OPTIMUM DESIGN CRITERIA FOR SOLAR HOT WATER SYSTEMS

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ABSTRACT

This paper is concerned with the optimisation of some design criteria of SHW systems intended for residential and hotel applications. For this purpose, a system model based on TRNSYS programme has been used to correlate the performance and cost effectiveness of the system with a number of key design criteria which include the Collector to Consumer Factor (FCC) expressed in m^2 of collector per consumer and the Collector to Load Factor (FCL) expressed in m^2 of collector per annual GJ of thermal load.

KEYWORDS

Solar energy, simulation, TRNSYS, solar collector, storage, payback period, solar fraction, hotel.

INTRODUCTION

The production of service hot water for domestic use by means of solar energy constitutes one of the most popular and economically feasible applications of solar energy in the world. The sizing of a solar hot water (SHW) system, however, is a complex problem involving a number of interrelated factors such as the collector size and efficiency, the storage tank size, the hot water consumption pattern, the solar radiation and a number of economic parameters. The components of a SHW system must be well selected, properly sized, and carefully assembled in order to ensure that the system will function properly and cost-effectively.

In a previous study, Michaelides *et al.* (1992), used the TRNSYS programme (Klein *et al.*, 1990) to investigate the optimum collector slope and size for active solar hot water systems intended for residential applications in Cyprus. According to that study the optimum collector slope is 35° from horizontal while the optimum collector size in terms of number of consumers is 1 m^2 per consumer, based on a storage factor of 50 litres per m^2 of collector. In terms of annual thermal load, the optimum collector size was found to be 0.45 m^2 of collector per annual GJ. In the present study the same model is used to investigate the optimum collector size for active solar hot water systems intended for hotel applications.

THE SIMULATION MODEL

The system concerned is a forced circulation solar system comprising a flat plate solar collector and an insulated storage tank having the performance characteristics described in Table 1. It is also equipped with a circulating pump, an optional collector/storage heat exchanger and all necessary control devices for the efficient operation of the system. An oil-fired boiler is also included in the system to act as auxiliary heater in case of insufficient solar radiation.

Three different scenarios have been used in the simulations, based on three different hot water consumption patterns taken from Michaelides (1993); these consumption profiles differ in magnitude and time distribution from those applying to residential applications. They are referred to as HOT1, HOT2 and HOT3 and they correspond to 40, 50, and 60 litres of daily hot water consumption per person, respectively (figs. 1 and 2).

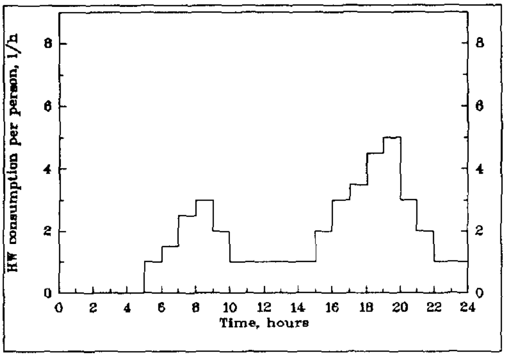

Fig. 1. Hot water consumption profile HOT1

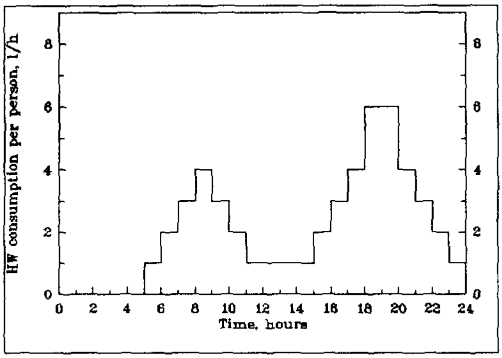

Fig. 2. Hot water consumption profile HOT3

In the present study, the performance of the system is expressed in terms of its solar fraction, *f*, which is defined as the fraction of the hot water load provided by solar. Monthly average values of the daily solar radiation and air temperatures (Meteorological Service, 1975, 1985) have been supplied to the TRNSYS Weather Generator subroutine to generate hourly data required for the simulations. A large number of economic and other parameters have also been used as inputs to the system model; some of these are shown in Table 1.

TABLE 1. Simulation parameters

Slope of the collector efficiency curve, $F_R(\tau\alpha)_n$	0.78
Intercept of the collector efficiency curve, F_RU_L	24.4 kJ h^{-1} K^{-1} m^{-2}
Collector mass flux	50 kg h^{-1} m^{-2}
Collector slope	35° from horizontal
Storage factor	50 l m^{-2}
Backup fuel cost rate	7.4 US$/GJ
Backup fuel inflation rate	5%/yr

A number of simulations were run to investigate the optimum size of the collector for each scenario, i.e the surface area of the collector which brings about maximum savings throughout the lifetime of the system. The annual solar fraction of the system has also been related to the collector size.

SIMULATION RESULTS AND DISCUSSION

The simulation results were used to plot the graph of fig. 3 which shows the variation of annual solar fraction and per capita life cycle savings with the collector to consumer factor (FCC) for the three scenarios. It is interesting to note that the solar fraction increases with collector area. The situation, however, is not the same with the life cycle savings which reach a maximum corresponding to about 0.8 m^2 per consumer for the low load profile, 1 m^2 per consumer for the medium load profile and 1.2 m^2 per consumer for the high load profile. This means that the optimum collector to consumer factors are 0.8, 1 and 1.2 m^2 per consumer respectively for the low, the medium and the high hotel load profiles, as compared to 1 m^2 per consumer in residential applications.

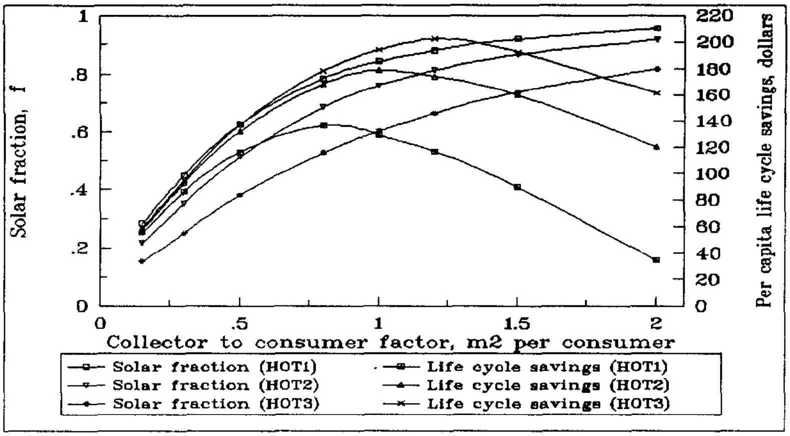

Fig. 3. Optimisation of collector size for hotel applications

It is also useful to relate the solar fraction and life cycle savings to the dimensional factor FCL which involves the collector size and the annual hot water load. For this purpose, the results of simulations were used to plot the graphs of figures 4 and 5, which show the variation of the annual solar fraction and life cycle savings with FCL, for the low and high load profiles respectively. From the above figures it can be seen that the value of FCL for the low load profile HOT1 is about 0.4 m^2 per annual GJ and that of the high load profile HOT3 is approximately 0.3 m^2 per annual GJ which show that the optimum collector sizes are different and are dependent on the load profile. For the medium load profile HOT2 the corresponding FCL is approximately 0.35 m^2 per annual GJ.

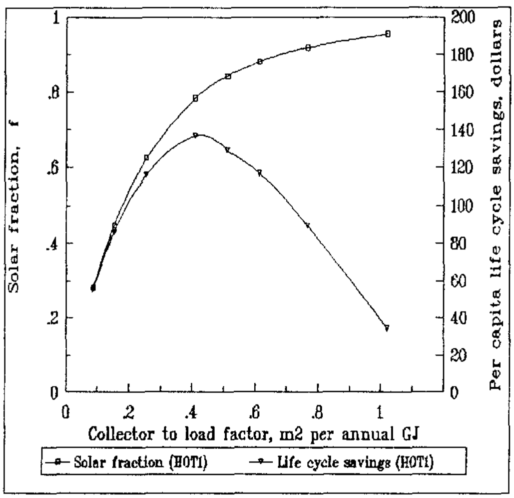

Fig. 4. Optimisation of collector to load factor for hotel application HOT1

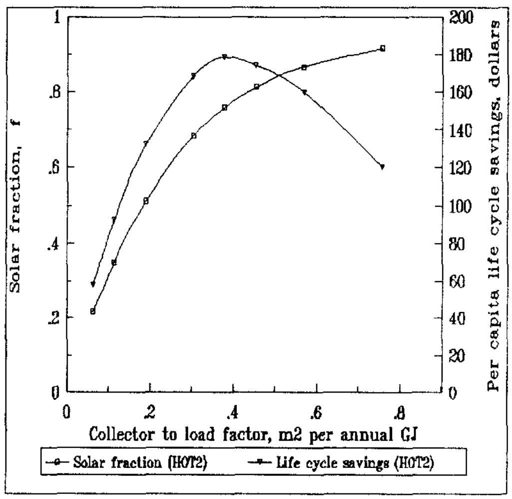

Fig. 5. Optimisation of collector to load factor for hotel application HOT2

The above graphs can be used to determine the collector size for a pre-selected annual solar fraction, provided that the consumption pattern is one of those used in the simulations or similar to them.

A summary of the results concerning optimum collector sizes and payback periods for hotel applications is shown in Table 2. The payback periods corresponding to the optimum design criteria, for the low load profile HOT1 is 8 years while for high load profile HOT3 this figure reduces to 7 years. The difference is attributed to the fact that consumption profile HOT3 assumes a higher load (60 l of water at 60 °C as compared to 40 l at 50°C for HOT1) which results to an increased utilisation of the collectors and generally the solar system.

TABLE 2. Optimum design criteria for hotel applications

Load profile	OPTIMUM		Solar fraction	Payback period years
	FCC m^2/consumer	FCL m^2/GJ		
HOT1	0.8	0.4	0.80	8
HOT2	1.0	0.35	0.75	7
HOT3	1.2	0.3	0.65	7

In the preceding simulations the conventional fuel and the back up energy were assumed to be diesel oil which is the traditional energy source used for service water heating in the hotel industry in Cyprus due to its low cost (7.4 dollars per GJ as compared to 36 dollars per GJ for electricity).For the purpose of comparison, a set of simulations have been run for an economic scenario which assumed electricity as conventional and back up energy. The simulation results demonstrated that the solar system would be a cost effective and attractive alternative with a payback period of about 4 years and an annual solar fraction of nearly 0.9.

CONCLUSIONS

The computer simulations showed that the optimum collector size for active solar hot water systems intended for hotel applications varies between 0.8 and 1.2 m^2 of collector per consumer, depending on the hot water consumption pattern and the category of hotel, which indicates that a larger collector is economically justified as the consumption of water increases. The corresponding solar fraction varies from 0.80 to 0.65 which means that 80 to 65% of the annual heat requirements respectively are met by solar energy.

In terms of the annual thermal load, the optimum collector size varies between 0.3 and 0.4 m^2 of collector per annual GJ of thermal load for low and high hot water consumption profiles respectively, as compared to 0.45 for residential applications.

REFERENCES

Klein, S.A. *et al.* (1990). *TRNSYS, a Transient Simulation Program (version 13.1).* Solar Energy Laboratory, University of Wisconsin.

Meteorological Service (1975). *Local Climates in Cyprus. Meteorological Paper No 6.* Ministry of Agriculture and Natural Resources, Republic of Cyprus.

Meteorological Service (1985). *Solar Radiation and Sunshine Duration in Cyprus. Meteorological Paper No 10.* Ministry of Agriculture and Natural Resources, Republic of Cyprus.

Michaelides I.M. (1993). *Computer simulation and optimisation of solar heating systems for Cyprus.* PhD thesis, University of Westminster, London.

Michaelides I.M, Lee W.C and Wilson D.R. (1993). Computer Simulation and Optimisation of Solar Water Heating Systems. *Proceedings ISES Solar World Congress,* Budapest,Hungary, Vol. 5, 157–162.