

4. The yearly solar contribution of the simulated system is as high as 63% assuming a daily water consumption of 160 lt at 50 deg C, throughout the year and 89% when the daily water consumption is assumed to decrease to 120 lt at 45 deg C.

5. The performance of a thermosyphon solar heating system depends on many parameters which have to be exploited through simulation and experimental studies. These studies are necessary to obtain a detailed understanding of the system behaviour and lead to more efficient designs.

NOMENCLATURE

Collector area
Collector tilt angle
Specific heat of working fluid
Diameter of collector inlet & outlet pipes
Diameter of collector headers
Diameter of collector risers
Number of parallel collector risers
Slope of the collector efficiency curve
Intercept of the collector efficiency curve
Collector flow rate per unit area
Collector flow rate per unit area at test conditions
Total radiation incident on the (tilted) collector surface
Monthly average of the daily radiation incident on a horizontal surface
Length of inlet and outlet piping
Length of collector headers
Thermosyphon flow rate
Load flow rate
Auxiliary energy input to tank
Useful energy collection
Fraction of the load that is met by solar (Solar contribution)
Ambient air temperature
Environmental temperature for losses from storage

T.	Temperature of the fluid at the collector inlet
T_o	Temperature of the fluid at the collector outlet
T_s	Thermostat set temeprature
$(UA)_s$	Conductance for heat loss from storage tank
$(UA)_s$	Conductance for heat loss from pipes
H_c	Vartical distance between outlet and inlet of collectors
H_a	Height of auxiliary heating element above bottom of tank
H_o	Vertical distance between outlet of tank and inlet to collector
H	Height of collector return above bottom of tank
D_s	Diameter of storage tank
H_{th}	Height of auxiliary thermostat above bottom of tank
Paux	Auxiliary energy input to tank
Vs	Storage tank volume

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