Determination of Hourly Temperature Variation in the Elements of a Poultry Brooder Pen Heated by Trombe Wall.

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ABSTRACT

This study was undertaken to use computer simulation to determine the hourly temperature variation in the elements of a large scale poultry chick brooder pen heated solely by the Trombe wall system. The elements include the glass cover, the air gap, the Trombe wall surfaces, the brooder room, and the room surfaces. It was found that the average temperature of the brooder room ranges from 29.94ºC to 35.86ºC. The Trombe wall back surface temperature was almost constant at 40.05ºC. Hence an optimum brooding temperature requirement of between 25ºC and 32ºC (depending on the age of the bird) was easily met.

(Keywords: poultry production, chick brooder, Trombe wall system, computer simulation, temperature variation)

INTRODUCTION

There is a growing need for protein to feed the rapidly expanding population in developing countries. This has caused farmers and scientists to pay more attention to poultry production, particularly chickens which are raised for both meat and eggs (Olaniyan, 2004a; Agbo, 2004; Olaniyan, 2004b). But, the current trend in the prices of the two products – chicken and eggs – indicates that there is a widening gap between demand and supply. This is attributed to such factors as high-energy consumption cost as well as inefficient and inappropriate production technology employed by the farmers. This technology includes the use of conventional sources of energy for the brooding of the chicks.

The sources are electricity and fossil fuels, both of which are not only non-renewable sources of energy, but also pollute the environment in which the birds are brooded (Okonkwo, 1993; Okonkwo and Aguwamba, 1997).

The only 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.

The sun is an inexhaustible source of energy having at present enough capacity to continue to emit into space 3.86×10^{23}J of energy every second for the next four to five billion years (Morrison et al.,1995; Nichelson, 1999; Morgan, 1962). Of this total, only a tiny fraction, 1.7×10^{17} J/s, is received by the Earth and its atmosphere. A world population of 10 billion with a total power need per person of 10KW would require about 10^{14}W. It is thus apparent 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 (Igball, 1983).

However, large-scale utilization of solar energy is fraught with problems due to 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 cycle, a regular annual cycle and is unavailable during period 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 pen. When applied to poultry brooding, the special merits of the passive solar energy include the fact that (a) it is not affected by non-availability of electricity or frequent power failures (which are 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. Installed passive solar system can last for decades without supplementary energy supply and with little maintenance cost.

The rational design of a solar thermal system requires a 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 modeling is computer simulation. Results from computer simulation of solar systems are very helpful for system design since they allow one to learn about a complex interactions of a large number of variables in a short time whereas experiments are time consuming and costly(Kreith and Kreider,1978).

The purpose of this paper is to use computer simulation to determine for a whole year the hour by hour temperature of the elements of the Trombe wall heated poultry brooder pen designed by Okpani (2009). But since only monthly mean daily values of meteorological data are available, calculations are performed for an average day each month. A computer program is drawn to read the meteorological data for the representative day of the month and calculate the hourly temperature at designated parts of the system using the design parameters.

MATERIALS AND METHODS

For the purpose of thermal analysis, the system is depicted as shown in Figure 1. The design parameters and the meteorological data used are shown in Tables 1 and 2, respectively, and the flow chart is shown in Figure 2.

The modeling equations are derived from consideration of heat and mass balances for each component element of the system.

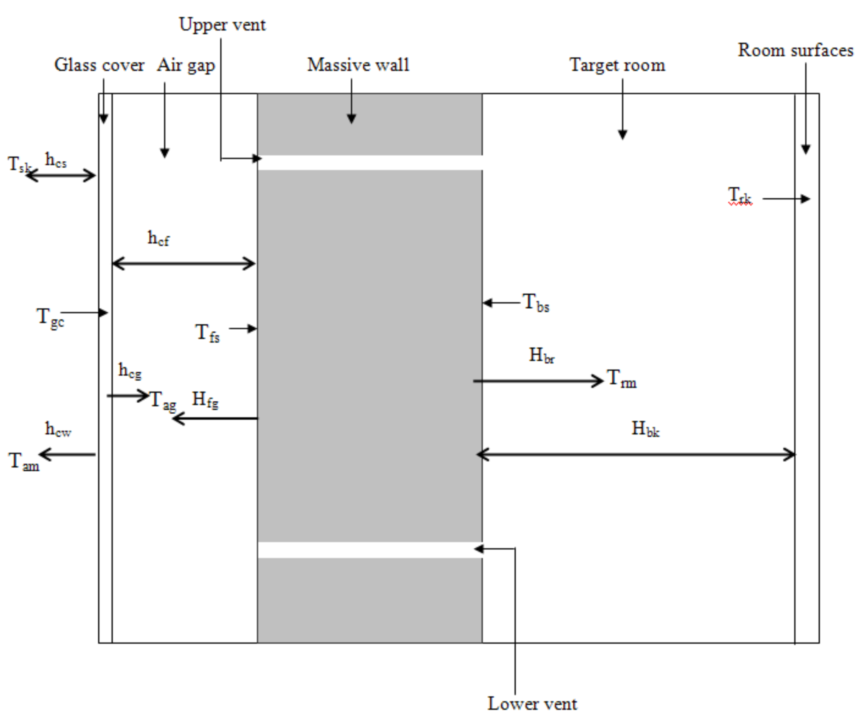

Figure 1: Trombe Wall System Heat Transfer Parameters.

Table 1: Design Parameters

Description	Value
Room floor area	11.925 m^2
Room walls area	23.520 m^2
Room roof area	11.925 m^2
Room total surface area	47.370 m^2
Floor U-value	0.72 $Wm^{-2}K^{-1}$
Wall U-value	2.92 $Wm^{-2}K^{-1}$
Roof U-value	0.115 $Wm^{-2}K^{-1}$
Room mean U-value	1.660 $Wm^{-2}K^{-1}$
Door crack length	4.50 m
Window crack length	2.70 m
Door area	1.190 m^2
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 coating absorbance	0.870
Trombe wall outer surface IR emittance	0.090
Trombe wall inner surface IR emittance	0.880
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	0.350
Air viscosity at 300K	1.983×10^{-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)	6.47º N

Table 2: Meteorological Data.

Month	HM	VW	TX	TN	TV	NC
JAN	16.0992	2.81	34.5	24.6	29.0	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	29.0	161
JUL	14.2344	3.12	30.9	24.9	27.8	199
AUG	14.3748	3.28	30.0	24.4	27.3	239
SEP	15.2424	3.75	31.3	24.4	27.9	261
OCT	14.5800	2.50	31.8	24.6	28.3	292
NOV	17.298	2.39	33.8	26.0	29.8	322
DEC	16.4556	2.87	34.0	25.3	29.6	347

KEY: HM=Monthly mean daily solar radiation on a horizontal surface (MJ m^{-2} day^{-1}) from *Renewable Energy for Rural Industrialization and Development in Nigeria,* Abuja: UNIDO (Dec. 2003); VW=Monthly mean wind velocity (ms^{-1}) from *Renewable Energy for Rural Industrialization and Development in Nigeria,* Abuja: UNIDO (Dec. 2003); TX=Monthly mean daily maximum temperatures (ºC) from the records of the Nigerian Meteorological Agency, South Eastern Zone, Akanu Ibiam International Airport, Enugu.; TN=Monthly mean daily minimum temperatures (ºC) from the records of the Nigerian Meteorological Agency, South Eastern Zone, Akanu Ibiam International Airport, Enugu.; TV=Monthly mean daily average temperatures (ºC) from the records of the Nigerian Meteorological Agency, South Eastern Zone, Akanu Ibiam International Airport, Enugu.; NC = Characteristic day number for the month.

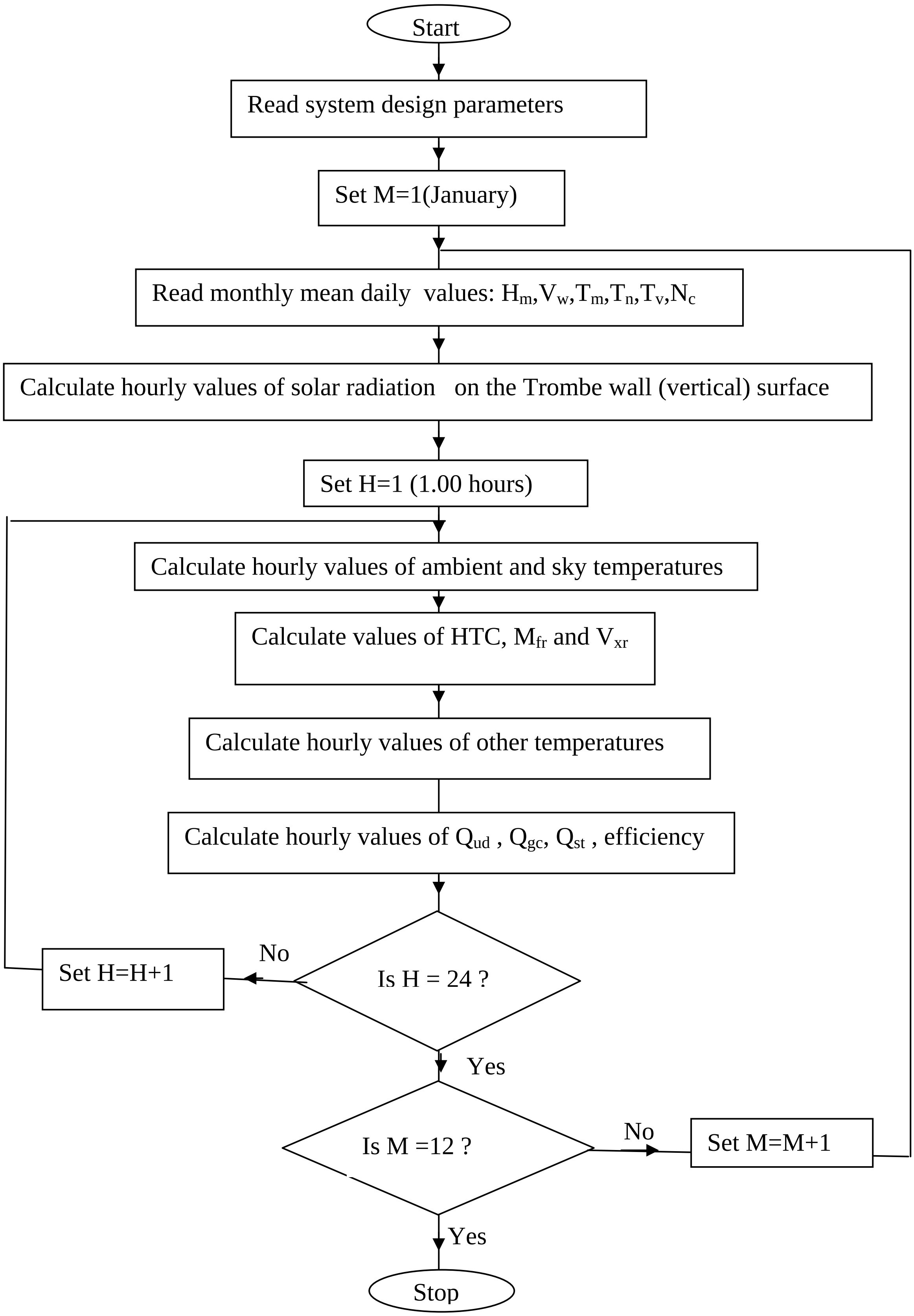

Figure 2: Flow Chart for the Computer Program.

The Glass Cover: The glass cover gains heat by absorption of some of the incident solar radiation and through radiation from the Trombe wall front surface. It loses heat through radiation to the sky and convection to ambient and the air gap. The energy balance equations is given by (Shtrakov and Stoilov, 2005; Ong ,1995a; Ong, 1995b):

$$\alpha_g I_{gc} + h_{cf}\left(T_{fs} - T_{gc}\right) = h_{cw}\left(T_{gc} - T_{am}\right) + h_{cg}\left(T_{gc} - T_{ag}\right) + h_{cs}\left(T_{gc} - T_{sk}\right) \quad \textbf{(1)}$$

where α_g is the absorbance of the glass cover I_{gc} is the hourly total radiation on the glass cover, h_{cf} is the radiation heat transfer coefficient between the glass cover and the Trombe wall front surface, h_{cw} is the wind convection heat transfer coefficient from the glass cover, h_{cg} is the convection heat transfer coefficient from the glass cover to the air gap, h_{cs} is the radiation heat transfer coefficient between the glass cover and the sky, T_{fs} is the Trombe wall front surface temperature, T_{gc} is the glass cover temperature, T_{am} is the ambient temperature T_{ag} is the air gap average temperature and. T_{sk} is the sky temperature.

Air Gap Thermo Circulation: The air gap gains heat through convection from the glass cover and the Trombe wall front surface. It loses heat by exchanging hot air with cold air from the room. The energy balance equation is given by (Bansal and Gour, 1997; Bilgen and Chaaban,1982):

$$\frac{\dot{m} c_{pa} T_{ag} - T_{rm}}{A_{tw}} = h_{cg}\left(T_{gc} - T_{ag}\right) + h_{fg}\left(T_{fs} - T_{ag}\right) \quad \textbf{(2)}$$

where $\dot{m}$ is the mass flow rate of the air in the air gap, c_{pa} is the specific heat capacity of air at constant pressure, h_{fg} is the convection heat transfer coefficient from the Trombe wall outer surface to the air in the air gap, T_{rm} is the brooder room temperature and A_{tw} is the surface area of the Trombe wall.

Trombe Wall Bulk Material: At any point x from the Trombe wall front surface heat transfer is by conduction according to Fourier's law. This is given by (Shtrakov and Stoilov, 2005; Zrikem and Bilgen, 1987):

$$\alpha \frac{\partial^2 T_w}{\partial x^2} = \frac{\partial T_w}{\partial t} \quad \textbf{(3)}$$

where $\alpha = k_w/\rho_w c_w$ is the thermal diffusivity, T_w is the temperature of the Trombe wall at a point x from the outer surface and at the time t, k_w, ρ_w and c_w are respectively the thermal conductivity, density, and specific heat capacity of the Trombe wall material.

Trombe Wall Front Surface: The Trombe wall front surface gains heat by absorption of the incident solar radiation. It loses heat through conduction into the bulk material, radiation to the glass cover and convection to the air gap. The energy balance equation is given by (Shtrakov and Stoilov, 2005; Rogers and Mayhew, 1980):

$$-k_w\left(\frac{\partial T_w}{\partial x}\right)_{x=1} = I_w + h_{cf}\left(T_{gc} - T_{fs}\right) + h_{fg}\left(T_{ag} - T_{fs}\right) \quad \textbf{(4)}$$

where I_w is the solar radiation absorbed by the Trombe wall.

Trombe Wall Back Surface: The Trombe wall back surface gains heat by conduction from the bulk material. It loses heat though convection to the room and radiation to the surfaces of the room. The energy balance equation is given by (Shtrakov and Stoilov, 2005; Rogers and Mayhew, 1980):

$$-k_w\left(\frac{\partial T_w}{\partial x}\right)_{x=L} = h_{br}\left(T_{rm} - T_{bs}\right) + h_{bk}\left(T_{rk} - T_{bs}\right) \quad \textbf{(5)}$$

where h_{br} is the radiation heat transfer coefficient from the back surface of the wall to the brooder room, h_{bk} is the radiation heat transfer coefficient between the Trombe wall back surface and the surfaces of the room, T_{bs} is the Trombe wall back surface temperature, T_{rm} is the brooder room temperature, T_{rk} is the average temperature of the room's surfaces.

Target Room: The total energy input to the room is the sum of the energy conducted through the wall, Q_{tw} and that transferred into the room through the upper vent by natural convection of air in the air gap, Q_{ag}. The heat losses consist of the transmission heat loss, Q_{tl} and the ventilation loss, Q_{vl}. The energy balance equation is given by (Bansal and Gour, 1997):

$$Q_{tw} + Q_{ag} = Q_{tl} + Q_{vl} \quad \textbf{(6)}$$

Q_{tw}, Q_{ag}, Q_{tl}, and Q_{vl} are given respectively by:

$$Q_{tw} = h_{cr} A_{tw} \left(T_{bs} - T_{rm} \right) \quad \textbf{(7)}$$

$$Q_{ag} = 2\dot{m} c_{pa} \left(T_{ag} - T_{rm} \right) \quad \textbf{(8)}$$

$$Q_{tl} = \sum U_i A_i \left(T_{rk} - T_{am} \right) \quad \textbf{(9)}$$

$$Q_{vl} = V_x \rho_a c_{pa} \left(T_{rm} - T_{am} \right) \quad \textbf{(10)}$$

where U_i is the U value of the room surface i and A_i is the corresponding area, V_{xr} is the volumetric exchange rate of the air flow, ρ_a is the density of air and c_{pa} is the specific heat capacity of air.

The air exchange rate between the room and the environment include that which occurs actively through opened windows and doors and passively by infiltration through pores and cracks.

The active air exchange is used to manually regulate the temperature of the brooder room by opening the window for a period of time so that some of the hot air inside can be exchanged for cooler air from outside. The time t the window is left open is derived from a consideration heat balance between the exchanging fluids and is given by:

$$t = \frac{V_{rm} \left(T_{ra} - T_{rd} \right)}{V_w A_{wd} \left(T_{rd} - T_{am} \right)} \quad \textbf{(11)}$$

where V_{rm} is the volume of air in the room, V_w is the velocity the air entering the room, A_{wd} is the area of the window, T_{ra} is the actual room temperature and T_{rd} is the desired room temperature.

For passive air exchange because of infiltration the American Society of Heating Refrigeration and Air conditioning Engineers (ASHARE) shows that the volume exchange rate in m^3s^{-1} for a second level fitting is given by (Igbal, 1983).

$$V_{xr} = \frac{(2L_{cd} + L_{cw})(a_{wd} + b_{wd} \rho_a V_w / 4)}{3600} \quad \textbf{(12)}$$

where L_{cd} is the door crack length, L_{cw} is the window crack length, ρ_a is the density of air, V_w is the velocity of wind and the infiltration function constants a_{wd} and b_{wd} are respectively, 1.3 $m^2 s^{-1}$ and 0.049 $m^4 s kg^{-1}$.

A computer program is drawn to read the meteorological data for the representative day of the month and calculate the hourly temperature at designated parts of the system using the design parameters and the modeling equations. The flow chart for the computer program is shown above in Figure 2.

RESULTS AND DISCUSSION

Figures 3 to 14 show the hourly temperatures of the ambient (TA), sky (TS), glass cover (TC), air gap (TG), Trombe wall front surface (TF), Trombe wall back surface (TB) and brooder room (TR) for the characteristic day in the months of January to December.

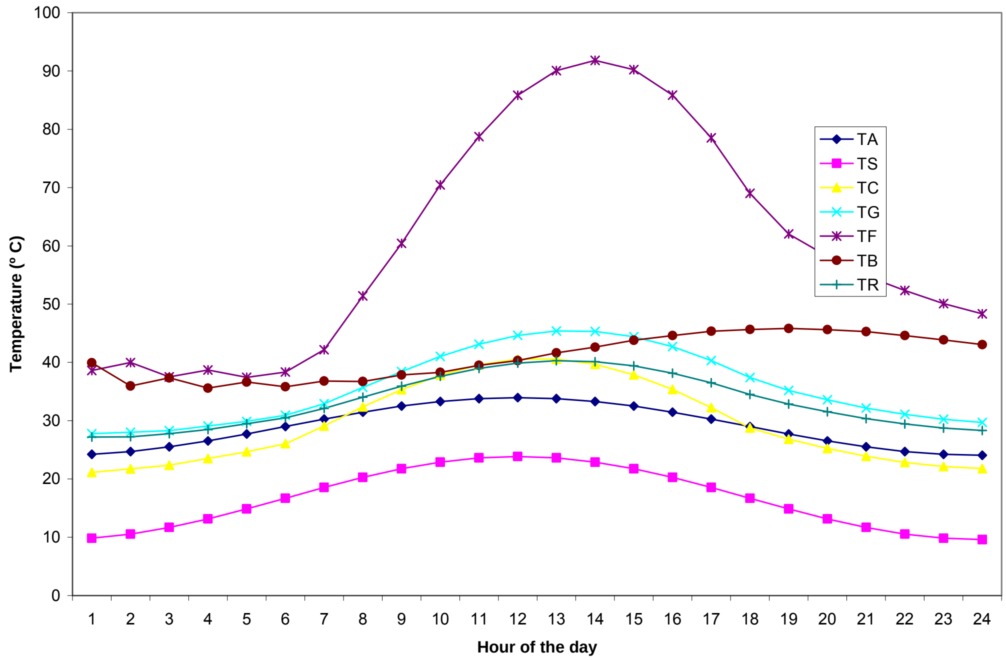

Fig. 3: Hourly Temperature (° C) Data for the Characteristic Day in the Month of January

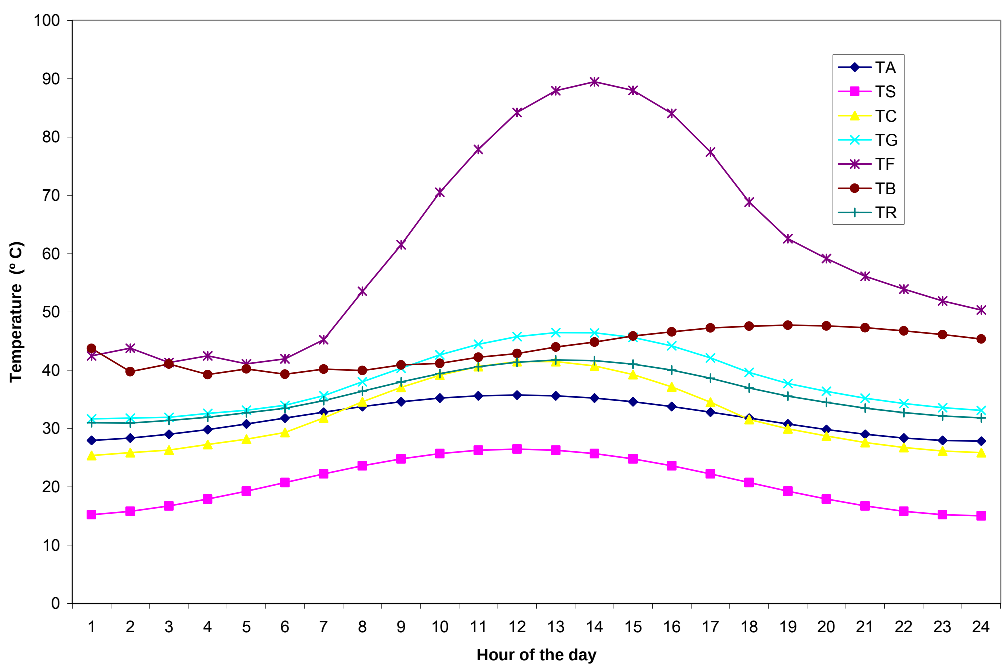

Fig. 4: Hourly Temperature (° C)Data for the Characteristic Day in the Month of February

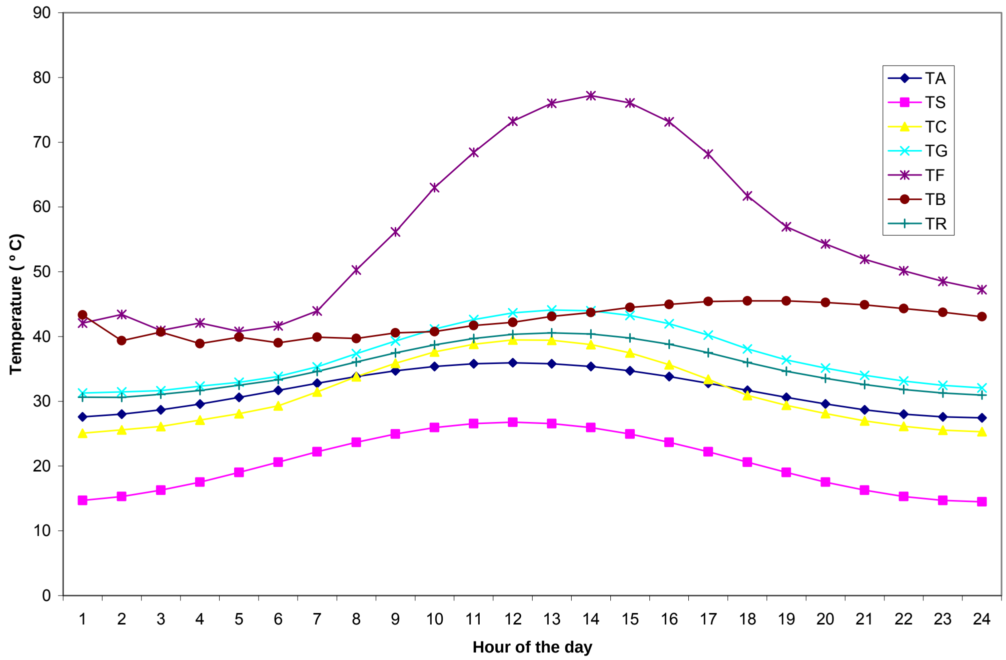

Fig. 5: Hourly Temperature (° C) Data for the Characteristic Day in the Month of March

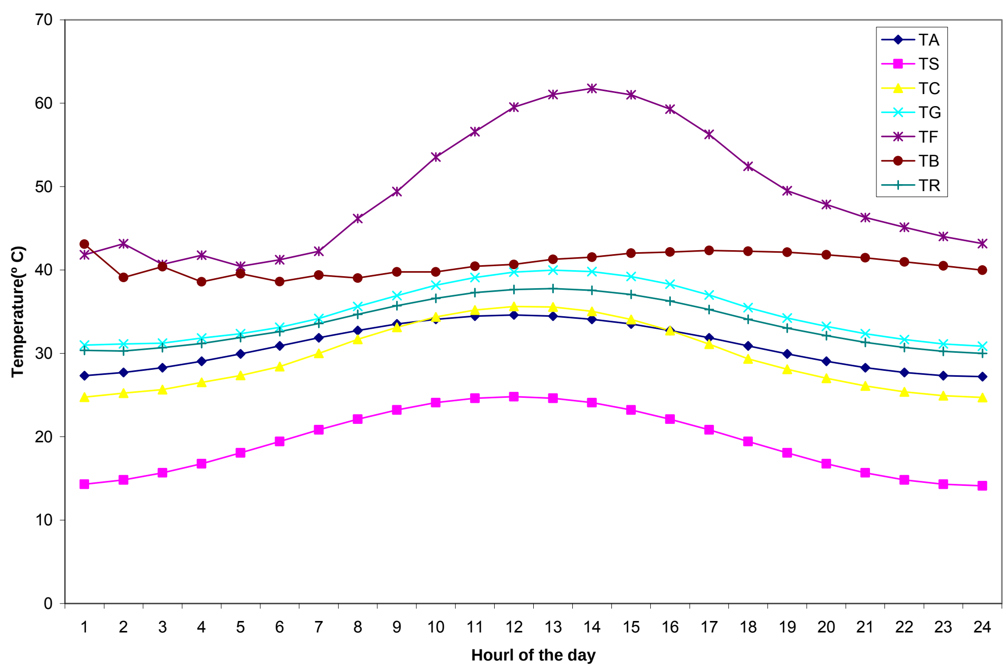

Fig 6: Hourly Temperature(º C) Data for the Characteristic Day in the Month of April

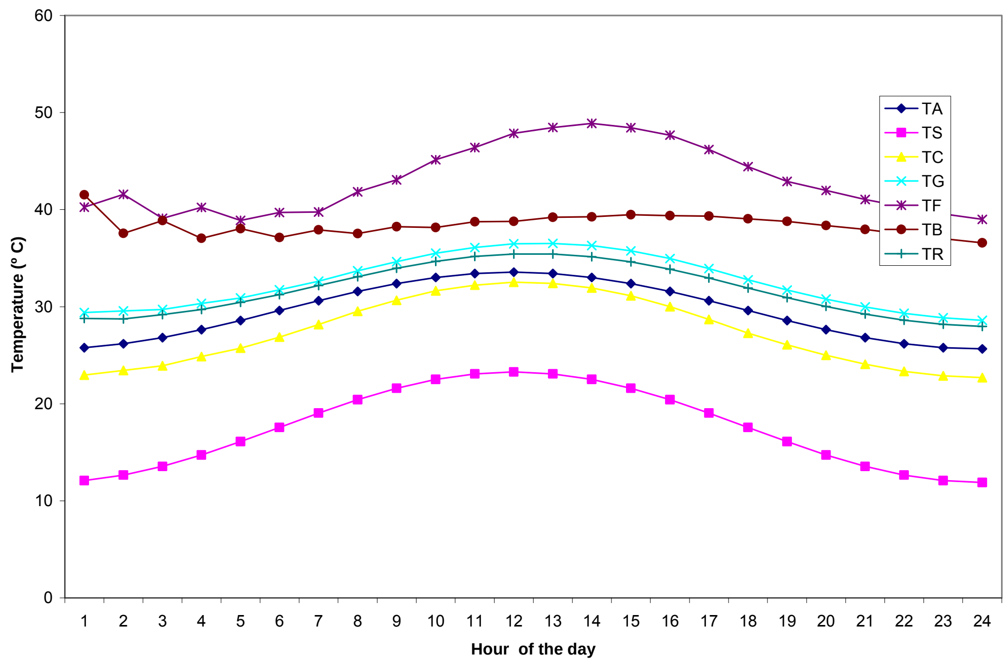

Fig. 7: Hourly Temperature (º C)Data for the Characteristic Day in the Month of May

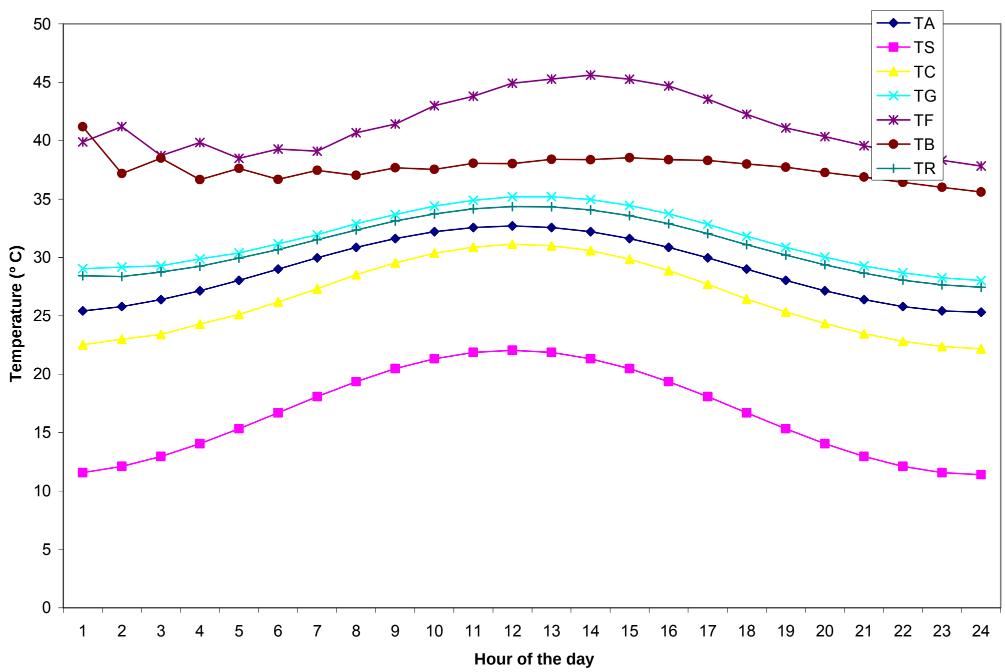

Fig. 8: Hourly Temperature (º C) Data for the Characteristic Day in the Month of June

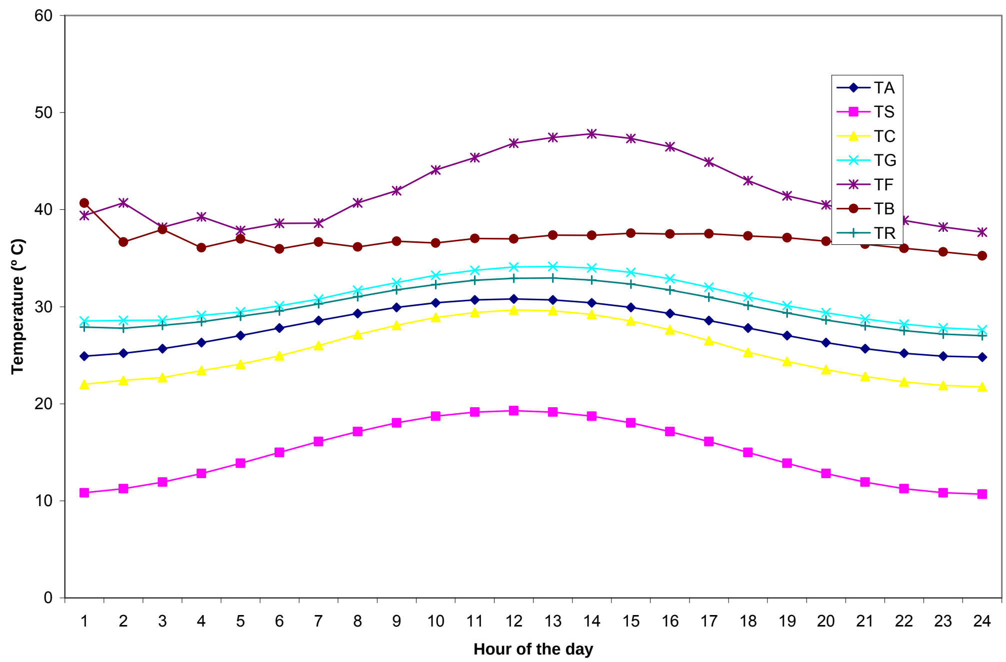

Fig. 9: Hourly Temperature (º C) Data for the Characteristic Day in the Month of July

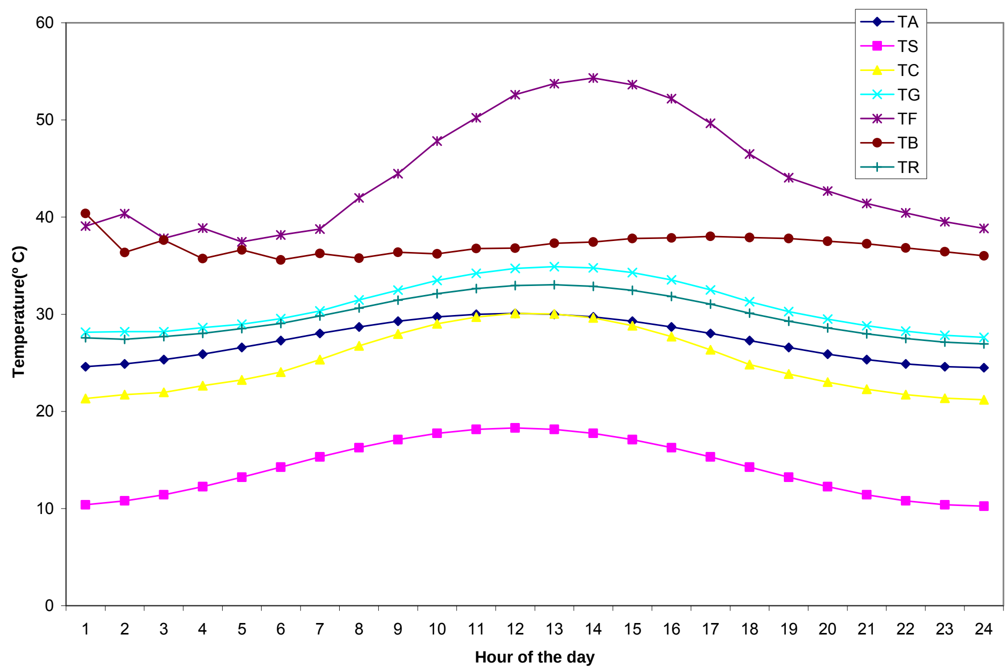

Fig. 10: Hourly Temperature (º C)Data for the Characteristic Day in the Month of August

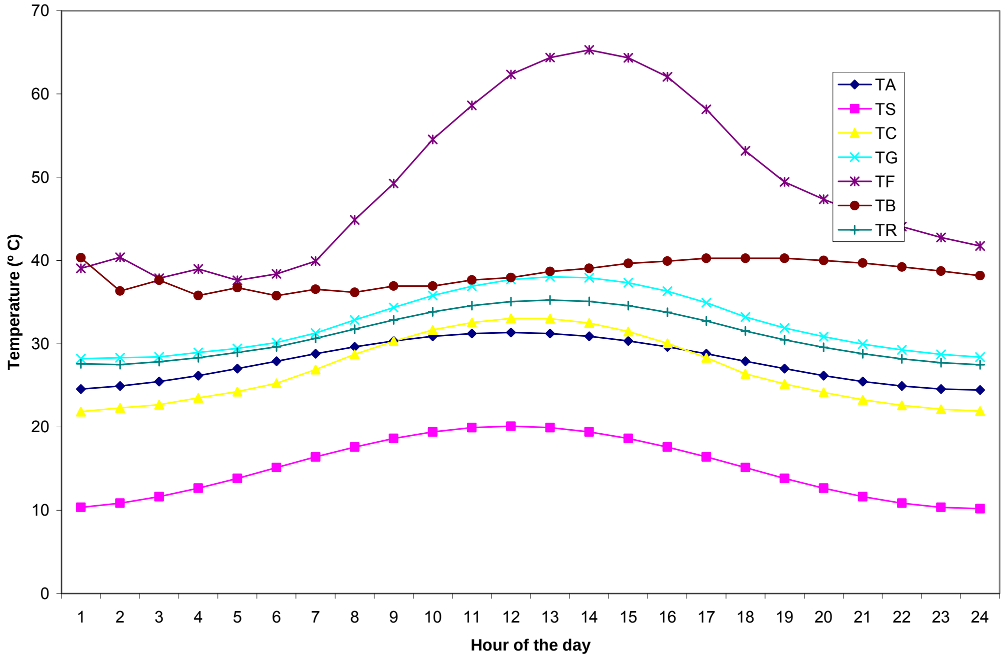

Fig. 11: Hourly Temperature (º C)Data for the Characteristic Day in the Month of September

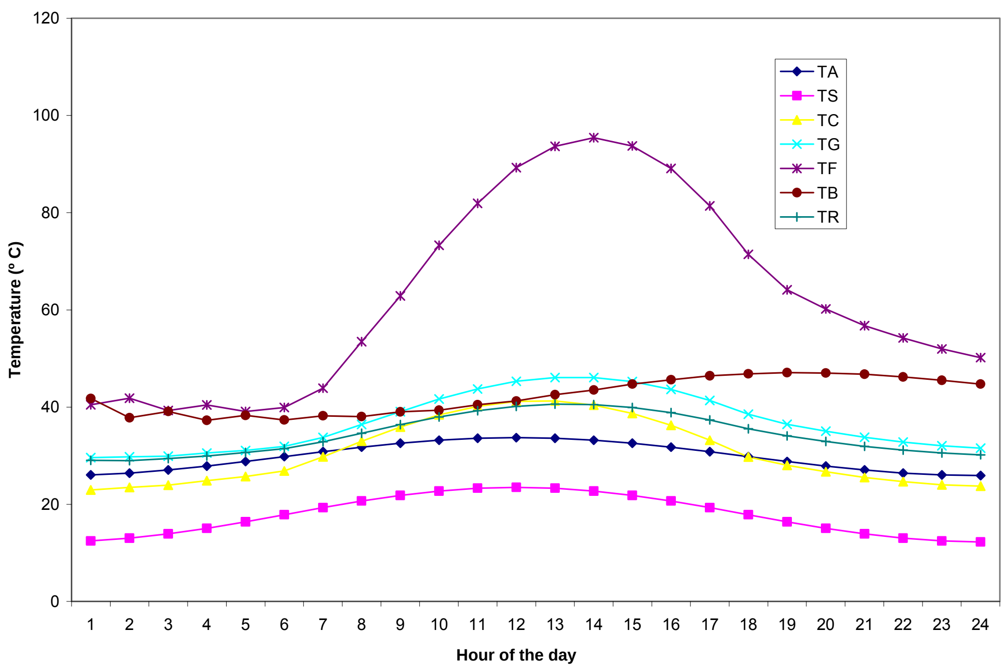

Fig. 13: Hourly Temperature (º C) Data for the Characteristic Day in the Month o fNovember

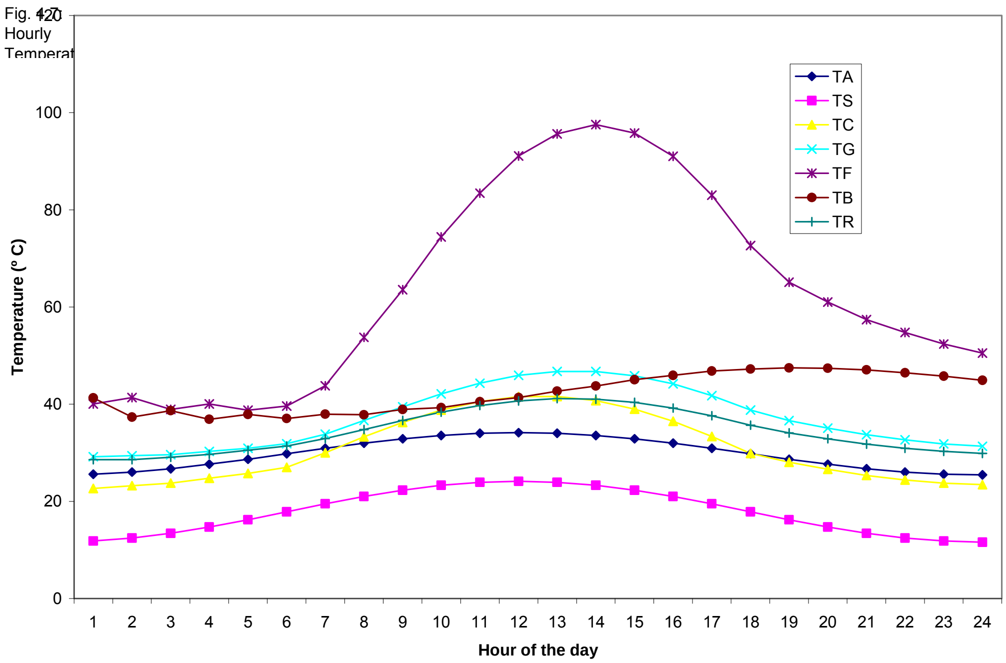

Fig. 14: Hourly Temperature (º C) Data for the Characteristic Day in the Month of December

From Figures 3 to 14, we see that the Trombe wall back surface and the brooder room temperatures are always higher than the ambient temperature and are also relatively constant. The average value of the Trombe wall back surface temperature ranges from 36.93ºC in July to 43.66ºC in February while the average value of the brooder room temperature ranges from 29.86ºC in August to 35.94ºC in February. These figures show clearly that it is possible to create an environment heated with solar energy but independent of fluctuations of weather. This is the ideal condition for poultry.

As mentioned earlier, the temperature comfort zones for poultry brooding are 35^{O}C for week 1, 31 – 29^{O}C for week 2, 29 – 27^{O}C for week 3, and 25^{O}C (ambient) from week 4 onwards. Hence these findings show that the optimum brooding temperature requirement can easily be met. This is achieved by opening the window for a period of time so that the hot air inside can be exchanged with the cooler air outside. This time was derived as a function of the actual room temperature, the desired room temperature, the ambient air temperature, and area of the window. The values obtained here are close to those obtained by Echiegu (1986) and Okonkwo (1993a).

CONCLUSION

The findings listed above are in close agreement with the values obtained by other scholars. Echiegu (1986) constructed a solar energy heated poultry brooding pen using water as the energy storage medium and obtained a brooding temperature of 25–35ºC. Likewise, Okonkwo (1993) built a bigger model but still using water as the solar energy storage medium and obtained a brooding temperature of 27-32º C. The results of this study show that an almost temperature of 29-35ºC can be obtained in the brooder room even if solar radiation is cut off for some consecutive days and this can be achieved without sacrificing convenient relative humidity and proper air circulation.

In view of the foregoing it can be concluded that it is possible to create the optimum temperature, relative humidity, and air velocity for poultry chick brooding by using solar energy to heat the pen. This fact has great socio-economic impact on the citizens of this country as noted by Okonkwo and Aguwamba (1997).

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the management and staff of the Nigerian Meteorological Agency South East Zone, Akanu Ibiam Airport Enugu, for their cooperation in willingly giving them access to their records as well as UNIDO, Abuja, for the data obtained in their publication: *Renewable Energy for Rural Industrialization and Development in Nigeria..*

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SUGGESTED CITATION

Okpani, P.E. and M.N. Nnabuchi. 2009. "Determination of Hourly Temperature Variation in the Elements of a Poultry Brooder Pen Heated by Trombe Wall". *Pacific Journal of Science and Technology.* 10(2):905-918.

Pacific Journal of Science and Technology