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# FEASIBILITY OF THERMOSYPHON SOLAR WATER HEATING SYSTEM UTILIZATION IN BEAUTY AND HAIRDRESSING SALONS IN NIGERIA

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**ABSTRACT:** *Beauty and Hair Dressing Salon business in Nigeria relies heavily on electricity utilisation for water heating and production. But, electricity is erratic and epileptic and, not readily available. This means that alternative energy source must be sought for. In this study, the feasibility of providing needed electricity supply for hot water production with Thermosyphon Solar Water Heater (TSWHs) is presented. An experimental setup in which TSWH technology with 1.44m*$^2$ *flat plate solar collector was designed, fabricated and tested under weather conditions of Minna for three months. Data for the design and fabrication of the test system (quantity of hot water and temperature requirements) were collected from randomly selected twenty prominent beauty and hairdressing salon in Minna for four weeks. Maximum temperatures of 70°C and 84°C were obtained on moderate and clear sunny days respectively. From the results of the experimental study, the option of using TSWHs technology to meet the hot water needs of Nigeria is feasible.*

**KEYWORD**: Solar Energy, Thermosyphon**,** Beauty, Hairdressing Salon, Water Heating, Utilization

## INTRODUCTION

Small and Medium Scale Enterprises (SMEs) have been adjudged as the engine of economic growth in Nigeria **[**Ogundipe and Apata, 2013]. Beauty and Hairdressing Salon, as one of the Small and Medium Scale Enterprises (SMEs), is a lucrative and one of the fast-growing businesses in Nigeria. It offers job opportunity to many Nigerians, particularly, the women fold and men fold are currently and gradually aspiring to be in the business. Hot water is used for several purposes that include hair services, relaxers, perms, colours, shampoo, conditioning, curling, reconstructing, weaving, nail services, manicures, pedicures, polish and sculptures nails in almost all round the year. The business is heavily dependent on electricity for these activities. Pilot study and preliminary investigation by the authors revealed that water heating accounts for 60% to 70% of energy demand and, the energy for heating currently comes from electricity. However, the shocks from the energy crisis in Nigeria have created some wedges on the effective operation and management of SME.

Nigeria, like most other developing countries, is grappling with the task of providing sufficient amounts of electricity to meet her needs and development. Apart from the fact that electricity is not readily available, it is insufficient, the supply is not constant, unreliable, epileptic and erratic as well as not contemporaneous with the demand for it and unpredictable power outages are frequent [Ogundipe and Apata, 2013; Ijemaru *et al.*, 2014; Abimbola *et al.*, 2015]. This fundamental challenge had forced the operators to rely on fossil fuel powered generators and



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kerosene stoves to keep their businesses going and in many instances when the demand to quickly heat a small amount of water for sanitizing equipment arises.

Beyond the fact that these sources of power provision have adverse effect on health as well as environmental impacts, they also cause noise and air pollution [Agbo *et al*., 2010; Ijemaru *et al.*, 2014; Abimbola *et al.*, 2015]. Besides, it is expensive and a huge cost to the business when one uses our current unit cost of petrol and kerosene to calculate it [Ogundipe and Apata, 2013; Arekete, 2013]. Moreover, paying for the energy bills is a challenge due to typical budgetary limitations. In fact, epileptic and erratic electricity supply coupled with the reliance on fossil fuel powered generators and kerosene stoves have almost crippled small and medium scale enterprises in Nigeria [Ogundipe and Apata, 2013]. Furthermore, the epileptic nature of electricity had led to scarcity of petrol and kerosene because, the citizens have resulted to using generator and kerosene powered equipment to provide energy for use [Onakoya *et al.*, 2013].

To address the problem of energy consumption while preserving a clean environment, the answer to the present challenge or imbroglio may be found in the installation of solar water heating systems (SWHS). SWHS are proven technology that can shield them from scarce, epileptic and erratic power supply [Ijemaru *et al.,* 2014; Seveda, 2015; Kolhe *et al.,* 2015]. This technology has the potential to substitute the natural gas and electricity in all climates [California Solar Centre, 2005; US Army Corps of Engineers, 2011; Sarma *et al.,* 2014].

Among the various types of SWHS, thermosyphon SWHS are the most economical and large-scale application for harnessing solar energy for hot water production, all over the world, especially for low temperature thermal systems [Samanci and Berber, 2011; Liu *et al.,* 2012; Sarma *et al.,* 2014; Ko, 2015; Kolhe *et al.,* 2015]. Earlier studies have shown that SWHS utilising thermosyphon are the simplest, most efficient and effective solution for domestic, small institutions and in applications where water demand is low or medium [Husted, 2007; The Need Projects, 2009, Arekete, 2013; Sarma *et al.*, 2014, Okoronkwo *et al*., 2014; Balusamy and Sadhishkumar, 2014; Ko, 2015; The Need Projects, 2016]. Its relative simplicity and reliability for hot water production in the domestic and commercial sectors has been proven to be economically viable [Jiang *et al*., 2010; Liu *et al*., 2012; Abu-Mulaweh, 2012; Shukla *et al*., 2013; Arekete, 2013; Sarma *et al*., 2014, Balusamy and Sadhishkumar, 2014; Ko, 2015]. It has been shown also that the system can be designed, developed and constructed in a house within a manageable budget [Abu-Mulaweh, 2012]. The system also finds useful application and acts as a renewable energy source in regions where there is an acute shortage of electricity and in rural areas where electricity or clean energy may not be available for heating but with abundant sunlight [Arekete, 2013; Ogie *et al*., 2013]. The system is found to be suitable for moderate climates where temperatures do not get to zero degrees centigrade [US Army Corps of Engineers, 2011; Homola, 2012]. However, with sufficient anti-freeze and overheat protection, it will function in any climate. Solar water heating utilising thermosyphon is attractive because it requires no auxiliary electrical components or a heat exchanger and pumps to heat and circulate water through the collectors [Husted, 2007; Samanci and Berber, 2011; Abu-Mulaweh 2012; Liu *et al*., 2012; Ayompe and Duffy, 2013; Arekete, 2013; Sarma *et al*., 2014; Shukla and Sumathy, 2014; Seveda, 2015; Kolhe *et al*., 2015]. Temperature in the storage water tank is a function of the buoyancy-induced flow of heated water from the water heater [Abu-Mulaweh, 2012]. For thermosyphon flow, the system setup relies on a phenomenon of natural convention (warm water rises) to circulate water through the collectors and to the tank [Abu-Mulaweh, 2012; Arekete, 2013; Okoronkwo *et al*., 2014]. Thermosyphon system, also, has the feature that under low or no sunshine, the temperature of water in the collector and the supply



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leg are similar and circulation automatically stops, leaving the warm and less dense water in the storage tank above the cooler and denser water in the collector and the pipelines [Arekete, 2013]. Thermosyphon solar water heater is also found to effectively transfer the heat it absorbs to the tank water [Vina and Alagao, 2010]. The ratio of heat transfer to the water to the useful heat reached is as high as 90% [Vina and Alagao, 2010]. The key advantages of solar water heaters based on thermosyphon principle have been summarised by Ogie *et al*., [2013], Okoronkwo *et al*., [2014], Sarma *et al*., [2014] and Kolhe *et al*., [2015] as follows: easiest and cheapest to build and operate; easier to maintain and less vulnerable to mishaps; can withstand mild sub-zero temperature; more reliable and long-lasting since there are no moving parts; scalable - no fuel cost- and, it is portable. However, the thermal performance of the system depends on the design characteristics and manufacturing quality of all system components [Jiang *et al*., 2010; Abdollah and Hassan, 2011; Abu-Mulaweh, 2012; Ogie *et al*., 2013]. These advantages (ease of operation and simple maintenance etc), together with favourable cost, as well as the encouraging results from previous studies suggest that thermosyphon technology can be adopted in beauty and hairdressing salon to provide the needed energy for hot water production.

There have been studies on the feasibility, suitability and performance profile of thermosyphon solar water heater for hot water production in Nigeria. The survey of the literature has shown diverse results. But, the consensus is that the adoption of TSWH technology, to meet the hot water needs of Nigeria, is feasible and viable. However, most past studies have focused on its use, application and suitability for hot water provision in homes [Akanmu, 2012; Ogie *et al*., 2013; Ijemaru *et al*., 2014; Okonkwo, 2014], hostels [Akanmu, 2012; Akanmu and Bajere, 2015] and hospitals [Rikoto and Garba, 2015].

## LITERATURE REVIEW

In Nigeria, the development, modeling and performance analysis of thermosyphon solar heating system have been reported in literature. Ogueke *et al*. [2009] reported a comprehensive review on the performances, uses and applications, as well as factors considered for the selection of solar water for domestic and industrial applications. Water heating systems were grouped into two broad categories (passive and active), each of them operating in either direct or indirect mode. The results showed that the active systems generally have higher efficiencies (35%–80%) than those of the passive systems. However, they are more complex, expensive and, are mostly 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, they reported that passive systems are less expensive, easier to construct and install and are mostly suitable for domestic applications and in applications where load demand is low or medium.

Agbo [2011] reported the performance profile of a thermosyphon solar water heater developed by the National Centre for Energy Research and Development, at the University of Nigeria, Nsukka. The performance evaluation was based on the mathematical models that described the test system and some measured experimental data. The performance results indicated that the test system has a maximum average daily collector efficiency of 0.658 and a mean system temperature of 81$^{o}$C. The efficiency of the collector dropped to an average seasonal value of 0.54 with a negligible variation across the three climatic seasons covered in the study. Akanmu



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[2012] investigated, experimentally, the long-term thermal performance of a closed thermosyphon 4 nos. serially connected flat-plate solar water heating system under weather conditions of Minna to determine its suitability to meet the hot water requirement of the community of twenty students. Results showed that the system is capable of meeting 70 – 100% hot water requirement for bathing in a community-based built-environment in Minna. Thermal efficiency up to 48% was achieved and an average water temperature in the tank of the range 45$^o$C to 90$^o$C was achieved. Detailed thermal efficiencies of the system were determined and presented. The experimental results were compared to the results found in the literatures and they showed good agreement. Ogie *et al*., [2013] designed and constructed a solar water heating system based on thermosyphon principle for domestic use. 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 into the system. Maximum fluid output temperature, 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. Arekete [2013] designed, constructed and tested a thermosyphon solar water in Akure, South-west Nigeria (Latitude 7.30$^o$N and Longitude 5.25$^o$E) using a flat plate collector covered with double glazing layers tilted at an angle 20$^o$ to the horizontal. The surface of the collector was darkened to improve its absorption capacity. Readings were taken for a period of six days. With an ambient temperature of 36$^o$C, a maximum hot water temperature of 73$^o$C was recorded during the experiment. In addition, hourly collector's efficiency increased slightly until 2.00 pm in the afternoon. Okoronkwo *et al*. [2014] presented the performance evaluation of a thermosyphon water heating system using a compound parabolic solar collector. The system investigated consisted of a compound parabolic collector, an absorber/receiver, a hot water storage tank, a cold-water storage tank, water returning pipe and the support stand. Series of performance tests were carried out on the system under the high-intensity solar insolation in Owerri, Imo state Nigeria. Results obtained showed that the thermosyphon system can produce domestic heating water of a temperature of about 90$^0$C. The temperature profiles plotted indicated that the system designed is strongly dependent on the prevailing weather condition. The study also showed that the absorber surface temperature can go above 100$^0$C under the Owerri climate. The heating power obtained during the experiment gave a net heating power of about 3952kJ. The efficiency of the system ranges over 43% - 69%. Ijemaru *et al*. [2014] explored the use of thermosyphon solar water heater to fulfil the hot water requirements in Nigeria. Through modelling, the efficiency of the system and major factors affecting the system were determined. The result of the study showed that if the efficiency of the system is increased, the area is increased resulting in an increase in the volumetric flow. Rikoto and Garba [2015] presented the results of performance analysis of a solar water heating system installed at the Bayero University, Kano, New Campus Clinic located at latitude 12.1$^o$N. Two flat plate collectors of 1m$^2$ each, with a single glazing were used as a heat exchanger. Readings taken for a period of three months (April-June) showed that the system could satisfy most of the warm water requirements of the clinic. In another study, Akanmu and Bajere [2015] presented detailed experimental observations of temperature and flow distribution of a thermosyphon solar water heating system with four flat plate collectors, connected in series under the weather conditions of Minna for a calendar year, to determine its suitability in meeting the hot water requirement for bathing in residential apartments. Results showed that the system is capable of meeting 70% – 100% hot water requirements and an average of 65.5$^o$C water temperatures can be obtained daily with high temperatures reaching 90$^o$C on excessively hot days. A mass flow rate



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averaging 55kg/hr was achieved for the system. Tsoho *et al*. [2015] designed, constructed and tested a thermosyphon solar PV/T water heating system which could be used for domestic purpose. Solar energy is received by the PV surface which then utilizes a small fraction of the incident solar radiation to produce electricity. Maximum fluid output temperature, solar insolation, thermal and electrical outputs are 63.2$^{o}$C, 957W/m$^2$, 509.5W and 140W, respectively, obtained on a sunny day.

## METHODOLOGY

This study focuses on design and experimental performance analysis of thermosyphon solar water heating system for use in Beauty and Hairdressing Salons. This section gives an overview of the design procedures for the experimental solar water heating system adopted in this study. It is further outlined in the following formats.

### Climate and Solar Energy of the Study Area

The key to the performance of a solar water heater is the amount of solar energy received by an area, time of the day, the season of the year, the cloudiness of the sky, and how close it is to the earth’s equator. The investigation was carried out at Federal University of Technology, Minna (Gidan Kwano Campus). Minna, the headquarters of Niger State in Northcentral geo-political zone of Nigeria, lies on latitude 09.37°N and longitude 06.32°E and is 265.4 m above sea level. The various solar site analysis performed showed that the location has enough available sunshine to meet solar energy required efficiently and economically [Ibeh *et al*., 2012; Okonkwo and Nwokoye, 2014]. Tables 1-3 present the monthly mean daily solar irradiation, global solar radiation, temperature data as well as clearness index of Minna. The mean value obtained (5.41 kWh/m$^2$/day) is not far from the 5.78 kWh/m$^2$/day and 5.9 kWh/m$^2$/day found in literature (Nkué and Njomo, 2009; Ayangma *et al*., 2008; Kapseu *et al*., 2012]. This means that Minna is a very suitable location for implementing solar technologies because the country is located near the equatorial line.

**Table 1. Monthly Mean Solar Irradiation over a Flat-Horizontal Surface in Minna (kWh/m$^2$/day)**

| **Months** | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Solar Insolation** | 5.67 | 5.95 | 6.18 | 6.03 | 5.63 | 5.07 | 4.55 | 4.29 | 4.75 | 5.36 | 5.80 | 5.68 |
| Yearly mean value = 5.41 | | | | | | | | | | | | |

**Source:** http://sunbird.jrc.it/pvgis



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**Table 2. Monthly values of measured global solar radiation**

| Month | H | n/N |
|---|---|---|
| January | 16.22 | 0.522 |
| February | 17.66 | 0.614 |
| March | 18.22 | 0.580 |
| April | 18.08 | 0.599 |
| May | 17.28 | 0.574 |
| June | 16.16 | 0.452 |
| July | 14.70 | 0.358 |
| August | 14.18 | 0.310 |
| September | 16.62 | 0.511 |
| October | 17.88 | 0.625 |
| November | 18.36 | 0.757 |
| December | 16.42 | 0.577 |

**Source:** Ibeh *et al*., [2012]

**Table 3. Monthly mean daily temperature data and solar radiation for Minna (2000 - 2012)**

| Month | $\overleftarrow{T}_{max}$ (°C) | $\overleftarrow{T}_{min}$ (°C) | $\frac{\overleftarrow{T}_{max}}{\overleftarrow{T}_{min}}$ ($\theta$) | $\overleftarrow{H}_N$ (MJm²day⁻¹) | $\overleftarrow{H}_\alpha$ (MJm²day⁻¹) | Clearness Index $\overleftrightarrow{K}_\tau = \frac{\overleftrightarrow{H}_N}{\overleftrightarrow{H}_\sigma}$ | $\frac{\overleftrightarrow{n}}{\overleftrightarrow{N}}$ |
|---|---|---|---|---|---|---|---|
| Jan | 34.6 | 20.6 | 0.60 | 16.5 | 32.1 | 0.5137 | 0.5866 |
| Feb | 37.2 | 23.3 | 0.63 | 17.3 | 34.6 | 0.5013 | 0.6456 |
| March | 38.7 | 25.6 | 0.66 | 18.3 | 37.0 | 0.4953 | 0.5917 |
| April | 36.8 | 25.3 | 0.69 | 18.3 | 37.9 | 0.4825 | 0.6047 |
| May | 33.8 | 24.1 | 0.71 | 17.5 | 37.4 | 0.4664 | 0.5893 |
| Jun | 31.3 | 22.5 | 0.72 | 16.2 | 36.8 | 0.4409 | 0.4557 |
| Jul | 29.8 | 22.1 | 0.74 | 15.0 | 37.0 | 0.4060 | 0.3883 |
| Aug | 28.9 | 22.0 | 0.76 | 14.4 | 37.5 | 0.3830 | 0.3483 |
| Sep | 30.0 | 21.6 | 0.72 | 16.7 | 37.1 | 0.4496 | 0.5028 |
| Oct | 31.9 | 21.9 | 0.69 | 18.0 | 35.1 | 0.5125 | 0.6245 |
| Nov | 35.1 | 20.5 | 0.58 | 18.4 | 32.0 | 0.5655 | 0.7732 |
| Dec | 38.7 | 19.8 | 0.56 | 16.6 | 31.2 | 0.5325 | 0.6943 |

**Source:** Okonkwo and Nwokoye [2014]

### Preliminary data for the sizing and construction of the experimental solar water heater

The present study is aimed at satisfying the water heating need of beauty and hairdressing salon in Nigeria. This necessitated the collection of preliminary data such as daily hot water needs and temperature requirements for sizing the experimental solar water heater. To obtain this information the researchers visited some prominent beauty and hairdressing salons in the study area to gather data on daily hot water use in litres in various times of the day, incoming cold-water temperature and hot temperature requirements for various activities, which lasted for four weeks. To estimate hot water use, we installed a meter and track usage and, temperature requirements were determined using a mercury-in-glass thermometer.



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**Description of the Experimental Setup**

The main components of the experimental thermosyphon solar water heater used in this study were a flat plate collector, insulated storage tank with connecting pipes fitted between them to convey cold water from the bottom of the storage tank which flows by gravity through a water supply pipe connected to the collector's header pipe to the inlet of the collector at the base. Flat plate collector (FPC) was used in this study because it requires minimal maintenance, mechanically simple and with low installation cost. The collector (painted black) consisted of a galvanized sheet, 108 cm by 107 cm by 1mm thick absorber plate integrated with 12mm inside diameter water copper riser and 18mm inside diameter header pipes, and placed in a 110cm by109cm insulated-wooden-casing covered with 109cm by 108cm by 4mm thick ordinary glass clipped to the wooden casing using 0.5mm thick stainless steel. A wooden lathe was fixed to the wooden casing to disallow the absorber plate from having direct contact with the bottom of the casing. The void between the collector plate and the bottom of the wooden casing was filled with 50mm thick polyurethane foam, which served as insulation to prevent bottom heat loss. An insulated storage water tank is integrated with the system. This arrangement ensured that energy emitted by the absorber plate cannot escape through the glass, thus temperature rises. The hot water tank was placed above and close to the collector to ensure that the thermosyphon principle works properly.

To calculate system output, the measurements recorded included the temperature of cold water coming from the hot water storage tank to the collector (collector inlet), hot water coming from the collector to the top of the hot water storage tank (collector outlet water), the temperature of incoming cold water into the hot water storage tank from the overhead cold water tank (hot water storage tank's water inlet) and the temperature of hot water storage tank's outlet hot water temperature or any drawn – off to the loads. On the collector, the following readings were carried out: temperatures and solar radiation intensity which were recorded hourly between the hours of 7:00 am and 6.00 pm each day, for one week. All temperature measurements were done using a mercury-in-glass thermometer while Solar insolation was measured by means of a digital Solarimeter placed on the same surface inclination with the collector plate. The whole setup was stationed in the open field in the study area and was tilted at angle $19^o$ to allow for effective tracking of the sun radiation. The stand on which the storage tank was placed/mounted was made of 50mm by 50mm wood as support and 25mm by 300mm wooden board as base for water storage tank, adequately braced with 50mm by 50mm wood to withstand the weight of the tank, water content and wind pressure. Wooden stand was chosen because it is relatively cheap, readily available, its construction is simple and it saves time. Schematic diagram of the thermosyphon system under analysis is illustrated in Figure 1.



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**Figure 1**. Image of the thermosyphon system

*Selection and Sizing of the Storage Tank*

The choice shape of water tank selected was cylindrical due to its least observed area/volume ratio though very difficult and expensive to construct. The size of the tank was achieved by taking transpose of equation 1 for various parameters required with respect to the total volume of water required for hairdressing and beauty salon, which was obtained from preliminary data presented in Table 4.

$$C = \frac{\pi d^2 h}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$Where;$

$C = Capacity\ of\ Water\ tank\ (m^3)$

$d = Diameter\ of\ water\ tank\ (m)$

$h = Depth\ of\ water\ tank\ (m)$

From preliminary data, the total volume of water required per day in a hairdressing and beauty salon was 267 litres. Hence;

$$Capacity\ of\ water\ tank = 267\ litres\ + 12.4\%\ (allowances)$$

$$Capacity\ of\ water\ tank = 267\ litres\ + 33\ litres$$

$$Capacity\ of\ water\ tank = 300\ litres$$



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$$Capacity\ of\ water\ tank = \frac{300}{1000}\ (m^3)$$

$$Capacity\ of\ water\ tank = 0.3m^3$$

Taking the depth of water tank (h) to be 1.2m (assumed), the diameter of the water tank was calculated using equation (1)

$$C = \frac{\pi d^2 h}{4}$$

$$0.3 = \frac{3.142 \times d^2 \times 1.2}{4}$$

$$d = \sqrt{\frac{1.20}{3.77}}$$

$$d = \sqrt{0.32}$$

$$d = 0.57m$$

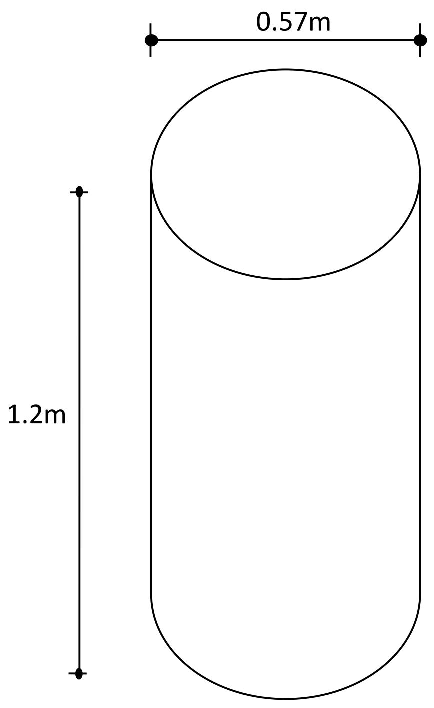


**Figure 2**. **Water storage tank**



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## Construction of the Water Storage Tank

The storage tank consisted two layers. Galvanized metal sheet was rolled to designed diameter of internal and external wall or layer of the storage tank. The base of both layers of the tank was sealed, by welding to the base, respective measured and cut galvanized sheets. Three holes were made on the body of both layers at specified positions, which served for fixing cold and hot water pipes. The outer surface of the inner layer was insulated/lagged using polyurethane foam of designed thickness (50mm) and, thereafter, inserted into the hollow of the outer layer of the storage tank. Sealing the top of the inner layer puts it in readiness for top cover insulation. Prior to the top cover sealing was drilling of a hole at the centre of the top plate cover - of both inner and outer layers of the tank - for fixing of the fluid loading tube (pipe). Having insulated the top of the tank, inserted and fixed the fluid loading tube, the top plate of the outer layer was then welded to seal up the tank. The cross section of the storage tank is as shown below.

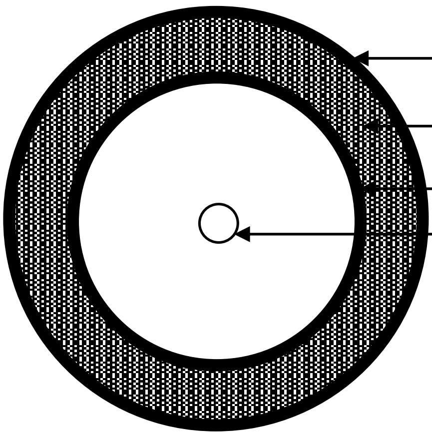


**Figure 3. Cross section of the water storage tank**

## Tilt angle of collector and orientation

The collector was meant to be inclined at angles equal to the latitude of Minna plus a variant of $10^0$ to $15^0$. In this view, the length of the collector becomes the hypotenuse. The tilt angle was achieved as shown below;

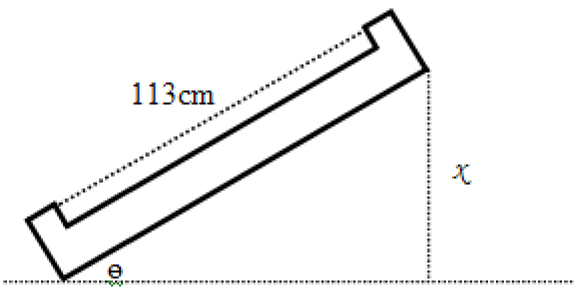


**Figure 4. Collector showing tilt angle and orientation**



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Since the hypotenuse was known, the opposite side of the collector's inclination angle was calculated by employing the principle of SOH CAH TOA;

$$Sin\ \theta = \frac{x}{113}$$

$$x = 113\ sin\ \theta \ldots\ldots\ldots (3.2)$$

$$But\ \theta = tilt\ angle\ of\ collector = Local\ Latitude\ + 10^o$$

$$\therefore \theta = 9^o 39' + 10^o$$

$$\therefore \theta = 19^o 39'$$

$$\therefore \theta = 19^o$$

$$The\ opposite\ side\ of\ the\ collector's\ inclination\ angle\ becomes;$$

$$x = 113\ sin\ 19^o 39'$$

$$x = 113\ \times\ 0.3363$$

$$x = 38cm.$$

The orientation of the collector was due south for receiving optimum solar radiation and giving better performance.

**Collector's Performance Analysis**

*Thermal Performance*

The thermal performance of the collector was calculated using first law of energy balance i.e. the instantaneous energy balance. Considering the first law of thermodynamics, for flat plate collector, a useful energy collected is equal to energy absorbed by the collector plate minus heat loss to surroundings.

$$Q_U\ = \left(I_t T\alpha - U_L(T_P - T_a)\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

*Where,*

*QU = useful energy delivered by the collector*

*$I_t$ = The solar energy received on the upper surface of the sloping collector structure of tilted surface*

*T = Fraction of the incoming solar radiation that reaches the absorbing surface transmissivity.*

*α = Fraction of the solar energy reaching the surface that is absorbed*

*$U_L$ = The overall heat loss coefficient in $w/m^2$*

*$T_P$ = Average temperature of upper surface of the absorber plate in $^oC$*

*$t_a$ = Atmospheric temperature in $^oC$*



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Considering the useful energy of a collector with respect to the total area of collector, equation 2 becomes;

$$Q_u = A_P\big(I_t T\alpha - U_L(T_P - t_a)\big)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Similarly, applying a correction or heat removal factor, the resulting equation is;

$$Q_u = F_R A_P(I_t T\alpha - U_L(T_P - t_a))\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

But, the average temperature of upper surface of the absorber plate in $^0$c is given by the following equation;

$$T_P = \frac{Tf_i + Tf_o}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Hence, equation 4 becomes;

$$Q_u = F_R A_P\left(I_t T\alpha - U_L\left(\frac{Tf_i + Tf_o}{2}\right) - Ta\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

In a typical liquid collector, average plate temperatures are usually 5 to 10$^0$C above inlet liquid temperature. For convenience, Equation (4) can be modified by substituting inlet fluid temperature of a suitable factor.

$$Q_u = F_R A_P\big(I_t T\alpha - U_L(t_i - t_a)\big)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Where:

$t_i = The\ temperature\ of\ the\ fluid\ entering\ the\ collector.$

$F_R = A\ correction\ or\ a\ heat\ removal\ factor\ having\ a\ value\ less\ than$ 1.0

$A_P = Total\ collector\ area\ in\ m^2$

The correction or a heat removal factor was calculated using equating equations 3 and 7 as illustrated below viz;

$$A_P\big(I_t T\alpha - U_L(T_P - t_a)\big) = F_R A_P\big(I_t T\alpha - U_L(t_i - t_a)\big)\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Transpose of equation (8) gives:



ISSN 2055-0197(Print), ISSN 2055-0200(Online)

$$F_R = \frac{\left(I_t T\alpha - U_L(T_P - t_a)\right)}{\left(I_t T\alpha - U_L(t_i - t_a)\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

*Collector's Efficiency (η)*

$$\eta = \frac{Q_U}{I_T A_P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

$$\eta = \frac{F_R A_P\left(I_t T\alpha - U_L(T_P - t_a)\right)}{I_T A_P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

$$\eta = \frac{F_R A_P I_t T\alpha}{I_T A_P} - \frac{U_L(T_P - t_a) F_R A_P}{I_T A_P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

$$\eta = F_R T\alpha - \frac{F_R U_L(T_P - t_a)}{I_T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

Neglecting correction heat removal factor,

$$\eta = T\alpha \quad - \quad \frac{U_L(T_P - t_a)}{I_T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

Relating equation (14) to equation of a straight line;

$\eta = Efficiency\ of\ the\ collector$

$F_R T\alpha = Intercept\ on\ y - axis$

$F_R U_L = Slope\ or\ Gradient$

## RESULTS AND DISCUSSIONS

### Quantity and Temperature requirements of water in Hairdressing Salon

Table 4 shows the quantity of water in litres and temperature requirement for various times of the day. It could be observed from the table that temperature ranges from 36$^o$C to 79$^o$C depending on the activities and operations carried out as earlier mentioned. In terms of quantity of hot water needed, it can be observed from the table also that they required about 300 litres of hot water per day, for their operations and activities.



ISSN 2055-0197(Print), ISSN 2055-0200(Online)

**Table 4. Mean hot water and temperature requirements for beauty and hairdressing Salon in Nigeria**

| Quantity of water for various times of the day (Litres) | Cumulative Quantity of Water (Litres) | Temperature (˚C) | Time (Minutes) |
|---|---|---|---|
| 7 | 7 | 36 | 10.25 |
| 8 | 15 | 37 | 11.13 |
| 34 | 49 | 47 | 12.40 |
| 18 | 67 | 43 | 12.50 |
| 10 | 77 | 37 | 13.15 |
| 6 | 83 | 40.5 | 13.30 |
| 14 | 97 | 38 | 14.07 |
| 8 | 105 | 40 | 14.40 |
| 8.5 | 113.5 | 40.5 | 14.50 |
| 8 | 121.5 | 39 | 15.04 |
| 12 | 133.5 | 36 | 15.10 |
| 4 | 137.5 | 79 | 15.20 |
| 9 | 146.5 | 38 | 15.29 |
| 17 | 163.5 | 40 | 15.29 |
| 6 | 169.5 | 37 | 16.05 |
| 8 | 177.5 | 37 | 16.05 |
| 8.5 | 186 | 38 | 16.38 |
| 20 | 206 | 44 | 16.58 |
| 20 | 226 | 39 | 16.58 |
| 24 | 250 | 42 | 18.00 |
| 17 | 267 | 38 | 19.45 |

## Thermal Performance and Efficiency Analysis

The performances of the system under investigation are presented in Tables 5 and 6. Table 5 is a detailed analysis of the performance of the system in a moderate sunny day. It depicts the temperature profile of the solar water heater from 7.00hr to 18.00 hr, but the asterisk at 18.00hr indicates rainfall and so no reading was taken at such time. The readings were taken on an hourly basis. The system attained a maximum temperature of 70°C on a moderately clear day, which occurred at 13.00h of the day. This value decreases with time to about 45°C at 17.00h of the day. Though heat losses were observed, the water temperature recorded at the end of the day will still meet the comfort level temperature for hair washing. The efficiency of the collector decreases as it gains more energy due to an increase in the heat loss factor. The highest efficiency on this day was 0.753 while the lowest efficiency was 0.696. The efficiency of the system can be improved by reducing heat losses to the minimum. This can be achieved by appropriate choice of materials, insulation and specification.



ISSN 2055-0197(Print), ISSN 2055-0200(Online)

**Table 5. Performance of collector in moderate sunny day**

| TIME (Hr) | $T_{in}$ ($^OC$) | $T_{out}$ ($^OC$) | $T_p$ ($^OC$) | $T_a$ ($^OC$) | WIND SPEED (m/s) | $T_p–T_a$ ($^OC$) | $U_L(T_p–T_a)$ | $I_T$ | $\frac{U_L(T_p–T_a)}{I_T}$ | ŋ |
|---|---|---|---|---|---|---|---|---|---|---|
| 7.00 | 28 | 25.0 | 26.5 | 23.4 | 1.00 | 3.1 | 22.66 | 1903.84 | 0.012 | 0.753 |
| 8.00 | 28 | 46.0 | 37.0 | 23.5 | 2.00 | 13.5 | 98.69 | 2003.22 | 0.049 | 0.716 |
| 9.00 | 28 | 46.5 | 37.3 | 25.5 | 2.00 | 11.8 | 86..26 | 1986.97 | 0.043 | 0.722 |
| 10.00 | 28 | 44.0 | 36.0 | 25.8 | 1.50 | 10.2 | 74.56 | 1971.68 | 0.038 | 0.727 |
| 11.00 | 28 | 56.0 | 42.0 | 27.0 | 2.00 | 15.0 | 109.65 | 2017.55 | 0.054 | 0.711 |
| 12.00 | 28 | 66.0 | 47.0 | 29.0 | 3.50 | 18.0 | 131.58 | 2046.22 | 0.064 | 0.701 |
| 13.00 | 28 | 70.0 | 49.0 | 29.5 | 2.50 | 19.5 | 142.55 | 2060.56 | 0.069 | 0.696 |
| 14.00 | 28 | 64.0 | 46.0 | 29.9 | 6.00 | 16.1 | 117.69 | 2028.06 | 0.058 | 0.707 |
| 15.00 | 28 | 60.0 | 44.0 | 29.7 | 1.50 | 14.3 | 104.53 | 2010.86 | 0.052 | 0.713 |
| 16.00 | 28 | 54.0 | 41.0 | 29.0 | 2.00 | 12.0 | 87.72 | 1988.88 | 0.044 | 0.721 |
| 17.00 | 28 | 45.0 | 36.5 | 29.3 | 3.50 | 7.2 | 52.63 | 1943.01 | 0.027 | 0.738 |
| 18.00 | 28 | * | * | 22.7 | 1.50 | * | * | * | * | * |

Figure 5 shows the hourly variations of collector's efficiency on a moderately sunny day during the experimental observation. The pattern of the graph above reveals that the hourly variation in the efficiency of the collector was minimal and does not reduce drastically. As the efficiency increases to a certain point, it then reduces and later increases again. The intercept of the straight line on y – axis is 0.765 while the slope ($U_L$) is 1w/m$^2$k.

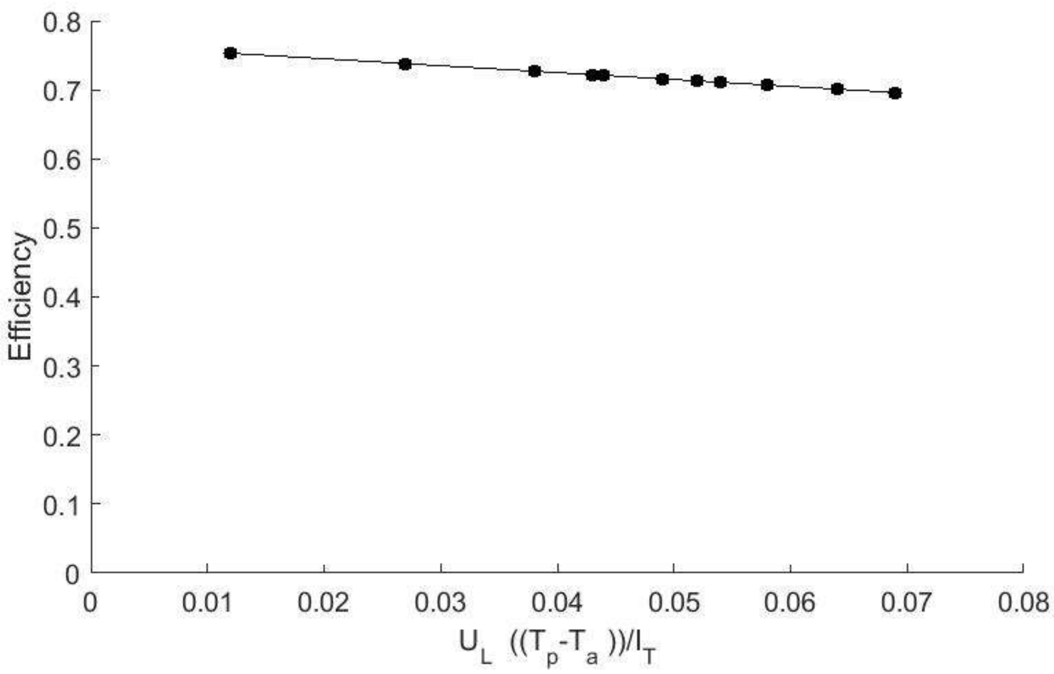


**Figure 5. Variation in efficiency of the system on average moderate sunny day**



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Table 6 is an evaluation of the performance of the system on an average sunny day during the period of observation. It shows the temperature profile of the solar water heater from 7.00hr to 18.00 hr. The readings were taken hourly. The system attained a maximum temperature of 84°C on an average clear day, which occurred at 14.00h of the day. The highest efficiency on this day was 0.755 while the lowest efficiency was 0.673.

**Table 6. Performance of collector in an average sunny day**

| TIME (Hr) | $T_{in}$ (°C) | $T_{out}$ (°C) | $T_p$ (°C) | $T_a$ (°C) | WIND SPEED (m/s) | $T_p - T_a$ (°C) | $U_L(T-T_a)$ | $I_T$ | $\frac{U_L(T_p-T_a)}{I_T}$ | η |
|---|---|---|---|---|---|---|---|---|---|---|
| 7.00 | 26 | 24 | 25.0 | 22.30 | 1.50 | 2.70 | 19.74 | 1900.02 | 0.010 | 0.755 |
| 8.00 | 26 | 37 | 31.5 | 22.80 | 1.00 | 8.70 | 63.60 | 1957.35 | 0.032 | 0.733 |
| 9.00 | 26 | 64 | 45.0 | 23.50 | 1.50 | 21.50 | 157.17 | 2079.67 | 0.076 | 0.689 |
| 10.00 | 28 | 79 | 53.5 | 26.10 | 1.50 | 27.40 | 200.29 | 2136.03 | 0.094 | 0.671 |
| 11.00 | 28 | 60 | 44.0 | 28.00 | 1.50 | 16.00 | 116.96 | 2027.10 | 0.058 | 0.707 |
| 12.00 | 28 | 78 | 53.0 | 28.00 | 1.50 | 25.00 | 182.75 | 2113.10 | 0.086 | 0.679 |
| 13.00 | 30 | 82 | 56.0 | 29.50 | 1.50 | 26.50 | 193.72 | 2127.44 | 0.091 | 0.674 |
| 14.00 | 31 | 84 | 57.5 | 30.60 | 1.50 | 26.90 | 196.64 | 2131.26 | 0.092 | 0.673 |
| 15.00 | 32 | 76 | 54.0 | 31.00 | 1.50 | 23.00 | 168.13 | 2093.99 | 0.080 | 0.685 |
| 16.00 | 32 | 63 | 47.5 | 31.10 | 2.50 | 16.40 | 119.88 | 2030.92 | 0.059 | 0.706 |
| 17.00 | 33 | 46 | 39.5 | 30.90 | 3.00 | 8.60 | 62.87 | 1956.40 | 0.032 | 0.733 |
| 18.00 | 33 | 36 | 34.5 | 29.60 | 3.00 | 4.90 | 35.82 | 1921.04 | 0.019 | 0.746 |

The pattern of the graph below also reveals that the hourly variation in the efficiency of the collector was minimal and does not reduce drastically. As the efficiency decreases to a certain point, it then increases again. The graph intercepted on y – axis at 0.760 as the product of the transmissivity and absorptivity i.e. Tα. Also, the slope being interpreted as the $U_L$ = 1w/m$^2$k. The solar fraction of the collector, on the average was 0.69 and the average coefficient of performance was 6.0.



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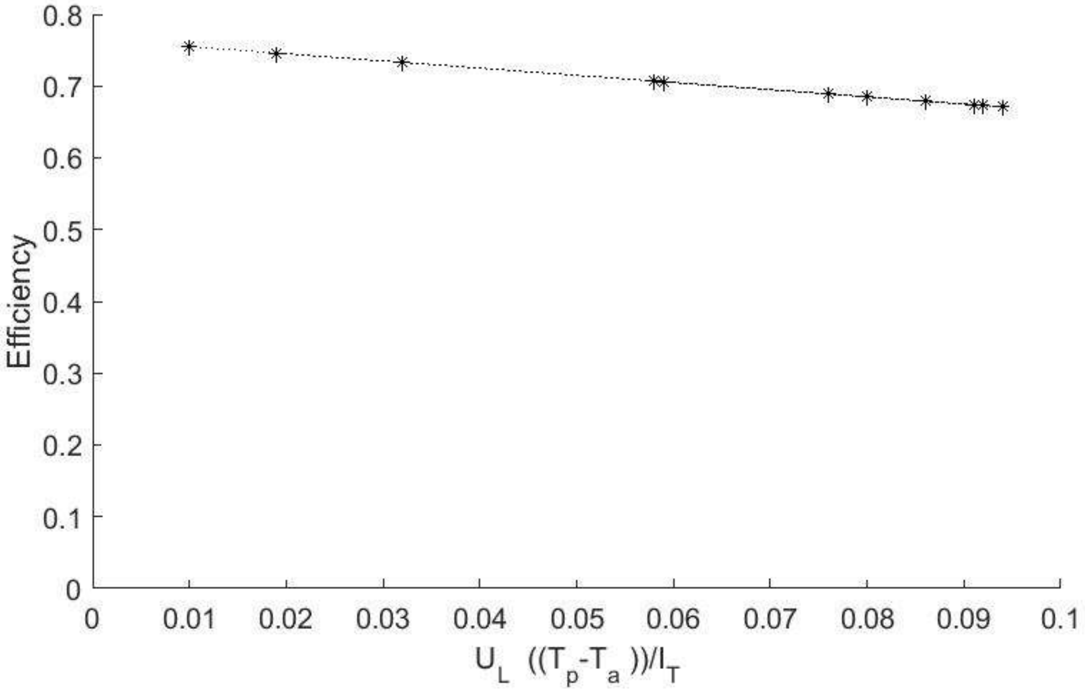


**Figure 6**. **Variation in efficiency of the system on average sunny day**

## CONCLUSIONS

The feasibility of TSWH to supply hot water fully or partially to meet the need of beauty and hairdressing salon in Nigeria via experimental investigation has been conducted. The results from the experiment showed that:

i. The system attained a maximum temperature of 70°C on a moderately clear day, which occurred at 13.00h of the day. This value decreases with time to about 45°C at 17.00h of the day.

ii. The system attained a maximum temperature of 84°C on average sunny clear day, which occurred at 14.00h of the day.

iii. The highest efficiency obtained on a moderate sunny day was 0.753 while the lowest efficiency was 0.696.

iv. The highest efficiency on the average clear sunny day was 0.755 while the lowest efficiency was 0.673. Although heat losses were observed, the water temperatures recorded suggest that TSSW can meet the hot water needs of beauty and hairdressing salons in Nigeria.



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