*International Journal of Latest Research in Engineering and Technology (IJLRET)*
*ISSN: 2454-5031*
*www.ijlret.com‖ Volume 2 Issue 4‖ April 2016 ‖ PP 52-60*

# Design and application of a solar water heater in a temperate region: a case study of obudu cattle ranch

Jerome .G.Egbe[1], Godwin A.Akeke[2], Daniel .N. Abara[3], Stephen .A. Takim[4], Edmond G.Ewah[5],

*1, 2, 5 Department of Civil Engineering, Cross River University of Technology, Calabar- Nigeria*
*3 Department Electrical & Electronics Engineering, Cross River University of Technology*
*4 Department of Mechanical Engineering Cross River University of Technology, Calabar- Nigeria*

**ABSTRACT**: The Obudu Cattle Ranch is located in Obaniku local government area in northern part of Cross River State. The Ranch was established in 1949 in the then Obudu local government areas now Obaniku. The Ranch is about 332 km from Calabar, the Capital of Cross River State with an altitude of 1,716 metres and located on a plateau of about 1,575.76 metres above sea level. The Ranch has 11 km of unwinding road with 22 bends makes movement into the Ranch quite exhilarating. Similarly, the Ranch has temperature ranges from $26^0{}_C$ to $32^0{}_C$ during the dry season and $4^0{}_C$ to $10^0{}_C$ during the raining season respectively.Solar water heating (SWH) systems use solar collectors and a liquid handling unit to transfer heat to the load, generally via a storage tank.In this research paper the system only works in the months of 1-3, 10 and 12, however the water temperature is not high enough to be used in heating and therefore the system is inefficient due to fluctuations in the Cattle Ranch weather condition, but some places in the Obudu Local Government Areas the Solar heating system can work very efficiently and perfectly. As the irradiance and ambient temperature increase the system slowly increases in efficiency, where the system peaks between months 8 and 9 (~38%) the ambient temperature and irradiance begins to decrease from months 9-12, so does the efficiency, and it can be demonstrated that from the location chosen the system generates power in months 1-11; however, in month 12 there is power lost from the system to the environment. The system only works in the months of 1-3, 10 and 12 respectively.

**KEYWORDS:**Obudu Cattle Ranch, Solar Water, Heating Systems, Thermal Fluid, Storage Tank

## 1. INTRODUCTION

The Obudu Cattle Ranch is located in Obaniku local government area in northern part of Cross River State.The Ranch was established in 1949 in the then Obudu local government areas now Obaniku.The Ranch is about 332 km from Calabar, the Capital of Cross River State with an altitude of 1,716 metres and located on a plateau of about 1,575.76 metres above sea level. The Ranch has 11 km of unwinding road with 22 bends make movement into the Ranch quite exhilarating. Similarly, the Ranch has temperature ranges from $26^0{}_C$ to $32^0{}_C$ during the dry season and $4^0{}_C$ to $10^0{}_C$ during the raining season respectively. The use of solar radiation to heat water was first devised by Clarence M. Kemp in 1891 [10].

In 1895, Kemp sold the patent to two business men to make use of the design in the California area [10].Solar water heating (SWH) systems use solar collectors and a liquid handling unit to transfer heat to the load, generally via a storage tank. The liquid handling unit includes the pump(s) used to circulate the working fluid from the collectors to the storage tank and control and safety equipment. When properly designed, solar water heaters can work when the outside temperature is well below freezing and they are also protected from overheating on hot and sunny days. Many systems also have a back-up heater to ensure that all of a consumer's hot water needs are met even when there is insufficient sunshine.

"In the early 1900s, several researchers focused their attention to improving the design of the SWH systems to make them durable and efficient. Solar Water Heating (SWH) systems were commercialised on a wider scale in the early 1960s."[12]. Following a recent (2013) review of advances in solar water heating systems by[12], the review looked at the wide spread application of both domestic and industrial SWH systems.According to [12], some 70 million houses world-wide were reported to be using SWH systems. Solar water heating is not only environmentally friendly but requires minimal maintenance and operation cost compared to other solar energy applications. The systems were also cost effective with an attractive payback period of 2–4 years depending on the type and size of the system [12].

Similarly, an extensive research has been performed to further improve the thermal efficiency of solar water heating, since its initial design in 1891. However, [12] focused mainly on the design aspects of SWH systems, with the first part of the paper providing a consolidated summary on the development of various system components that included the collector, storage tank and heat exchanger. The later part of the paper covered the alternative refrigerant technology and technological advancements in improving the performance as well as the cost effectiveness of the SWH system [12].

**1.1 THEORY AND DESIGN**

The proposed design will utilise the setup designed by [3], along with the flow design by [1], as shown in figure2. The passive design chosen allows for the design to be manufactured cheaper than an active system, while also requiring no moving parts. This allows the design to be implemented in almost any environment. Active Solar Water Heating Systems unlike passive systems, use one or more pumps to circulate the working fluid in the system. Active systems can be categorised into direct circulation and indirect water heating systems. In the direct or open-loop systems, water from the storage tank is directly circulated to the collector to be heated by solar energy, whereas in the indirect active system the heat transfer fluid is circulated through the collector and rejects heat through a heat exchanger to the water in the storage tank [12].

**2.1 TEMPORARY HARD WATER**

Usually, when temporary hard water is been heated, the dissolved material in water separates. This separated material in turn accumulates in several parts of the collector system. The formation of scale is faster in FPC based system than in ETC based system. Similarly, the formation of scale alsotakes place in ETC based system as well. In temporary hard water, indirect heating through heat exchanger is recommended. In the application of indirect heating the formation of scale takes place at the heat exchanger surface, which can be easily cleaned at periodic intervals. However, newer technologies are coming in where inner surface of the collector tubes are treated with special chemical to reduce formation of scale.

**2.2 PERMANENT HARD WATER**

Permanent hard water does not create problem in the operation of flat plate collector based system. However, if the system remains filled with water during dry season and is overheated repeatedly, concentration of the dissolved solids goes up causing formation of scale over a period of time.

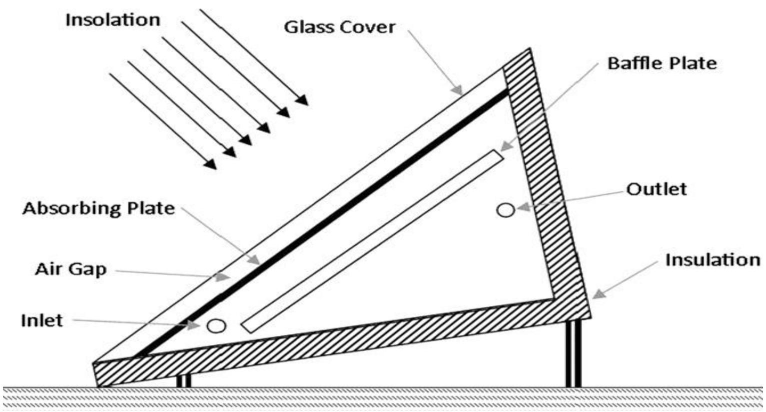


**Figure 1:** Triangular built-in-storage water heater [6].

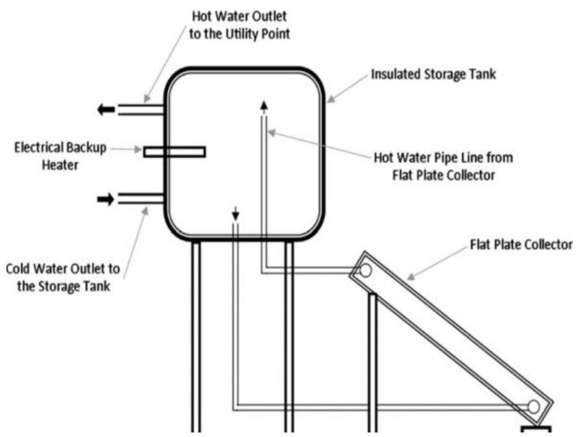


**Figure 2**: A typical Thermo syphon

It should be noted that the vertical temperature changes where irradiance stays constant and has no effect. This was demonstrated by Horace Benedict in 1791. Generally speaking, the system designed in this research paper explores the use of solar water heating in cold remote places, at higher latitudes where both low irradiance and ambient temperatures occur.

### 2.3 PARAMETER ASSUMPTIONS

The following assumptions shown in Table 1 below, were made to demonstrate the application of the design, along with the irradiance data and ambient temperature for the temperate region.

**Table 1: Assumptions Used During the Design**

| Parameters | Description |
|---|---|
| Collector | Glazed, $5.0m^2$ |
| Slope | $60^0$ facing south |
| Storage | Fully fixed, $0.4m^2$ |
| Heat Exchanger | 70% effectiveness |
| Location | Obudu Cattle Ranch, Cross River State, Nigeria. |

### 3.0 THE DESIGNS

The design section show the necessary steps required to take the irradiation from the sun and convert it into usable solar water heating system. Some necessary terms related to the design are defined next.

### 3.1 Radiation Effects:

As given in [1], the irradiance flux is calculated using the following equation,

$$\Gamma = \tau_{cov} A_P G \quad (1)$$

Where,

| | | | | |
|---|---|---|---|---|
| $\Gamma$ | = | 0.5789kW | = | The radiant flux of the plate. |
| $\tau_{cov}$ | = | 0.7 | = | The transmittances of any transparent cover that may be used to protect the plate from the wind. |
| $A_p$ | = | $5.0m^2$ | = | The exposed area of the plate. |
| G | = | $0.1654kW/m^2$ | = | The irradiance of the collector. |

The fraction of radiant flux absorbed given by

$\alpha_p$ = 0.8

Hence, the actual absorbed, $(\Gamma_\alpha)$ is calculated as,

$$\Gamma_\alpha = \tau_{cov} \alpha_p A_p G \qquad (2)$$

Where:

| | | | | |
|---|---|---|---|---|
| $\Gamma_\alpha$ | = | 0.4632kW | = | The actual radiant flux absorbed by the plate. |
| $\tau_{cov}$ | = | 0.7 | = | The transmittances of any transparent cover that may be used to protect the plate from the wind. |
| $A_p$ | = | $5.0m^2$ | = | The exposed area of the plate. |
| G | = | $0.1654kW/m^2$ | = | The irradiance of the collector. |

The Efficiency of the Collector ($\boldsymbol{\eta_c}$) is given by the following equation,

$$P_u = \eta_c A_p G \; (3)$$

Where:

| | | | | |
|---|---|---|---|---|
| $P_u$ | = | 0.219kW | = | The transmittances of any transparent cover that may be used to protect the plate from the wind. |
| $\eta_c$ | = | 0.2644 | = | The efficiency of the collector. |
| $A_p$ | = | $5m^2$ | = | The exposed area of the collector. |
| $G$ | = | $0.1654kw/m^2$ | = | The irradiance measured in the plane of the collector. |

As the efficiency of the collector ($\eta_c$) is a result of the capture efficiency ($\eta_{pf}$) and the transfer efficiency ($\eta_{sp}$), the following equation can be utilised:

$$\eta_c = \eta_{pf} \eta_{sp} (4)$$

Where:

| | | | |
|---|---|---|---|
| $\eta_c$ | = 0.2664 | = | The efficiency of the collector. |
| $\eta_{pf}$ | = 0.7 | = | The fraction of $P_{net}$ transferred to the fluid. |
| $\eta_{sp}$ | = 0.3777 | = | The capture efficiency. |

Also from [1], in many operational solar heating systems, the temperature of the plate is unknown. Therefore the collector efficiency ($\eta_c$) is predominately calculated from the temperature of the fluid. In those situations the following equation is applied:

$$\eta_c = \frac{P_u}{(AG)} \quad (5a)$$

$$\eta_c = \eta_{pf}\,\tau_{cov}\,\alpha_p - \frac{\eta_{pf}\,U_L(T_p - T_a)}{G} \quad (5b)$$

Where:

| | | | |
|---|---|---|---|
| $\eta_c$ | = 0.2644 | = | The efficiency of the collector. |
| $\eta_{pf}$ | = 0.7 | = | The fraction of $P_{net}$ transferred to the fluid. |
| $\tau_{cov}$ | = 0.7 | = | The transmittances of any transparent cover that may be used to protect the plate from the wind. |

**3.2 Temperature Effect**

The Heat Loss Rate (L) is computed with the assumption that since the plate is hotter than its surroundings, it loses heat at a particular rate. The rate of heat loss from [1] is given by,

$$L = \frac{(T_p - T_\alpha)}{R_L} \quad (6)$$

Where:

| | | | |
|---|---|---|---|
| L | = 0.1507kW | = | The rate of heat loss. |
| $T_p$ | = 20.85$^0$C | = | The temperature of the plate. |
| $T_\alpha$ | = 7.28$^0$C | = | The temperature of the surrounding. |
| $R_L$ | = 0.09 | = | The resistance to heat loss from the plate to the outside environment. |

Also from [1], the net heat flow ($P_{net}$),

$$P_{net} = \Gamma_\alpha - L \quad (7)$$

Where:

| | | | |
|---|---|---|---|
| $P_{net}$ | = 0.3124kW | = | The net heat flow into the pipe. |
| $\Gamma_\alpha$ | = 0.4632kW | = | The actual radiant flux absorbed by the plate. |
| L | = 0.1508kW | = | The rate of heat loss. |

The net heat flow into the plate can also be expressed in accordance with the Hottel-Whillier-Bliss equation

$$P_{net} = \tau_{cov}\,\alpha_p A_p\, G - \left[\frac{T_P - T_a}{R_L}\right] \quad (8)$$

Where:

| | | | |
|---|---|---|---|
| $P_{net}$ | = 0.3124kW | = | The net heat flow into the pipe. |
| $\tau_{cov}$ | = 0.7 | = | The transmittances of any transparent cover that may be used to protect the plate from the wind. |
| $\alpha_p$ | = 0.8 | = | The fraction of flux actually absorbed. |
| $A_p$ | = 5.0m$^2$ | = | The exposed area of the plate. |
| G | = 0.1654kW/m$^2$ | = | The irradiance of the collector. |
| $T_p$ | = 20.85$^0$C | = | The temperature of the plate. |
| $T_a$ | = 7.28$^0$C | = | The temperature of the surrounding. |
| $R_L$ | = 0.09 | = | The resistance to heat loss from the plate to the outside environment. |

With the inclusion of the overall heat loss coefficient the net heat flow equation can be simplified using the following equation:

$$P_{net} = A_P[\tau_{cov}\,\alpha_P\, G - U_L(T_P - T_a)] \quad (9a)$$

$$P_{net} = A_P\, G\left[\tau_{cov}\,\alpha_P - \frac{U_L(T_P - T_a)}{G}\right] \quad (9b)$$

Where:

| | | | |
|---|---|---|---|
| $P_{net}$ | = 0.3124kW | = | The net heat flow into the pipe. |
| $\tau_{cov}$ | = 0.7 | = | The transmittances of any transparent cover that may be used to protect the plate from the wind. |
| $\alpha_p$ | = 0.8 | = | The fraction of flux actually absorbed. |
| $A_p$ | = 5.0m$^2$ | = | The exposed area of the plate. |
| G | = 0.1654kW/m$^2$ | = | The irradiance of the collector. |
| $U_L$ | = 2.22 | = | The overall heat loss coefficient. |
| $T_p$ | = 20.85$^0$C | = | The temperature of the plate. |
| $T_a$ | = 7.28$^0$C | = | The temperature of the surrounding. |

Taking into consideration the capture efficiency the net heat flow can be further simplified in accordance with [1], using the following equation:

$P_{net} = \eta_{sp} A_P G$(10)

Where:

| | | | |
|---|---|---|---|
| $P_{net}$ | = 0.3124kW | = | The net heat flow into the pipe. |
| $\eta_{sp}$ | = 0.3777 | = | The capture efficiency. |
| $A_p$ | = 5m$^2$ | = | The exposed area of the plate. |
| G | = 0.1654kw/m$^2$ | = | The irradiance of the collector. |

As given in [1], the overall heat loss coefficient is calculated using the following equation:

$U_L = \frac{1}{R_L A_p}$(11)

Where:

| | | | |
|---|---|---|---|
| $U_L$ | = 2.222 | = | The overall heat loss coefficient. |
| $A_p$ | = 5.0m$^2$ | = | The exposed area of the plate. |
| $R_L$ | = 0.09 | = | The resistance to heat loss from the plate t environment. |

In accordance with [1], the capture efficiency ($\eta_{sp}$) is as follows:

$$\eta_{sp} = \tau_{cov}\,\alpha_p - \frac{U_L(T_p - T_a)}{G}\eta_{sp} < 1 \qquad (12)$$

Where:

| | | | |
|---|---|---|---|
| $\eta_{sp}$ | = 0.3777 | = | The capture efficiency. |
| $\tau_{cov}$ | = 0.7 | = | The transmittances of any transparent cover that may be used to protect the plate from the wind. |
| $\alpha_p$ | = 0.8 | = | The fraction of flux actually absorbed. |
| $U_L$ | = 2.222 | = | The overall heat loss coefficient. |
| $T_p$ | = 20.85$^0$C | = | The temperature of the plate. |
| $T_a$ | = 7.28$^0$C | = | The temperature of the surrounding. |
| G | = 0.1654kW/m$^2$ | = | The irradiance of the collector. |

### 3.3 The Produced Water

The useful output power from the collector ($P_u$) is calculated using the following equation,

$P_u = \eta_{pf} P_{net}$(13)

Where:

| | | | |
|---|---|---|---|
| $P_u$ | = 0.219kW | = | The output power from the collector. |
| $\eta_{pf}$ | = 0.7 | = | The fraction of $P_{net}$ transferred to the fluid. |
| $P_{net}$ | = 0.3124kW | = | The net heat flow into the plate. |

And the energy absorbed by the water (E) is given as in [1] as,

$E = mc\Delta T_f = P_u \Delta t$(14)

The expression in (14) holds true because the energy absorbed by the water (E) equals the useful output power from the collector ($P_u$), minus the change in temperature given as$\Delta t$.

Where:

| | | | |
|---|---|---|---|
| $E$ | = 0.2187kJm$^3$/kgh | = | The energy absorbed by the water. |
| $m$ | = 0.3m$^3$/h | = | The static mass of water being heated. |

| | | | |
|---|---|---|---|
| C | = 4.2 kJ/kg$^0$C | = | The specific heat capacity of water. |
| $\Delta T_f$ | = 0.1735$^0$C | = | The change in temperature of the fluid. |

In accordance with John [1], the useful output power from a collector when mass *m* is **static** and the fluid is being heated, then the following equation can be applied.

$P_u = mc\frac{\Delta T_f}{\Delta t}$(15)

Where:

| | | |
|---|---|---|
| $P_u$ | = | The useful power output from the collector. |
| $m$ | = | The static mass of water being heated. |
| c | = | The specific heat capacity of water. |
| $\Delta T_f$ | = | The change in temperature of the fluid. |
| $\Delta t$ | = | The change in temperature. |

However when the useful output power from a collector has a mass *m*, which flows through the collector over a period of time, then the following equation can be applied.

$P_u = mc(T_2 - T_1)$(16)

Where:

| | | | |
|---|---|---|---|
| $P_u$ | = 0.219kW | = | The useful power output from the collector. |
| $m$ | = 0.3m$^3$/h | = | The static mass of water being heated. |
| C | = 4.2kJ/kg$^0$C | = | The specific heat capacity of water. |
| $T_1$ | = 7.12$^0$C | = | The temperature of water that enters the collector. |
| $T_2$ | = 7.2935$^0$C | = | The temperature of water that leaves the collector. |

**Table 2: Computation of Data**

| Month | G [kWh/m$^2$] | $T_a$ [$^0$C] | $T_1$ [$^0$C] | $T_2$ [$^0$C] | $T_p$-$T_a$ [$^0$C] | L [kW] | $\Gamma_\alpha$ [kW] | $P_{net}$ [kW] | $\eta_{sp}$ | $\eta_c$ | Efficiency [%] | $P_u$ [kW] | E [kJm$^3$/kghr] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.1121 | -6.7 | 4.00 | 4.0043 | 27.5500 | 0.3061 | 0.3138 | 0.0077 | 0.0138 | 0.0096 | 0.9646 | 0.005 | 0.0054 |
| 2 | 0.1479 | -6.1 | 2.00 | 2.0637 | 26.9500 | 0.2994 | 0.4142 | 0.1147 | 0.1551 | 0.1086 | 10.8582 | 0.080 | 0.0803 |
| 3 | 0.1583 | -1 | 3.00 | 3.1114 | 21.8500 | 0.2428 | 0.4433 | 0.2006 | 0.2533 | 0.1773 | 17.7333 | 0.140 | 0.1404 |
| 4 | 0.1754 | 6.2 | 4.50 | 4.6824 | 14.6500 | 0.1628 | 0.4912 | 0.3284 | 0.3744 | 0.2621 | 26.2087 | 0.230 | 0.2299 |
| 5 | 0.1908 | 12.3 | 7.50 | 7.7441 | 8.5500 | 0.0950 | 0.5343 | 0.4393 | 0.4604 | 0.3223 | 32.2306 | 0.308 | 0.3075 |
| 6 | 0.2250 | 17.7 | 8.50 | 8.8306 | 3.1500 | 0.0350 | 0.6300 | 0.5950 | 0.5289 | 0.3702 | 37.0222 | 0.417 | 0.4165 |
| 7 | 0.2363 | 20.6 | 11.00 | 11.3660 | 0.2500 | 0.0028 | 0.6615 | 0.6587 | 0.5576 | 0.3904 | 39.0354 | 0.461 | 0.4611 |
| 8 | 0.2113 | 19.7 | 12.00 | 12.3215 | 1.1500 | 0.0128 | 0.5915 | 0.5787 | 0.5479 | 0.3835 | 38.3532 | 0.405 | 0.4051 |
| 9 | 0.1904 | 15.5 | 9.00 | 9.2632 | 5.3500 | 0.0594 | 0.5332 | 0.4737 | 0.4976 | 0.3483 | 34.8295 | 0.332 | 0.3316 |
| 10 | 0.1475 | 9.3 | 9.00 | 9.1581 | 11.5500 | 0.1283 | 0.4130 | 0.2847 | 0.3860 | 0.2702 | 27.0192 | 0.199 | 0.1993 |
| 11 | 0.0971 | 3.3 | 8.00 | 8.0427 | 17.5500 | 0.1950 | 0.2718 | 0.0768 | 0.1583 | 0.1108 | 11.0798 | 0.054 | 0.0538 |
| 12 | 0.0950 | -3.5 | 6.00 | 5.9975 | 24.3500 | 0.2706 | 0.2660 | -0.0046 | -0.0096 | -0.0067 | -0.6713 | -0.003 | -0.0032 |
| Yearly Avg. | 0.1654 | 7.28 | 7.12 | 7.2935 | 13.5700 | 0.1508 | 0.4632 | 0.3124 | 0.3777 | 0.2644 | 26.4390 | 0.219 | 0.2187 |

## 4. RESULTS DISCUSSION

The calculations shown in table 2 display a strong connection between the temperature of the measured water in the system against the temperature of the location and the irradiance going into the system.

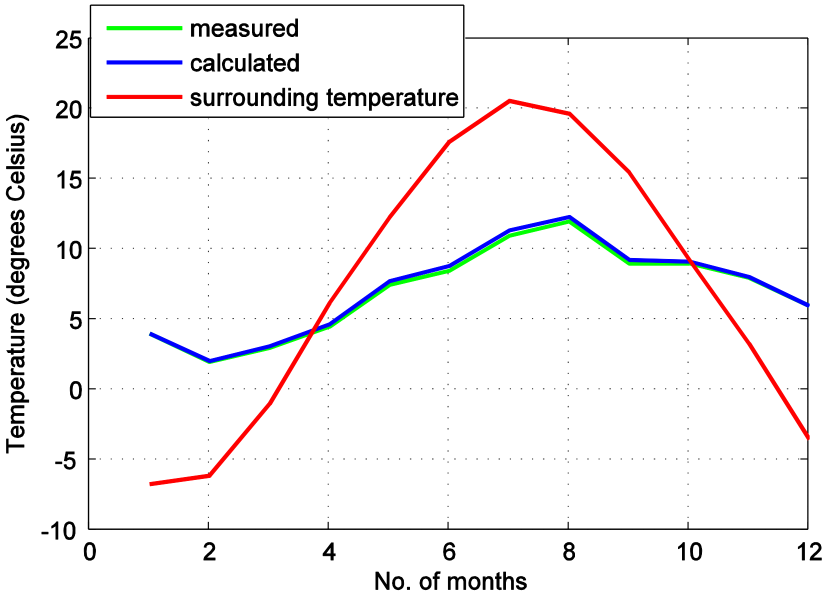


**Figure 3**: Comparison of the Calculated ($T_2$) and the measured ($T_1$) water temperature

From a power perspective as shown in figure 3, it can be demonstrated that from the location chosen the system generates power in months 1-11; however, in month 12 there is power lost from the system to the environment.

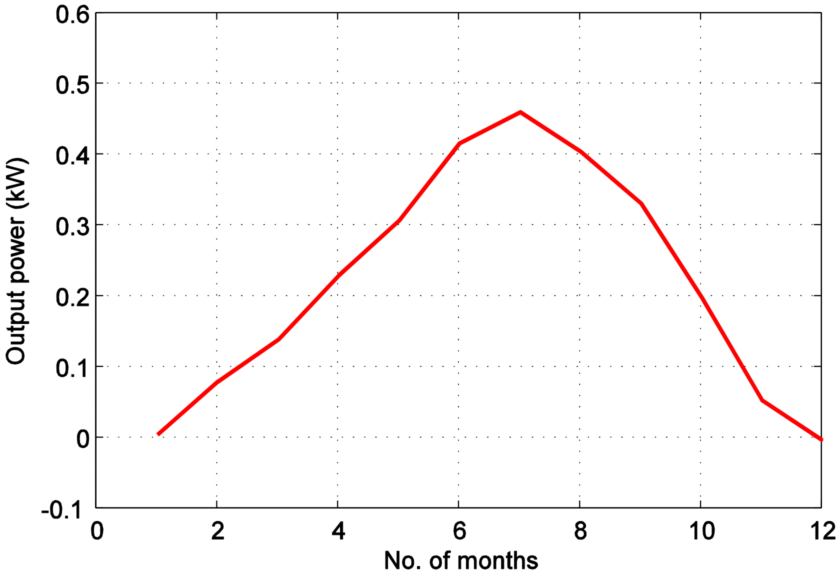


**Figure 4**: The output power produced over a 12 month period

In months 1-2 the efficiency of the system is ~0% (figure 4). As the irradiance and ambient temperature increase the system slowly increases in efficiency, where the system peaks between months 8 and 9 (~38%). As the ambient temperature and irradiance begins to decrease from months 9-12, so does the efficiency.

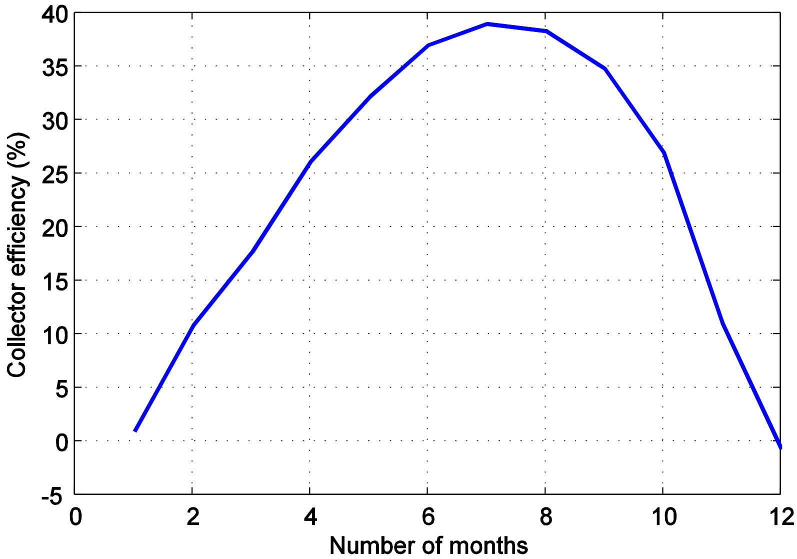


**Figure 5**: The efficiency of the collector over a 12 month period

Comparing figure4 and figure 5, it can be seen that there is no direct relation between the power produced by the system and the efficiency. The power of the system peaks at around month 7, compared to the efficiency peaking around month 8-9.

## 5. CONCLUSION

The system only works in the months of 1-3, 10 and 12, however the water temperature is not high enough to be used in the heating process and therefore the system is inefficient due to fluctuations in the Cattle Ranch weather condition but some places in the Obudu Local Government Areas the Solar heating system can work very efficiently and perfectly. Between the months of 4 and 9 the water in the system is not heated and it is colder than the outside temperature making the system redundant and it should be switched off to conserve energy. These results obtained related to the low average radiance and the extreme cold temperatures at the location and therefore it could be recommended to have the system installed in some locations of the Cattle Ranch. The system would benefit from the addition of a possible separate storage tank, rather than a combined system; however this would increase the overall space and cost. Research into alternative fluids within the system would also be of benefit. In this paper, water was used due to current fluids being non-environmentally friendly. Current research is looking into the use of carbon-dioxide; this would also help increase the efficiency. At present some incentives are available from governments in different states which will provide easy financing and also capital subsidy.There are several issues to be addressed while evaluating life cycle cost of solar water heating system. These factors are interest rate, inflation rate, unit cost of electricity, operation & maintenance cost and solar water heater service life. All these factors are affected by fluctuations in the economy, government policies, electricity tariff, etc.

## REFERENCES

[1]. John Twidell., Tony Weir., *“Renewable Energy Resources*”. Second edition. Oxon: Taylor and Francis, 2006.

[2]. Ministry of Natural Resources Canada, *“Clean Energy Project Analysis: RETScreen Engineering & Cases Textbook”* 2001-2004.

[3]. Kaushik S C., Kumar R, Garg H P. “*Effect of baffle plate on the performance of a triangular built-in-storage solar water heater.”*Energy Conversion and Management, 1995; 36: 337–42.

[4]. Invent Now, *“Hall of Fame: Clarence M. Kemp”*, National Inventors Hall of Fame, 2010. http://www.invent.org/hall_of_fame/438.html [assessed 21st March, 2016.]

[5]. NASA Technical Note D-5353 *“Solar Absorptances and Spectral Reflectance’s of 12 Metals for Temperatures Ranging from 300-500K”*. Lewis Research Centre, Cleveland Ohio, 1969. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19690022517_1969022517.pdf [assessed 28th March, 2012.]

[6]. Kusterer M. J, “*NASA Surface Meteorology and Solar Energy”*. NASA Langley, 2013. http:// http://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?&num=101134&lat=43.65&submit=Submit&hgt=100&veg=17

&sitelev=&email=fb00055@surrey.ac.uk&p=grid_id&p=swvdwncook&p=avg_dnr&step=2&lon=-79.39 [assessed $28^{th}$ March, 2016.]

[7]. Regents of the University of Minnesota, *"Window Technologies: Glass (Visable Transmittance)"* University of Minnesota and Lawrence Berkeley National Laboratory, March, 2016]. http://www.commercialwindows.org/vt.php [assessed $28^{th}$ March, 2016.]

[8]. The Engineering Toolbox, "*Water Thermal Properties"*, The Engineering Toolbox, no date. http://www.engineeringtoolbox.com/water-thermal-properties-d_162.html [assessed $28^{th}$ March, 2016.]

[9]. The Engineering Toolbox, *"Emissivity Coefficients"*, The Engineering Toolbox, no date. http://www.engineeringtoolbox.com/emissivity-coefficients-d_447.html [assessed $28^{th}$ March 2016.]

[10]. KempCM. "*US patents no. 451384"*,$28^{th}$ April1891.(US PatentRecords).

[11]. University of Surrey, ENGM214, *"Process Modelling and Simulation – Coursework 2012-2013: Part 1."*

[12]. *Ruchi et al., 2013,''Recent advances in the solar water heating systems'': A review.*