Mitigating Climate Change by The Development And Deployment of Solar Water Heating Systems

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Abstract

Solar energy is becoming an alternative for the limited fossil fuel resources. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat, which can be used in water heating systems. A commonly used solar collector is the flat-plate. A lot of research has been conducted in order to analyse the flat-plate operation and improve its efficiency. Conventional methods of water heating with hot plates, gas burners, paraffin stoves, sawdust cookers, coal burners, firewood burners release CO_2 into the atmosphere and other pollutants. This study presents an alternative way of heating water using solar radiation thus optimizing fully the solar renewable energy which is eco - friendly. Ogun State in Nigeria was used as a case study. The solar radiation for the state was explored with an annual average of 4.775 kWh/m^2/day recorded. The designed system comprised storage tanks (Inlet and Outlet) and the collector unit which comprises wooden casing (35.375 X 17.25cm), copper tube (9 meters long and 0.5mm^2 in diameter), and aluminium foil (33 X 17cm). Test result for the unlagged and lagged storage tank for water temperature at various angles of inclination (2.5° - 20.0°) were on the average 27.8°C and 28.3°C respectively for the inlet temperature and 60.1°C and 63.0°C for the outlet temperature respectively. Also, the outlet temperature increased as the angle of inclination increased with angle 15° (angle of inclination for optimum insolation) having the highest outlet temperature of 64^{o}C. Beyond 15°, the outlet temperature decreased. At an angle of 15°, the efficiency of the SWHS was 72.5% and the power saved 2.7985 kW. The cost of the unit is put at ₦21,400 ($145) as at August, 2012. In the area of agriculture, this Solar Water Heating System (SWHS) can provide hot water for pen cleaning. In diary operations, it can be used to provide heated water to clean or sterilize equipment and to warm and stimulate cows' udders. The unit developed can be applied for the purpose of reducing the cost of energy, dealing with environmental challenges and improving the use of energy (management and efficiency) hence serving as a climate mitigation process as this can be extended for water heating for domestic and other industrial purposes.

Keywords: SWHS, Insolation, Renewable energy, Climate change mitigation.

1.0: Introduction

Solar energy happens to be a naturally occurring renewable source of energy that is gotten directly from one of the major heavenly bodies known as the sun. It has been in existence since the creation of the world and of mankind, but its potentials have not been and could not be harnessed as a result of ignorance and lack of the right technology, until now as a result of increase in the demand of power energy supply for human consumption, basically for industrial, commercial and domestic use.

The total deposit of fossil fuels left on earth is not up to the amount of energy that could be supplied in a couple of days by the sun which happens to be the root of all energy sources. Therefore, there is a need to changeover to renewable energy sources because of the skyrocketing cost of oil and gas in the production of electricity and the effects of pollutants to climate change (including global warming and ozone layer depletion)especially when it comes to the area of domestic and commercial water heating, solar energy can be a very good substitute to the conventional way of water heating. One of the biggest uses of electricity, gas and oil is the heating of water in the home, and in offices, schools and hospitals. Solar water heating is a very simple and efficient way to tap energy from the sun and use it. Solar water heaters concentrate diffused solar radiation into thermal energy (NASA, 2012).

Basically the energy received from the sun comes in two forms: the uninterrupted which is known as direct radiation (called sunshine) and the interrupted or the diffuse radiation which has been scattered in the atmosphere by clouds and dust pollution and appears to come from all over the sky. The uninterrupted has more power intensity and therefore can be reflected in any direction you want it but because of the low intensity of the diffuse radiation, it cannot be directed. Even if you try, whenever it hits a mirror, it is reflected off again in many directions.

Since the detection and knowledge of the benefits of solar energy which also happens to be the root of all other sources of energy and harnessing the power, man has thought of different ways and methods to which it could be utilized especially as an alternative to other sources such as electricity (generated from hydropower system) which can then be used wherever and whenever desired depending on the design and construction. It is now commonly used in homes for various domestic use, majorly heating, such as swimming pool warming, water heating in kitchens, laundries and bathrooms, solar cookers, food dryers, solar pond and more.

In some parts of the world where the sun is very intense and very high for a large part of the year, solar energy method will be so much appropriate for such areas such as the Northern part of Nigeria, Britain where usually half of the solar radiation is direct and the other half is diffuse such that on very sunny days, more solar radiation can be gotten.

Although solar energy source proves to be a very solid and good way of generating power, it has its limitations, some of which cannot be altered in any way as a result of its natural existence and occurrence. Some of the limitations are

1. The sun is not usually out every time of the year. Even when it is out at times, it may not be enough to cater for our energy requirements and needs depending on its intensity.
2. The facilities required to harness this energy resource are very expensive to put in place.
3. Management of these facilities requires special attention and training on the equipment to avoid misuse.

2. Literature Review

In many parts of the world there is a growing awareness that renewable energy has an important role to play in extending technology to the farmer in developing countries to increase their productivity (Waewsak *et al.* 2006). Solar thermal technology is a technology that is rapidly gaining acceptance as an energy saving measure in agricultural applications (Bukola, 2008). It is preferred to other alternative sources of energy such as wind and shale, because it is abundant, inexhaustible, and non-polluting (Akinola, 1999; Akinola *et al* 2006; Akinola, *et al.* 2006).

Bukola (2006) performed design and experimental analysis of flow inside the collector of a natural circulation solar water heater. The result shown was that the system performance depends very much on both the flow rate through the collector and the incident solar radiation and the system exhibited optimum flow rate.

Soteris A. Kalogirou (2004), performed an analysis of the environmental problems related to the use of conventional sources of energy and the benefits offered by renewable energy systems. The various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors were followed by an optical, thermal and thermodynamic analysis of the collectors and a description of the methods used to evaluate their performance. The thermal performance of the solar collector was determined by obtaining values of instantaneous efficiency for different combinations of incident radiation, ambient temperature, and inlet fluid temperature.

Fanney *et al.* (1998) performed side by side experimental investigations to evaluate the influence of the thermal performance of solar domestic hot water systems. The system was a direct solar hot water system utilizing a natural circulation return tube to the storage tank. Result of the system show improvements in the overall system performance as a result of lowering the collector fluid flow rate.

Volker *et al*. (2002) performed the results of an experimental study conducted in a water solar flat plate collector with laminar flow conditions to analyse the flow distribution through the collector. Measurements were carried out to determine the discharge in each riser, as well as pressure measurements to investigate the relation between junction losses and the local Reynolds number. Analytical calculations based on the measured relations are used in a sensitivity analysis to explain the various possible flow distributions in solar collectors.

Duffie *et al*. (1991) performed annual simulation to monitor the thermal performance of a direct solar domestic hot water system operated under several controlled strategies. According to Duffie *et al*. (1991), higher flow rate leads to higher collector efficiency factor. However, it also leads to higher mixing in tank and therefore, a reduction in the overall solar water heating system efficiency.

Solar water heaters can operate in any climate. The performance of these heaters varies depending on how much solar energy is available at that locality, and more importantly on how cold the water coming into the system is. The colder the incoming water, the more efficiently the solar water heating system operates. A large number of studies have examined the performance of solar water heating systems. Very recently, Jaisankar *et al* (2011) reported a comprehensive review on solar water heaters. They reported that the efficiency of solar thermal conversion is about 70% when compared to solar electrical direct conversion system, which has an efficiency of only 17%. Owing to its ease of operation and simple maintenance, solar water heating systems play an important role in domestic, as well as industrial sector(Hosni *et al.*, 2012).

The first published analysis of thermosyphon solar water heater circuit was by Close (1962). There have been many other publications on the analysis of these systems but they are all based on the original formulation. For verifying the theoretical results, he tested two thermosyphon systems with different characteristics and the results conformed well to those predicted.

Gupta *et al*. (1968) modified the model of Close to take into account the heat exchange efficiency of the collector absorber plate, and thermal capacitance. They also found experimentally that the flow rate of a thermosyphon water heater can be increased by increasing the relative height between the collector and storage tank, but the efficiency is not increased. The efficiency can be increased by reducing the loop resistance.

Ong (1974) extended the work of Close and Gupta *et al*. by using a finite difference solution procedure. The theoretical prediction of flow rate has been compared with the measured flow rate using dye trace inject.

Hussein (2003) obtained a comprehensive understanding of the transient thermal behaviour of a two-phase thermosyphon flat plate solar collector. He investigated theoretically and experimentally under unsteady-state conditions. His governing equations of the different components of the collector are presented and generalized in dimensionless forms, and comparison between the experimental and simulated results showed considerable agreement.

Zerrouki *et al.* (2002) considered natural circulation of a compact thermosyphon solar water heating system produced and commercialized in Algeria. Their calculations and measurements were performed on mass flow rate, temperature rise and fluid and absorber temperatures inside the thermosyphon of parallel tube design.

Karagholi *et al.* (2001) analyzed the thermal performance of the thermosyphon water heater unit to show its applicability in Bahrain. Their results show that the system is quite suitable for application in Bahrain weather conditions.

Chuawittayawuth *et al*. (2002) presented details of experimental observation of temperature and flow distribution in natural circulation solar water heating systems. They found that the temperature values at the riser tubes near the collector inlet are generally much higher than those at the other risers on a clear day, while on cloudy days, the temperatures are uniform. They concluded that the temperature of water in the riser depends on its flow rate. They also carried out the measurements of the glass temperature.

As far as analytical studies are concern, they can only predict the overall performance of the system in whole and no detailed information can be obtained from them. Belessiotis *et al*. (2002) performed analytical study of a thermosyphon solar water heater with horizontal storage tank and verified the results by experiments.

Various studies reviewed above have shown the importance of performance improveement of the collector in solar water heating.

In communities throughout the developing world, poor households struggle to meet their hot water needs. Some households rely on biomass to heat water. In many countries demand for fuel wood is one of the principal contributors to deforestation.

Others rely on electricity or liquid fuels such as propane to heat their water. These fuel options are unsustainable as they are costly to households and contribute to the buildup of greenhouse gases in the atmosphere. Many communities face limited or intermittent access to fuel and/or electricity, limiting their ability to access hot water for hygiene and domestic uses.

One potential solution to this problem is the use of solar energy to heat water. Solar water heating technology is used in many parts of the world including the U.S., China, India, and the Middle East. Systems have been adopted for a wide range of use patterns and climate conditions. However, most existing systems are geared toward wealthy clients. These systems often include sophisticated pumping systems and advanced materials. While these systems are profitable to their developers, they are often far beyond the financial constraints of households in poor communities of developing countries.

Today, engineers and scientists can harness solar energy with common materials and basic technologies. The simplest version is the batch solar water heater, consisting of a water tank, a dark absorber to capture the sun’s radiation effectively, and a sheet of glass to create a greenhouse effect. Water enters at the bottom and is ‘baked’ in the sun.

As it warms, hot water travels to the top of the tank due to its lower density. When the water is ready for use, cool water is supplied to the inlet and hot water flows out the top. Batch heaters systems can also include insulation to help maintain the temperature of the heated water.

Access to a low cost solar water heater would provide numerous benefits to households in developing communities. Many households could reduce their fuel costs by eliminating or reducing their need for wood, gas or electricity to heat water. Substituting traditional fuel sources with solar energy would reduce carbon emissions. Further reduction in biomass consumption would relieve stress on depleted forests. There are also health benefits associated with solar hot water due to lessened exposure to toxins and pollutants released from burning fuels. By enabling access to hot water, households could improve their health and hygiene.

Solar water heaters are typically used for the production of domestic hot water. In the UK, $4m^2$ of good quality flat plate collector can produce 60% of domestic hot water demand. Flat plate collectors have the advantage that they can be integrated into the roof structure improving appearance and reducing costs.

Traditionally the output of solar thermal systems has not been rated in kilowatts but just the area of the collector. This is because of the variable efficiency of the collector over the range of conditions that it night work.

The world saw a rapid growth of the use of solar warm water after 1960, and the rate of use of solar energy as a source of energy has grown so high in recent times at a very rapid progression especially in terms of heating applications. Many households have diverted into using the solar means to do most of their heating chores since it is cheap, affordable, simple, easy to construct and maintain, neat and does not bring about pollution such as emission of greenhouse gases and other dangerous pollutants and even down to industrial use which is now popular in Japan and Austria.

Nigeria happens to be one of the few countries that have not really adopted the use of solar water heating methods considering the fact that the intensity of the sun in many areas of the country is so much such as the northern parts where the sun is at highest intensity.

This is also known as Pumped solar water heaters. Since most solar collectors are fitted on the roofs of houses, a thermosyphon system will not be convenient, as it is difficult to site the tank above the collector, in which case the system will need a pump to circulate the water. In this case, we now employ the use of the pumped solar water heaters that use a pumping device to drive the water through the collector. It comes in two types; the direct active systems circulate water directly to the collector and back to the storage tank, while indirect active systems circulate transfer fluid, the heat of which is transferred to the water in the storage tank.

The advantage of this system is that the storage tank can be sited below the collector. The use of a pump allows the storage tank to be located lower than the collector since the circulation of water is enforced by the pump thereby allowing storage tank to be located out of sight if desired.

Because of the fact that active systems allow freedom in the location of the storage tank, the tank can be located where heat loss from the tank is reduced, e.g. inside the roof of a house. This increases the efficiency of the solar water heating system.

3. Methodology

3.1 Solar insolation: how much heat is available

The sun is the energy source but we need to know how much of the sun’s energy reaches a particular place. Solar Insolation is the amount of electromagnetic energy (solar radiation) incident on the surface of the earth. Basically that means how much sunlight is shining down. By knowing the insolation levels of a particular region we can determine the size of solar collector that is required. An area with poor insolation levels will need a larger collector than an area with high insolation levels. Once you know your region's insolation level you can more accurately calculate collector size and energy output.The values are generally expressed in $kWh/m^2/day$. This is the amount of solar energy that strikes a square metre of the earth's surface in a single day. This value is averaged to account for differences in the days' length. Metrological data from the National Aeronautics and Space Administration (NASA) is used. The NASA website has 22+ years of metrological data stored according to longitude and latitude.

Table 1: Monthly Solar Insolation for Major Towns in Ogun State

	Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m²/day)							
	OTA	**ILARO**	**IJEBU IGBO**	**SHAGAMU**	**IKENNNE**	**ABEOKUTA**	**IJEBU ODE**	**IFO**
JANUARY	5.57	5.20	5.32	5.30	5.32	5.50	5.28	5.24
FEBRUARY	5.74	5.41	5.48	5.48	5.50	5.70	5.49	5.45
MARCH	5.66	5.41	5.37	5.48	5.46	5.64	5.46	5.43
APRIL	5.34	5.18	5.21	5.25	5.23	5.35	5.21	5.20
MAY	5.01	4.71	4.79	4.79	4.77	5.09	4.76	4.72
JUNE	4.51	4.00	4.15	4.07	4.05	4.57	4.04	4.00
JULY	3.89	3.91	3.88	3.99	3.98	4.00	3.95	3.91
AUGUST	3.73	3.92	4.04	3.99	3.98	3.79	3.98	3.98
SEPTEMBER	4.05	4.04	3.96	4.12	4.10	4.11	4.09	4.06
OCTOBER	4.62	4.52	4.44	4.59	4.56	4.70	4.55	4.51
NOVEMBER	5.18	4.90	4.95	4.98	4.96	5.11	4.95	4.92
DECEMBER	5.37	5.12	5.21	5.20	5.19	5.35	5.17	5.13
ANNUAL AVERAGE	**4.89**	**4.69**	**4.73**	**4.77**	**4.76**	**4.91**	**4.74**	**4.71**

Average Insolation for all the towns is 4.775 kWh/m^2/day

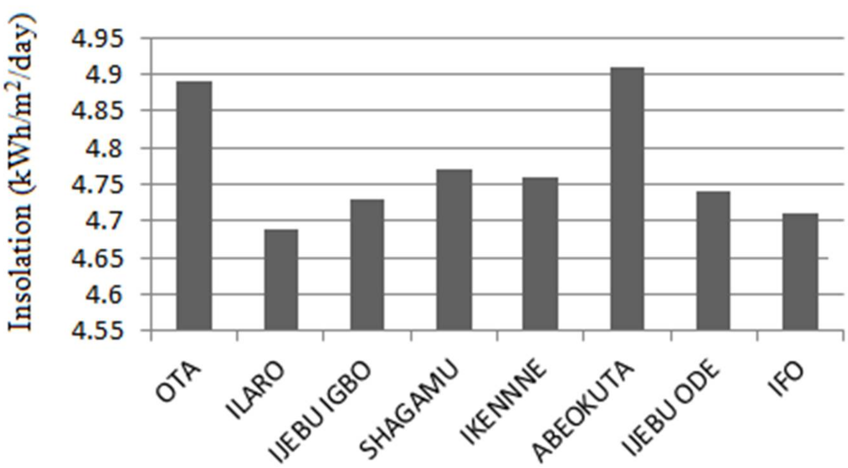

Figure 1: Graph showing average monthly solar insolation for Ogun State Nigeria

3.1.2: Conduction: heat transfer

In the construction of the Solar Heating System, thermal conductivity is a high priority consideration. The materials with the highest thermal conductivity are metals. The heat received via radiation must be conveyed to the water via conduction.

Table 2: Thermal conductivity of some metals at 68°F (20°C)

Material	Thermal Conductivity (Btu/(hr°Fft))
Pure Copper	223
Pure Aluminium	118
Stainless Steel	7-26
Pure Iron	42
Pure Silver	235

From Table 2, the SWHS is designed with Copper pipes and fins because Copper, a good thermal conductor, and cost effective with respect to pure silver .

3.1.3: Collector overall heat loss coefficient(U_L)

Heat loss is not to be taken lightly, because it determines how hot the water can become. U_L, the loss factor, is mainly determined by the number of covers and the wind speed. It also increases a little at high absorber temperatures. Typically, for one cover $U_L = 5.5$ W/m^{2}K and for two covers $U_L = 3.0$ W/m^{2}K. The solar collector in the SWHS uses one cover due to the availability and cost considerations of the cover material.

3.1.4: Transmission coefficient of glazing

Radiation passing through the glazing material is said to be transmitted. Transmittance varies not only for different materials but also varies with the wavelength of the radiation. It is therefore desirable to know the spectral transmittance of glazing for solar water heating systems. Ideally, the glazing should be very transparent to incoming shortwave radiation but opaque to outgoing long wave (thermal) radiation, because radiant losses may account for over 70 per cent of collector heat loss.

Table 3: Transmission Coefficients Of Sample Materials.

Material	Transmission coefficient
Single 4mm glass or acrylic sheet	0.85
double 4mm glass	0.72
Teflon thin film	0.95
Tedlar thin film	0.9

Transmission coefficients of sample materials, all of these can be reduced by 1 or 2% due to dirt, up to 8% in dry dusty areas.

3.1.5 Absorptance and emissivity

Radiation striking an object is absorbed if the energy is retained by the material. For example, a black hose left in the sun heats up as it absorbs energy from the sun. The percentage of incoming radiation that is absorbed by a material is referred to as its absorptance and is a measure of the ease with which a material or surface collects energy. Table 4 presents absorptance for various materials in sunlight. The best materials are those with high absorptance and very low emittance.

The high absorptance and low cost of black paint makes it a good choice for the Solar Water Heating System.

Table 4: Absorptance and emissivity of sample materials

Material	Absorptance	Emissivity
Black Paint	0.95	0.875
White Paint	0.2	0.9
Polished Aluminium	0.1	0.05
Selective Surfaces	0.85-0. 95	0.12-0.08

3.2 Efficiency of collector

In the design of the "Automated Solar Water Heater System" the collector area is another important design consideration. Using the efficiency equation of the flat plate collector, this is given as the heat gained by water with respect to the actual solar energy received by the flat plate collector.

$$mc_p\Delta T = A_c I\eta \quad (3.1)$$

Where m = mass of water in Kilograms (kg)

C_p=Specific heat of water(J/g°C)

ΔT= Temperature difference (Outlet Temperature – Inlet Temperature ^{o}C)

A_c= Area of Collector

I = intensity of solar radiation, (W/m^2)

η = Collector efficiency

The equation simply equates the heat acquired by the collector to the heat received by the water. If the Collector Area (A_c) is made the subject of the formula, equation 3.1 becomes

$$A_c = \frac{mc_p\Delta T}{\eta I} \quad (3.2)$$

The equation above requires us to know the mass of water to be heated, the specific heat of water (c_p) which is a constant (4.18 J/g^{o}C), the outlet and inlet water temperature, the solar insolation of the environment and the efficiency of the collector. All parameter are known except the efficiency of the collector which is a value set by the materials used for construction and some constants. The efficiency of the collector therefore must be calculated.

Equation 3.3 shows the instantaneous thermal efficiency (η) equation for flat plate collectors.

$$\eta = F_R\tau\alpha - F_R U_L\left(\frac{T_i - T_a}{I}\right) \quad (3.3)$$

Where F_R = Collector heat removal factor

I = Intensity of solar radiation, W/m^2

T_i = Inlet fluid temperature, °C

T_a = Ambient temperature, °C

U_L = Collector overall heat loss coefficient, W/m^2 K

τ = Transmission coefficient of glazing

α = Absorption coefficient of plate

The equation shows that the efficiency of a flat plate collector is dependent on the Transmission coefficient of glazing (τ), the Absorption coefficient of plate, collector heat removal factor (F_R), intensity of solar radiation (I), ambient temperature (T_a), inlet fluid temperature (T_i) and the collector overall heat loss coefficient (U_L).

For the SWHS from the efficiency equation, F_R,τ,α and U_L are fixed by the collector design. T_i, T_a and I are variables determined by the application. This simply implies that the solar collector efficiency can change when T_i, T_a and I are changed. Using Ogun State as a case study the following where decided in design

Transmission coefficient of glazing (τ) will be 0.85 because a single 4mm sheet of glass will be used in glazing. The Absorption coefficient of plate will be 0.95 because the collector plate will be painted black. The collector heat removal factor (F_R) is 0.9, intensity of solar radiation (I) is 4.775kWh/m^2/day from metrological data from NASA. The ambient temperature (T_a) is estimated at 25.7^{O}C from metrological data from NASA and inlet fluid temperature (T_i) can vary at any point but it is assumed to be 22^{O}C in the mornings and the collector overall heat loss coefficient (U_L) is 5.5W/m^2K because only one layer of glazing is used.

Using equation 3.3, if all temperature is converted to kelvin the efficiency η, will be 73.1%.

3.3 Collector tubing

There are different sizes of the copper tube used in the collector. They vary from ½ - 1 inch. The ½ inch copper tube was used because of more heating per surface area. The small size of the ½ inch copper tube allows for more copper tube per surface area of collector.

3.4 Collector casing

The casing of the collector is part of the requirements of the flat plate collector. The purpose of the casing is to provide the collector with some insulation, so as to better prevent heat loss into the environment. Protect the collector by making the collector more presentable. The collector casing is made of wood since wood is better insulator than any metal.

3.5 Collector placement: angle of inclination

Solar collectors must be installed pointing to the right direction to capture most of the sun energy to transform in electricity or heat. The position can be a position-fixed or seasonally adjusted. For a collector to function optimally, it should be inclined at a specific angle, and large deviations from the optimum angle will result in important losses in energy produced.

The direct sun power incident on a solar collector depends not only on the power contained in the sunlight, but also on the angle between the solar collector and the sun. When the absorbing surface and the sunlight are perpendicular to each other, the power density on the surface is equal to that of the sunlight (in other words, the power density will always be at its maximum when the solar panel is perpendicular to the sun).The solar collectors must be tilted from the horizontal to a degree not more than 15°.

3.6 Power saved

Through the use of the automated solar water heater, dependency on electric power can be reduced which would lead to savings on power.

The power input of the solar water heater can be calculated as:

$P_i = I\tau\alpha$

Where P_i = power input

τ = cover transmissivity

α= surface black absorbtance

The power output can be calculated as:

$P_o = P_i \cdot \eta$

3.7 Summary of design parameters

These are as presented in Table 5.

Table 5: Design specification for the solar water heating system.

Component	Specification
Collector Area	
Length	9 meters
Collector Tube/Pipe	Copper
Diameter	0.5 Inches = 0.0127 meters
Length	9 meters
Inclination of flat plate collector	10°
Absorber	Copper Painted Black (emissivity = 0.875)
Number of glass cover	One (4 mm thick)
Aluminium foil	
Length	0.84 meters
Breadth	0.45 meters

4. Construction methods

Figure 1 shows the heat collector system whilst Figure 2 shows the entire solar water heating system including the storage tank. The copper tube was bent to form a coil shape with the fins attached to it. It was painted black in order to absorb more heat from the sun, basically converting solar energy to heat energy. This copper tube need to be placed in a case. A wooden case was made to hold copper tube. The wooden case was also painted black. Aluminium foil was placed at the back of the wooden case. The reason for this is that the backing should not warm up but only the collector is to absorb heat. The foil will take any sun that was not absorbed by the collector on the first pass and bounce it back over the collector for another try at absorption.

The glass is then placed on top of the wooden case. The glass cover will keep all the heat inside the panel for further absorption. This serves to trap all the infrared radiation from the sun inside our panel where our collector will absorb it. Light can pass through glass, but heat cannot.

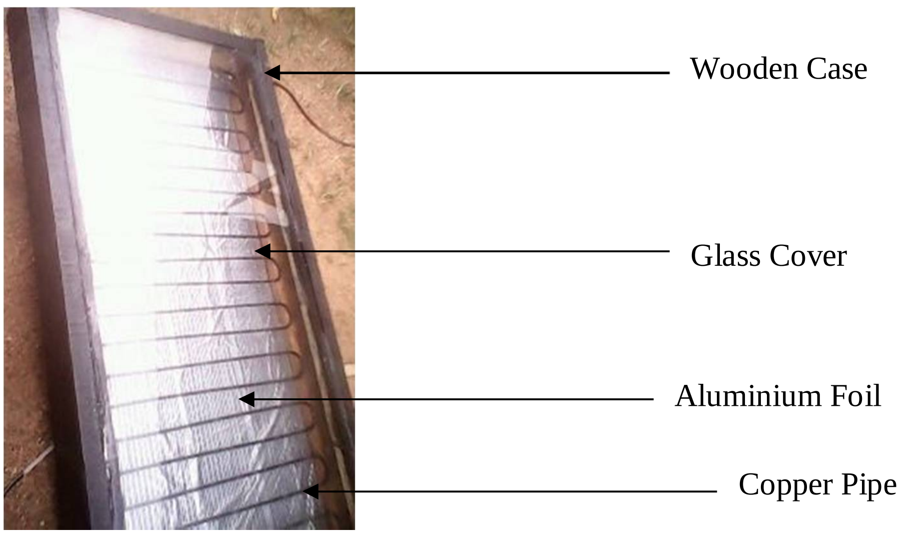

Figure 1: Solar water heating (heat collector) system

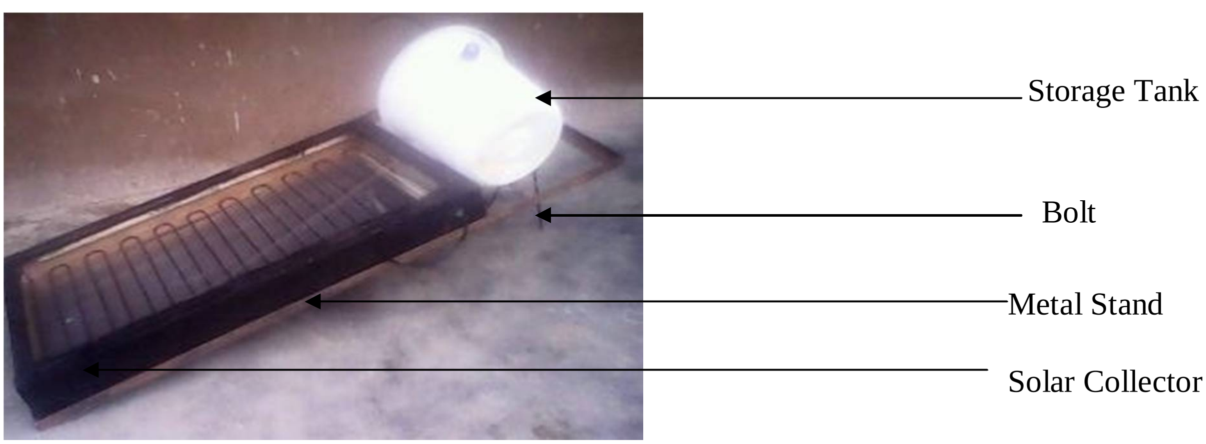

Figure.2: The solar water heating system with the stand

4.1 Advantages of the solar water heating system

- Full incorporation of solar system as a source of energy for domestic consumption
- Provide a cheaper and more effective way of generating energy for domestic and commercial purposes
- Evaluate the performance of the solar water heater prototypes ensuring easy construction, repair, and maintenance.
- Provide an alternative for the conventional method of water heating for domestic and commercial use.
- To provide average individuals with ease and accessibility to an alternative source of energy which is affordable, clean and much less dangerous
- To fully optimize the solar renewable energy source available for domestic and commercial water heating.
- Pollution free

4.2 Performance evaluation/test and results

The performance of the Solar Water Heating System was evaluated to determine its reliability in terms of

- Efficiency
- Power Saved

Testing was carried out on a daily basis between 12 pm and 5 pm for ten days in Camp Abeokuta Ogun State. The inlet fluid temperature and outlet fluid temperature was measured using a thermometer. Table 6 shows the average values of the inlet temperature and the outlet temperature per day and the average for the whole test period.

Table 6: Inlet Temperature And Outlet Temperature Of Water In The SWHS

	Date	Inlet Temperature (°C)	Outlet Temperature (°C)
Day 1	09/07/2012	28.2	58.3
Day 2	10/07/2012	28.0	60.0
Day 3	11/07/2012	27.8	59.3
Day 4	12/07/2012	28.0	60.7
Day 5	13/07/2012	27.5	59.7
Day 6	14/07/2012	26.5	60.0
Day 7	15/07/2012	27.0	60.7
Day 8	17/07/2012	28.0	60.7
Day 9	18/07/2012	28.5	59.3
Day 10	19/07/2012	28.5	62.3
Average		**27.8**	**60.1**

Testing was also carried out for different angles of the solar collector to the horizontal surface. The inlet fluid temperature and outlet fluid temperature was measured using a thermometer. Table 7 shows the average values of the inlet temperature and the outlet temperature per day (for different angles) and the average for the whole testing period. A graphical representation of the water heating ability of the developed unit are shown in Figure 3 and 4

Table 7: Inlet and outlet temperature of water in the SWHS at different angles

		Day 1	Day 2	Day 3	Day 4	
Degree (°)	**Temperature (°C)**	**15/08/2012**	**16/08/2012**	**17/08/2012**	**21/08/2012**	**Average**
2.5	Inlet Temperature	28.5	28.3	28.0	28.3	**28.3**
	Outlet Temperature	58.2	58.3	58.0	58.7	**58.3**
5.0	Inlet Temperature	28.5	28.3	28.0	28.3	**28.3**
	Outlet Temperature	58.8	59.3	58.3	60.8	**60.0**
7.5	Inlet Temperature	28.5	28.3	28.0	28.3	**28.3**
	Outlet Temperature	60.3	60.0	59.8	60.8	**60.3**
10.0	Inlet Temperature	28.5	28.3	28.0	28.3	**28.3**
	Outlet Temperature	60.7	60.0	60.7	62.3	**61.0**
12.5	Inlet Temperature	28.5	28.3	28.0	28.3	**28.3**
	Outlet Temperature	62.7	62.3	62.3	64.8	**63.0**
15.0	Inlet Temperature	28.5	28.3	28.0	28.3	**28.3**
	Outlet Temperature	64.3	65.3	63.7	65.0	**64.6**
17.5	Inlet Temperature	28.5	28.3	28.0	28.3	**28.3**
	Outlet Temperature	60.8	60.7	60.3	60.2	**60.5**
20.0	Inlet Temperature	28.5	28.3	28.0	28.3	**28.3**
	Outlet Temperature	58.3	59.8	57.8	60.5	**59.1**

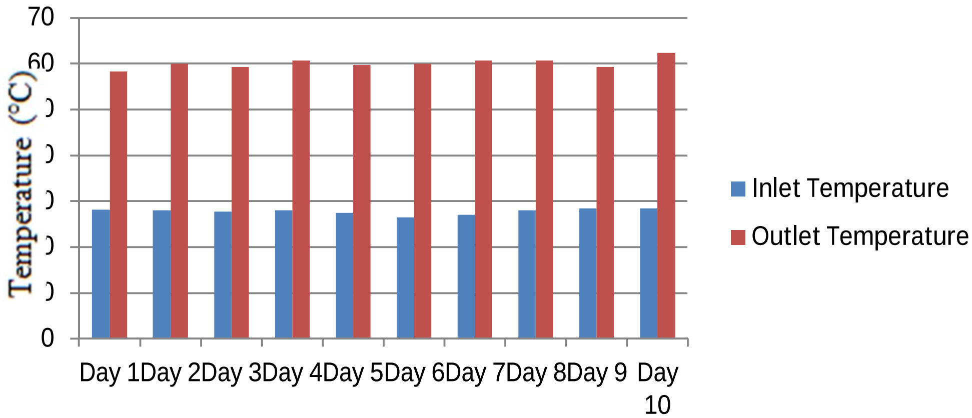

Figure 3: Inlet and outlet temperature of water

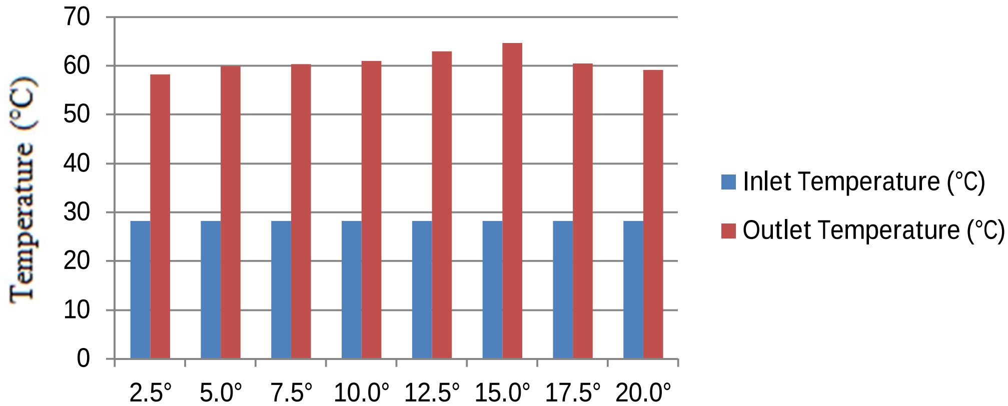

Figure 4: Inlet and outlet temperature for the average values at different angles

Efficiency of the SWHS

$$\eta = F_R\tau\alpha - F_R U_L \left(\frac{T_i - T_a}{I}\right)$$

$$\eta = 72.5\ \%$$

Power saved by the SWHS
P_i = 3.86 kW
$P_o = P_i \cdot \eta$
P_o= 2.7985 kW
For a 6 hour period of effective sunlight in a day, the total power output of the solar water heater in a day can be calculated as 16.92 kWh.

5.0 Conclusions

An SWHS has been developed using locally available materials. The developed unit can be deployed for use in the domestic, commercial sectors. The SWHS is environmentally friendly and a system and can readily be used as an alternative water heaystemting s. Consideration can be given to retrofitting the currently used conventional water heaters.

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