

IMPACT OF HOT WATER USAGE PATTERN AND LOCATION ON ECONOMICS OF SOLAR WATER HEATING SYSTEMS

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SYNOPSIS

This paper presents the variation in the economics of solar water heating systems based on water usage pattern and location. The auxiliary heating requirement was obtained by computer simulation of the performance of solar water heating system. The simulation was performed using the software Transient System Simulation Program. Two hot water usage patterns and three locations (Pune, Mumbai and Chennai) were selected for the parametric analysis with two different sizes of solar water heaters. Economic analysis included calculation of percentage savings, payback period analysis and cost of unit electricity saved. The results of the exercise indicate that the savings in electricity by solar heating depends on the water usage pattern and the location. The results help in selection of proper size of solar water heating systems. Economical analysis showed 250 lpd was found to be most cost effective for Pune, with payback period about 2.5 years and cost of saved energy about Rs. 1.5/kWh. The cost of energy saved for 250 lpd systems was found to be less than Rs.2/kWh for the patterns and locations selected.

1. INTRODUCTION

Renewable energy sources can play a vital role in the developing countries like India. Renewable energy technologies in India have been promoted through R&D, demonstration projects, dissemination projects/programmes supported by government subsidies and fiscal incentives. The contribution of renewable energy has not been significant in the overall energy scenario [1]. It is important to identify the factors that affect the diffusion process of renewables. For the study of the diffusion process of the systems, it is important to understand the effect of design and operating on the rate of adoption at the micro-level.

Though there is a significant potential for renewables, the actual number of adoption has been relatively low. Solar water heating system is a relatively mature solar thermal technology that has reached the stage of commercialization in India [2]. Solar thermal technologies have a natural advantage in India due to the fact that the average radiation is 4.5–6 kWh/m²/day with an average of 280 clear days in a year. The technical potential has been estimated as 140 million sq.m. of collector area [3]. More than 0.70 million sq.m. of collector area has been installed so far in the country for water heating [4]. The collector area installed is less than 1% of the estimated potential.

It is expected that the end-user, decision to opt for a renewable energy system will be influenced strongly by its economic viability. This paper analyses the impact of different parameters on economics of solar water heating systems (SWHS).

2. PARAMETRIC ANALYSIS

Savings in the electrical heating requirement is the main economic contribution of using solar water heating system (SWHS). Figure 1 shows the schematic of solar water heating system. Thus, requirement of auxiliary heating requirement for SWHS was evaluated by computer simulation.

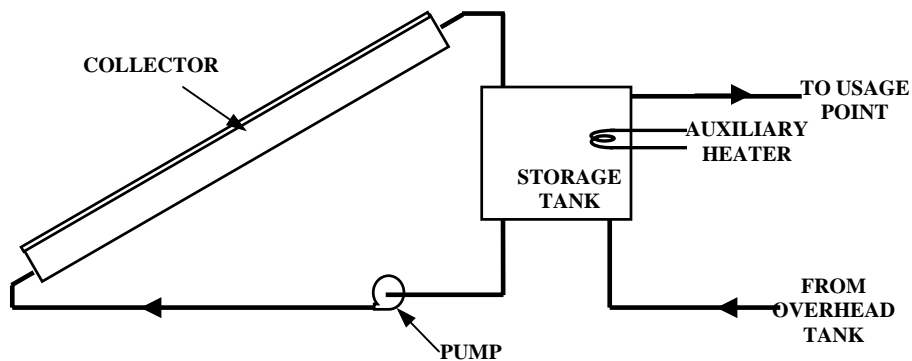


Fig. 1: Schematic of solar water heating system.

The computer software TRNSYS [5] was used for simulation of solar water heating systems. Transient System Simulation Program (TRNSYS) has been developed at Solar Energy Laboratory, University of Wisconsin and can simulate various components used in collection of solar energy. TRNSYS was used for simulation of solar water heaters and electric water heaters. Weather data and hot water use profile are inputs to the software and output is auxiliary and parasitic energy required for water heating.

The parameters considered for the analysis were

- (i) Water usage pattern (number, timing and quantity of draws).
- (ii) Weather conditions (ambient temperatures and insolation).
- (iii) Sizes of solar water heaters.
- (iv) Economic (Cost of SWHS, price of electricity).

3. SIMULATION INPUTS

Figure 2 shows the information flow diagram of a sample TRNSYS program for solar water heating system. The components of the SWHS considered are solar collector, pump, storage tank and auxiliary electric heater. The inputs for simulation include the hot water usage pattern, system specifications and weather data.

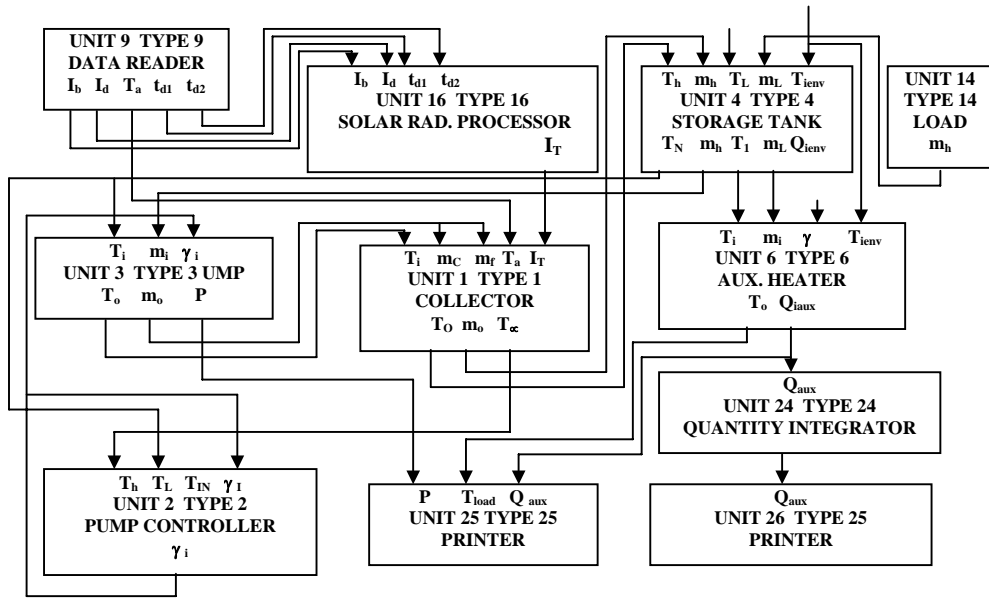


Fig. 2: Information Flow Diagram of TRNSYS Program for Solar Water Heating System

Equation used for calculation in simulation of unit of flat plate collector

$$\eta = \frac{Q_u}{A_p I_T} = F_R(\tau\alpha) - F_R U_L \frac{(T_i - T_a)}{I_T} \quad (1)$$

$$\text{Efficiency curve } \eta \text{ vs. } (T_i - T_a)/I_T \quad (2)$$

where η is efficiency

Q_u is rate of energy gain (kJ/h)

A_p is total collector area (m²)

I_T is incident radiation (kJ/m²-h)

$F_R(\tau\alpha)$ is intercept efficiency

$F_R U_L$ is negative of slope of efficiency curve

T_i is temperature of fluid entering collector inlet (C)

T_a is ambient temperature (C)

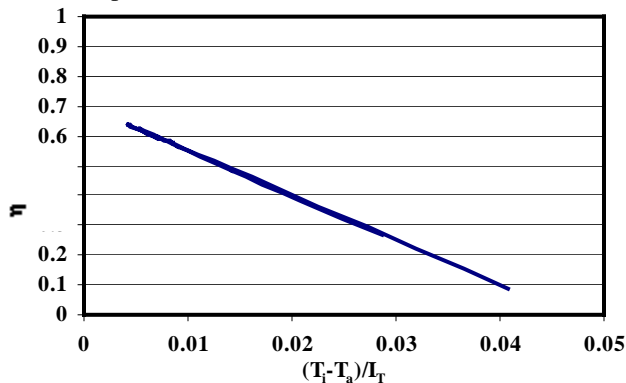


Fig. 3: Efficiency curve

3.1 Hot Water Usage Pattern Selected

In literature, several standard water usage patterns are reported for US, Europe [6,7]. However, there are relatively fewer studies of Indian load patterns. Gadgil [8] provides an example of a residential water usage pattern. This pattern is used to estimate a standard pattern for six-residence building with two adults and two children in each residence [9]. Total water used in this pattern is 1080 litres. This standard pattern is compared with an average usage pattern. This pattern was obtained by distributing the total hot water used in a day for the total usage period. This pattern was considered to understand the effect of hot water usage pattern on the economics of solar water heating systems. Figure 4 and 5 show the standard hot water usage pattern and average pattern respectively. The end use temperature is set at 40 °C.

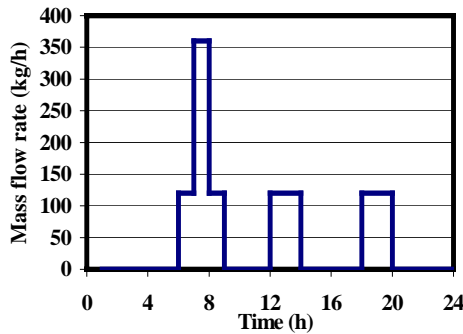


Fig. 4: Standard Hot Water Usage Pattern (WUP-1)

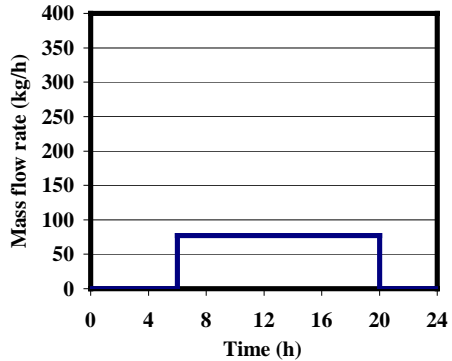


Fig. 5: Average Hot Water Usage Pattern (WUP-2)

3.2 Weather Data

Monthly average hourly ambient temperatures, monthly average hourly global radiation and monthly average hourly diffuse radiation for the selected locations were obtained from Mani [10]. These data were used in the weather data file, an input to the simulation. Figures 6 and 7 compare the average monthly ambient temperatures and total monthly incident radiation respectively for the three locations selected. The annual average temperature for Pune, Mumbai and Chennai were found to be 25 °C, 26.7 °C and 27.9 °C respectively. Table 1 shows the average of weather data for the selected locations.

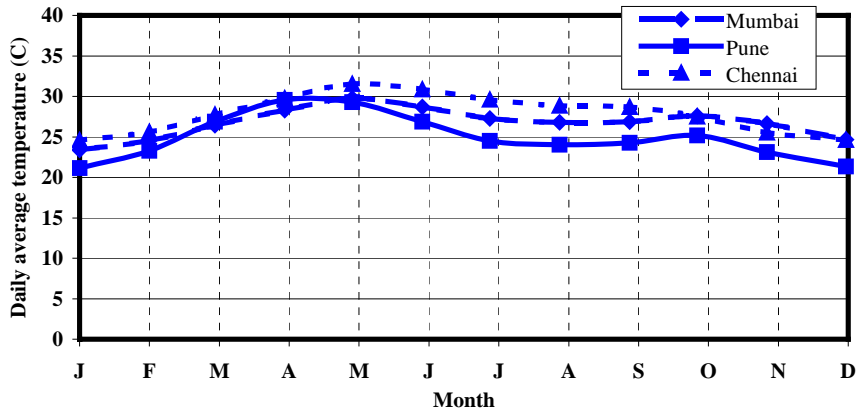


Fig. 6: Monthly variation in ambient temperature

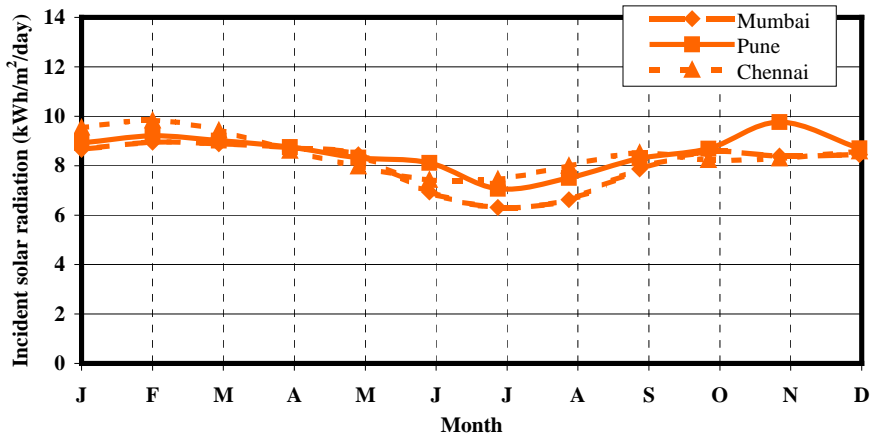


Fig. 7: Monthly variation in incident solar energy

Table 1: Average ambient conditions of selected locations

LOCATION	WEATHER DATA (ANNUAL AVERAGE)	
	AMBIENT TEMPERATURE (°C)	INCIDENT SOLAR RADIATION (kWh/m ² /day)
Pune	25.0	8.5
Mumbai	26.7	8.1
Chennai	27.9	8.5

3.3 Sizes of solar water heating systems

Solar water heating system with tank capacity of 125 lpd has a collector absorber area of 2m² is designed for 60 °C. By simulation at designed load condition, the average temperature at load was found to be 70 °C. For the daily load of 1080 litres at 40 °C, the calculated capacity requirement of SWHS was found to be 340 lpd, 340 lpd and 290 lpd for Pune, Mumbai and Chennai, respectively. So the systems selected were for simulation 250 lpd and 375 lpd systems with collector area of 4 m² and 6 m² respectively.

Table 2 shows the combination of all the parameters considered for this study. There were a total of 12 combinations.

Table 2: Matrix for parametric analysis of solar water heating systems

Locations	Capacity of SWHS	Water Usage Pattern (WUP)
Pune	250lpd	Standard water usage pattern (WUP-1) Average water usage pattern (WUP-2)
Mumbai	(4m ² collector area)	
Chennai	375lpd (6m ² collector area)	

4. SIMULATION OUTPUTS

The simulation was run on yearly basis and the outputs were on monthly average basis. A typical day was selected for each month to study the variations on an hourly basis. The simulation outputs include the temperature variation and energy inputs at different points. The output used for economic analysis was the auxiliary electric energy required for each set of parameters. Figures 8 and 9 show the energy pattern and temperature variation respectively for a typical day for all the three locations. These patterns are obtained for the standard water usage pattern for 250 lpd system.

The simulation output is used for economic analysis. Outputs included hourly data for each month for both water usage patterns for all the three locations. The simulation output also includes the gain of solar energy by SWHS.

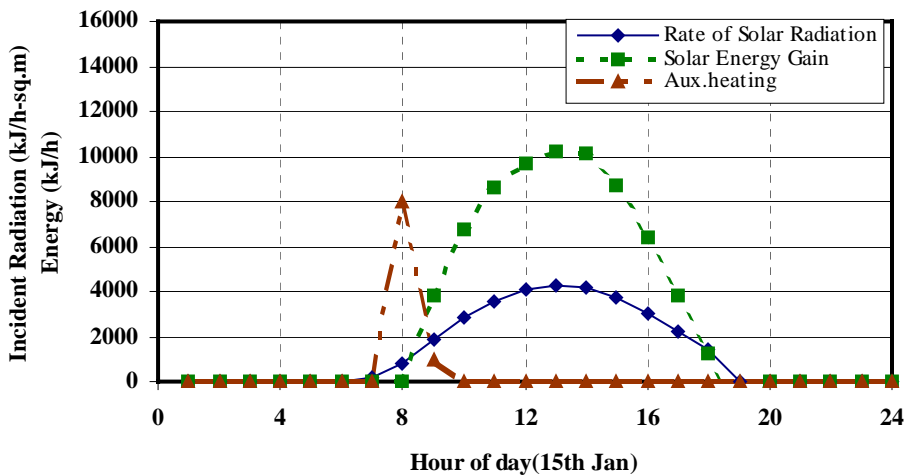


Fig. 8: Energy flow/ Solar Radiation for a typical day of Pune (250 lpd- WUP-1)

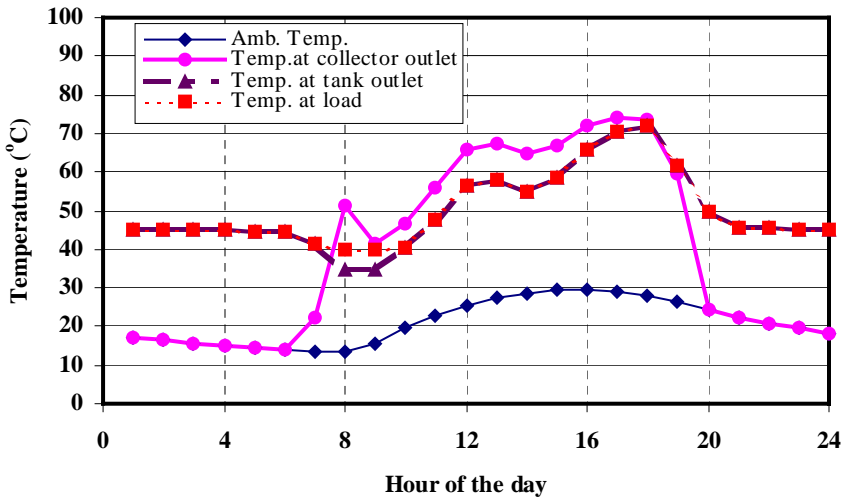


Fig. 9: Temperature profiles for a typical day of Pune (250 lpd -WUP-1)

5. ECONOMICAL ANALYSIS

Economical analysis includes the calculation of savings in electricity cost, payback period and cost of energy saved. The electricity requirement for an electric geyser is computed as a base case for each of the options. The different usage patterns result in different electricity requirements due to differences in the ambient temperatures. Annual electrical energy consumption for two water usage pattern of an electric geyser is given in Table 3.

Table 3: Annual electrical energy consumption

LOCATION	ELECTRICAL ENERGY CONSUMPTION (kWh/year)	
	WUP-1	WUP-2
Pune	7282	5940
Mumbai	6248	5436
Chennai	5637	4935

5.1 Savings in Electricity Cost

The electricity saved is calculated with respect to the condition when there is no SWHS and water is heated with electric heater. In the simulation, the system considered is a forced flow system and so there is sum amount of electricity consumed by the pump, which is reflected in the savings.

Figure 10 shows the monthly electrical energy required for the standard water usage pattern for electrical heater. Figure 11 shows the auxiliary electrical energy for standard water heater for 250lpd system expressed as the percentage of the electrical energy required in the electric heater. These figures compare the electricity requirements and savings for all the three locations for the standard pattern for 250 lpd SWHS.

5.2 Comparison of savings with different capacities of solar water heating systems

Out of the two capacities selected, simulation showed that in case of 375 lpd SWHS no auxiliary heating was required to meet the hot water requirement for the selected patterns. This was seen for all the three locations selected.

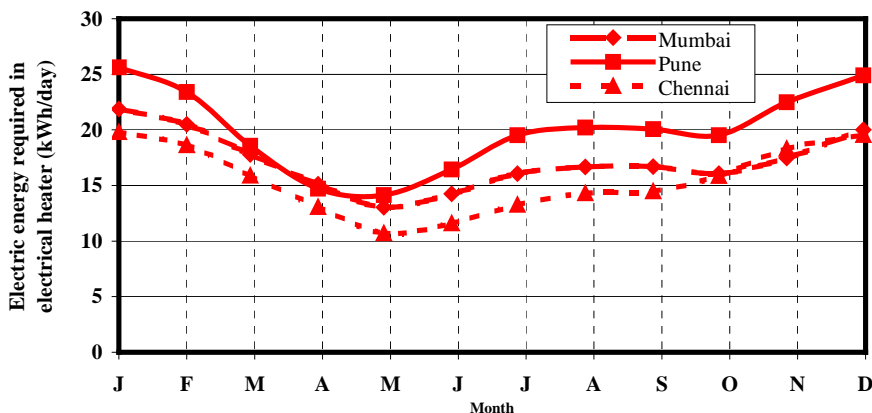


Fig. 10: Monthly variation in energy requirement for electrical heater (WUP-1)

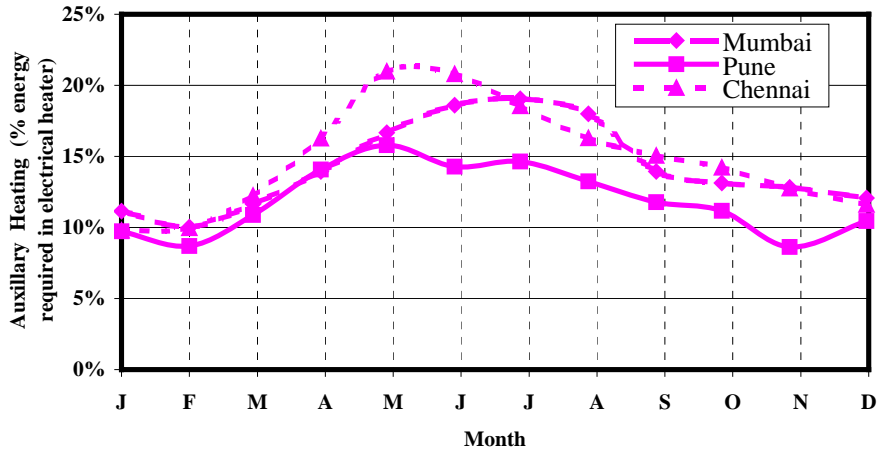


Fig.11: Monthly variation in auxiliary heating energy requirement (250 lpd -WUP-1)

5.3 Comparison of Savings for Different Patterns

Figure 12 shows the energy usage patterns for the average usage pattern for 250 lpd system in Pune. The percentage savings in case of 375 lpd system is same for both the patterns as there is no auxiliary heating required in all three locations for both the patterns. The only electricity used is that for pumping.

Figure 13 shows the percentage savings in electricity for all the different combination. Annual electricity savings is tabulated in Table 4

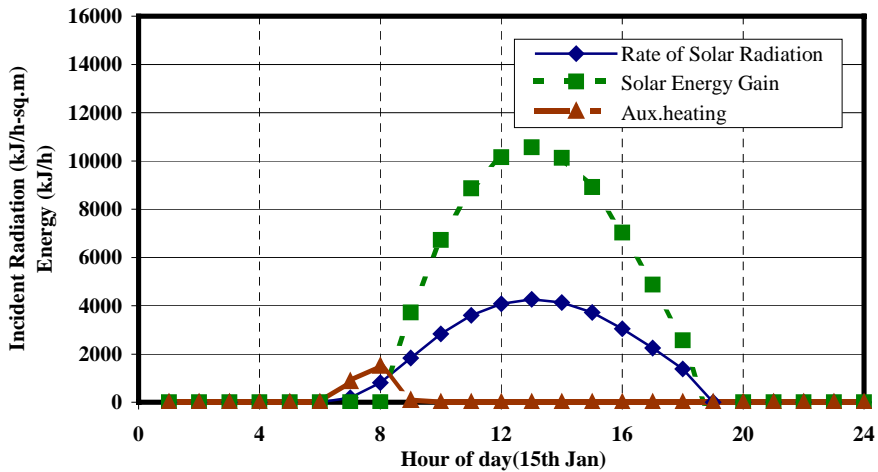


Fig. 12: Energy flow/ Solar Radiation for a typical day of Pune (250 lpd - WUP-2)

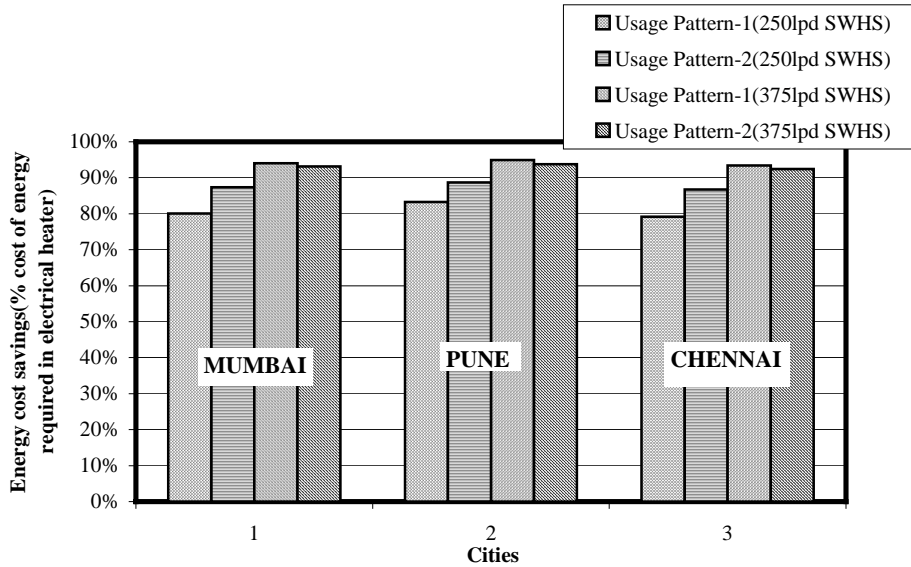


Fig. 13: Savings for the three cities for two usage patterns

Table 4: Annual electrical energy savings

LOCATION	ELECTRICAL ENERGY SAVINGS (kWh/year)			
	(% electrical energy required for electric heating)			
	WUP-1		WUP-2	
	250 lpd	375 lpd	250 lpd	375 lpd
Pune	6063 (83%)	6911 (95%)	5270 (89%)	5569 (94%)
Mumbai	5001 (80%)	5874 (94%)	4749 (87%)	5062 (93%)
Chennai	4464 (79%)	5266 (93%)	4282 (87%)	4564 (92%)

5.4 Payback Period Analysis

The payback was calculated for all the combinations. Cost of domestic 100 litres capacity is in the range Rs.15000-20000 [3]. The input data for calculation is tabulated in Table 5.

Table 5: Input data for calculation of payback period and cost of electricity saved

1.	Cost of SWHS for 1m ² of collector area	Rs. 10,000/-
2.	Unit cost of electricity	Rs. 2.80/kWh
3.	Cost of 250 lpd system	Rs.40,000/-
4.	Cost of 375 lpd system	Rs.60,000/-
5.	Discount rate is taken as	20%
6.	Life of solar water heating systems	20 years

$$\text{Simple payback period} = \frac{\text{Capital cost}}{\text{Annual savings}} \quad (3)$$

Table 6 shows the payback period for combinations considered. The payback period for the incremental investment for 375 lpd systems instead of 250 lpd systems is also calculated.

$$\text{Payback for incremental investment} = \frac{(\text{Capital cost of 375 lpd SWHS} - \text{Capital cost of 250 lpd SWHS})}{(\text{Savings for 375 lpd system} - \text{Savings for 250 lpd system})} \quad (4)$$

Table 6: Payback periods for different combinations

LOCATION	SIMPLE PAYBACK PERIOD (year)			
	WUP-1		WUP-2	
	250 lpd	375 lpd	250 lpd	375 lpd
Pune	2.35	3.01	2.71	3.85
Mumbai	2.86	3.65	3.00	4.23
Chennai	3.20	4.07	3.34	4.70

The payback period of incremental cost for 375 lpd systems was found as 8-9 years and 20-25 years for the standard and average hot water usage patterns respectively.

5.5 Cost of electricity saved

The marginal cost of electricity is about Rs. 2.00/kWh. Cost of electricity saved helps to show the cost benefits in the electricity saved using solar water heating system.

$$\text{Cost of saved energy} = \frac{\text{Annualised capital cost}}{\text{Annual energy saved}} \quad (5)$$

$$\text{Annualised capital cost} = \text{Capital cost} \times \text{CRF} \quad (6)$$

$$\text{Capital Recovery factor (CRF)} = \frac{d \times (1+d)^n}{[(1+d)^n - 1]} \quad (7)$$

where d is the discount rate and n is life of SWHS

Results of the calculations made are tabulated in Table 7.

Table 7: Cost of electricity saved for different combinations

LOCATION	COST OF ELECTRICITY SAVED (Rs./kWh)			
	WUP-1		WUP-2	
	250 lpd	375 lpd	250 lpd	375 lpd
Pune	1.35	1.78	1.56	2.21
Mumbai	1.64	2.10	1.73	2.43
Chennai	1.84	2.34	1.92	2.70

6. RESULTS AND DISCUSSION

6.1 Effect of Hot Water Usage Patterns on Economics

From the patterns studied, it is clear that water usage patterns play an important role for economics and selection of SWHS. Both the payback period and the cost of electricity

saved are lower in case of standard water usage pattern for all three locations and two sizes. This can be attributed to the peak demand in the early morning hours. Thus, the position of peak demand is important with respect to the auxiliary heating requirement.

6.2 Effect of Location on Economics

Economics of SWHS is affected by the weather conditions. The ambient temperatures and the solar radiation together affect the amount of the auxiliary heating required. The economics have been found to be most effective for Pune, amongst all three cities selected, for all water usage patterns and capacities. The savings in electricity for Mumbai and Chennai are 80-90% and 70-82% of that in case of Pune, respectively. This difference in savings with location is due to difference in ambient temperature and insolation.

6.3 Effect of SWHS Capacity on Economics

The percentage savings in electricity cost increases with the increase in capacities of solar water heating systems. The savings for electricity cost varies from 79% to 89% for 250 lpd systems. Although the total hot water consumption per day was 1080 litres, no auxiliary heating was required for 375 lpd systems. Thus the evaluation of savings helps in selection of the capacity of SWHS. The payback period depends entirely on the combination of SWHS capacity, hot water usage pattern and location for installation of SWHS. The payback for incremental capital cost of 375 lpd system over 250 lpd SWHS is found to be 8-9 years for standard pattern which is not economically viable.

7. CONCLUSIONS

The economics of any solar water heating systems depend upon the weather data, hot water usage pattern and the location. This analysis will help in estimating the potential of solar water heating in an area. Economic analysis shows that 250 lpd system is most economical for Pune for standard hot water usage pattern. Both payback period and cost of energy saved are lowest in this case. Though, the economical analysis shows 250 lpd systems to be more economical but it should be noted that no auxiliary heating is required for 375 lpd systems. The cost of energy in case of 250 lpd SWHS varies between Rs. 1.35 and Rs. 1.92, which are lower than marginal cost of electricity. The hot water usage pattern may vary with location due to different ambient conditions and habits of inhabitants. Thus selection of appropriate size of solar water heating systems should be done for the specific usage pattern with the ambient conditions for each location.

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