Journal of
Food Processing & Technology

OPEN ACCESS Freely available online

Research Article

Design, Construction and Performance Evaluation of a Trombe Wall Poultry Day-Old Chick Brooding House

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ABSTRACT

The recent increasing interest shown in passive solar heating is motivated by their capacity of providing thermal comfort and energy saving. Among the passive solar heating, Trombe wall system has aroused great attraction for its simple design. This is because Trombe wall system could be easily adopted in animal husbandry. As a consequence, its use is encouraged in commercial poultry day old chicks production systems. In this study a passive solar heating system using Trombe wall for poultry day old chicks brooding house was designed, constructed and the performance evaluation conducted at the University of Nigeria, Nsukka, Nigeria latitude 6°56'N. The Trombe wall powered poultry house is capable of handling about 2000 broiler day old chicks per batch for a period of five weeks brooding session. The major components of the poultry brooding house were a Trombe wall system measuring 10 m × 8.08 m with 0.25 m wall thickness for solar energy heat collection and storage and a brooding room measuring 80.8 m2 floor area. Physical elements and biological performance of the poultry brooding house were experimentally monitored in order to determine the parametric functionality of the poultry brooding house. Physical elements tested include ambient condition, temperature and relative humidity of the brooding house while the biological test performance evaluation was conducted using poultry day old chicks for four weeks in three replicates. Results of the performance evaluation of the Trombe wall poultry house showed that physical elements measured as temperature and relative humidity of the brooding room ranged between 28°C-35°C and 56%-76% when the ambient condition was between 18°C-37°C and 45%-87% respectively while solar irradiance for the period was between 76 W/m2-860 W/m2. The biological performance showed that the chicks maintained an average live weight of 786.1g after four weeks of brooding operation with average 3% mortality rate. These results showed that Trombe wall system could be a useful heating alternative for poultry day old chicks brooding operation especially in the tropics and cold regions where the conventional heat supplying systems are unreliable, unsustainable and expensive.

Keywords: Design; Construction; Brooding; House; Poultry; Trombe wall

INTRODUCTION

Poultry industry has emerged as the most commercialized and fastest expanding segment in the animal husbandry subsector but still faces with many problems. As with many other agricultural operations, poultry production is challenged with tight profit margins due to the ever-increasing energy costs, which placed much financial burden on poultry farmers. The opportunities to lower high cost in poultry production include many combinations of measures such as conservation, efficiency and renewable energy options. Among the varying options, solar as renewable energy offers the most attractive opportunity because it is environmentally friendly and sound with less economic burden on poultry growers more especially in the tropics where the availability of solar radiation is all the year round [1,2].

Provision of heat for poultry chicks is a basic necessity for the survival and optimum performance of young chicks during the brooding period. Quality of heat supplied during poultry brooding determines the level of physical and physiological development and mortality rate of chicks [3,4].

Typically, in Nigeria, majority of farmers often use a collection of kerosene bush lamps/stoves or the combination of both to supply the heating requirements of hatcheries and box nurseries for poultry operation. Though the farmers are in the majority, they have their scope of operation seriously limited by the high cost

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Received: August 20, 2021; **Accepted:** August 30, 2021; **Published:** September 04, 2021

Citation: Okonkwo WI, Akubuo CO, Ohagwu CJ (2021) Design, Construction and Performance Evaluation of a Trombe Wall Poultry Day-Old Chick Brooding House. J Food Process Technol 12:908.

of heating power or the total absence of it [5]. Fossil fuel usage in poultry production is characterized by environmental pollution, fire outbreak, scarcity and the unavailable in some cases while power supply outages render the use of grid electricity unprofitable. These may have accounted for the loss of huge sum of capital and high mortality rate experienced in poultry production systems in Nigeria. For successful poultry production, alternative methods of meeting the energy needs in the industry have to be evolved [6]. Such alternative energy resources should be one that is sustainable, pollution and fire outbreak free, and moreover should be inexpensive. Solar energy looks the best alternative energy option at least for now. This is because solar energy is a clean cheap energy to harness, and is widely available all the year round in the tropics. Many studies have been carried out on solar energy application on different aspects of poultry production systems. However, studies showed that there is much need for further research interest and innovation into the use of solar in poultry production especially the use of Trombe wall system [4,7,8].

The concept of Trombe wall system as heating device in poultry house is not common in the tropics. Its application however, in residential and commercial buildings in temperate regions is known. Trombe wall is an indoor climate control device that provides thermal comfort and indoor air quality in a building. In this direction, the integration of passive solar in building is one strategy for sustainable development and increasingly encouraged by international regulations. Passive solar techniques can reduce annual heating demand up to 25%. Trombe walls, can harmonize the relationship between humans and the natural environment and are widely used because of advantages such as simple configuration, high efficiency, zero running cost and so on. In addition to being environmentally friendly, using a Trombe wall in building can reduce buildings energy consumption up to 30%. So utilizing Trombe wall system in poultry brooding systems and operations could prove innovative, sustainable and cost effective on the long run [6,9].

Poultry brooding houses need little heating during the day when the sun is shining and the environmental temperature is at its peak in the tropics. However, they frequently need some supplemental heating at night when the outside temperature reaches the daily minimum. In most tropical countries, night temperature often falls as below as 21°C necessitating supplemental heating of the poultry brooding system in order to sustain day old chicks during brooding operation. Heat storage in Trombe wall system could allow solar energy usage when it is needed most, for instance in poultry brooding operation during the off sunshine hours. Heat storage using Trombe wall system smoothens and narrows the wide temperature fluctuations witnessed in solar heated air facilities. With proper sized heat storage unit, excess day time solar heat could be stored for later use without over heating a building. Thermal storage walls do not admit direct sun light into a building as do direct gain systems. This reduces sunlight damage to furniture and eliminates the glare of sunlight, which may be distracting to the building occupants. Trombe wall provide greater security and requires little maintenance. Optimum thickness of Trombe wall system range between 0.15 m-0.3 m. One problem confronting poultry farmers in the tropics is sustained power for day old chick brooding operation. Using Trombe wall system as energy storage and heat dissemination device in poultry houses could sustain the heat needs in poultry day old chick brooding operation. In this study, the development of a Trombe wall system for day old poultry chick brooding operation in Nigeria is presented. The aim of the work was to develop a Trombe wall poultry brooding house as an alternative to conventional poultry day old chicks brooding houses and undertake performance evaluation of the Trombe wall solar powered poultry brooding house using day old chicks as test samples [10].

MATERIALS AND METHODS

Description of the Trombe Wall Poultry House

Figure 1 shows the Trombe wall day old poultry brooding house utilized for this study while in Figure 1 is the cross sectional view of the Trome wall day old poultry brooding house showing the operational principle. The poultry house is located at the National Centre for Energy Research and Development (NCERD), University of Nigeria, Nsukka, Nigeria. The house is a passive type solar powered system that explores the use of Trombe wall as heating element supplying the poultry brooding room with energy. The brooding room has an internal dimension measuring 10 m × 8.08 m given a total floor area of 80.8 m^2 for 2000 day old chicks' capacity for a brooding period of six weeks at a recommended floor brooding space of 0.04 m^2 per chick plus 10% of brooding space for drinkers and feed troughs [3]. The poultry house was designed for commercial poultry brooding operation. The wall is made of 0.25 m thick solid blocks, corresponding to commercially available standard block size plus plaster in the Nigerian building system (Figures 1 and 2).

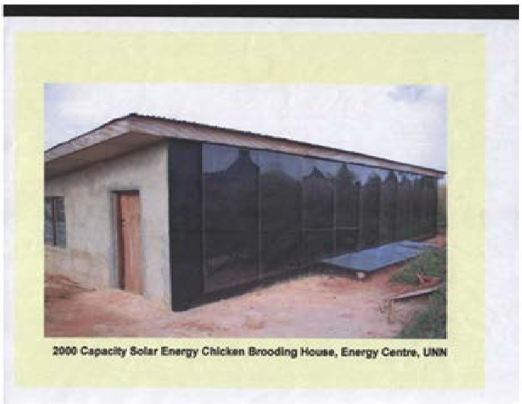

Figure 1: 2000 capacity Trombe wall day-old poultry brooding house.

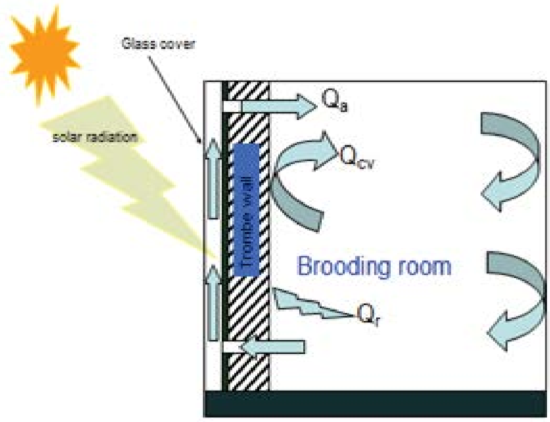

Figure 2: Heat transfer mechanism within a typical Trombe wall poultry house.

The south oriented facing wall of the house formed the Trombe wall system which was coated with black paint for solar energy absorption and storage. Heat proceeds into the brooding room by conduction, convection and radiation heat transfer from the Trombe wall system. The wall is covered with a glass cover to reduce heat losses from the outer wall. Three pairs of air vents each located at the upper and lower positions facilitate heat transfer from the airspace into the brooding room by convection. The roof of the brooder was sealed with asbestos ceiling sheet to prevent heat losses from the brooding room to the ambient environment. Two openings both at the east and west ends of the house facilitate constitute air ventilation and control in the brooding room. Entrance into the brooder was by a wooden door located at the west end of the house. No night insulation was provided for the brooder. Trombe wall with natural convection performs best without night insulation [11].

THEORICAL CONSIDERATION

Poultry production requires the provision of heat in an enclosed environment in order to keep the body temperature of the poultry within a comfort zone. The reason is that the poultry perform maximally under this condition without the adverse effect of environmental change in climate. Of the three major stages in poultry development namely egg incubation, day old chicks brooding and rearing of chicks, only egg incubation and day old chicks brooding operations need heating. Brooding day old chicks needs between 4-6 weeks for a complete operation. Brooding system with evenly distributed temperature regime of between 26°C-35°C has considerable merit for a successful operation depending on the age of the chicks. This enables wider distribution of birds in environmentally suitable areas with more space available for the chicks. This improves growth and reduces the likelihood of disease outbreak by chicks clustering in one end due to non-uniformity of temperature leveling. To ensure even spread of chicks in a brooding house, the room temperature is very important and must be within a range. A temperature range of 32°C to 35°C could be a good reference point in the tropics (Figure 3).

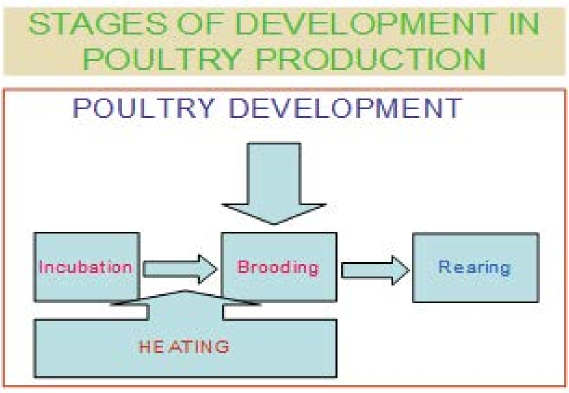

Figure 3: Stages of heat needs in poultry brooding.

In passive solar energy poultry chick brooding operation, heating is achieved by natural means without any augmentation. Energy supply is solely from solar radiation stored in sensible heat material using Trombe wall system for example. The principle at which solar energy collection, storage and utilization for poultry operation is illustrated using Figure 4. While Figure 3 showed the developmental stages in poultry production Figure 4 showed the principle and mechanisms used in harvesting solar radiation for the day old poultry brooding operation. Out of the three major stages in poultry development only egg incubation and day old brooding need heat for survival. Rearing by itself does not need further heat.

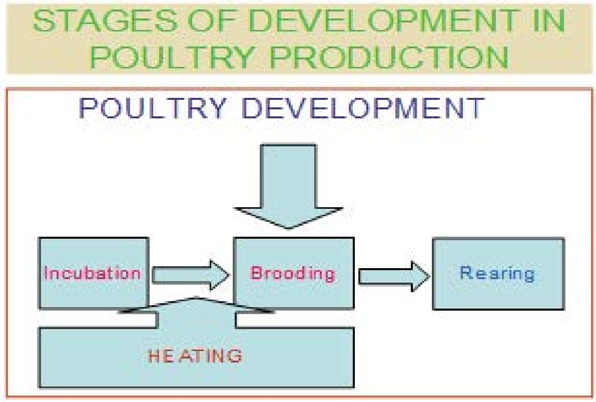

Figure 4: Principles and mechanisms of passive solar energy poultry production.

Heat and Mass Transfer Calculations

In determining the total heat load of the Trombe wall poultry day old brooding house, considerations were given to the metabolic heat production of chicks and heat energy coming from the Trombe wall as a heating device. From thermodynamic equilibrium the brooding room heat load was estimated using equation 1 given as:

$$Q_b = Q_{Ls} - (Q_T + Q_{CK}) \qquad (1)$$

Where,

Q_b=Brooding room heat load, W

Q_{Ls}=Total heat loss from the brooding room through the walls, W

Q_{CK}=Heat production rate by chicks, W

Q_T=Heat supplied into the brooding room through the Trombe wall, W

Radiant solar energy passing through the glass cover and the air space is absorbed by the black coated surface of the Trombe wall, stored in the wall and conducted through the masonry into the brooding room. By considering the radiant energy striking the Trombe wall surface, the overall brooder heat load was estimated by equation 2.

$$I_2 - Q_{ST} = Q_b \qquad (2)$$

Where

I_2=Net solar input after losses from glass cover, W

This was given as in equations 3-6.

$$I_2 = I_1 A\alpha\varepsilon - (h_c + h_r) A (T_{wo} - T_g) \qquad (3)$$

Q_{ST}=Heat stored by Trombe wall, W

I_1=Daily solar radiation intensity, W

A=Trombe wall surface area, m^2

α=Trombe wall solar absorptance

ε=Trombe wall solar emittance for this work 0.73 and 0.90 were chosen for the absorptance and emittance respectively.

h_c=Convection heat transfer coefficient,W/m°C

h_r=radiation heat transfer coefficient, W/m2°C

T_{wo}=Trombe wall outside surface temperature,°C

Tg =Temperature of glass, °C

$$h_c = 5.7 + 3.8 V_w \quad (4)$$

Where

V_w=wind speed

5 m/s as world average (5)

h_r was calculated using the expression equation 6.

$$h_r = \frac{\partial(T_{wo}^2 - T_g^2)(T_{wo} - T_g)}{1/\varepsilon w + (A/Ag)(1/\varepsilon g - 1)} \quad (6)$$

Where

ð=Boltzmann constant = 5.669 × 10^{-8} W/m^2 K4

εw=emissivity of Trombe wall

εg=emissivity of glass (0.26)

A/Ag = ratio of Trombe wall area to that of glass=1

Average values of Two and Tg were taken to be 47.5°C and 31.7°C respectively.

Heat stored by the Trombe wall system was estimated by (equation 7).

$$Q_{ST} = \rho_c L_T A C_{pc} \left(T_{wi} - T_{wo}\right) \quad (7)$$

Where

C_{PC}=Specific heat capacity of Trombe wall, J/kg°K

ρc=Density of wall, kg/m^3

L_T=Thickness of Trombe wall, m

A=Area of Trombe wall, m2

T_{wi}=Inside surface room Trombe wall temperature,°C

T_{wo}=Outside surface Trombe wall temperature,°C

Q_{ST}=Total heat stored by Trombe wall, W

The heat supplied by the Trombe wall system into the brooding room was estimated by equation 8.

$$Q_T = Q_{cd} + Q_r + Q_{cv} + Q_a \quad (8)$$

Where

Q_{cd}=Conduction heat transfer through the Trombe wall, W

Q_r=Radiation heat transfer through the Trombe wall, W

Q_{cv}=Convection heat transfer, W

Q_a=Heat transferred due to air circulation through the air vents, W.

The Trombe wall was considered as a medium with steady state heat conduction. For a steady state heat conduction in a massive wall Fourier's heat states equation 9.

$$Q_{cd} = k_c A \frac{T_{wi} - T_b}{L_T} \quad (9)$$

Where

k_c=Thermal conductivity of wall, W/m°C

A=Area of Trombe wall, m^2

L_T=Thickness of Trombe wall, m

T_{wi}=Trombe wall inside surface temperature,°C

T_b=Brooder design temperature,°C

Since the Trombe wall was painted black at both surfaces, it was regarded as a perfect radiator of radiant energy from its surfaces at a rate given by equation 10.

$$Q_r = 5.669 \times 10^{-8} A \left(T_{wi}^{\ 4} - T_b^{\ 4}\right) \quad (10)$$

Convection heat transfer, Qcv was estimated by the equation (11)

$$Q_{cv} = hA \left(T_{wi} - T_b\right) \quad (11)$$

Where

h=Convection heat transfer coefficient =8.29 W/m^2 °C [11].

Heat entrance, Qa, through the air vents into the brooding room was estimated by (equation 12).

$$Qa = v_a \ell_a C_{pa} (T_a - T_b) \quad (12)$$

Where,

V_a = area of Trombe wall vent, m^2

ρa=density of air 1.172 kg/m^3

C_{pa}=Specific heat capacity of air, 1008J/kg°C

The rate of metabolic heat production of the chicks was estimated by equation 13.

$$Q_{CK} = qWN \quad (13)$$

Where,

q=heat production per hour per body weight of chicks

W=Average body weight of chicks, kg

N=Number of chicks

Heat loses from the Trombe wall brooding house were mainly from glass windows (vent), wooden door, walls and ventilating vent (chimney). The heat losse through the glass windows was estimated by Fourier's heat conduction equation 14 given as:

$$Q_{wi} = \frac{k_g A_g}{L_g}(T_b - T_e) \quad (14)$$

Where,

Q_{wi}=Heat loss through glass window, w

K_g=Thermal conductivity of glass, W/m°C

A_g=Total surface area of glass, m^2

L_g=Thickness of glass, m

T_e=Environmental temperature, °C

While heat loss through a wooden door was estimated by

Figure 5 Day old chicks during brooding session and eight weeks old chicks inside Trombe wall poultry brooding house respectively (A): Day old chicks during brooding session; (B): Eight weeks old chicks inside Trombe wall poultry brooding house respectively.

$$Q_d = K_d A_d \quad (15)$$

Where,

K_d=Thermal conductivity of door (wood), W/m°C

A_d=Area of wooden door, m^2

L_d=Door thickness, m

Heat losses through the other walls other than the Trombe wall was estimated by

$$Qc = \frac{K_c A_c}{L_c}(T_b - T_e) \quad (16)$$

Where,

Q_c=Heat loss through concrete walls, W

K_c=Thermal conductivity of wall, W/m°C

L_c=Thickness of wall, m

A_c=Total surface are of walls, m^2

PERFORMANCE EVALUATION

The test performance evaluation of the 2000 chicks capacity Trombe wall powered poultry brooding house was carried out at the National Centre for Energy Research and Development (NCERD), University of Nigeria, Nsukka, Nigeria latitude 6.8°N. Two types of performance evaluation were conducted to determine the parametric ability and the efficiency of the poultry brooding house. These tests carried out were the physical and biological performance evaluations. The physical evaluation involved the monitoring of the micro-climatic elements measured as temperature and relative humidity while the biological evaluation involved the use of live broiler poultry day old chicks as test samples. The ambient environmental conditions were monitored simultaneously using standard known instruments. The experiment was conducted between the months of July-October otherwise considered critical period for poultry day old chick brooding operation in Nsukka, Nigeria. The average environmental temperatures fluctuate between 18°C minimum and 37°C maximum. Figure 5 showed the day old chicks during and after brooding at eight weeks old respectively.

RESULTS AND DISCUSSION

The varied measured hourly solar radiation intensity over the period

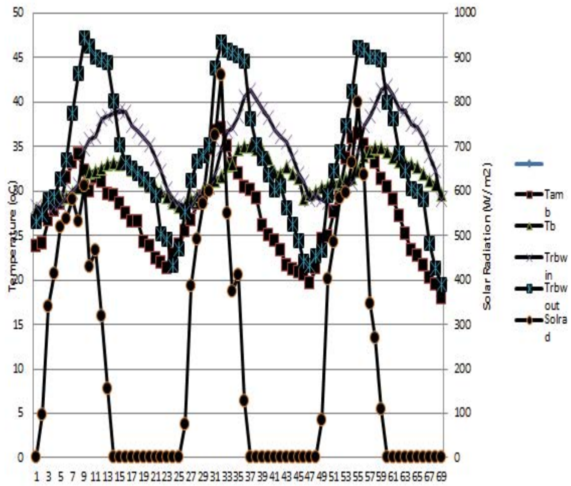

Figure 6: Temperature and solar radion profiles vs time (day).

of the experimental study showed sinusoidal shape. The maximum solar radiation intensities were recorded between 12 noon and 2 pm hours of the day while the minimum values were recorded during the morning and late hours of the day with these values 76W/m^2 and 860W/m^2 respectively. Temperature variation of the Trombe wall (inner and outer) surfaces were 27°C and 30.28°C minimum, and 39.36°C and 47.36°C maximum respectively (Figure 6) while the brooder relative humidity was between 56%-76% when the ambient condition was 45%-87%.

T_{rbwout}=Trombe wall outside wall temperature, °C

T_{rbwin}=Trombe wall inside wall temperature, °C

T_b=Brooding room temperature, °C

T_{amb}=Ambient temperature, °C

Sol_{rad}=Solar radiation, W/m^2

To determine the efficiency of the poultry brooding house 2000 day old broiler chicks per batch was used to evaluate the house at three replicates. Measurements were taken at for four (4) days intervals and these lasted for four weeks (28 days) per batch of brooding session. Figures 7 and 8 showed the body weight and cumulative feed consumption and, average weight gain and feed consumption versus age. At the end of four weeks brooding period an average body weight of 786.1 g was observed from initial body weight of 52.2 g while cumulative feed consumed within the same period was 1253 g when the average weight gain was 184.3 g at 318.3 g average feed rate consumption per chick. These values compared favourably to 96.3 g and 298.7 g. The Trombe wall system showed better thermal load leveling compared to hot water storage tank on roof. Observation showed that the body weight increased with increase in the amount of feed consumed per period. For the first eight days the average body weight was higher than the cumulative feed [8]. However, the trend changed towards the end of brooding session. This was attributed to the fact that chicks consume more feed as they grow older than the rate at which feed is converted to flesh. Feed conversion rate decrease at old age. Better feed conversion ratio was observed between the 8th and 16th day of the brooding operation at 1.35 and 1.42 respectively than 2.6 at the first 4 days and 8 days (Figure 9). At this period chicks make better use of feed consumed. At the end of the performance evaluation the system showed high efficiency with 3% mortality rate.

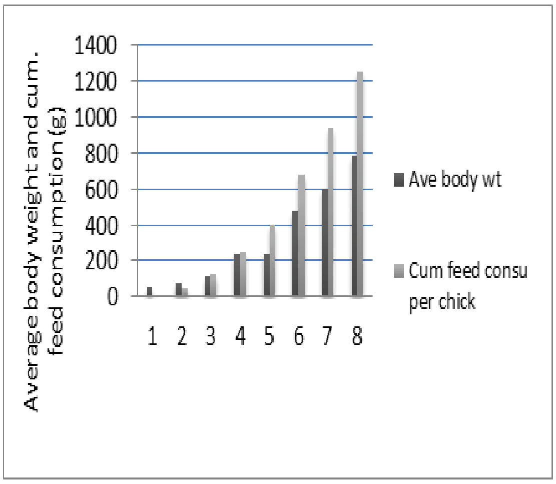

Figure 7: Average body weight and cumulative feed consumption versus time (days).

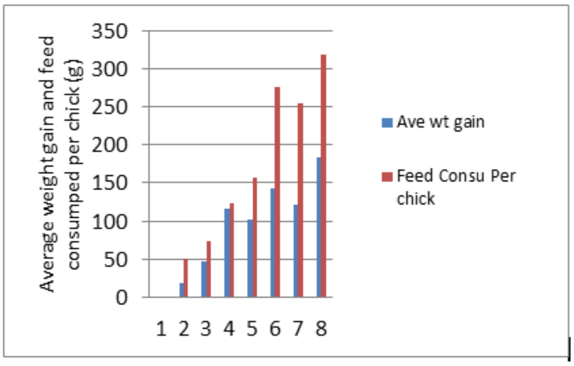

Figure 8: Average weight gain and feed consumed per chick versus time (days).

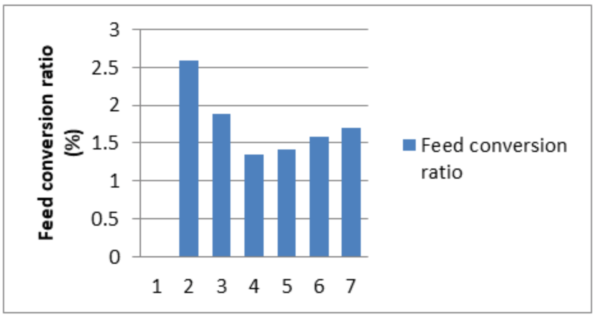

Figure 9: Feed conversion ratio versus age of chicks (days).

CONCLUSION

This study has shown that Trombe wall passive solar energy heat storage and dissemination system could maintain and sustain brooding operations environmental needs within the acceptable range without supplemental or auxiliary heating. This could be an alternative heating device in poultry day old brooding operations. Records showed that the Trombe wall solar energy powered poultry brooding house could maintain temperature range of 28°C-35°C and relative humidity of 55%-87%. Performance evaluation showed improved solar brooded chicks with high efficiency of 3% mortality rate. This is an indication that Trombe wall system utilization in poultry production heating is practicable and could be an important and useful alternative to expensive conventional energy heating devices. The application of Trombe wall system in poultry production will improve and boast poultry production in benign environment more especially in the tropical countries.

ACKNOWLEDGEMENT

1. The authors sincerely acknowledge the support received from the African Centre of Excellence for Sustainable Power and Energy Development (ACE-SPED), University of Nigeria, Nsukka Nigeria that necessitated the timely completion of this study.
2. The authors equally express their appreciation to the Tertiary Education Trust Fund (TETFUND), Nigeria for sponsoring the trip to present the study at an International conference of the American Society of Agricultural and Biological Engineers (ASABE).

REFERENCES

1. Heise H, Crisan A, Theuvsen L. The poultry market in Nigeria: Market structures and potential for investment in the market. Int Food and Agribus Manag Rev. 2015;18:197-222.
2. Okonkwo WI, Akubuo CO. Design, construction and performance evaluation of a trombe wall poultry chick brooding house. Trans ASABE. 2018:1.
3. Oluyemi JA, Roberts FA. Poultry production in warm wet climates. Macmillan Press Ltd.
4. Okonkwo WI, Akubuo CO. Trombe wall system for poultry brooding. Int J Poult Sci. 2007; 6(2):125-130.
5. Okonkwo WI, Anazodo GU, Akubuo CO, Echiegu EA, Iloeje OC. The UNN passive solar poultry chick brooder-further improvement and preliminary test. Nig. J. solar Energy. 1992;11:32-40.
6. Hordeski MF. Dictionary of energy efficiency technologies. The Fairmont Press.
7. Uzodinma EO, Ojike O, Etoamaihe UJ, Okonkwo WI. Performance study of a solar poultry egg incubator with phase change heat storage subsystem. Case Studies in Ther Engineer. 2020;18:100593.
8. Echiegu EA. The development and testing of a passive solar energy heated poultry brooder. Niger J Solar Ener. 1986;11:32-40.

9. Hu Z, He W, Ji J, Zhang S. A review on the application of Trombe wall system in buildings. Renewable and Sustainable Energy Reviews. 2017;70:976-987.

10. Richard JW. Passive Solar Heating. Int J Poult Sci. 1983;6:1-7

11. Nayak JK, Bansal NK, Sodha MS. Analysis of passive heating concepts. Solar Energy. 1983;30(1):51-69.