Investigation of the Collection Efficiency of a Poultry Brooder Pen Heated with Solar Energy.

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ABSTRACT

A large-scale poultry chick brooding pen heated solely with a passive solar energy collection and storage system. The Trombe wall system was designed to make use of locally available building and energy storage materials. This study was undertaken to use computer simulation to determine the hourly variation of its efficiency. It was found that the hourly efficiency is generally minimum in the morning and maximum in the evening. Also the daily average efficiency of the system increases from 19.20% for the characteristic day in January to 50.35% in June and then decreases to 19.22% in December.

(Keywords: poultry brooding, passive solar, Trombe wall system, efficiency simulation)

INTRODUCTION

Poultry is an essential component of the agricultural sector in that it is a major source of protein of high biological value needed for optimum health of the citizenry. It also provides raw materials for some industries and promotes crop agriculture through provision of manure (Olaniyan 2004, Agbo 2004). But, there is a widening gap between demand and supply of poultry products. This is attributed to such factors as high-energy consumption cost as well as inefficient and inappropriate production technology employed the farmers. The technology includes the use of conventional sources of energy for the brooding of chicks. Common sources of electricity and fossil fuels used are not only non-renewable but also pollute the environment in which the birds are brooded (Okonkwo 1993a, Echiegu 1993, and Okonkwo and Aguwamba 1997).

The solution to this problem is to use a source of energy that is renewable, affordable, and environmentally friendly for poultry chick brooding, which is the most delicate period in poultry production. The energy from the Sun meets these requirements. Okpani (2002) found that if the irradiance on only 1 percent of the Earth's surface could be converted into useful energy with 10 percent efficiency, solar energy could provide the energy needs of all the people on Earth.

However, large-scale utilization of solar energy is fraught with problems due to the two main limitations of solar energy. The first limitation is the low flux density of solar radiation. This necessitates the use of large surfaces to collect solar energy. The second limitation is its intermittency. Solar energy has a regular daily and regular annual cycle, and is unavailable during periods of bad weather. These daily and seasonal variations in irradiance, exacerbated by variations due to weather, introduce special problems in storage and distribution of this energy which are entirely different from problems involved in the utilization of conventional energy sources as mentioned by Berg (1976) and Iqball (1983). These problems are solved by the use of a passive solar energy system, the Trombe wall system, to heat poultry brooding pens.

When applied to poultry brooding, the special merits of passive solar energy include the fact that (a) it is not affected by non-availability of electricity or frequent power failures (which are a very common feature in developing countries), (b) it creates a pollution-free environment conducive for poultry brooding, (c) it is free from fire hazards, (d) it produces birds of highly improved biological performance, and (e) the cost of energy for brooding is zero (beyond the capital cost of the system). Installed passive solar systems can last for decades without supplementary energy supply and with little operations or maintenance cost (Echiegu 1986, Okonkwo, 1993b).

The rational design of a solar thermal system requires knowledge of the dynamic interaction of all solar system components, namely solar collection, thermal storage fluid circulation, energy distribution, and controls. Although essential and valuable experience can be gained by testing solar systems in the field, the generalization of experimental results and their applications in other locations can best be handled by a modeling approach. A very useful and accurate type of modeling is computer simulation. Results from computer simulation of solar systems are very helpful for system design since they allow one to learn about complex interactions of a large number of variables in a short time whereas experiments are time consuming and costly.

The purpose of this paper is to use computer simulation to determine, for a whole year, the hour-by-hour efficiency of the designed poultry brooder pen heated by the Trombe wall system. But since only monthly mean daily values of meteorological data are available, calculations are performed for the representative or characteristic day of each month.

MATERIALS AND METHODS

Figure 1 shows the Trombe wall system heat transfer parameters. The temperatures designated are sky (T_{sk}), ambient (T_{am}), glass cover (T_{gc}), air gap (T_{ag}), Trombe wall front surface (T_{fs}), Trombe wall back surface(T_{bs}), brooding room(T_{rm}) and brooding room surfaces (T_{rs}).

The hourly efficiency η_p of the Trombe wall system is given by (Bansal and Gour, 1997; Knowles,1983):

$$\eta_H = \frac{Q_{ud}}{Q_{gc}} \qquad (1)$$

where Q_{ud} is the total useful energy delivered into the room during the hour and Q_{gc} is the solar energy incident on the glass cover during the same period. The total useful energy delivered to the room is given by:

$$Q_{ud} = Q_{ag} + Q_{tw} \qquad (2)$$

where Q_{ag} is the heat transferred into the room by the heated air in the air gap and Q_{tw} is the heat transferred by conduction through the Trombe wall and radiation from the wall's back surface to the room. Q_{tw} is given by:

$$Q_{tw} = h_{cr} A_{tw} \left(T_{bs} - T_{rm} \right) \qquad (3)$$

where h_{br} is the radiation heat transfer coefficient from the back surface of the wall to the brooder room. Q_{ag} is given by:

$$Q_{ag} = 2\dot{m} c_{pa} \left(T_{ag} - T_{rm} \right) \qquad (4)$$

where $\dot{m}$ is the mass flow rate, and c_{pa} is the specific heat capacity of air. $\dot{m}$ is given by (Bansal and Gour, 1997; Zrikem and Bilgen, 1987):

$$\dot{m} = \rho_a A_v F_r \sqrt{\frac{g D_v \left(T_{ag} - T_{rm} \right)}{T_{ag} + T_{rm}}} \qquad (5)$$

where ρ_a is the density of air, A_v is the upper vent area, F_r is Froude number ($0.6 \le F_r \le 0.8$), and D_v is the vertical distance between the upper and the lower vents.

The solar energy incident on the glass cover during an hour is given by:

$$Q_{gc} = A_{gc} I_{gc} \qquad (6)$$

where A_{gc} is the glass cover surface area and I_{gc} is the hourly total solar radiation on the glass cover.

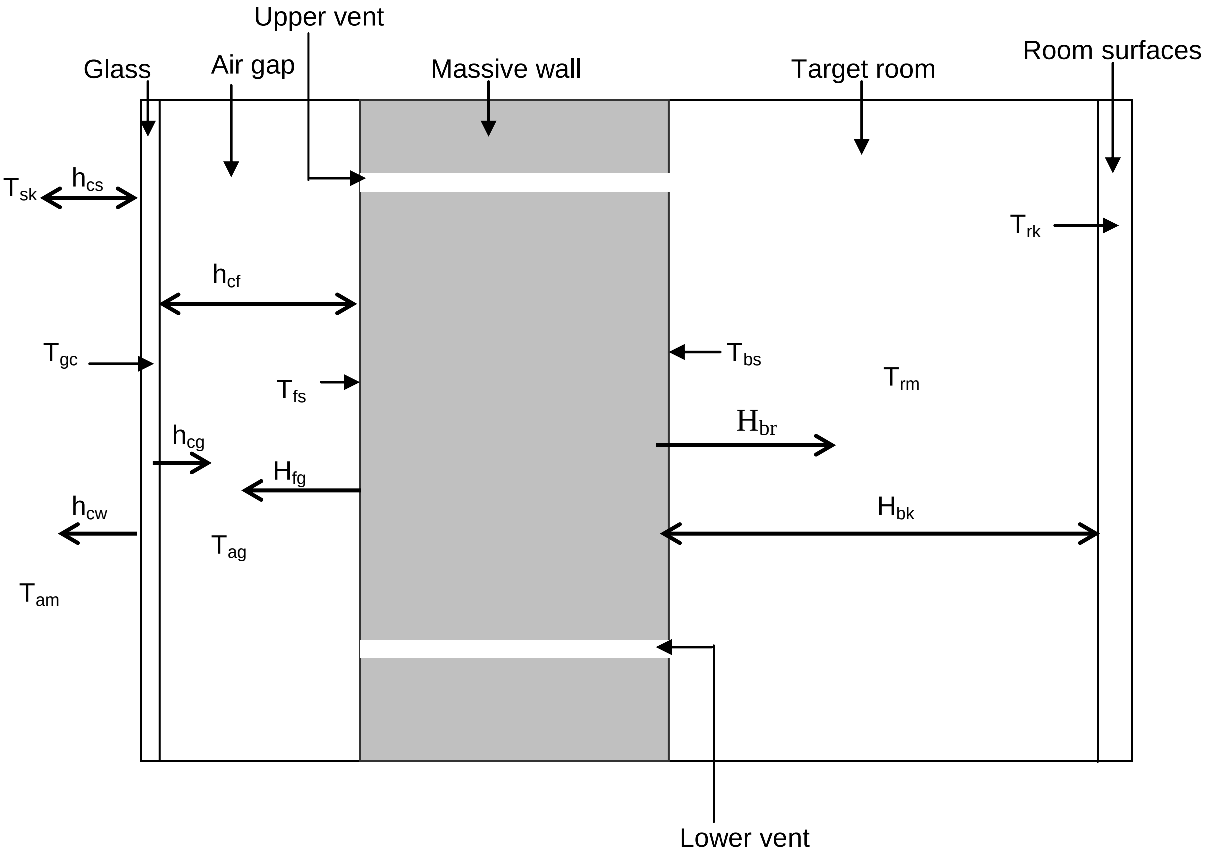

Figure 1: Trombe Wall System Heat Transfer Parameters.

The daily efficiency is given by:

$$\eta_D = \frac{\sum Q_{ud}}{\sum Q_{gc}} \tag{7}$$

The design parameters and the meteorological data used are shown in Tables 1 and 2, respectively.

A computer program is drawn to use the design parameters meteorological data for the representative day of the month as inputs and calculate the hourly and daily efficiencies of the system. The flow chart for the computer program is shown in Figure 2.

RESULTS AND DISCUSSION

The variation of the hourly solar radiation for the months of January to December is shown in Table 3. It can be observed that for a particular representative day of the month, solar radiation increases from a minimum in the morning to a maximum at noon and then decreases to a minimum again in the evening. This is expected since the monthly mean daily solar radiation on a horizontal surface is analyzed to give a sinusoidal hourly solar radiation on the Trombe wall (vertical) surface (Drew and Selvage 1979). For a particular hour, the month to month variation follows roughly the monthly mean daily values.

Figures 3, 4, 5, and 6 show the variation of the hourly efficiency for the characteristic day in the months of January to March, April to June, July to September, and October to December, respectively. It can be seen that for any representative day of the month the hourly efficiency increases continuously from 9.00 to 16.00.

Table 1: Design Parameters.

Window area	0.455 m^2
Trombe wall surface area	6.30 m^2
Trombe wall height	1.40 m
Trombe wall thickness	0.30 m
Trombe wall specific heat capacity	880 Jkg^{-1}K^{-1}
Trombe wall density	2720 kg m^{-3}
Trombe wall thermal conductivity	1.41 Wm^{-1}K^{-1}
Trombe wall surface outer coating absorbance	0.87
Trombe wall outer surface coating IR emittance	0.09
Trombe wall inner surface IR emittance	0.88
Trombe wall upper vent area	0.096 m^2
Distance between upper and lower vents	1.155 m
Air gap width	0.050 m
Glass cover short wave absorbance	0.065
Glass cover IR emittance	0.941
Glass cover short wave transmittance	0.896
Ground reflectance	0.35
Air viscosity at 300K	1.983 x 10^{-5} kgm^{-1}
Air density at 300K	1.7774 kg $^{-3}$
Air specific heat capacity at constant pressure	1005.7 Jkg^{-1}K^{-1}
Air conductivity	0.026 Wm^{-1}K^{-1}
Space interval	0.02 m
Time interval	3600 s
Tilt angle	90º
Latitude(Enugu)	7.55º N

Table 2: Meteorological Data.

Month	Monthly Mean Daily Solar Radiation on a Horizontal Surface (MJ m^{-2} day^{-1})	Monthly mean wind velocity (ms^{-1})	Monthly Mean Daily Maximum Temperatures (º C)	Monthly Mean Daily Minimum Temperatures (º C)	Monthly Mean Daily Average Temperatures (º C)	Characteristic Day Number for the Month
JAN	16.0992	2.81	34.5	24.6	29	17
FEB	17.6508	3.03	36.7	28.8	31.8	45
MAR	18.0468	3.37	35.1	26.6	31.7	74
APR	18.9316	3.37	34.6	27.2	30.9	105
MAY	17.9316	3.05	33.8	25.9	29.6	135
JUN	15.5952	2.95	32.7	25.3	29	161
JUL	14.2344	3.12	30.9	24.9	27.8	199
AUG	14.3748	3.28	30	24.4	27.3	239
SEP	15.2424	3.75	31.3	24.4	27.9	261
OCT	14.58	2.5	31.8	24.6	28.3	292
NOV	17.298	2.39	33.8	26	29.8	322
DEC	16.4556	2.87	34	25.3	29.6	347

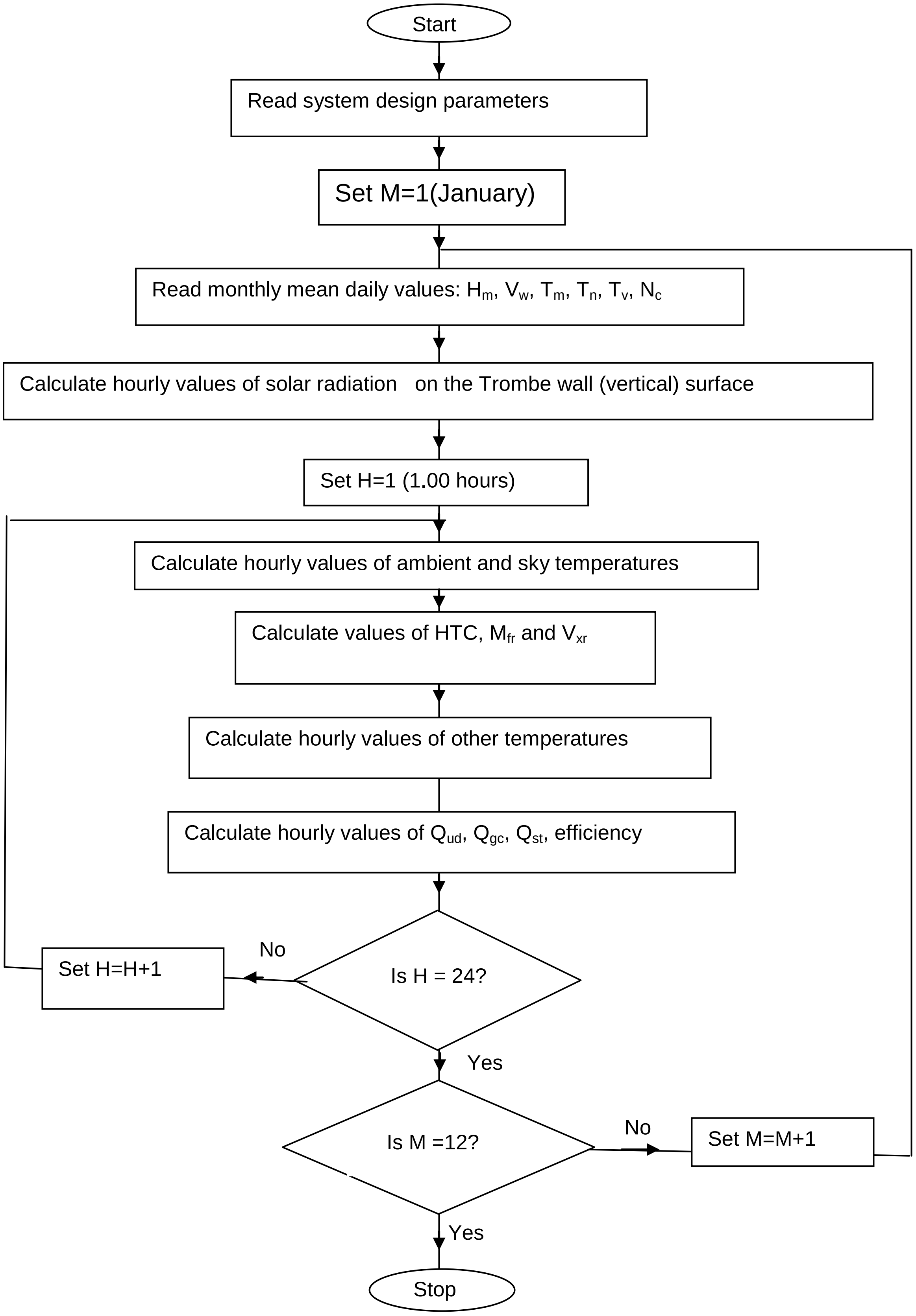

Figure 2: Flow Chart for the Computer Program.

Table 3: Hourly Solar Radiation ($Jm^{-2}h^{-1}$) on the Glass Cover for the Characteristic Day in the Months of January through December.

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
07.00	4.60E+5	4.16E+5	3.08E+5	1.79E+5	7.68E+4	5.36E+4	8.43E+4	1.47E+5	2.37E+5	3.21E+5	4.85E+5	5.04E+5
08.00	8.90E+5	8.03E+5	5.94E+5	3.46E+5	1.48E+5	1.04E+5	1.63E+5	2.83E+5	4.59E+5	6.19E+5	9.36E+5	9.73E+5
09.00	1.26E+6	1.14E+6	8.41E+5	4.89E+5	2.10E+5	1.47E+5	2.30E+5	4.00E+5	6.49E+5	8.76E+5	1.32E+6	1.38E+6
10.00	1.54E+6	1.39E+6	1.03E+6	5.99E+5	2.57E+5	1.79E+5	2.82E+5	4.90E+5	7.94E+5	1.07E+6	1.62E+6	1.68E+6
11.00	1.72E+6	1.55E+6	1.15E+6	6.68E+5	2.87E+5	2.00E+5	3.15E+5	5.47E+5	8.86E+5	1.20E+6	1.81E+6	1.88E+6
12.00	1.78E+6	1.61E+6	1.19E+6	6.92E+5	2.97E+5	2.07E+5	3.26E+5	5.66E+5	9.17E+5	1.24E+6	1.87E+6	1.95E+6
13.00	1.72E+6	1.55E+6	1.15E+6	6.68E+5	2.87E+5	2.00E+5	3.15E+5	5.47E+5	8.86E+5	1.20E+6	1.81E+6	1.88E+6

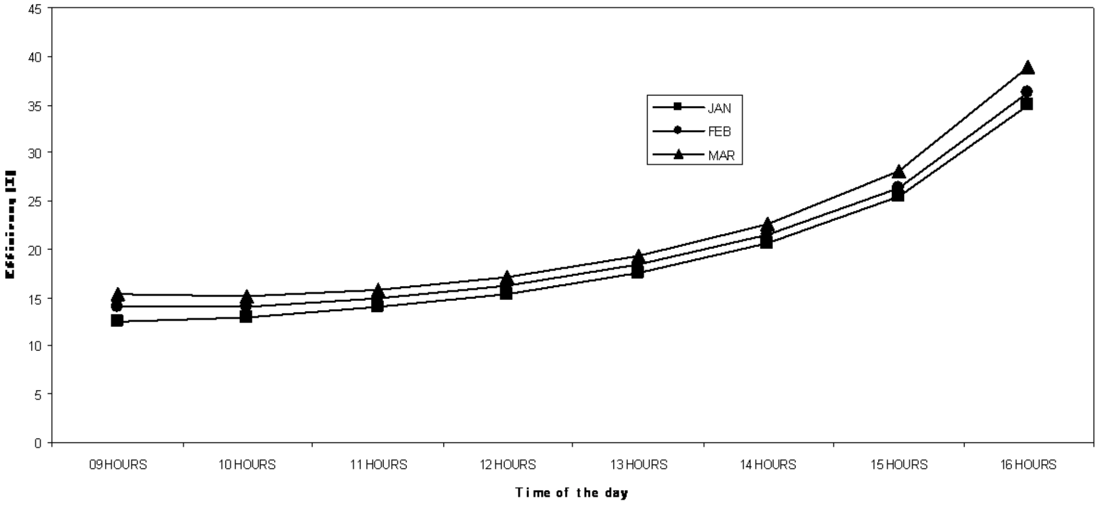

Figure 3: Variation of the Hourly Efficiency for the Characteristic Day in the Months of January-March.

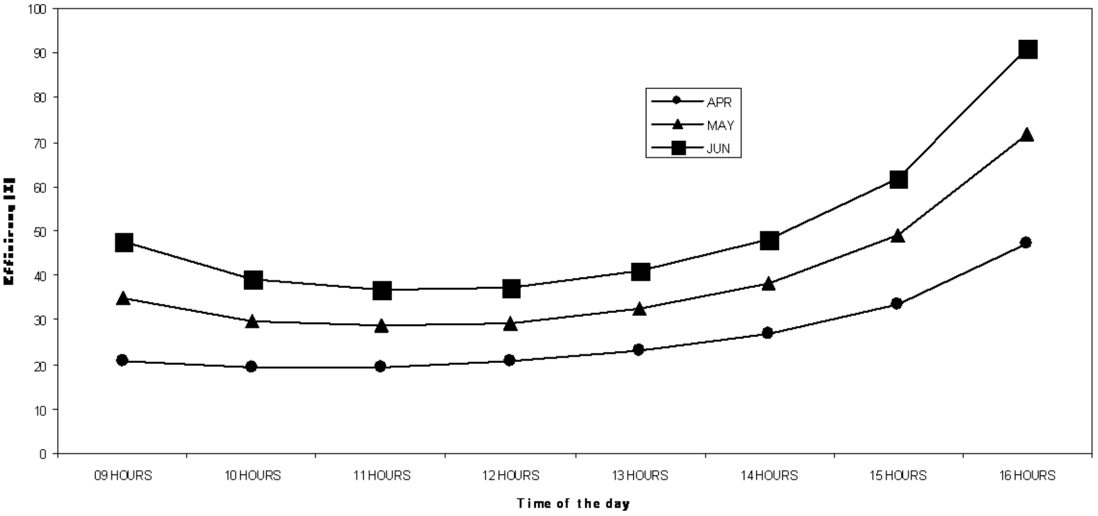

Figure 4: Variation of the Hourly Efficiency for the Characteristic Day in the Months of April-June.

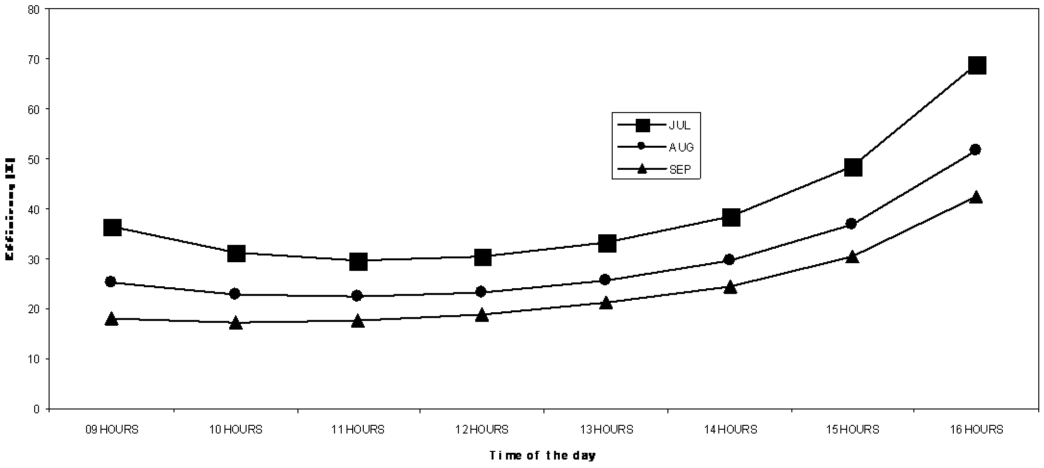

Figure 5: Variation of the Hourly Efficiency for the Characteristic Day in the Months of July-September.

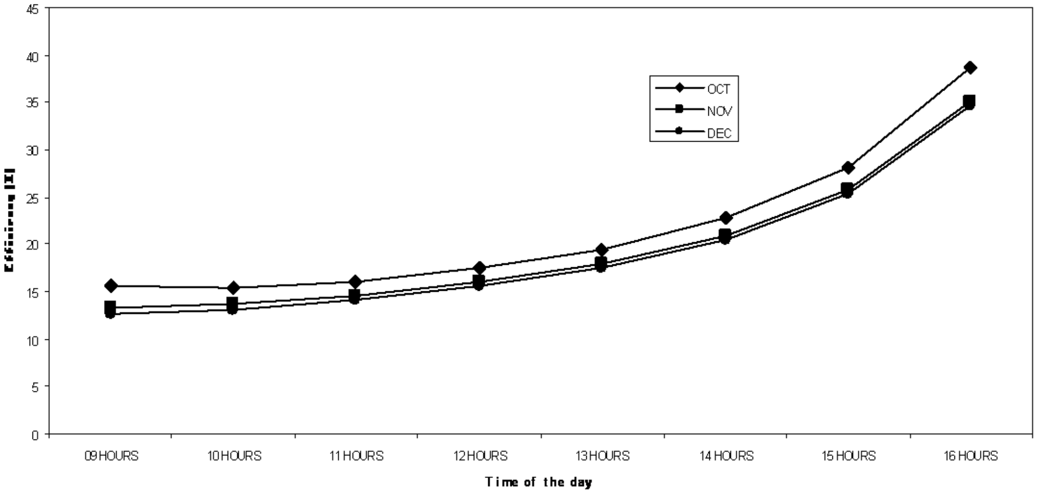

Figure 6: Variation of the Hourly Efficiency for the Characteristic Day in the Months of October-December.

Figure 7 shows the variation of daily efficiency for the months of January to December. It can be observed that the daily average efficiency increases from 19.20% in January to 50.35% in June and then decreases to 19.22% in December.

Comparing the daily and hourly variations of efficiency with variation of solar radiation in Table 3 we can see that generally the periods that have high solar radiation are associated with low efficiency and vice versa. This trend is the opposite of what is obtainable with ordinary solar collectors (Kreith and Kreider, 1978). But the Trombe wall system is not an ordinary solar collector because it incorporates energy storage capacity. Hence, for the periods when solar radiation (the input energy) is low, the total energy transmitted to the brooder room (the output energy) a large part of which is the stored energy, is relatively high. Hence the efficiency is relatively high. This is in harmony with the results obtained by Pine (1997). The comparatively high efficiency of the system indicates that the project is worth the effort and finance needed to construct it. Hence it is highly recommended.

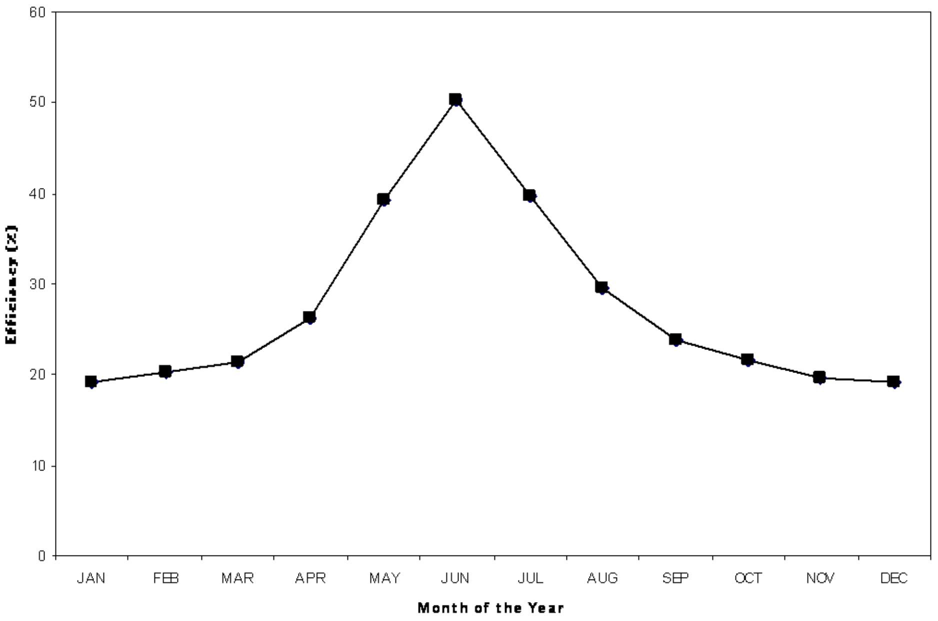

Figure 7: Variation of Daily Efficiency for the Characteristic Day in the Months of January-December.

CONCLUSION

These findings are in close agreement with the values obtained by other scholars. Examples include Echiegu (1986) and Okonkwo (1993a) to name but two. The results of this study show that a high efficiency in the transmission of solar energy from the glass surface of the Trombe wall system to the brooder room can be obtained. This fact has great socio-economic consequences as noted by Okonkwo and Aguwamba(1997) in view of the importance of poultry.

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REFERENCES

1. Agbo, A.D. 2004. ”Venturing into Poultry Business on Micro–Level”. *National Agriculture Focus*. 1(5): 1.
2. Bansal, N.K. and Gour, B.C. 1997. ”Application of U and g values for Sizing Passive Heating Concepts”. *Solar Energy*. 57(5):361-372.
3. Berg, C.A. 1976. “Potential for Energy Conservation in Industry”. *Annual Review of Energy*. 1:519 – 534.
4. Drew, M.S. and Selvage, R.B.C. 1979. “Solar Heating System Performance Estimation Using Sinusodial Inputs”. *Solar Energy*. 23(5):435-442.
5. Echiegu, E.A. 1986. “The Development and Testing of a Passive Solar Heated Poultry Chick Brooder”. M. Eng. Dissertation. Department of Agricultural Engineering, University of Nigeria, Nsukka, Nigeria.
6. Iqball, M. 1983. *Introduction to Solar Radiation*. Academy Press: New York, NY.
7. Kreith, F. and Kreider, J.F. 1978. *Principles of Solar Engineering*. McGraw-Hill: New York, NY.
8. Olaniyan, T. 2004. “Heat Stress in Broilers”. *National Agriculture Focus*, 1(5):8.

9. Okonkwo, W.I. 1993a. "Design and Construction of a Medium Scale Passive Solar Energy Chick Brooder". M. Eng Dissertation. Department of Agricultural Engineering, University of Nigeria, Nsukka, Nigeria,

10. Okonkwo, W.I. 1993b. "Performance Evaluation of a Medium Scale Passive Solar Energy Brooding System". *Nigerian Journal of Solar Energy*. 12:51–60.

11. Okonkwo, W.I. and Aguwamba, J.C. 1997. "Socio-Economic Impact of Solar Energy Brooding System". *Proceedings of the International Conference on Power Systems Operation and Planning*, 276–280.

12. Okpani, P.E. 2002. "Aerosol Mass Loading at a Sub-Saharan Site", M.Sc. Dissertation. Department. of Physics, Usmanu Danfodiyo University, Sokoto, Nigeria.

13. Rogers, C.F.C. and Mayhew, Y.R. 1980. *Engineering Thermodynamics- Work and Heat Transfer*. Longman Group Ltd.: London, UK.

14. Shtrakov, S. and Stoilov, S. 2005. "A. New Approach for Finite Difference Method for Thermal Analysis of Passive Solar System". Seminar, Department of Computer Systems, S-W-University: Blagoevgrad, Bulgaria.

15. Suri, R.K., Ayyash, S., and Al-madani, K. 1983. "Performance Analysis of Solar Space Heating System". *Solar Energy*. 31(2):145-151.

16. Zrikem, Z and Bilgen, F. 1987. "Theoretical Study of a Composite Trombe-Michael Wall Solar Collector System", *Solar Energy*. 39(5): 409-419.

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