Design for Temperature-Controlled Solar Heated Chick Brooder

Okolie Paul Chukwulozie[1], Okafor Emeka Christian[2*], Chinwuko Emmanuel Chuka[2],Ubani Nelson Obinna[3], Okenwa Ugochukwu[3]

[1]Correspondance Email: pc.okolie@unizik.edu.ng

Abstract— Brooding is the care of the chicks from a day old to six weeks. The current design consists primarily of the provision of modulated heat against the background of natural and artificial brooding system of brooding that is prone to fire hazard. This work therefore presents a design for a brooder that makes uses of solar as source of the required heat in the housing. The overall heat transfer coefficient of the door was determined as 3.846W/m^{2}^{0}C and transmission heat loss through door (Q_d) results to 30.15W. Then the heat transfer coefficient is 1.780 such that the total heat of 80.63W is loss through the walls. Based on the results, it was recommended that if there are several chicks, the temperature can usually be a little lower as the chicks keep each other warm and single chicks have fewer options to self-regulate; In many cases the heating can be moderated once the temperature was regulated down to 21 degrees Celsius.

Index Terms—Brooding, Energy, Heat, Insulation, Solar Collectors, Temperature.

1. INTRODUCTION

Nigeria receives about 4.851x 10^{12} KWh of energy per day from the sun. This is equivalent to about 1.082 million tons of oil Equivalent (mtoe) per day, and is about 4 thousand times the current daily crude oil reduction, and about 13 thousand times that of natural gas daily production based on energy unit. According to Bala et al (2000), Nigeria is endowed with an annual Average daily sunshine of 6.25 hours, ranging between about 3.5 hours at the coastal areas and 9.0 hours at the far northern boundary. This huge energy resource from the sun is available for about 26% only of the day.

Solar chicken brooders of various sizes have been developed by national centre for energy research and development (NCERD), Nsukka. The chicken brooders use solar radiation as source of heat in place of electricity bulbs, kerosene lamps or stoves to provide heat for freshly hatched chickens. The technology eliminates the emission of product gases that are hazardous in health of both man and chicken (Iloeje, 1997). Some design however has provision for feeding and watering of chickens as well as collection and discharge of chicken droppings. Solar egg incubators are also available (Ileoje, 1997, Okeke, 2002, Oparaku, 2007).

Okonkwo and Akubuo (2001), utilized a water storage tank constructed with 2mm thick galvanized metal sheet measuring 3m x 1m x 2m insulated with wooden materials, 5cm thick to control the brother temperature. Studies (Okonkwo *et al.,* 1993; Okonkwo and Agunwamba, 1997, Rockby *et al.,* 1983) showed that conventional energy consumption in poultry production is quite enormous and therefore expensive. Nonetheless, these studies did not include an explicit design consideration for temperature control and thorough housing material conductivity, a gap which the current study intends to fill.

2. MATERIAL AND METHODS

Selection of material of construction is dependent on the properties of the materials that give better performance. The design consisted of a flat plate collector mounted on a stand with variable angle of inclination, the thermal performance of a collector was determined using the first law of energy balance (Samtos et al, 2005). Comprehensive evaluation of environmental conditions around Awka-Anambra state Nigeria (the area where the research was carried out**)** informed the selection of design ambient temperature T_a to be 27^{0}c; Design brooder chamber temperature T_b = 34^{0}; Design brooder chamber relative humidity = 70%; Design ambient air relative humidity = 50%; The only heat gain considered is that due to metabolic process in the chicks. The heat (Q) is obtained from = 3.5Mass $^{0.75}$. The design model of (Duffie and Beckman, 1976; Duffie and Beckman 1991; Meinel and Marjorie 1976; Santos, Queiroz and Borges, 2005) as reported and validated by (Bello and Odey**,** 2009) were used in order to determine the heat transfer along the plate, an assumption of temperature gradient being negligible is taken in the direction of flow, the rate of useful energy gain (W) was then computed.

3. RELEVANT MATHEMATICAL FORMULATIONS

The energy loss at a given temperature depends on the overall energy loss coefficient, U_c and the area of the collector through which heat is lost. The energy loss coefficient could be reduced by second glazing of the absorber plate or by surrounding the collector plate by a vacuum.

$$q_u = I_c A_c I \alpha_s \tau_s - U_c A_c (T_c - T_a) \qquad (1)$$

Where Ac = Area of the collector absorber plate (m^2); I_c = Global insulation on plane of the collector (W/m^2); τ_s = Net solar transmitivity of gracing; α_s = Solar absorptivity of collector plate; U_c = Overall heat loss coefficient ($W/m^2 .C$); T_c = average collector plate surface temperature (^0C); T_a = Ambient air temperature (^0C). Thermal efficiency η_c is given by

$$\eta_c = \frac{q_u \eta_0}{A_c I_c} - U_c \frac{(T_c - T_a)}{I_c} \qquad (2)$$

Where; η_0 = the optical efficiency of the collector, equivalent to the product; $\alpha_s \tau_s$ in equation (1). For a simple flat-plate configuration, the optical efficiency; η_0 = (cover transmitivity) x (solar absorptivity); for which the value of τ_s ranges from 0.75 – 0.95 and α_s from 0.90 – 0.95. For concentrating collectors;

$$\eta_0 = \rho_s \tau_s \gamma \qquad (3)$$

Where; ρ_S = Solar Reflectivity of the concentrator reflector surface; γ = intercept factor.

Collector Plate Temperature, T_c is eliminated from the efficiency relation by using by using collector heat removal efficiency factor, F_R. This because of the difficulties encountered in trying to obtain the collector temperature.

$$F_R = \frac{I_c \tau_s \alpha_s - U_c (T_c - T_a)}{I_c \tau_s \alpha_s - U_c (T_{f1} - T_a)} \qquad (5)$$

$$Q_u = F_R A_c \left[I_c \tau_s \alpha_s - U_c (T_{fi} - T_a) \right] \qquad (6)$$

In order to avoid admission of surplus radiation into the housing, the design excluded window on the east and west walls. However, two windows are required for the proper ventilation on the south and north walls.

Considerations for transmission heat loss through the floor and wall

The floor comprises sheet of plywood with thermal conductivity of $0.118 W/m^0C$ and thickness 0.005m, hard wood of thickness 0.04m, and insulation material of wood fiber (soft wood) of thickness 0.06m and thermal conductivity of $0.043 w/m^0C$

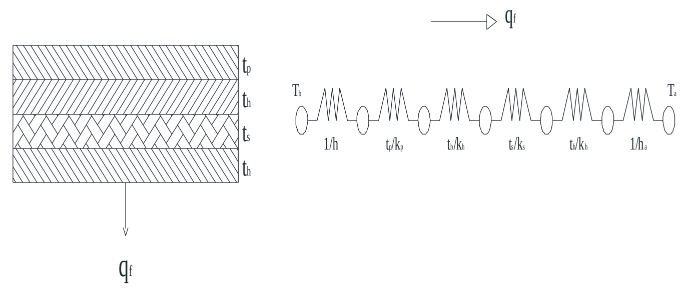

Fig. 1: heat transfer section of the floor and network

The overall heat transfer coefficient, U_f is therefore obtained from (7);

$$1/U_f = 1/h_b + \frac{t_p}{K_p} + \frac{t_h}{K_h} + \frac{t_s}{K_s} + \frac{t_h}{K_h} + \frac{1}{h_a} \qquad (7)$$

Heat loss from the floor, Q_f is

$$Q_f = A_f U_f (\Delta T)_f \qquad (8)$$

The walls comprise hardwood and insulation wood fiber as in the floor.

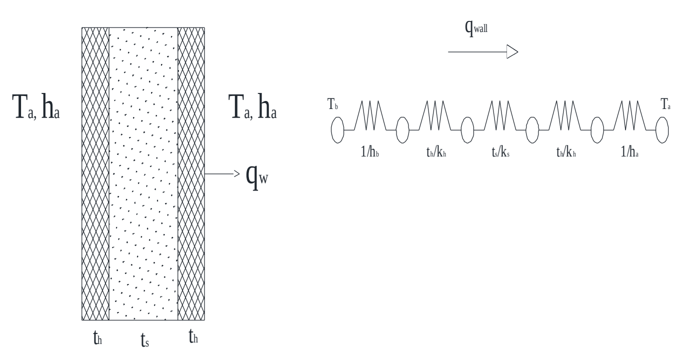

Fig 2. Heat transfer section of the wall and network

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Considerations for transmission heat lost through the roof

The roof is made corrugated iron sheet inclined at 16.22^0. According to (Oguike 1991), with the assumptions that the thermal resistance of the roofing material is negligible considering its thickness which is very thin, and its high thermal conductivity; There is a ceiling that shields the room from the roof; therefore heat loss by transmission is only through the roof.

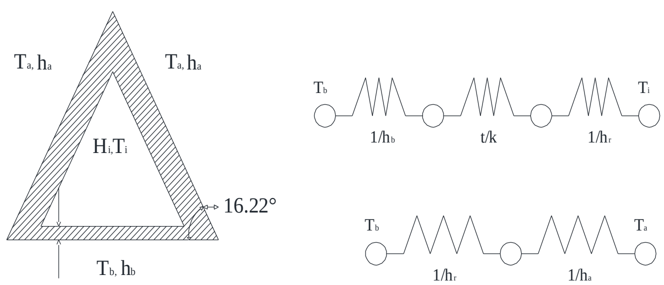

Fig 3. Heat transfer section of the roof and network

The heat transfer through the roof is given by

$$Q_r = UA_{cel}(T_b - T_a) \quad (9)$$

$$Q_r = U_{cel}A_{cel}(T_b - T_i) \quad (10)$$

$$Q_r = U_rA_r\,(T_i - T_a) \quad (11)$$

$$U = \frac{1}{U_{cel}+(A_{cel}/U_rA_r)} \quad (12)$$

Where U_{cel} = Heat transfer coefficient from brooder to attic; U_r = Heat transfer coefficient attic to ambient; U = Overall heat transfer coefficient through the roof; A_{cel} = Area of the ceiling; A_r = Area of the roof; T_b = Boarder house temperature; T_a = Ambient temperature ; T_i = Attic air temperature. According to (Ashrae, 1981), air exchange per hour is used for residential building because of the average sized windows. This design specified smaller windows such that air method becomes insufficient. Therefore, crack length method is used and rate of air flow through closed windows is given as:

$$V = KP^n \quad (13)$$

Where K = proportionality constant; P = pressure difference across window; n = exponent flow which is between 0.5 to 1.0

4. RESULTS AND DISCUSSION

The overall heat transfer coefficient of the door was determined as $3.846W/m^{20}C$ and transmission heat loss through door (Q_d) results to 30.15W. Then the heat transfer coefficient is obtained from (7) as 1.780 such that the total heat loss through the walls is Q_{wall} = 45.30 + 35.33 = 80.63W. Considering ventilation requirement for poultry, using small wooden windows, and based on the optimum air exchange rate of poultry and velocity of air flow of $0.85m^3$/hr bird and 0.4m/s respectively, the air flow rate for 100 chicks in m3/s is found to be $0.0236m^3/s$. Thus each window will be of area = $0.0295m^2$. Assuming a square window thickness, 0.02m, Length of window = 0.172m, Width of window = 0.172m. A single door is required and located on either south or north wall. The dimension of the door is thickness = 0.02m, height 1.4m, width 0.7m.

Table 1: design specifications for solar heated chick brooder

Medium of Heat Loss	Heat transfer coefficient (U) $W/m^{20}C$	Area A m^2	Total heat loss Q (W)
Windows	3.846	0.1183	3.64
door	3.846	0.98	30.15
Floor	0.5486	5.02	19.28
Walls	0.5617	8.96	80.63
roof	2.6682	5.02	227.46

The average mass of the bird was calculated to be 1.045 and U_t gave $1.956W/m^2\,^0C$ and thickness is 0.0324m, thus the optimum insulation thickness is specified as 3.5cm or 35mm. The air flow rate per hour associated with weight of a bird at each age per bird and the velocity is recorded and presented in table 2, specifying the weight of bird at each age and ventilation requirement for brooder.

Table 2. Recorded weight of a bird at each age of brooding

Age of fouls (week)	ventilation (m^3/Bird/hour)		air movement velocity (m/s)	average mass (g)
	Min	Max		
Week 1	0.162	1.296	0.2	37.5
Week 2	0.324	1.296	0.3	92.5
Week 3	0.456	1.296	0.3	189
Week 4	0.612	3.888	0.4	328
Week 5	0.695	4.248	0.4	556
Week 6	0.817	6.48	0.4	688

In a similar concern, the variation of surface conductance with air velocity is represented in figure 4. Indicating a near linear property.

Table 3. Infiltration through windows (m^3/s-m^2frame)

Type of material	Material grading	Specific Infiltration (m3/s-m2 frame)
Wood frame small	MTRGA	0.01016
Wood frame, weather stripped	MTRGB	0.00381
Wood frame large	MTRGC	0.00762
Metal frame small	MTRGD	0.00762
Metal frame, weather stripped	MTRGE	0.00381
Metal frame large	MTRGF	0.00508

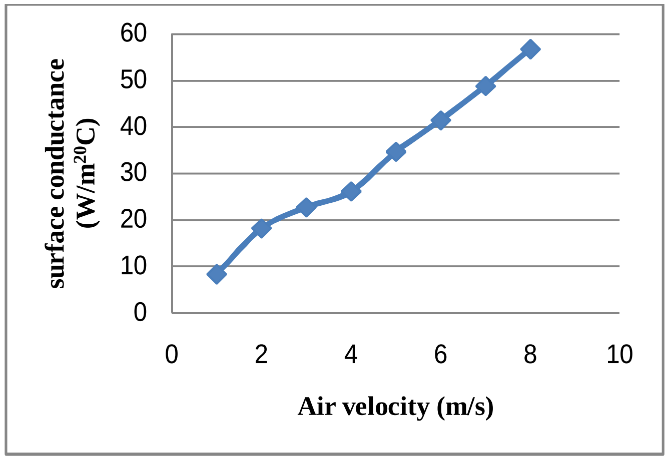

Fig. 4: Variation of surface conductance with Air velocity

For the brooder air velocity of 0.4m/s, by interpolation, h_b = 10.05 W/m^{20}C. Using the world recognized outside standard velocity of 5m/s, then h_a = 28.143 W/m^{20}C. Thermal conductivity for hard wood, k = 0.16W/m^0C. The overall heat transfer coefficient of the network is U_w = 3.846W/m^{20}C. According to (Doserient) provided the room is painted white or light colour, the following correction factors can be applied for temperature; East wall 2; West wall 2; North wall 1; South wall 1. Then, the total heat transmitted through the window is such that total heat transmitted through the window as shown in fig 6 is 3.64W, while total rate of infiltration through the windows as shown in table 3 is 1.202 X $10^{-3}m^3$/s. For the four wooden small frame-windows. Rate of infiltration through the door becomes 2.529 X $10^{-5}m^3$/s, giving a total infiltration of 1.227 X $10^{-3}m^3$/s.

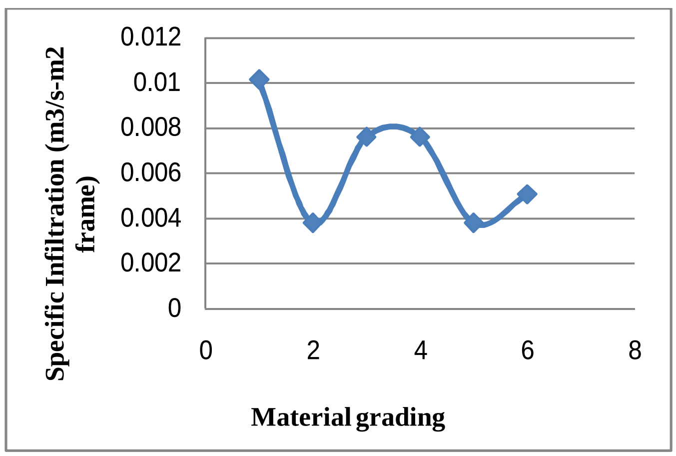

Fig. 5: Recorded Infiltration through windows

This recommended average rate of infiltration value of crack is because infiltration also depends on rate of door opening and closing. Air enters through the direction of the wind and leaves through the leeward opening by the side with the highest opening; the total rate of infiltration through the windows therefore is 1.202 X $10^{-3}m^3/s$ and for the four wooden small frame-windows, the rate of infiltration through the door is 2.529 X $10^{-5}m^3/s$ hence total infiltration was computed as 1.227 X $10^{-3}m^3/s$.

Similarly, the heat loss by infiltration considered as the sum of sensible heat load and latent heat load for which the rate of infiltration in the brooder gave 1.227 X $10^{-3}m^3/s$ and density of air in the brooder house at atmospheric pressured of 1.013 X $10^5N/m^2$. Assuming an ideal gas for air, then total heat loss from the brooder resulted 285.30W and heat load of the brooder gave 113.23W

From the heat transfer network of the ceiling and attic, the ceiling thickness of 0.015m and ceiling thermal conductivity of 3.32W/m^{0}C were employed for the computation of total heat loss through the roof and transmission that equals 227.46W, however, the door is of the same thickness and material as the window, and exposed to the same brooder condition and outside ambient condition. Thus the overall heat transfer coefficient of the door is 3.846W/m^{2}^{0}C

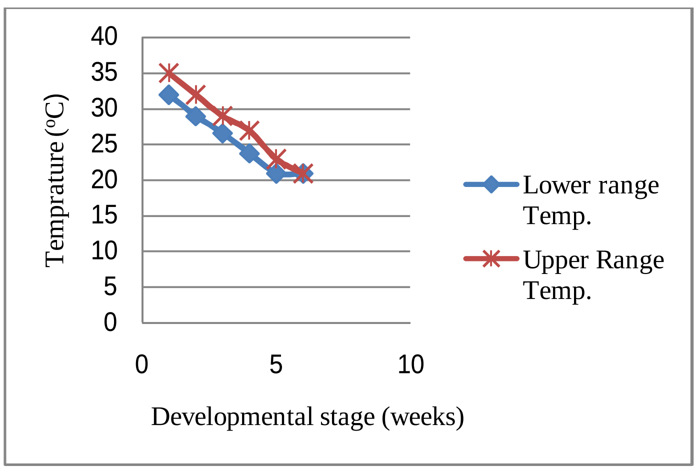

Fig 6. The upper and lower range brooder temperature variably decreased as the chick develops

In general, parent hatched chicks are likely to be more comfortable at lower brooder temperatures due to the hen occasionally leaving the nest. However, the prevailing weather conditions should be taken into account. Thus the design implementation maintained a warm brooder up to the correct temperature before adding the chicks. A non-breakable thermometer at "chick level" was used to obtain the temperature value in table 4, which can serve as a guide temperature to monitor the temperature; the results were compared with (Oguike, 1991) and found reliable.

Table 4. Recorded results of chick brooder temperature

Age of Poultry (feathered) Chick	1st Week	2nd Week	3rd Week	4th Week	5th Week	6th Week +
Temperature ⁰C	32 - 35	29 - 32.	26.6 - 29	23.8 - 27	21 - 23	21

Collector Specification

The average daily irradiation of the location over the year is given this value is used to specify the area of the flat plate collector under the calculated heat load. Form collector area required. The total heat required = heat load = 120.18W. Heat from collector and collector efficiency, assuming 40% for a simple cover plate; Heat form collector therefore is specified as 1689.82W, such that considering a square plate with length of 0.27m; Width of 0.27m; Area of 0.0729m^2 and absorber plate made of steel plate with thickness 0.005m. The plate is coated with a flat black paint with absorptivity and emissivity of 0.95 and 0.97 respectively. A single green house grade fiber glass of transitivity 0.80, and emissivity of 0.90 serves as the top cover. The insulation is made of saw dust material because its availability. The enclosure is made from corrugated iron sheet material, the selection of materials of the both collector is based on the economic important and the availability of the materials.

5. CONCLUSIONS

There is abundance of sunshine in Africa as a constant and in Nigeria as country. This solar energy can be harnessed for human use. The study gave an overall heat transfer coefficient, U_f of 0.5486 W/m^{2} ^{0}C and Heat loss from the floor, Q_f = 19.28W. The idea of this work is to make it very cheap for the local farmers to use manure to reduce drastically, the cost of energy in agriculture. In this paper effort has been made to use local material so as to reduce the cost that will be involved in the construction to the tune of about NGN 150,000.00 depending on the prevailing market condition.

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Also the design was made taking into consideration the local condition of the rural areas and enough safety factor applied to ensure reliability of the brooder chamber. The temperature control ensures that maintenance of temperature between 34^{0}c to 24^{0}c can be achieved. The brooder can further be optimized for temperature-controlled enclosures for hatching and raising baby birds. It can be extended for used by agricultural breeders of poultry, commercial purveyors of domestic birds such as parakeets and canaries, and wildlife rescue. It can also be employed by rehabilitation and repopulation scientists for saving endangered species, and for individuals who make small-scale purchases of baby chickens and ducklings or need to nurse a sick or injured bird. Finally, if there are several chicks, the temperature can usually be a little lower as the chicks keep each other warm. Single chicks have fewer options to self-regulate. In many cases the heating can be removed once the temperature was regulated down to 21 degrees Celsius, however, if outside temperatures are much cooler, then the lamp needs to stay on and temperatures have to be slowly reduced to be close to that of the temperature they are going to be maintained in.

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ABOUT THE AUTHORS

Okolie, Paul Chukwulozie is a lecturer at the department of Mechanical Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria. He has his Masters of Engineering in Industrial/Production Engineering from the same university, and currently, a Ph.D student at the department of Mechanical Engineering, Nnamdi Azikiwe University Awka,Anambra State, Nigeria.

He is a member of Council For the Regulation of Engineering In Nigeria(COREN), Nigeria Society of Engineers,International Association of Engineers,Nigerian Institute of Management and his research interests are Design,Production and IndustrialEngineering.He has authored so many journals and Papers.

Okafor, Emeka Christian is an Independent Researcher and currently, a Ph.D Student at the department of Industrial/Production Engineering, Nnamdi Azikiwe University Awka,Anambra State, Nigeria.He has his Masters of Engineering in Industrial/Production Engineering from the same University.He is a member of Nigeria Society of Engineers,International Association Of Engineers,Nigerian Institute Of Management and his research interests are Design,Production and Industrial Engineering.He has authored so many journals and Papers.

Chinwuko, Emmanuel Chuka is a lecturer at the department of Industrial/Production Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria. He has his Masters of Engineering in Mechanical/Production Engineering from the same university, and currently, a Ph.D student at the department of Mechanical Engineering, Nnamdi Azikiwe University Awka,Anambra State, Nigeria. He is a member of Council for the Regulation of Engineering in Nigeria (COREN), Nigeria Society of Engineers, International Association of Engineers, and his research interests are Industrial and Production Engineering. He has authored so many journals and Papers.

Ubani, Nelson Obinna is a lecturer at the department of Mechanical Engineering, Micheal Okpara University of Agriculture Umudike,Abia State, Nigeria. He has his Masters of Engineering in Mechanical/Production Engineering from Nnamdi Azikiwe University Awka,Anambra State, Nigeria , and currently, a Ph.D student at the department of Mechanical Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria. He is a member of Council For The Regulation of Engineering In Nigeria (COREN), Nigeria Society of Engineers, International Association of Engineers, Nigerian Institute of Management and his research interests are Thermal,Design and Production Engineering. He has authored so many journals and Papers.

Okenwa, Ugochukwu is a lecturer at the department of Mechanical Engineering, Micheal Okpara University of Agriculture Umudike,Abia State, Nigeria. His research interests are Design and Production Engineering.