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Research Article

Design and Construction of a Solar Water Heater Based on the Thermosyphon Principle

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Abstract A solar water heating system for domestic use has been designed and constructed using locally available materials. Solar energy is received by a flat-plate collector consisting of a thin absorber plate, integrated with underneath grids of fluid carrying tubes, and placed in an insulated casing with a transparent glass cover having a cold and a hot water tank integrated in the system. The radiation emitted by the absorber plate cannot escape through the glass, thus increasing its temperature. The water gets heated and flows into a storage tank through thermosyphon principle. Maximum fluid output temperature, the collector temperature, and insolation of 55 °C, 51 °C, and 1,480 W/m^2, respectively, were obtained on a sunny day. This solar water heating system finds useful application and acts as a renewable energy resource in regions where there is abundant and consistent sunlight.

Keywords thermosyphon; heat; solar water heaters; solar energy; design and construction

1. Introduction

Renewable energy resources of which the sun is a good example are those resources which undergo a faster replenishment rate within a relatively short time than the rate at which they are utilized or depleted. The energy of the sun is generated from the nuclear fusion of its hydrogen into helium, with a resulting mass depletion rate of approximately 4.7×10^6 tons per second. The earth's population currently needs 15 terawatts of power in total, but the solar radiation that reaches the earth on a continuous basis amounts to 120,000 terawatts; hence, just a fraction of the suns energy reaching the earth will cover the bulk of energy requirements [2].

About 36 years ago, the world experienced a major oil crisis which started a new way of energy thinking which focused on developing alternative energy resources, which would be renewable and environmentally friendly. Several challenges such as the increase in oil demand accompanied with oil price rise, depletion of oil reserve, reduced availability of fossil fuel, ozone layer depletion, health hazards, relatively tangible problems of aesthetics to problems of environmental conservation, and global climate change and other air pollution issues caused mainly by burning of these hydrocarbon as a source of heat energy, has led to the drive to use environmentally friendly and renewable alternative sources of heat energy to eliminate or minimize these negative effects. Presently, solar and other alternative energy resources are being harnessed for various applications such as power generation, air-conditioning, space heating, domestic hot water system, etc. [5].

Solar energy being transmitted from the sun through space to earth by electromagnetic radiation must be converted to heat before it can be used in a practical heating or cooling system. Since solar energy is relatively dilute when it reaches the earth, the size of a system used to convert it to heat on a practical scale must be relatively large. Solar energy collectors, the devices used to convert the suns radiation to heat, usually consist of a surface that efficiently absorbs radiation and converts this incident flux to heat which raises the temperature of the absorbing material. A part of this energy is then removed from the absorbing surface by means of heat transfer fluid that may either be liquid or gaseous. One of the simple forms of solar energy collectors built is the flat-plate collector. It differs in several respects from more conventional heat exchangers. The later usually accomplish a fluid-to-fluid exchange with high heat transfer rates but with emitted radiation as an unimportant factor.

Focusing systems have the following challenges which are absent in flat-plate collectors: complications of optical characteristics of concentrator, non-uniform fluxes on the absorbers, wide variation in shape, temperature and thermal loss characteristics of absorbers, and introduction of additional optical factors into the energy balance. Flat-plate collectors unlike focusing systems are designed for applications requiring energy delivery at moderate temperatures up to perhaps 80 °C above ambient temperature. They have the advantages of using beam and diffused solar radiation, not requiring orientation toward the sun, no significant optical loss terms, and requiring little maintenance.

In a review of solar water heating systems for domestic and industrial applications carried out by Ogueke et al. [13], water heating systems were grouped into two broad categories (passive and active), each of them operating in either direct or indirect mode. They reported their performances, uses and applications, and factors considered for their selection. The active systems generally have higher efficiencies, their values being 35%–80% higher than those of the passive systems. They are more complex and expensive. Accordingly, they are most suited for industrial applications where the load demand is quite high or in applications where the collector and service water storage tank need not be close to each other or for the applications in which the load requires more than one solar collector. On the other hand, the passive systems of which this work is an example are less expensive and easier to construct and install. They are most suitable for domestic applications and in applications where load demand is low or medium.

Chuawittayawuth and Kumar [3], in their work, presented details of experimental observations of temperature and flow distribution in a natural circulation solar water heating system and its comparison with the theoretical models. The measured profile of the absorber temperature near the riser tubes (near the bottom and top headers) conformed well with the theoretical models. The values at the riser tubes near the collector inlet were found to be generally much higher than those at the other risers on a clear day, while on cloudy days, these temperatures were uniform. The mean absorber plate and mean fluid temperatures during a day were estimated and compared with theoretical models. The temperature of water near the riser outlets was found to be fairly uniform especially in cloudy and partly cloudy days at a given plane during a day. The temperature of water in the riser was also found to depend on its flow rate. Measurements of glass temperature were also carried out in the work.

Michaelides et al. [11] presented experimental investigation of the night heat losses of hot water storage tanks in thermosyphon solar water heaters. Utilizing the method suggested by ISO 9459-2:95, they tested three typical thermosyphon solar water heating systems with different storage tank sizes. The results were analyzed to quantify the night heat losses and to investigate the effect that these may have on the system daily performance. Analysis of the results showed that a linear behavior of the heat losses with the night mean ambient temperature exists. The research confirmed that the night loss is one of the most important sources of energy loss in thermosyphonic systems.

Photovoltaic thermal technology (PV/T) which refers to solar thermal collectors that use PV cells as an integral part of the absorber plate are examples of systems which generate both thermal and electrical energy simultaneously [8, 10]. They can generate electricity and produce hot air or hot water at the same time. Spiral flow absorber collectors, which are designed in the form of a continuous coil or tube having at least one inlet and outlet so as to allow fluid to enter and to exit from coil, respectively, help to improve on the combined PV/T efficiency and the mass flow rate [8]. The study carried out by Ibrahim et al. [8] showed that spiral flow absorber collector at temperature of 55 °C (panel temperature) achieved the best mass flow rate at $0.011\,\mathrm{kg\,sec^{-1}}$ and generated combined PV/T efficiency of 64%, with 11% of electrical efficiency and power maximum of 25.35 W; while a single-pass rectangular collector absorber obtained the best mass flow rate at $0.0754\,\mathrm{kg\,sec^{-1}}$, when the surface temperature was 392 °C, generated combined PV/T efficiency of 55%, with 10% of electrical efficiency and maximum power of 22.45 W.

Some countries like Nigeria have abundant available solar energy from which useful energy can be harnessed for several purposes (despite the draw-back of night heat losses); hence, the development of this low cost solar water heater (constructed using a high percentage of locally available materials) aimed at providing energy for heating water for domestic use with all the attendant advantages. Being low cost, some features that will increase its cost were not integrated in the system so that it will be affordable by a larger population of the people.

2. Materials and methods

A careful study of already existing solar water systems was done; and a choice was made on the type of system to be designed with focus on simplicity, installation, and maintenance cost as well as durability [1, 3, 4, 6, 9, 14]. Use of locally available materials was made a matter of priority. A flat-plate collector was used as the absorber. It was integrated with underneath grids or coils of fluid carrying tubes and placed in an insulated casing with a glass or transparent cover. A cold water tank placed above and a hot water tank below incorporated with a thermometer and a carriage are integrated in the system. The water gets heated up and flows into a storage tank through thermosyphon principle. The performance of the thermosyphon system depends upon the size and capacity of the storage tank, the thermal capacity of the collector, and the connecting pipes including fluid flow and on the pattern of hot water use [1]. All components were designed for and constructed in line with the design values obtained. The system was tested on a normal sunny day, rainy day, and cloudy day between the hours of 7:00 a.m. and 6:00 p.m.; and results collected were tabulated.

Principle of operation of a flat-plate solar water heater

The solar radiation passes through the glass in front of the absorber plate and strikes the flat black surface of the absorber plate where the solar energy is absorbed as heat (i.e., by increasing the internal energy). This causes the flat-plate collector to become very hot, and so the water contained in the risers and headers bounded to the plate also absorb the heat by conduction. The water inside the tubes (risers/headers) expands and so becomes less dense than the cold water from the storage cylinder. On the principle of thermosyphon, hot water is pushed through the collector and rises by natural convection to the hot water storage tank and cold water from the cold water tank simultaneously descends to the bottom header of the collector by gravity pull. Therefore, there is circulation as a result of an increase in temperature and volume of the warmer water to the hot water storage tank. The circulation continues as hot water goes out, while cold water comes in.

Solar water heaters based on thermosyphon principle have the following advantages: simplicity and low cost, requires no electrical supply, need no controller or pump, easy to install, can withstand mild sub-zero temperature, is reliable and long-lasting since there are no moving parts, scalable (several collectors can be connected in parallel to increase hot water supply), is easy to build and operate, no fuel cost, provides heated water of about 70 °C or within the range, and is portable. They, however, have the following disadvantages: cannot withstand mains pressure, cannot give higher temperature water, are affected by weather conditions, very useful only during the dry season, and can be more practicable and useful in the sunny regions.

Design analysis

The domestic solar water heater has been divided into the following components namely: storage tank, absorber plate, and fluid passage pipes. The amount of solar radiation falling on a surface normal to the rays of the sun outside the atmosphere of the earth (extraterrestrial) at mean earth-sun distance (D) is called the solar constant, I_0. The intensity of the sun varies along with the 11-year sunspot cycle. When sunspots are numerous, the solar constant is high (about 1367 W/m^2); when sunspots are scarce, the value is low (about 1,365 W/m^2) [12]. Eleven years is not the only "beat," however. The solar constant can fluctuate by ~0.1% over days and weeks as sunspots grow and dissipate. The solar constant also drifts by 0.2% to 0.6% over many centuries, according to scientists who study tree rings. Initial measurement by NASA indicated the value of solar constant to be 1,353 W/m^2 (±1.6%). This value was revised upward, and the present accepted average value of the solar constant is 1,367 W/m^2.

$$\text{Efficiency } (\eta) = \frac{\text{Useful energy collected by the collector } (Q_u)}{\text{Solar incident illumination upon the collector } (I) \times \text{Collector area } (A_C)}$$

$$Q_u = IA_C - Q_{\text{loss}}$$

$$Q_u = IA_C\Gamma\alpha - Q_{\text{loss}}$$

where Q_{loss} = heat loss by the collector

Γ = transmitivity of the glass and α = absorbtivity of the collector

Q_{loss} is related to the overall heat loss coefficient (U_L) by

$$Q_{\text{loss}} = U_L A_C (T_p - T_a).$$

Therefore

$$Q_u = IA_C\Gamma\alpha - U_L A_C (T_p - T_a) \tag{1}$$

$$Q_u = A_C \left[I\Gamma\alpha - U_L (T_p - T_a) \right]. \tag{2}$$

The average solar insolation constant (I) of Warri, Delta State, Nigeria, obtained from the Energy Research Centre, NSUKKA on September 26, 2010 is 1,470 Wm^{-2}.

Design of collector area

Collector area (A_C) is the ratio of the quantity of heat required (Q_w) to raise the temperature of water from T_{in} to T_{out} to the energy absorbed by the collector over a specified period of time

$$\text{Collector area } (A_C) = \frac{Q_w}{\mu I} = \frac{M_w C_w \triangle T}{\mu I}$$

Q_w = Useful energy absorbed by the water

$$Q_w = M_w C_w (T_{\text{out}} - T_{\text{in}}) = \rho V C_w (T_{\text{out}} - T_{\text{in}}).$$

Volume of water on the collector plate is given by:

$$V = \frac{\mu \times \text{Re}}{\rho \times D},$$

where Re = Reynolds no for lamina flow, ρ = Density of water, μ = Viscosity at temperature of 70 °C, V = Volume of water obtained after 30 sec, D = Diameter of pipe.

Desired volume of water to be obtained from the system is 3.1 liters, therefore useful energy absorbed by the water for 1 h (3,600 sec)

$$= \frac{Q_w}{t} = \frac{\rho V C_w (T_{\text{out}} - T_{\text{in}})}{3,600}$$

$$= \frac{10^3 \text{ Kgm}^{-3} \times 3.1 \times 10^{-3} \times 4,200 \text{ JKg}^{-1}\,°\text{C}^{-1} \times (70-25)}{3,600}$$

$$Q_w = 162.75 \text{ W}$$

I = 1,470 W/m^2, average efficiency for flat-plate collector (η) = 40%, and viscosity of water at 70 °C (μ) = 0.4

$$\text{Area of collector } (A_C) = \frac{Q_W}{I\mu} = \frac{162.75}{1,470 \times 0.4} = 0.2767 \text{ m}^2.$$

This is the minimum requirement; hence, we chose 1 m^2 as the area of collector A_C.

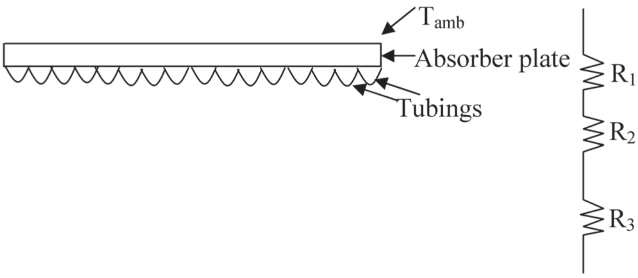

Figure 1: Diagrammatic description of a solar collector plate.

Mass flow rate

Mass flow rate of water within the collector plate area is given by

$$M_f = \frac{\text{Mass}}{\text{Time}},$$

where $t = 30\,\text{sec}$ = time to drain 3.1 liters of water within the collector.

$$\text{Mass} = \text{Density}\ (\rho) \times \text{volume}\ (v),$$

where $\rho = 10^3\ \text{kg/m}^3$ and $V = 3.1$ liters $= 3.1 \times 10^{-3}\ \text{m}^3$

Mass $= 10^3\ \text{kg/m}^3 \times 3.1 \times 10^{-3}\ \text{m}^3 = 3.1\ \text{kg}$

Mass flow rate $(M_f) = \frac{3.1}{30} = 0.1$ kg/sec.

Heat loss coefficient

In order to determine the overall heat loss coefficient U_L for a given system, we resort to derivation of a valid formula. The method of arriving at such a formula is a very rigorous one and involves energy balance and complete analysis. Hence, we used formulation of a mathematical model through thermal analysis of the solar collector system assisted in revealing the stated result with controlled variable using a diagrammatic description of a collector plate shown in Figure 1

$$\text{Total thermal resistance}\ (R_T) = R_1 + R_2 + R_3,$$

where

$$R = \frac{T_2 - T_1}{Q}$$

$$Q = I A_C \Gamma \alpha$$

$$\therefore R = \frac{T_2 - T_1}{I A_C \Gamma \alpha}.$$

Since all heat losses are approximately through conduction on both edges and bottom only.

The Nusselt number calculated using the formula giving by Hollands et al. [7] is given by:

$$\text{Nu} = 1 + 1.44 \left[\frac{1 - 1708\,(\sin 1.88\beta)^{16}}{R_a \cos\beta} \right] \left[\frac{1 - 1708}{R_a \cos\beta} \right] + \left[\left(\frac{R_a \cos\beta}{5830} \right)^{\frac{1}{3}} - 1 \right],$$

where β = the thermal expansion coefficient.

$\therefore$ Overall heat loss coefficient obtained is $6\ \text{W/m}^{-2}\ ^\circ\text{C}$.

Recall (2)

$$\begin{aligned} Q_u &= A_C\,[I\,\Gamma\alpha - U_L\,(T_p - T_a)] \\ &= 1\,[1{,}470 \times 0.88 \times 0.95 - 6\,(60 - 25)] \\ Q_u &= 1018.92\ \text{W/m}^2. \end{aligned}$$

Design of the cold and hot water storage tanks

The cold water storage tank is a single thin-walled cylinder of 30 liters capacity with a height (length of 560 mm) and since 1 liter $= 1{,}000\ \text{m}^3$

$$\therefore 30\ \text{liters} = 30 \times 1{,}000\ \text{m}^3 = 30{,}000\ \text{m}^3$$

therefore

$$\text{Volume}\ (V_T) = \text{Area}\ (A_T) \times \text{Height}\ (H_T).$$

But $A_T = \frac{\pi D_T^2}{4}$, therefore

$$V_T = \frac{\pi D_T^2}{4} H_T$$

$$D_T = \sqrt[2]{\frac{4V_T}{H_T \pi}} = \sqrt[2]{\frac{4 \times 30 \times 10^6\ \text{mm}}{560 \times 3.142}} = 261.2\ \text{mm}.$$

Therefore, diameter of the cold water tank (D_T) is 261 mm.

The pressure in the cold water tank at full capacity is given by

$$P_T = \rho w_1 g H_T,$$

where P_T = pressure at the cold water exit of the storage tank

g = gravitational acceleration (m/s^2)

ρ = density of cold water (kg/m^3)

$P_T = 1{,}000 \times 9.81 \times 0.56 = 5{,}493.6$ Pa or 5.5 KPa.

It means that as H_T increases, P_T increases. This increase in the pressure in the tank results in an increase in the flow rate of water through the flat-plate collector; hence, efficiency is improved because transfer of the entrapped heat in the collector to the water inside will be faster, thereby minimizing convection and other losses from collector.

Table 1: Coefficient of cubic expansion of water at various temperatures.

Temperature (°C)	$\gamma\ (\mathrm{K}^{-1}) \times 10^{-4}$
5–10	0.53
10–20	1.5
20–40	3.02
40–60	4.58
60–80	5.87

Pressure in the hot water storage tank at full capacity is given by

$$P_T^1 = \rho_{W2} g H_T{}^1$$

ρ_{W2} is the density of hot water

$$\begin{aligned}\rho_{W2} &= \rho_{W1}[1+\gamma\Delta T]^{-1}\\ &= 1{,}000[1+4.58\times10^{-4}\,\mathrm{K}^{-1}\times 45\,°\mathrm{C}]^{-1}\end{aligned}$$

where γ is the coefficient of cubic expansion of water at $70\,°\mathrm{C} = 4.58\times10^{-4}\,\mathrm{K}^{-1}$

$$\rho_{w2} = 979.81\ \mathrm{Kg/m^3}$$

$\therefore P_T^1 = 979.81\times 9.81\times 0.56 = 7{,}689.5\ \mathrm{Pa}$ or $7.7\ \mathrm{KPa}$.

Table 1 contains coefficient of cubic expansion of water at various temperatures.

Stress analysis on the tank

The cylindrical water tanks made up of mild steel material will be subjected to internal pressure due to the water inside them. The pressure is generally taken to be uniformly distributed over the internal surface of the tanks. If the wall thickness is equal to or less than 1/20 of the internal diameter, the vessel is said to be thin-walled; otherwise, it is taken to be a thick-walled vessel.

Tank specification

Material: Mild Steel Sheet
Yield Strength of mild steel, $\sigma = 26\ \mathrm{Kpsi} = 176\ \mathrm{MPa}$
Height of cold water tank $H_T = 0.56\ \mathrm{m}$
Height of hot water tank $H_T = 0.56\ \mathrm{m}$
Wall thickness of the tank, $t = 0.6\ \mathrm{mm}\ (0.0006\ \mathrm{m})$

From the above, for a thin-walled cylinder, wall thickness t is related to the diameter of the following inequality: $t \le \frac{1}{20} D_T$ for the cold water tank also for hot water tank. A bursting stress known as tangential or circumferential or hoop stress will be set up on the wall of the cylindrical tank caused by water pressure.

$$2\sigma_t H_T t - P_T D_T H_T = 0$$
$$2\sigma_t H_T t = P_T D_T H_T.$$

Therefore, tangential stress for cold water tank $\sigma_t = \frac{P_T D_T}{2t}$.

Also tangential stress for hot water tank $\sigma_t' = \frac{P_T' D_T'}{2t}$.

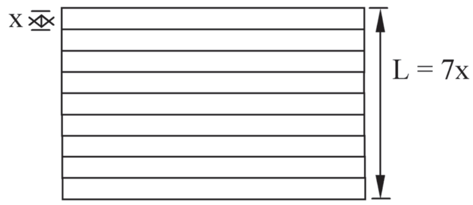

Figure 2: Spacing between pipes.

Where P_T' is internal pressure on hot water tank, while P_T is internal pressure for cold water tank.

Recall $P_T = \rho g H = 5{,}493.6\ \mathrm{N/m^2}$ and $P_T^1 = 7{,}689.5\ \mathrm{N/m^2}$

$$\sigma_t = \frac{5{,}493.6\times0.261}{2\times0.0006} = \frac{1{,}433.8}{1.2\times10^{-3}} = 1.2\ \mathrm{MPa}.$$

Since the cylinders are closed, the longitudinal stress σ_l exist because of the pressure upon the ends of the tank. Assuming stress to be distributed uniformly over the wall thickness, then,

$$\sigma_1 = \frac{P_T D_T}{4t} = \frac{1}{2}\sigma_t.$$

Also, $\sigma_1' = \frac{P_T' D_T'}{4t} = \frac{1}{2}\sigma_t'$

$$\therefore \sigma_1 = \frac{1}{2}\times1.2 = 0.6\ \mathrm{MPa}\quad\text{(cold tank)}.$$

For hot tank

$$\sigma_t^1 = \frac{7{,}689.5\times0.261}{2\times0.0006} = \frac{2{,}006.96}{1.2\times10^{-3}} = 1.7\ \mathrm{MPa}$$

$$\therefore \sigma_1 = \tfrac{1}{2}\times1.7 = 0.84\ \mathrm{MPa}\quad\text{(hot tank)}.$$

Pipe spacing

From Figure 2, $x = L/7$ where x is the spacing between pipes.

We chose a width of 0.9 m, i.e., $W_c = 0.9\ \mathrm{m}$ and pipe spacing of 0.10 m. Then number of equal "center to center" N_s

$$N_s = \frac{W_c}{0.10} = \frac{0.9}{0.10} = 9$$

$\therefore N_s - 1 = 9 - 1 = 8.$

Therefore, we specify eight parallel pipes with equal center spacing.

Pipe sizing

Below is the pipe sizing selected to obtain heat transfer needed:

Number of pipes used: 8 (i.e., two headers and six riser pipes).

Diameter of pipe: 1.27 cm, length of circulating pipe: 75 cm, diameter of inlet pipe 0.6 cm.

Distance between pipes and tank: 57 mm, length of pipes: 104 cm, drilled hole: 20 mm.

Length of pipe variations with heat intensity

For total heat intensity of 1,018.92 W/m^2, the heat conducted per length of pipe is 127.365 W/m; hence for the 8 pipes, assuming there is no heat lost, it is 8×127.365, which is 1,018.92 W/m^2. The required number of pipes is used for maximum transfer of heat to heat up the water efficiently at the required time.

Selection of materials

In the selection of materials needed for construction stage of this system, two essential factors, namely, the economic consideration (cost) and properties of the materials were considered.

The transparent cover

A transparent cover is needed in solar collector to help provide the "green house" effect necessary to heat up the water. A good cover material (transparent cover) should have high transmittance to ultraviolet radiation and low transmittance to infra-red radiation in order to trap the radiated heat from the absorber plate. Low-cost glass was preferred to plastic as the cover material in this work because it has high transmittance to visible light, low transmittance to infrared radiation, and stability. It suppresses the convective and relative losses from the top of the solar collector plate. However, the main disadvantage is that it has a low resistance to shatter.

Absorber plate (collector plate)

Some materials that could be used include copper, aluminum, mild steel, and galvanized iron. Copper is the best among these alternatives due to its high thermal conductivity, but it is very expensive. Aluminum, however, is used as absorber plate because it is relatively cheap compared to copper, has good means of welding or attachment to other materials despite its low weldability property, and has good thermal conductivity.

Collector/tank insulation

Insulation is very important to reduce heat losses in the collector and hot water storage tank in order to improve the efficiency. An ideal insulation arrangement should be made to eliminate heat loss by conduction, convection, and radiation from bottom and edges of the collector. Insulation material includes glass wool, sawdust, wood shavings, and Styrofoam. Styrofoam, however, was used because it is relatively cheap, is readily available, and has very low thermal conductivity.

Collector casing

This serves to hold the different component of solar collector together in a water tight single unit. Black mild steel (gauge 16) is used; this is because it is cheap, light, and also functions as an insulator due to its black surface. More so, mild steel does not deteriorate very rapidly when exposed to outside weather.

Figure 3: The designed and constructed solar water heater.

Frame/stand

For the frame and stand, mild steel is also used, with high flexural strength; the body is also painted with black paint.

Pipe (including risers/headers)

Galvanized steel pipes were used due to its rigidity and resistance to corrosion. This is very important since they function to hold the water to be used domestically.

Cold water tank

The cold water tank is made of rolled galvanized mild steel plate from the design calculation of the 30-liter tank.

Hot water storage tank

The hot water tank is made of a rolled galvanized. Steel also with the inside properly lagged to prevent heat loss. Figure 3 shows the designed and constructed solar water heater.

Table 2: System temperature variation and daily solar insulations for 4 October 2010.

Time (h)	Ambient temp (T_a) (°C)	Temp. in (T_{in}) (°C)	Temp. out (T_{out}) (°C)	Collector temp (T_c) (°C)	Insolation, G (W/m^2) (°C)
7.00	24.00	24.00	22.00	21.00	130.31
8.00	25.00	25.00	22.00	22.00	1,104.70
9.00	24.00	24.00	22.00	22.00	1,268.90
10.00	25.00	25.00	28.00	24.00	1,281.5
11.00	24.00	24.00	32.00	24.00	1,335.70
12.00	25.00	25.00	37.00	35.00	1,384.30
13.00	25.00	25.00	38.00	35.00	1,401.60
14.00	26.00	26.00	45.00	40.00	1,451.50
15.00	25.00	25.00	55.00	51.00	1,480.00
16.00	25.00	25.00	48.00	45.00	1,117.00
17.00	24.00	24.00	40.00	36.00	125.60
18.00	24.00	24.00	38.00	33.00	14.80

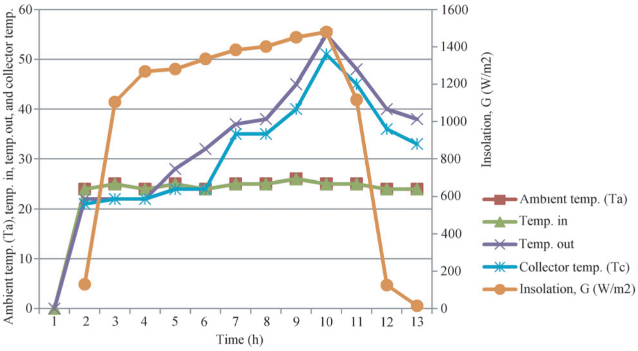

Figure 4: System temperature variation and daily solar insulations for 4th October 2010 (normal sunny day).

Testing/results and discussion

The cold water tank was filled with water after proper filtration. The valve was opened to allow water flow to the circulating pipes, which are made of riser and header pipes, through the carriage pipe (i.e., the inlet pipe). The water was heated up from the heat supplied by the absorber plate to the tubes integrated underneath the absorber plate; hence, by virtue of density difference between the cold water and hot water (i.e., the cold water goes down, while the hot water comes up), a flow is initiated (thermosyphon or natural convection). The hot water flows to the hot water storage tank, which has a gate valve to allow tapping when needed for use.

Table 2 and Figure 4 give test results of the system on a normal sunny day.

From the results, ambient temperature varied between 24 °C and 26 °C. Maximum fluid (water) output temperature and the collector temperature was obtained between noon and 4:00 p.m. The Insolation increased from a low value at 7:00 a.m. got to a peak between noon and 3:00 p.m. and then fell back to a low value.

3. Conclusion

A solar-powered water heater is a long-term investment that can help us save money and energy for many years. Like other renewable energy systems, solar-powered water heaters minimize the environmental effects of enjoying a comfortable, modern lifestyle at reduced costs because they do not have the hazards introduced by fossil fuels but are environmentally friendly and almost completely running cost free. The system designed in this work requires little or no maintenance because of the thermosyphon principle involved. It was made basically from locally available raw materials. It has no moving parts and almost the entire system works automatically, but there are some procedures to carry out to ensure proper functioning of the solar water heater and thus increase electricity savings:

(1) The glass should be cleaned regularly to remove dust and dirt that may have settled on the glass cover which will block the sun rays and will reduce the output of the system. Depending on the surrounding where it is kept, it is advisable to clean two or more times a week.
(2) Prevent any shade on the collector. Trim the branches of trees around the collector to allow as much sunlight to reach it.
(3) Ensure that there is always cold water supply to the tank and flush out the entire system to remove any floating and settled dirt at least once in a year.
(4) The glass seal should be checked from time to time.

The following recommendations are suggested to improve on the system:

(1) A pump can be introduced in the system with the storage tank being at any point below the collector. If this is adopted the heat removal efficiency will be high. Solar energy can be used instead of electrical energy to power the pump.
(2) An automatic gate valve can be incorporated for effective performance, in order to regulate the flow.
(3) A heat exchanger can be introduced for preheating of inlet water.
(4) An auxiliary heating system can be incorporated to be used when there is virtually no sunshine.

These additional features will however increase the overall cost of the system which this project seeks to minimize.

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