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The Use of Solar Powered Water Heater for Female University Students in South East Nigeria

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ABSTRACT

This research work reports the results of monitoring the temperature variation in three experiment models of natural circulation PV powered water heater of capacities 40, 90 and 140 liters built at the female hostel of Nnamdi Azikiwe University, Awka, Nigeria. From the general observations, the temperature of the systems does rise from ambient to about 45°C by midday. The increase in temperature gets to about 75°C by 3pm local time and gradually drops to about 38°C by 6:30pm local time. It was observed that in early mornings between 6-7am, the peak period for hot water demand by students, the temperature is about 10°C below ambient temperature of a fresh-water from the municipal supplies. It is imperative, from the research findings for a design modification of the system which is suggested in this paper. Moreover, the paper reported cost comparison of PV water heater with electricity for equivalent hot water demands.

Keywords: *PV water heater, ambient temperature, temperature variation, electricity.*

1. INTRODUCTION

PV water heater is a device that converts solar energy to heat energy. This energy is stored as sensible heat in the water for a short period.

Previously very many research works have been done towards enhancing the storage of the energy from the sun as well as improving the solar energy collector efficiency. Sambo (2003) reported a collector efficiency of up to 75%. These studies however have their attendant drawbacks owing to the fact that the conversion of the generated thermal energy into useful energy is inefficient due to its thermodynamic limitations. This therefore makes the option of direct application of the produced heat available one as in domestic solar water heating.

This research work studies the suitability, cost effectiveness and environmental benefits of hot water needs of resident university female students in the areas of bathing and washing. Amidst the obvious limitations of the systems, that available heat content of the system still makes the system useful for the purposes. The use to which a solar water heater is put therefore depends on the output heat and necessarily on the efficiency of the collector, [Beghi, 2000]. Hot water for domestic use requires a temperature of up to 60°C. However, water for bathing and washing requires a lower temperature attainable in thermosyphon solar water heaters. Emphasis is laid on the use of this system around 6:00-7:00 hours and 18:00 hours, as these are periods when demand for hot water is at its peak.

2. THEORY

2.1 Collector Efficiency

Collector efficiency is a measure of the collector performance defined as the ratio of the of the useful energy gain during anytime period to the incident solar energy over the same period. It is expressed as;

$$\eta = \frac{Q_u}{A_c I_T} \quad \text{-----} \quad (1)$$

The useful energy gain of the collector is given by the Hottel-Whiller equation [Yeh, 2003].

$$Q_u = A_c F_R \left[I_T T_g \alpha_p - U_L (T_f - T_i) \right] \quad \text{----} \quad (2)$$

Combining equations 1 and 2, and simplifying, we have;

$$\eta = F_R \left[T_g \alpha_p - U_L (T_f - T_i)/I_T \right] \quad \text{----} \quad (3)$$

Collector useful energy delivery rate is also given in terms of fluid inlet and outlet temperatures as;

$$Q_u = A(T_f - T_i) \quad \text{-----} \quad (4)$$

Substituting (4) in (2) yields the effective collector area, A_C as;

$$A_c = \frac{m_c c_p (T_f - T_i)}{F_R \left[T_g \alpha_p I_T - U_L (T_f - T_i) \right]} \quad \text{-----} \quad (5)$$

The quantity, F_R called the heat removal factor relates the actual useful energy gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature. Its value is calculated from the equation:

$$F_R \frac{G c_p}{U_L} \left[1 \ \exp\left(\frac{-U_L F^1}{G c_p} \right) \right] \quad \text{-----} \quad (6)$$

Where G and F^1 are the mass flow rate per unit collector area and the collector efficiency factor respectively.

2.2 Thermal Storage

Heat is stored as sensible heat in the water contained in the storage tank. The sensible heat storage utilizes the heat capacity and the change in the temperature of the water during the process of charging or discharging of the system. These parameters are system. These parameters are related to give the sensible heat

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gained or lost in changing temperature from an initial value T_i to final value, T_f as;

$$\Delta Q = M_w C_p (T_f - T_i) \quad ----- \quad (7)$$

$$= \rho V c_p (T_f - T_i) \quad ----- \quad (8)$$

The high specific heat capacity and density of water makes it a good heat storage fluid as reflected in equation (8). Assuming the specific heat capacity of water and its density are 4200J/kg K and 1000kg/m^3 respectively, equation (8) reduces to

$$\Delta Q = \rho V c_p (T_f - T_i) \times 10^{-3}\,Joules \quad ----- \quad (9)$$

$$= \frac{\rho V c_p (T_f - T_i) \times 10^{-3}}{3.6 \times 10^6}\,\text{KWh} \quad ----- \quad (10)$$

Where V is the water storage volume in liters (10^{-3}m=1 liter). The collector-storage tank energy balance is expressed as;

$$M c_p dT = Q_u - Q_L - UAc(T_s - T_a) \quad ----- \quad (11)$$

Where Q_L is the rate of heat removal by the load and T_s is the water temperature in storage tank. The useful heat gain may also be given as;

$$Q_u = \rho V c_p \frac{dT}{dt} \quad ----- \quad (12)$$

In the above equation, V is the volume of water in the storage tank;

$T(\approx T_{in} + T_{out})/2$ is the average tank temperature and dT/dt is the mean rate of change of average water temperature.

2.3 Payback Period:

The payback period is defined as the time required recovering an initial investment cost in a solar system through savings from reduced or avoided energy cost of a conventional fuel. A solar system does not pay itself off by replacing the conventional heating system but only by displacing the fuel, which would have otherwise been used. Paybacks vary widely depending on the efficiency of the system and the conventional energy cost in the area. They are shorter in areas with high energy costs for a well- designed and installed system. The annual fuel saving and the net investment cost of the system gives the payback, Pb as;

$$P_b = \frac{Net\,system\,investment\,cost}{Annual\,fuel\,savings} \quad ----- \quad (13)$$

3. EXPERIMENT

The performance of three different thermosyphon solar water heaters developed at the female hostel of Nnamdi Azikwe University, Awka were determined. The systems labeled A, B and C had collector areas of 0.3, 1.46 and 2.1m^2 respectively. Further they were single-glazed, with absorber plate made of 1mm thick galvanized steel sheets and coated with dull-black commercial paint. The flat-plate absorbers were inclined at 6^0(the local latitude) to the horizontal and facing due south. The storage tanks of capacities 35, 84 and 150 liters respectively were using insulated steel pipes. The systems under discussion are passive thus had no pumps or control.

The systems were monitored over different climatic conditions covering on ambient temperature range of 25 to 36^{o}C and daily global solar radiation of 7 to 16MJm^{-2}day^{-1}. The measured data from the systems inclined the following: temperature of the heated water, the global solar radiation and the ambient temperature. These values were taken on hourly basis. The temperature was measured using simple mercury-in-glass thermometer. A solarimeter was used to measure the global solarimeter was used to measure the global solar radiation. 10liters of water per person per day was adopted as a standard volume for bathing at an average temperature of 42^{o}C as comfort level temperature. For the purpose of cost comparison, the temperature profile of 10liters of water heater using electric heater was monitored at five minutes interval. This was done for ten different water samples from the municipal supply and the average temperature values used for the analysis. A 100W electric ring boiler was used and the electrical energy consumption and cost were evaluated according to the Enugu Electricity Development company (EEDC) current rating of ₦12.000 per kilowatt-hour. Based on this, the payback period of the system was evaluated.

4. RESULTS AND DISCUSSION

Fig. 1 shows the hourly temperature profile of the solar water heater from 7.00hrs to 18. 00 hrs under different climatic conditions. Fig 1a, 1b and 1c reflect the temperature profile on a cloudy day, clear day and harmattan -impacted day respectively. Heater C on the clear day attained a maximum temperature of 78^{o}C which occurred between 13.00hrs and 15.00hrs. This value however dropped with time to about 51^{o}C at 18.00hrs. The other heaters maintained a similar trend at slightly lower temperature values at the time points as in heater C; a behavior traceable to the different collector areas of the water heaters among other design variables. The impact of the climatic conditions is also obvious in the performance of the system as expressed in fig 1b and 1c. The heat loses not withstanding; the output heat from the system on a clear day at 18.00hrs can still serve for bathing given the comfort level temperature value adopted.

Table 1:

Temperature ^{o}C			
Time (hrs)	**Heater A**	**Heater B**	**Heater C**
7	25	23	24.5
8	28	24	24.0
9	32	25	28.0
10	38	30	38.0
11	40	41.0	52.0

12	44	54.0	68.0
13	43	43.5	50.0
14	38	38.0	45.0
15	39	42	41.0
16	36	37	38.0
17	34	35	37
18	32	32	35

Cloudy day

Temperature ^oC			
Time (hrs)	**Heater A**	**Heater B**	**Heater C**
7	22	21	20
8	23	22	20
9	30	24	28
10	38	38	48
11	42	50	61
12	52	62	76
13	58	70	80
14	60	68	76
15	62	65	75
16	58	60	72
17	55	59	62
18	40	55	50

Clear day

Temperature ^oC			
Time (hrs)	**Heater A**	**Heater B**	**Heater C**
7	22	20	20
8	24	22	23
9	38	30	32
10	42	42	58
11	50	57	64
12	55	60	64
13	58	62	62
14	62	64	64
15	58	60	60
16	52	54	54
17	42	44	44
18	35	38	38

Cloudy day

Heat (KJ)			
Day	**Heater A**	**Heater B**	**Heater C**
1	460	580	500
2	380	460	420
3	340	500	420
4	340	420	460
5	460	420	500
6	640	760	670
7	460	550	500
8	540	580	540
9	580	580	580
10	220	320	280

The water temperature in the early hours of the morning is far below this comfort level and is as a result of heat loses in the system.

From the foregoing, further design efforts should be encouraged towards enhancing the water storage in the system. Going for a sufficiently large collector area and storage tank may yield enough heat for all time supply, however, it does not solve the problem of heat loss and is not cost-effective. Proper insulation of the system will help reduce heat loss. The back-flow effect during the night hours, which characteristics thermosyphon solar water heater, can be minimized if a control valve is introduced to make for one directional flow. Table 1 shows the temperature values of the water at 14:00hrs for 10:00litres and a mirco quality from the same source. The values for the two volumes as reflected in the table show a negligible variation and attests to the thermal stratification in the storage tank.

Heater	Mean Temp	Sample Temp
A	60	58
B	64	62
C	68	76
A	64	59
B	68	62
C	72	76
A	62	60
B	68	63
C	70	75

Heater	Mean Temp	Sample Temp
A	64	63
B	67	64
C	71	78
A	69	68
B	72	67
C	76	80
A	68	67
B	72	67
C	76	81
A	64	63
B	71	65
C	73	77

Heater	Mean Temp	Sample Temp
A	58	58
B	63	57
C	66	67
A	66	62
B	68	60
C	70	75
A	74	74
B	70	66
C	73	76

The use of solar water heater is environmentally friendly, as it does not pollute. When a solar water heater replaces an electricity water heater, the electricity displaced over 20years represents more than 50 tones of avoidable carbon dioxide emissions alone. Table 2 presents the performance profile of 150liter capacity solar water heater. It shows that even with collector efficiency as low as 4%, hot water up to 81^0C can be obtained from the system. On the part of the government, attractive environmental policies will promote the use of solar water heater among other renewable energy utilities.

Table 2: Overall Thermal Performance of heater

Time	T_{out}	T_{in}	$\bar{T}$	T_a	$d\bar{T}/dt$	$\rho V c_p$	Q_u	I_o	η
10	47	30	38.5	28	1.05	42,000	90.417	496.3	0.03
12	76	30	53.0	32	1.75	42,000	84.583	902.5	0.04
14	81	30	55.5	32	1.68	42,000	14.583	1010.8	0.006
16	68	30	49.0	31	1.13	42,000	37.917	587.7	0.03
18	48	30	39.0	31	0.44	42,000	58.330	70.6	0.36

5. CONCLUSION

From the analysis reported it was shown that the option of adopting solar water heaters to meet the water heating needs of the female university students is indeed viable. It is more cost effective, environmentally friendly and suitable in comparison with the utilization of electricity. However the use of thermosyphon solar water heater for bathing purpose has the limitation of not being able to deliver hot water in the early hours of the morning. This only indicates that for an all round hot water supply, an improved design input is necessary in the system. A separate well-insulated hot water storage tank can be integrated in the system. This however requires further research verification for improvement.

REFERENCES

[1] Beghi, G. (2000), Performance of solar energy converter: thermal collectors and photovoltaic cells, Holland, D. Reidel Pub. Co.

[2] Bello, M. Sambo, A. (1990), simulation studies on pipe spacings for collectors and tank sizes for solar water heaters, Nigerian Journal of solar energy, 9, 13-23.

[3] Enibe, S.O, (2002), Recent Advances in Renewable energy applications in Nigeria and their policy implications. Renewable Energy; 28; 1899-1914.

[4] Furbo S. and Shad L., (2003), Thermal advantage for solar heating systems with glass cover with antireflection surfaces. Solar Energy; 74; 513-523.

[5] Karl, W and Gunnar, T., (2003), Solar conversion under consideration of energy and entropy. Solar energy, 74; 525-528.

[6] Yeh, H., H_O, C. and Yeh, C., (2003) Effect of aspect ratio on the collector efficiency of sheet and tube solar water heaters with the consideration of hydraulic dissipated energy. Renewable energy, 28, 1575-1586.