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INVESTIGATION OF DOMESTIC SOLAR WATER HEATING INSTALLATIONS IN MALTA

S.P. Borg, *C. Yousif and *R.N. Farrugia
Tel: (+356) 79604656, E-mail: spborg79@hotmail.com
*Institute for Energy Technology, University of Malta, Triq il-Port Ruman, Marsaxlokk, ZTN 09, Malta,
Tel: (+356) 21650675, (+356) 21652249, Fax: (+356) 21650615

ABSTRACT: Malta enjoys favourable weather conditions that encourage the use of solar water heating systems, but their market penetration has so far remained low. In an effort to identify the reasons behind this lack of impetus, the Institute for Energy Technology has devised a number of study programmes. This paper deals with one of those studies, namely the technical aspects of installed domestic solar heating systems. Results showed that there are a number of issues that are contributing towards lower solar water heating systems performance. Most of these shortcomings can be easily overcome, but it is clear that there is a need for proper training programmes for installers as well as better diffusion of information on the proper utilisation of this technology.

KEYWORDS: Solar Water Heating, Tilt, Azimuth, Technical Issues

1. INTRODUCTION

1.1 The Maltese Climate and Solar Energy

Like other areas in the Mediterranean region, Malta enjoys an abundance of sunshine and moderate temperatures for most of the year. Figure 1 shows a comparison of global horizontal solar radiation in some countries around the Mediterranean, including Cyprus and Israel, which are known to have some of the highest installed solar collector area per capita [1].

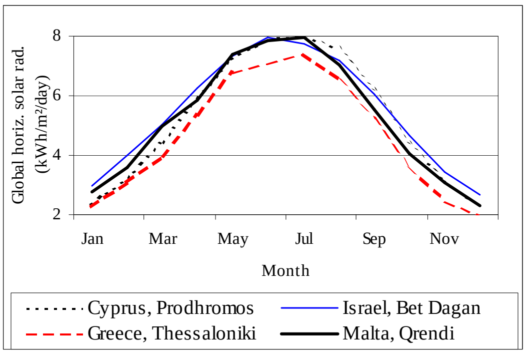

Figure 1: Global horizontal solar radiation for some Mediterranean cities.

1.2 Present Situation of SWH in Malta

During the past decade, solar water heating suppliers increased from a handful of importers to twenty-five companies in 2005, importing solar heating systems ranging from the classical flat-plate copper-tube collectors to the more advanced evacuated-tube systems and other innovative products such as the all-PVC fully recyclable solar heating system. Perhaps the most important development in this market was the breakthrough in the prices of evacuated tube solar heating systems, which have now become comparable to those of flat-plate systems. However, to date the total amount of installed systems is anticipated to barely surpass the 10,000 mark, which represents approximately 8% of the potential for solar systems in the domestic sector only.

The recent increase in electricity and fuel tariffs caused by the rising oil prices has prompted a boost in the sales of solar heating systems, that could be 40% higher in 2005 than those of last year [2].

There are presently two incentives for the purchase of solar water heating systems namely, Enemalta's waiving of the installation fees of electricity meters (amounting to Lm 70, equiv. to € 162) for new customers, provided that a SWH system is installed on the premises beforehand, effective as of June 2003 [3] and the Maltese Government's 2005 budgetary measure conceding a once-only payment of 15.25% of CIF value, up to Lm 50 (equiv. to € 116) of a solar water heating system for households [4]. However, these initiatives do not provide technical supervision or certification of these installations.

1.3 Technical Background

Based on previous research work [5], four characteristics were chosen as the main factors that optimise the performance of a domestic solar heating system. These characteristics were:

- Azimuth facing South (or up to 15º South-east or South-west);
- Tilt angle at 45º to the horizontal ± 5º;
- Hot Water Storage Capacity to Collector Area, (50-60 litres/m^2 for flat-plate collectors and 90-100 litres/m^2 for evacuated-tube collectors), and
- Hot water pipe insulation.

2. DATA COLLECTION

2.1 Questionnaire and on-site examination

A questionnaire was prepared beforehand for collecting data during the technical visits. It was divided into two parts:

The technical part of the survey analysed a number of issues, including:

- Size of collectors;
- Volume of hot water storage;
- Collector azimuth and tilt;
- Piping and insulation, and
- Checking for corrosion.

The main sections of this first part of the questionnaire were carried out by:

1. Measuring the relevant dimensions of the collector;
2. Checking for existing or possible shading;
3. Determining the azimuth and tilt of the collector;
4. Verifying the thermostat temperature setting, and
5. Checking for system deterioration, the condition of piping, insulation and possible leakages.

The second part of the survey dealt with the social aspects of hot water usage, such as:

- Trend of daily and seasonal hot water consumption;
- Routine maintenance on the system;
- Problems encountered in operation;
- Reduction in the electricity bill, and
- Background knowledge on SWH.

2.2 Target Visits

The main targets were the owners of domestic solar water heating systems. About 550 letters were sent to owners of solar systems, while another 120 letters were sent through Enemalta Corporation to customers, who had benefited from its incentive scheme during 2003 and 2004. About 17% of the owners (115 owners) confirmed their acceptance for the technical visits, which were carried out between July 2004 and August 2005.

2.3 Evaluation of questionnaires

The data from the surveys was collected and a statistical analysis performed, using a Microsoft® Access® database specifically designed for this project. One of the outputs of this study was to issue individual reports on the SWH systems and to send them to the owners to help them identify and redress any shortcomings in their current SWH system configuration. A general report was also sent to the different solar water-heating suppliers highlighting the main issues identified and encouraging them to take these into consideration during future installations. No doubt, this exercise revealed the need for training for installers as well as provision of more awareness to the owners with regards to the optimum use of such systems. All information was processed in accordance with the Data Protection Act.

2.4 Use of F-Chart

Extensive use of a simulation software programme, F-Chart®, was made to enable the analysis of certain features such as:

- Optimum amount of hot water usage;
- Best collector area needed, and
- Collector azimuth and tilt.

In the F-Chart programme other design values including the heat loss coefficient and the zero loss efficiency values may also be varied. Therefore, prior to each analysis the specifications of the particular heater under examination were listed in the programme and the specific weather conditions for Malta were input.

Three flat-plate and one evacuated-tube solar heaters currently available on the local market were modelled. In the report these are referred to as Models 1, 2, 3 for flat-plate and Model 4 respectively [5]. Model 1 had a flat plate collector and a hot water storage capacity to collector area of 70 litres/m^2. Both collector and pipes were made of copper and treated with a selective coating. Model 2 had a flat plate collector too with a storage capacity of 70 litres/m^2 but the pipes were bonded to a steel plate and were painted with a matt black paint. Model 3 was similar to Model 1 but had a storage capacity-collector area of 100 litres/m^2. Model 4 was a 30 tube evacuated SWH with a hot water storage capacity to collector area of about 100 litres/m^2.

The output of F-Chart included:

- Solar radiation incident on the collector;
- Total energy required to raise the water temperature to a certain temperature;
- Auxiliary energy required, and
- F-Ratio defined as the ratio of Useful Energy Absorbed to the Total Input Energy required to heat the water.

The results were then used as the reference characteristics of the solar water heating system and compared with real operating conditions, in particular with respect to the tilt angle and orientation of the collector, the water storage capacity to collector area and state of insulation on the hot water piping system.

3. DATA ANALYSIS

3.1 Analytical Analysis

3.1.1 Azimuth

Using F-Chart the influence of azimuth on the monthly energy collection was examined. Figure 2 shows a bar chart of monthly in-plane solar radiation falling on a Model 1 SWH tilted at 45° for azimuth angles between ±40° from the south. Similar tests were made for the other models.

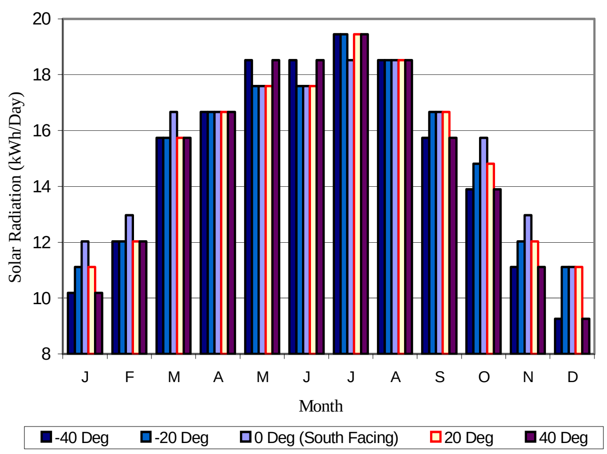

Figure 2: Variation of solar radiation with azimuth incident on a Model 1 solar water heater.

The maximum solar energy incident on the collector was during July. It is worth noting that, whereas the maximum daily energy absorbed was for south-facing collectors for the months between October and March, this is not so for the months between April and September. In fact while in April and August the orientation seemed to bear no effect whatsoever, between May and July the maximum was reached for orientations other than the south. This could be explained by the fact that the collector was inclined at 45° to the horizontal. However, for domestic use the most important months remain the ones with lower irradiation and hence the optimum azimuth would be facing south.

Figure 3 shows that the total energy falling on 1m^2 of collector between October and May is a maximum at 0° azimuth, while energy losses would occur for other angles. Orienting the collector 40° away from the south incurs an energy loss penalty as high as 7.5%. This is an averaged value for 8 months, but if one had to consider individual months, the losses would increase for wintertime. In January for example, a loss of 7.5% and 15% would be experienced for an azimuth of 20° and 40° respectively.

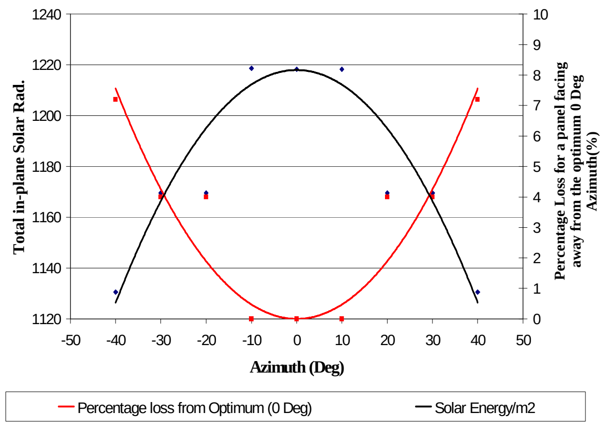

Figure 3: In-plane solar radiation (kWh/m^2) Oct.-May incident on 1m^2 of collector vs. azimuth.

From the site visits it was clear that enough knowledge existed on this aspect, with the majority of the collectors being oriented correctly between ±15° to south as shown in Figure 4. In this region, up to 1% of the optimum is lost on average. However over 20% still had their collectors oriented away from the suggested optimum range.

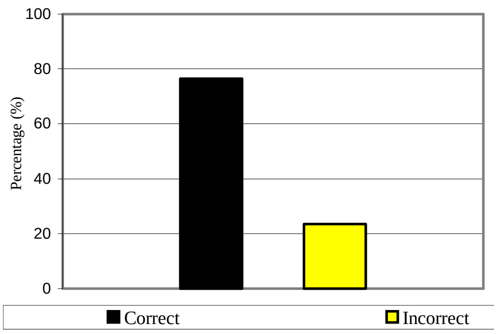

Figure 4: Percentage of correctly and incorrectly oriented systems.

3.1.2 Tilt Angle

Inclining the collector also affects the performance of the system for different periods of the year. Low tilt angles favour energy collection during summer while higher inclinations would optimise the performance for the other months as shown in Figure 5. Here, Model 2 oriented at an azimuth angle of 0º (facing south) was used as demonstration. Similar behaviour occurred for the other 3 models.

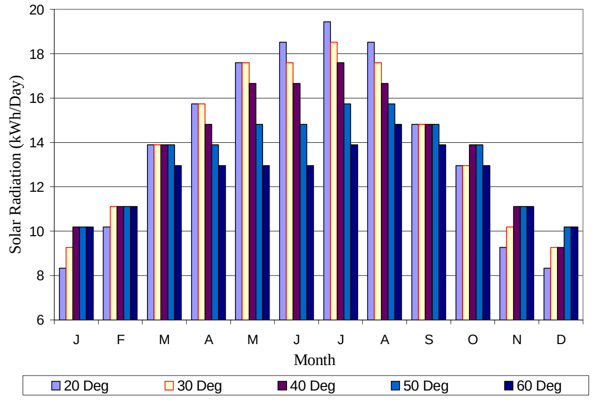

Figure 5: Variation of Solar Radiation with tilt falling on a Model 2 flat plate solar water heater.

For maximum overall collection of solar radiation between October and May, it was found that the optimum elevation angle of the panel would be around 45° to the horizontal as shown in Figure 6. An average energy loss of up to 7% would be expected for angles other than 45°. Such losses are higher during the winter months reaching a maximum of 13% in January for panels inclined at 20° to the horizontal.

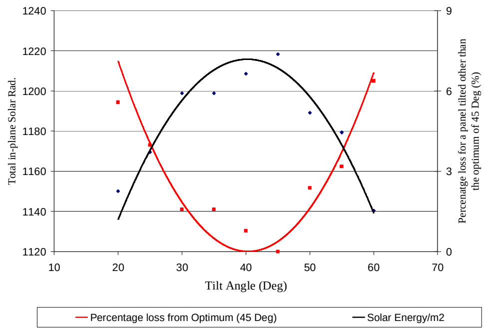

Figure 6: Total in-plane solar radiation (kWh/m^2) per unit of collector area, between Oct-May vs. tilt.

During the visits it was found that most of the SWH collectors were tilted correctly between 40° and 50°, with an average energy loss of less than 1%. But again, a good 20% were not inclined optimally as shown in Figure 7.

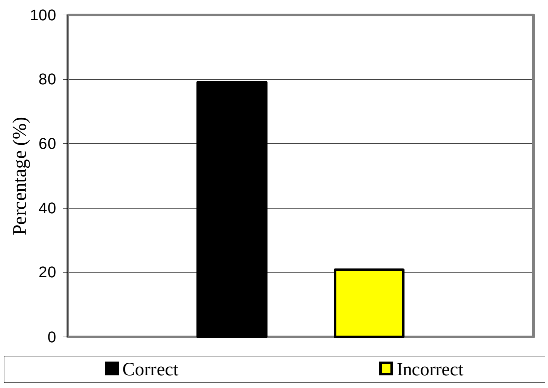

Figure 7: Percentage of correctly and incorrectly tilted systems.

3.1.3 Hot Water Storage Capacity to Collector Area Ratio

The analysis of the hot water storage capacity to collector area ratio assumed a typical daily hot water consumption of 160 litres for 4 persons [6]. Using F-Chart and varying the collector area for Model 1 (flat plate) and Model 4 (evacuated) two graphs were plotted as shown in Figure 8. Here, the F-Ratio was used as a measure of performance, since it demonstrates the contribution of solar energy in supplying energy to meet the demand of 160 litres.

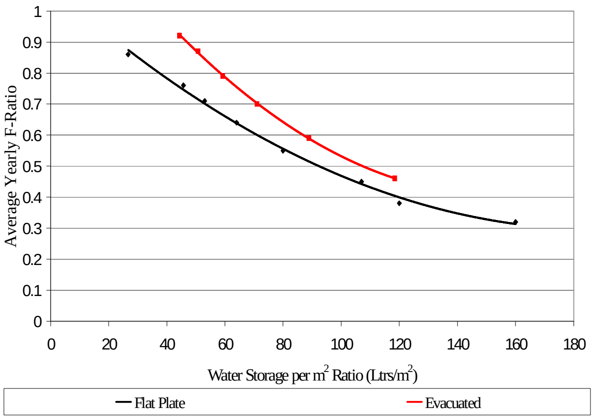

Figure 8: F-Ratio vs. Hot Water Storage-Collector Area Ratio.

It can be seen that the evacuated-tube SWH reached higher F-Ratios than flat-plate collectors. In fact, for a flat plate to reach an average F-Ratio of 0.6 it requires a collector area of at least 1m^2 for every 50 to 60 litres of hot water. One could also deduce that 90-100 litres would be sufficiently heated by 1m^2 of evacuated tube collector. The plots are averaged annual values and this must be kept in mind when discussing the possibility of using larger collector areas. Whereas increasing the collector area would increase the F-Ratio, systems operating in Mediterranean climates might have problems in summer due to overheating, apart from the fact that minimum amounts of hot water are used during this period. Moreover, the increase in the collector area would require a higher investment that may not be justified, when compared to savings.

On most occasions (60.9% of the visits), the solar collector area was less than the optimum volume of storage water, which would effectively result in lower hot water temperatures, unsatisfied owners and increased electricity consumption by the back-up electric booster rather than savings. The reason for inappropriate sizing could be attributed to the fact that systems are imported 'off the shelf' and were not custom-made to match the local weather conditions.

3.1.4 Insulation

Previous work [5] showed that pipe insulation is an effective means of reducing losses. Based on the physical parameters of piping and insulation typically used for these applications, which are polybuthylene piping and thermal insulation used in air-conditioning, it is clear that un-insulated pipes lose 50% more energy than insulated pipes.

Since the conditions of wind and outside temperature have major effects on thermal losses, a range of heat transfer coefficient (HTC) values were chosen to represent various conditions. Figure 9 shows that the heat loss per metre run, varies for insulated and un-insulated pipes at different ambient conditions, here represented by the outer heat transfer coefficient. The hot water was assumed to be stagnant in the pipe at 65°C, while the ambient temperature was set at 15°C.

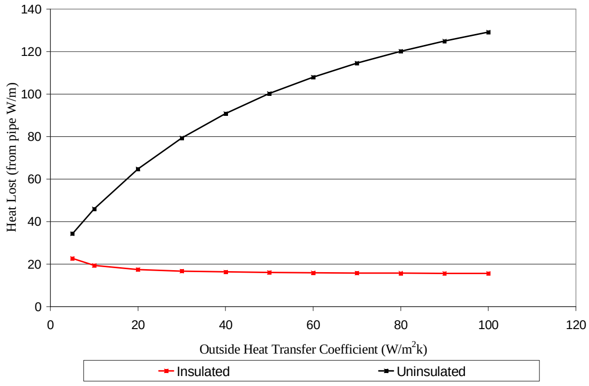

Figure 9: Heat lost per m of pipe vs. outside HTC.

If one considers the first point where the plots are closest, that is when there is no wind and therefore the outside air is stagnant, the heat lost per m from an un-insulated pipe is 11.55 Watts or 50% higher than the amount lost by an insulated pipe of the same diameter. As the wind speed increases, the heat lost due to convection from the un-insulated pipes increases drastically. On the other hand, in both cases the heat lost due to radiation decreases due to the fact that air would cool the pipe surface and reduce heat lost by radiation.

Figure 10 shows how the heat loss per m from un-insulated and insulated pipes varies with increase in water flow rate (inside the pipe), represented by the inner heat transfer coefficient.

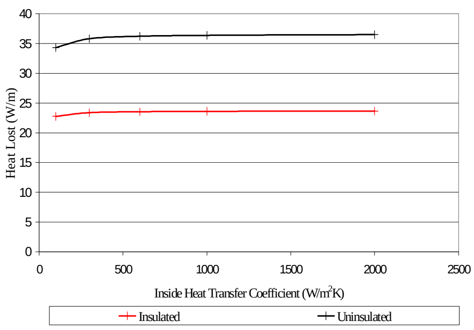

Figure 10: Heat lost per m of pipe vs. inside HTC.

It is evident that a variation in the flow rate of hot water does not alter the rate of thermal loss from the pipes. In fact this plot shows how under all conditions of supply un-insulated hot water pipes lose 50% more energy than insulated pipes.

In order to get an idea of how much energy is lost a typical situation was simulated [5]. An insulated pipe of length 15m exposed to stagnant outside conditions carrying flowing water was used as a model. For such conditions the energy loss per metre length is 23 Watts, yielding a total of 345 Watt over the whole length of the pipe. If the water is left flowing for 15 minutes, such as would be the case when taking a shower, the energy lost would be 86.25Wh. For a family of four this would lead to a total loss of 345Wh. Taking into consideration Model 2 in December, 3.58kWh are successfully absorbed and used to heat the water. This implies that without insulation the energy lost would be 14% of the energy absorbed by the solar water heater and for an insulated pipe this would drop to 10%.

About 44.3% of the 115 installations visited had insulated hot water pipes and most of these were affected on the owners' personal initiative. However, deterioration of the insulation was evident on 33.3% of these, implying that only 14.8% of the total installations visited had proper insulation. Tables 1 and 2 show these results in detail.

Table 1: Number of installations with insulated pipes.

Insulated	Amount (Number of Installations)	Percentage of Total (%)
Yes	51	44.3
No	64	55.7

Table 2: Number of installations with deteriorated insulation.

Deteriorated Insulation	Amount (Number of Installations)	Percentage of insulated Pipes (%)
Yes	17	33.3
No	34	66.7

3.2 Combined losses

Although the individual losses may seem small, the cumulative effect drastically undermines the performance of the systems. This study revealed that only about 23.5% of the systems visited were operating at good conditions, above 91% of the optimum. However, the majority had a combination of installation shortcomings, which if remedied would increase the system performance. Figure 11 shows the statistical distribution of the present situation of combined losses in the installed systems.

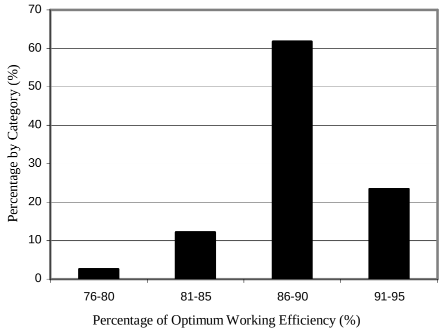

Figure 11: Percentage of Optimum

3.3 Use of Hot water

Matching the production and consumption of energy is an important criterion in the optimum use of renewable energy and solar water heating is no exception. For this reason, part of the questionnaire consisted in asking the owner about the household's use of hot water. Figure 12 shows the family categories that participated in the survey. The total number of participants in the survey was of 387 and as can be seen most families consisted of four persons or less.

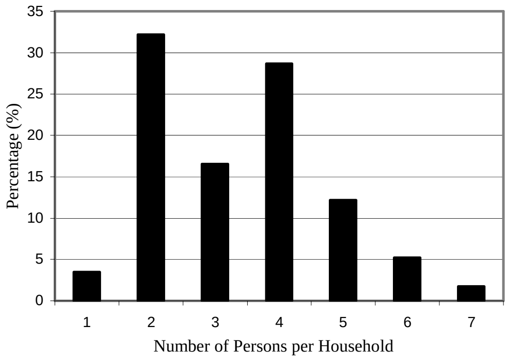

Figure 12: Distribution of number of members in the family.

Assuming that each person consumed about 40 litres of hot water per day in winter, a family of four would require at least 160 litres of hot water daily. In summer this value is estimated to go down to about 20 litres per person for a total of 80 litres for a family of four. Figure 13 shows the prevalence of taking showers over baths both in winter as well as well in summer.

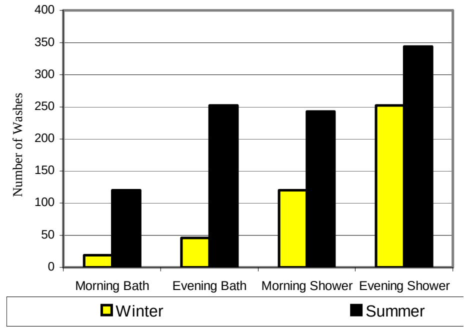

Figure 13: Number and time of washes

One problem that was evident from the replies of the interviewed customers was that quite a number of users need hot water both in the evening and early the morning after. As the cold water flows in after the evening showers, the tank's temperature drops leaving little hot water for use in the morning. This lifestyle seemed to have created a custom for about 43.5% of the users to switch on the booster daily for an hour or two in the morning before bathing. However, a good number of interviewed customers (56.5%) replied that during the day their booster is switched off and apart from switching it on during consecutive overcast days, they rarely use it. In order to overcome this issue, some solar water heating systems are now offering the possibility of controlling the time and quantity of cold water that is fed into the hot water storage tank.

3.4 Comparison of Models used in analysis

Part of the analysis done using F-chart consisted in comparing the different models used in the study under typical weather conditions [5]. The monthly average F-Ratio was taken as a measure of performance. Since the F-Ratio varies with the hot water demand, a typical pattern of total daily hot water usage for four persons was assumed for the four models. The pattern used was the following:

- December to March – 160 Litres
- Apr, Oct and Nov – 120 Litres
- May to September – 80 Litres

Figure 14 shows the resulting plots of the four models. Model 4, the 30 tube evacuated SWH had the highest F-Ratio. Model 1, which has both copper pipes and fins covered by a selective coating, is the second best. Model 2, which is a steel plate with copper pipes covered with black paint, is the one that uses most auxiliary heating for hot water supply. Model 3 comes somewhere in the middle, since although it has both copper plate and pipes, it has a large hot water storage capacity to collector area ratio, which sometimes prevents it form reaching an acceptable temperature of 55°C.

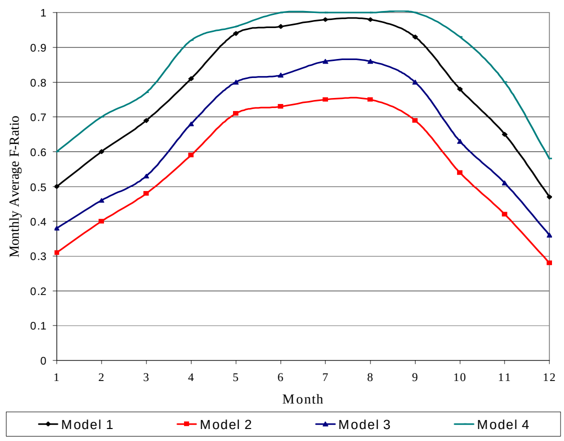

Figure 14: Monthly F-Ratio for the four Models.

3.5 Other Results

3.5.1 Thermostat Temperature

During the visits, 49.6% of the solar systems had a thermostat temperature higher than 65°C. This results in an unnecessary use of electricity and a complete defeat of the scope of the solar system. Especially in winter, if these powerful boosters are left on in the morning even for a short time, all the water in the tank is heated to an extent that when the sun comes up later in the day little solar energy is absorbed. The repeated occurrence of this scenario would lead to an even higher electric consumption than a traditional 80-litre electric heater. Whenever possible and with the permission of the owner the thermostat temperature was lowered to 60-65 ºC.

3.5.2 Reasons for installing a SWH

Another interesting outcome from the on-site visits were the reasons behind the motivation to install a SWH. Half of the respondents believed that the solar system would eventually lead to savings in electricity for heating water. Almost 30% also replied that they were environmentally conscious. About 10% have opted for a solar system in order to avoid installing multiple electric hot water boilers. Figure 15 shows all responses, noting that some responses gave multiple reasons.

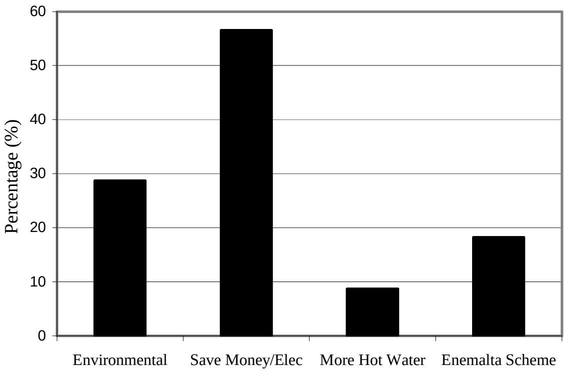

Figure 15: Reasons for installing a SWH

3.5.3 Popularity of Solar Water Heating Systems

When asked whether they would recommend a SWH system to other potential customers, 92.2% responded positively. However notwithstanding this fact only 29.6% of the interviewed commented that they had actually seen a reduction in the electricity bill. The main reason given for this statement was that together with the solar water heating system, an air-conditioning unit had also been installed. Others commented that the SWH had been installed since moving into the residence; therefore they could not make comparisons.

3.5.4 Use of Pump

During these home visits 58.3% of the installations had a pump installed on the water plumbing system including the solar system. A common issue was the use of a too powerful a pump for the application, leading to higher water consumption. There was also some doubt whether the pumps are causing a disruption in the stratification of water in the solar storage tank but it seemed that this was not experienced by the users. In fact, most solar systems had diffusers at the cold water inlet that would force the cold water to spread along the lower part of the tank. For those few cases that experienced hot water disruption a less powerful pump would be more appropriate and a temporary remedy could also be implemented by placing a valve between the pump outlet and the cold water inlet.

3.5.5 Incentive Schemes

Incentive schemes that promote the use of solar heating systems contribute towards enhancing the widespread application of such systems, however one must take care that the systems are installed properly. During the home visits, it was found that systems benefiting from any of the available incentives still had the same installation defects as the others. This calls for a closer monitoring exercise during the installation process in order to guarantee the optimum potential of savings and the attainment of the incentive's goals.

4. CONCLUSION

This report showed that there is room for improvements in the technical installation of SWH. There is a potential for improving the performance by up to between 10% and 15% depending on the feasibility of the modifications.

The fact that there are still more than 20% of the systems that were not placed at the optimum azimuth and tilt calls for more attention during installation. There is a need for training installers and to keep abreast of any developments in the field. They should be prepared for on-site fault diagnosis and be capable of implementing technical solutions fast.

Unsatisfied customers are potentially more effective in promoting their negative experiences. This would result in a sceptic attitude towards the potential benefits of solar heating and its widespread application.

Incentive schemes for solar heating should ideally be accompanied by a certification service, whereby the installation is checked and approved to comply with the optimum operating conditions for that particular site, depending on the purpose of use and type of solar system. Only then, one can guarantee that those systems would produce the aspired savings in electricity generation and a reduction of its related environmental impacts.

The forthcoming National Census 2005 will reveal the actual number of solar water heaters installed but the true savings can only be guaranteed if these systems are installed properly.

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