# Design & Performance Analysis of Portable Solar Water Heating System for Rural Areas: Himalayan Regions, India

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**Abstract:** Domestic Solar Water Heating systems (SWHs) have very low penetration specifically in the rural areas of Northern, Eastern and North-Eastern Himalayan States as the present SWHs are expensive, non-availability of good sun shine hours and weak manufacturing base & supply chain of this product in selected states of India. The paper is focused on design and field performance of developed low cost solar water heater for domestic applications for the rural areas of Himalayan regions. Field Performance data of Portable Solar Water Heating System (PSWHs) has been recorded during summer and winter months. It is observed that on solar Global Radiation of 3.28 kWh/m$^2$, the maximum temperature of hot water has reached 69 $^o$C at ambient temperature of 27 $^o$C within four to five hours showing a temperature difference of 42 $^o$C and maximum thermal efficiency of 74%.

**Key Words:** Solar Global Radiation, Low Cost & Light Weight Portable Solar Water Heater, Thermal Performance

## 1. Introduction

Solar water heating systems have huge amount of usage and applications in domestic purpose. The total installed capacity of SWHs in the Himalayan region amounts to 33000 sq. m, which is less than 1% of the total installed SWH capacity across India [1]. Most of the existing SWHs installations in these regions are either spread in the government agencies or in the framework of existing government programs. Some of the constraints of non-penetration of domestic based solar water heating systems in rural areas of Northern, Eastern and North-Eastern Himalayan states (Fig.1) are high installation cost, non-availability of the manufacturing base, spare parts & trained manpower and less number of good sunshine hours available.

On the basis of available average solar radiation and ambient temperature data (Global Radiation of about 4.1-4.3 kWh/m$^2$ /day & ambient temperature 16 $^o$C) in these regions, Solar Water Heating systems will operate approximately 200-220 days in a year [2-3]. Under these conditions, the traditional SWHs provide less quantity of hot water. In order to achieve the rated capacity of hot water, solar collector area has to be increased. This would increase the cost of installation and ultimately leads to increase the cost per litres of hot water. All these factors stated above create obstacles in penetration of the domestic solar water heating systems in rural areas of Himalayan Regions.

A market assessment study of solar water heating systems in these regions has been carried out under UNDP-GEF global solar water heating project. It was found that, there is a huge demand for low cost solar water heaters in the rural areas of Himalayan Regions [4].

Under this assignment, MNRE and UNDP-GEF has developed a low cost solar water heater for Domestic application keeping in view the requirement of rural areas of the Himalayan Region.

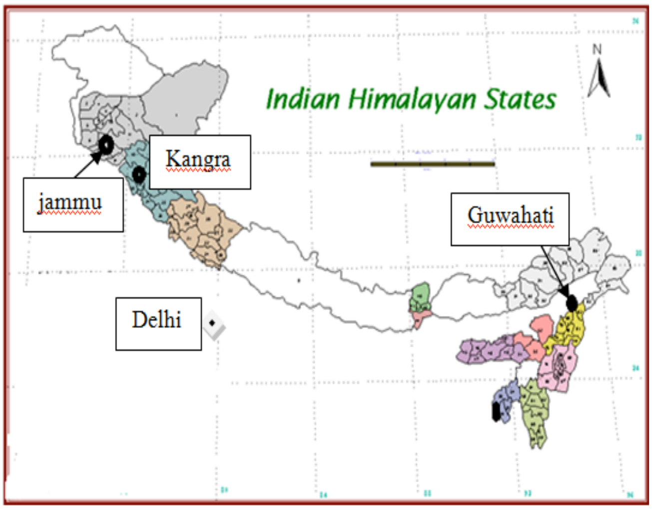



**Fig.1.** Himalayan Regions of India

The developed low cost solar water heater is basically a portable model. The portable solar water heating system is a simple modular design, where each panel is integrated with glazing, solar collector cum tank, insulation and handle cum stand. As the system is a combination of solar collector and tank together in one construction, it is the most economical way to have hot water from the solar energy (Global Radiation). Being a compact portable solar water heater the installation cost is zero. It can be installed in balconies, terraces, roofs, gardens and require a very small shadow free area.

## 2. Experimental Model & Operation

A.C Mintsa Do Ango et al., [5] developed a polymer type module of solar flat plate collector. The absorber plate of module is polycarbonate sheet and glass wool used for insulated. The module consists of 2 meters long, 20 cm wide & thickness of 6.2 cm which is painted with black colour on the absorber sheet.

The thermal efficiency of flat plate collector system mainly depends on solar radiation on the absorber plate and thermal losses (i.e. convection & radiation losses) [6].Double glazing with low emitting coating in the pane with improves the insulation and efficiency of the flat plate collector [7]. Martinopoulos et al [8] investigated a low cost polycomb polycarbonate collector & its performance analysis. The polycarbonate collector absorbs directly incident radiation by black colour coolant. A low cost plastic film solar flat plate collector has been investigated. The efficiency achieved from 45-70% at the global solar radiation 2 kWh/m$^2$ per day [9]. F. Giovannetti [10] investigation on the selective glass coating based on transparent conductive oxide for increase the performance of the flat plate collector. The efficiency increases to 60% higher than single glazed flat plate collector at the temperature difference of 50 kelvin between inlet temperature and ambient temperature & at global radiation of 500 W/m$^2$. Many Researcher have been investigated on the thermal behaviour of flat plate collector for evaluation its efficiency, study of performance on large flat plate collector ( made of copper & aluminium) but thermal behaviour & performance estimation on portable type solar water heating system is missing on publication.

The present system has been mainly conceived on the idea of portable type solar water heater and this system. However, special emphasis laid on incorporating the locally available material & design fabrication expertise. The glazed area of 500 mm×500 mm, weigh 5 kg when empty & having the water capacity of 12.5 Litres. The module has been designed in such a manner that it can easily carried in hand or on back. The front glazing is of poly carbonate thin sheet of 0.5 mm, which is tough, dimensionally stable, high impact resistance, and good temperature capability and un-breakable and expected life is 4-6 years. In PSWHs plastics and stainless steel sheet material has been used for the modular/Panel whereas the insulation used EPS thermo cool of 25mm. The inlet water is located at the top and outlet at the bottom of the PSWHs as given Fig. 2. PSWHs has to be kept in a fixed position (45$^o$) facing equator with the help of handle cum stand and move to follow the solar radiation with the help of sun tracker manually.


**Fig.2.** Experimental setup portable solar water heater

Cold water is to be filled in the morning from the top of the PSWHs and within four to five hours water archive temperature about 65-70 $^{o}$C as depending upon the global radiation.

### 3. Performance Analysis

The performance of PSWHs has been carried out by installing the system at the Out –Door Test Bed of National Institute of Solar Energy (NISE; formerly Solar Energy Centre), Ministry of New and Renewable Energy (latitude: 28$^{o}$ 25$^{/}$ 31.2$^{//}$ N & longitude: 77$^{o}$ 9$^{/}$ 18.8$^{//}$ E) shown in Fig.3. Portable solar water heating system has been evaluated and observations were recorded on the basis of field data collected (period of four hours in a day) for 12 months. For this thermal efficiency test following the standards IS 12933-5 have been performed [11].

To simplify the performance analysis, some of assumptions are made in this paper;

- Range of solar global radiation should be more than 2.5 kWh/m$^2$
- Range of wind speed should not exceed 5 m/s
- Surrounding ambient air temperature with accuracy is ±0.1ºC
- Range of PSWHs water inlet temperature with ±0.1

**Fig.3.** Field experimental set up at National Institute of Solar Energy

### 4. Experiment Performance Data

Some recorded data without night losses (4 hour) as shown in Table-1;

| Inlet Temp. of water $T_i$ ,°C | Ambient Temperature $T_a$,°C | Temperature of Hot water after Four hours $T_o$, °C | Temperature difference ΔT,°C | Mean Temperature $T_m$,°C | Global Radiation kWh/m$^2$ | Wind Speed m/sec |
|---|---|---|---|---|---|---|
| 27 | 32 | 69 | 42 | 48 | 3.28 | 1.06 |
| 28 | 31 | 64 | 36 | 46 | 3.33 | 3.6 |
| 24 | 28 | 66 | 42 | 45 | 3.12 | 2.3 |
| 27 | 29 | 70 | 43 | 48 | 3.2 | 1.2 |

The performance of PSWHs without night losses (i.e. 4-5 hours) and with night losses (i.e. 24 hours) as shown in Table-2;

| Without Night losses (4 hours) | | With Night Losses (i.e.24 hours) | |
|---|---|---|---|
| $T_i$ | : $27^0 C$ | $T_i$ | : $30^0 C$ |
| $T_o$ | : $69^0 C$ | $T_o$ | : $39.9^0 C$ |
| $Q_{use}$ | : $0.6\ kJ/sec$ | $Q_{use}$ | : $0.14\ kJ/sec$ |
| $G$ | : $3.28\,kWh/m^2$ | $G$ | : $6.96\,kWh/m^2$ |
| $\eta$ | : 74.3 % | $\eta$ | : 8.2 % |

Rate of useful energy extraction from the PSWHs;

$$Q_{use} = m\ C_p\ \Delta T \qquad (Eq.\ 1.1)$$

Thermal Efficiency (%);

$$\eta = Q_{use} / \left(A \times \sum G\right) \qquad (Eq.\ 1.2)$$

Mean Temperature ($T_m$);

$$T_m = T_i + \left(\frac{\Delta T}{2}\right) \qquad (Eq.\ 1.3)$$

## 5. Results and Discussions

The performance has been analysed for the period of four hours in day times i.e. 10:30 hours to 14:30 hrs. It is observed that, during the performance testing of portable solar water heating system, average field data on three parameters namely Temperature (°C), Global Radiation (i.e. Pyranometer tilted as per PSWHs test set up for measuring global radiation; kWh/m$^2$) and wind speed (m/sec) have been recorded.

Data of recorded parameters have been taken around the year. The performance of the recorded data in the month of May have been taken in this paper as shown in Fig. 4, 5&6. Fig.4 shows the temperature (°C), global radiation (kWh/m2) & wind speed (m/sec) has been recorded and found as 28.7 °C, 660 W/m$^2$ (3.3 kWh/m$^2$) & 3 m/sec respectively.

Fig.5 shows the maximum & minimum of air ambient temperature and its average whereas the maximum & minimum wind speed and its average shown in Fig.6. The different parameters recorded for the period of 4 hours as given Table-1.Maximum temperature of the hot water is 69 °C during 14:30 hours (i.e. 4 hours; 10:30-14:30 hours) at an average global radiation of 3.28 kWh/m$^2$ & ambient temperature of 27 °C.

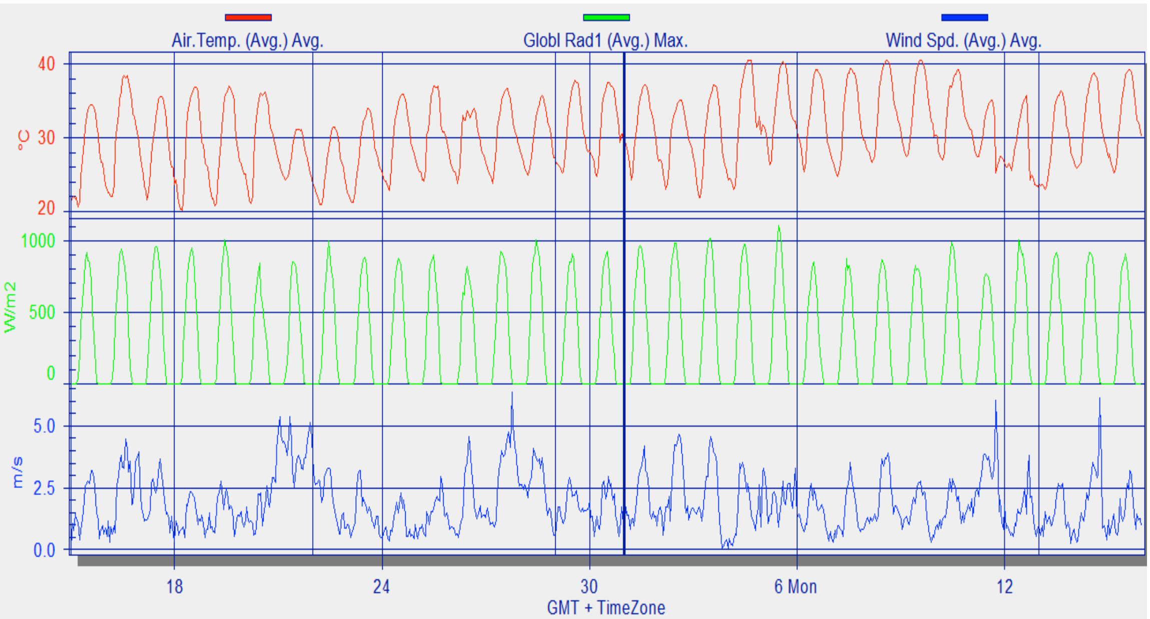



**Fig.4.** Average of temperature, global radiation & wind speed

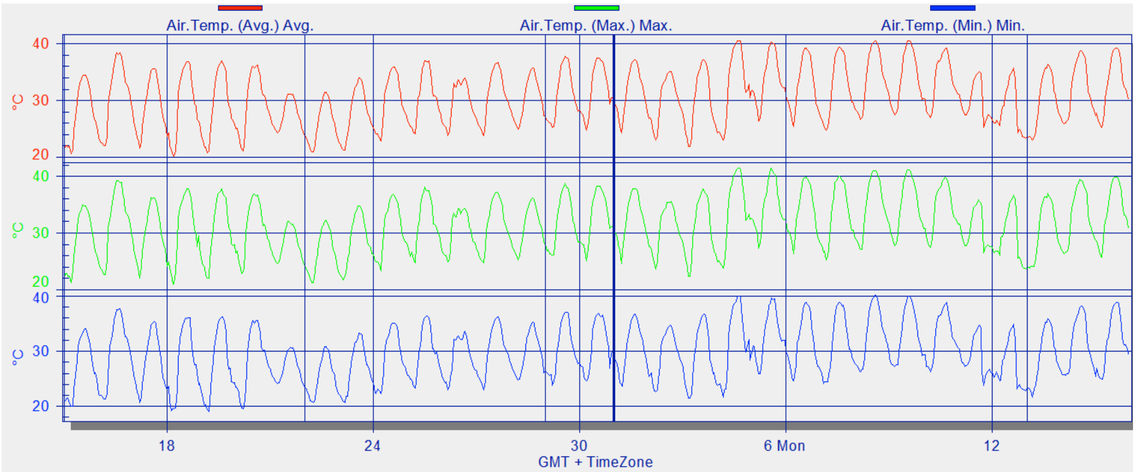



**Fig.5.** Maximum, minimum temperature & its average

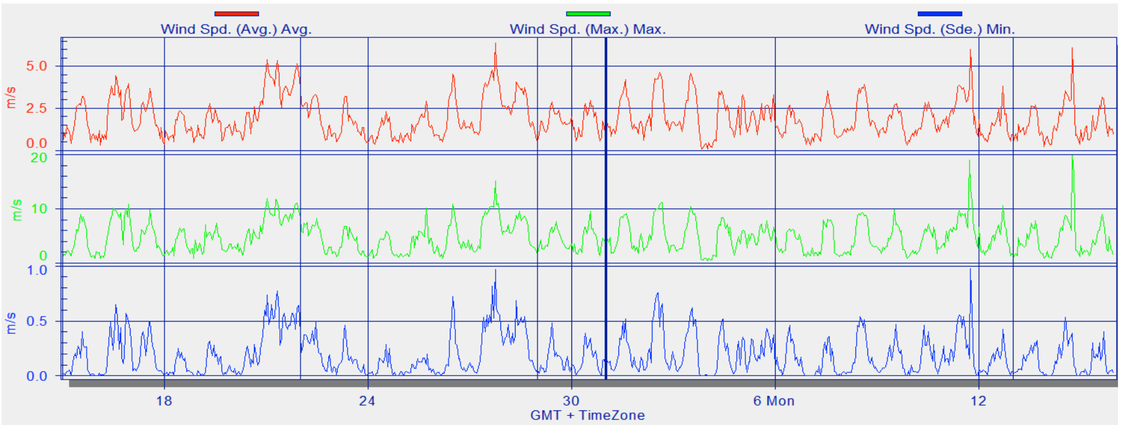



**Fig.6.** Wind speed of maximum, minimum & average

The maximum efficiency achieved to 74% as shown in Table 2. Detailed illustrations of temperature vis-à-vis time during the testing period at different global radiations and ambient temperatures of four hours have been taken in Fig.7.

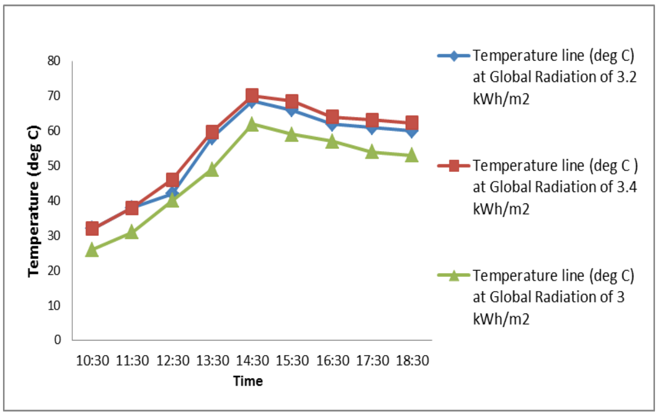



**Fig.7.** Temperature recorded corresponding to Time at different global radiation  (kWh/m$^2$)

The water temperature increased 35-40 $^{o}$C during the testing period. After testing the PSWHs taken inside the laboratory and observed that the temperature starts decreasing initially by 2 to 4 $^{o}$C till 16:30 hours and 6 to 9 $^{o}$C till 20:30 hours. The temperature recorded for the period of 24 hour as shown in Fig.8.

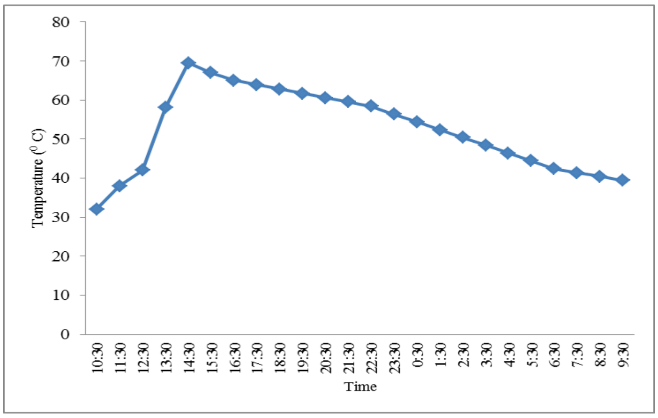
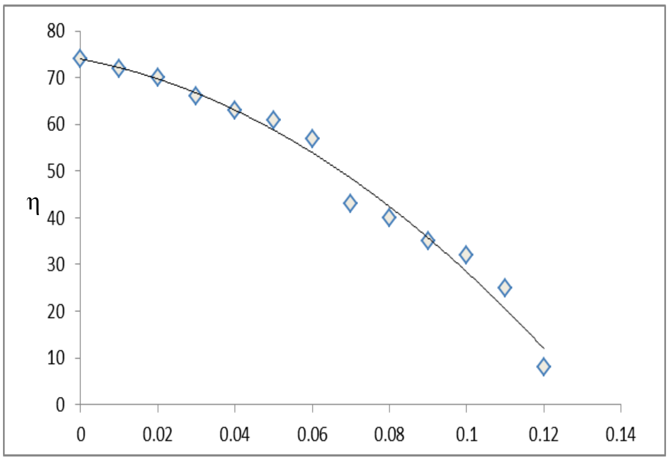



**Fig.8.** Temperature recorded (i.e.10:30 to next day 9:30 hours) corresponding with Time

It indicates that, the rate of fall of temperature of hot water increases (30-32 $^{o}$C) in the next morning due to convection and radiation losses as the PSWHs have thin insulated in hot water storage tank.

The experimental result shows that at efficiency has reached maximum to 74 % at global radiation of 3.28 kWh/m$^2$ with ambient temperature of 27 $^o$C. In the given plotted graph (Fig. 9), the x-axis has taken (Tm-Ta/G) because of both inlet temperature, outlet temperature & ambient temperature affecting the efficiency.




$T_m$-$T_a$/G

**Fig. 9.** Characteristics curve

## 6. Conclusion

Portable solar water heating system having capacity 12.5 litres specifically developed for Northern, Eastern and North-Eastern Himalayan States is simple, light weight, requires less maintenance, zero installation and commissioning cost. Another advantage of PSWH system over the traditional solar water heater is the front glazing which is of polycarbonate thin sheet is tough and unbreakable. From the analysis of Portable Solar Water Heating System, it is concluded that the rise in temperature is in the range of 37-43 $^o$C during the testing period of four hours. The hot water temperature recorded is in the range of 65 $^o$C to 70 $^o$C. Analysis of data recommends utilizing the hot water preferably within 16:00-23:00 hour. It also provides comfort to the beneficiaries and at the same time saves fossil fuel i.e wood which is traditionally being used for heating hot water in rural areas. The tentative market estimated cost of PSWH system is approximately □1000, which decided by MNRE & UNDP-GEF.

### Acknowledgements

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### Nomenclature

| | |
|---|---|
| $m$ | mass of water in the PSWH system |
| $C_p$ | Specific heat of the heat transfer fluid (J/kg $^o$C) |
| $Q_{use}$ | Rate of useful energy extraction from the solar collector,(Watt) |
| $T_a$ | Ambient air temperature, ($^o$C) |
| $T_i$ | Temperature of heat transfer fluid entering the collector, ($^o$C) |
| $T_o$ | Temperature of the heat transfer fluid leaving the collector, ($^o$C) |
| $\Delta T$ | Temperature difference ($^o$C) |
| $T_m$ | Mean Temperature ($^o$C) |
| $G$ | Solar irradiance on collector plane (W/ m$^2$) |
| $\eta$ | Efficiency of PSWH system (%) |

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