

# Modeling the Relationships between the Solar Energy, Trombe Wall Brooder System Parameters and the Brooding Characteristics of Indigenous Chicken

Mulindi S.A., Kanali C., Kituu G., Ondimu S. and Mutwiwa U.

Department of Agricultural and Processing Engineering, Jomo Kenyatta University of Agriculture and Technology, Nairobi

*Abstract— A brooder is a structure where chicken are kept for stimulating optimal growth. Smallholder poultry production in Kenya faces the challenge of appropriate energy source for brooding. The study evaluated by simulation and modelling the performance of a trombe wall in a small-scale brooder. The brooder system under study consist of brick walls and wooden slated floor. The internal dimensions of the brooder being 2.5 x 1.2 x 1.5 m. A dynamic model was used for predicting the brooding conditions based on; ambient temperatures, total solar radiation, ventilation size, thickness and colour of the heat absorption wall. The absorption coefficient for glazed brick is 0.35, absorption factor of black colour is 0.9, and the fraction of incident radiation absorbed is 0.89. Considering a wall thickness of 0.15m, thermal conductivity of 0.8 W/m K, density of bricks -1760 kg/m<sup>3</sup>, surface thermal resistance of the wall - 0.188 m<sup>2</sup>K, thermal wall surface area of 3.75 m<sup>2</sup> and the pen capacity at 30 chicks per square metre. The experimental model of the brooder was solved using a Matlab computer program with appropriate model equations. A case study of Eldoret town was used, where mean monthly solar radiation is 540Wh/m<sup>2</sup>/day to 640Wh/m<sup>2</sup>/day and daily ambient temperature of 14.2<sup>o</sup>C to 28<sup>o</sup>C. The resultant glazed brooder surface temperatures were 77<sup>o</sup>C to 85<sup>o</sup>C. In view of the appropriate brooding temperatures for day old chicks being 34<sup>o</sup>C while at 28 days of age required temperature range is 21-24<sup>o</sup>C. Consequently, the trombe wall can be used to optimally regulate brooder temperatures. Further, the design expert software was used to establish relationship within solar radiation, trombe wall surface temperatures and the optimal brooder envelope temperatures. The analyses showed a linear relationship amongst solar radiation, trombe wall surface temperatures and the optimal brooding temperatures. The results are appropriate*

*data for designing a brooder for physical and physiological studies of chicks.*

**Keywords— Brooder, chicks, design parameters, indigenous chicken, modeling, solar energy and temperatures.**

## I. INTRODUCTION

Brooding refers to early periods of growth when young chicks are unable to maintain their normal body temperature without the aid of artificial supplementary heat (Demeke, 2007). Low temperature results to high mortality rate due to salmonella infection, bunching and crowding with the accompanying evil of smothered chicks. Chicks that become overheated will experience problems like pasting, heat stress, dehydration and eventual death (Okonkwo, 1998). When birds are kept in environmental temperatures above or below their comfort zone, more energy must be expended to maintain body temperature. This extra energy will ultimately be supplied by the feed consumed. Therefore, the energy from the feed will be used to maintain body temperature instead of growth and development resulting in poorer feed conversion (Fairchild, 2012).

According to Kugonza, *et al.*, (2008) indigenous chickens have multipurpose functions in the village economy and the traditional capital system. However, one of the challenges to development of indigenous chicken is housing. Improved management (e.g., housing and breeding) will result in larger indigenous chicken flock sizes, since mortality due to diseases will be reduced (Wachira, *et al.*, 2009). The chick can be easily stressed if its body temperature decreases or increases by as much as one degree. The chick develops the ability to regulate its body temperature around 12 to 14 days of age (Fairchild, 2012). Therefore, it is important to regulate temperatures in the brooder to stimulate optimum growth and minimize mortality of the chicks.

Most of the current research on poultry has been done on disease prevention and control, nutrition and breeding; but limited studies have been done on housing and brooding systems of indigenous chicken. Further, the research on brooding of chicks has to a great extent been carried out using Broiler chicken. The growth rate and feed intake by broiler chicken are quite different from the indigenous chicken and layers. The smallholder chicken rearing is characterized by natural incubation of eggs leading to hatching of chicks in small batches of less than 15 chicks that rarely fit in conventional chick rearing systems. Synchronizing of incubation is an innovation recommended by livestock breeders; the practice is that chicks from two to four hens are given to one foster hen..

According to Ahiaba, *et al*, (2015), thriving of poultry production in developing countries where electricity supply has remained inadequate and unreliable, alternative methods of meeting the energy needs in agriculture and in the poultry industry specifically have to be evolved. These alternative energy needs cannot be over-emphasized, for energy is required at various stages of poultry production. Using biomass energy has the challenge of environmental degradation.

Large-scale utilization of solar energy is fraught with problems due to the low flux density of solar radiation and intermittency. This necessitates the use of large surfaces to collect solar energy. 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 declared by Berg (1976) and Iqball (1983). However, Nwanya and Ike (2012) assert that maintenance of proper brooding temperature is critical to the success of the brooding operation because it impacts on body weight gain.

The objective of this study was to develop the relationships between the incident solar energy, composite solar heating passive brooder system design parameters, and the brooding characteristics of indigenous chicken.

The brooding environment conditions can be predicted by conducting experiments or by using simulation models. Simulation methods provide a quick, less expensive and more flexible and repeatable way compared with the

experimental predictions (Ahmed and Kozai, 2005).

Further, simulation and modeling method is a safe way of conducting studies on animals like chicks to minimize the danger of exposing the chicks to adverse conditions which could lead to high mortality.

## II. METHODOLOGY

### 2.1 Study location

The simulation and modeling was conducted based on the climatic conditions of University of Eldoret ( 0.5207°N and 35.2763 °E) within Eldoret Town–UasinuGishu county in Kenya.

### 2.2 Study procedure

This study evaluates by simulation and modelling the performance of a trombe wall in a small-scale brooder. The brooder system under study consist of brick walls and wooden slated floor. The internal dimensions of the brooder being 2.5 x1.2 x 1.5 m. Thermal wall surface area of 3.75 m<sup>2</sup> and the pen capacity of 30 chicks per square metre.

A dynamic model was used for predicting the brooding conditions based on; ambient temperatures, total solar radiation, ventilation size, thickness and colour of the heat absorption wall. The temperature increase of outside surfaces due to the proportion of the absorbed solar radiation was computed using the equation below (Szokolay, 2004).

$$T_s = T_o + G \cdot \rho \cdot R_{so} \dots \dots \dots (1)$$

Where  $T_s$  (°C) surface temperature,  $T_o$  (°C) is the ambient temperature,  $G$  (W/m<sup>2</sup>) is the global irradiance,  $\rho$  absorption coefficient which depends on materials and colour,  $R_{so}$  (m<sup>2</sup>k/W) threshold level for surface thermal resistance. The

absorption coefficient for glazed brick is 0.35, absorption factor of black colour is 0.9 and the fraction of incident radiation absorbed is 0.89. Considering a wall thickness of 0.15m, thermal conductivity of 0.8 W/m K, density of bricks -1760 kg/m<sup>3</sup>, surface thermal resistance of the wall - 0.188 m<sup>2</sup>K, wall surface area of 3.75 m<sup>2</sup> and the pen capacity at 30 chicks per square metre. The experimental model of the brooder surface temperature was solved using a Matlab computer program with model equation (1). A case study of Eldoret town was used, where mean monthly solar radiation is as shown in Table (1). Global radiation  $G = 1353$  W/m<sup>2</sup>

Table 1: Mean monthly solar (kWh/m<sup>2</sup>/day) for Eldoret town.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0.62	0.64	0.62	0.58	0.58	0.56	0.53	0.53	0.60	0.57	0.55	0.61

The mean daily ambient temperature range is 14.2<sup>0</sup>C to 28<sup>0</sup>C.

The ventilation and air exchange rate are as given by equation (2) and three respectively;

$$\frac{1}{A_i^2} + \frac{1}{A_o^2} = \frac{(2C^2 GH(T_o - T_i))}{T_i V^2} \dots\dots\dots (2)$$

$$Nq = \rho C_p V(T_o - T_i) + (T_o - T_i) \epsilon A_s U_s \dots\dots\dots (3)$$

$$N_q = \rho C_p V \Delta T + \Delta T \sum_{s=1}^n A_s U_s \dots\dots\dots (4)$$

$$N_q - \Delta T \sum_{s=1}^n A_s U_s = \rho C_p V \Delta T \dots\dots\dots (5)$$

$$V = \frac{N_q - \Delta T \sum_{s=1}^n A_s U_s}{\rho C_p \Delta T} \dots\dots\dots (6)$$

A<sub>i</sub>-Inlet area of vents (m<sup>2</sup>),A<sub>o</sub>-Outlet area of vents (m<sup>2</sup>),C -discharge coefficient of vents (normally 0.6-0.65),g -acceleration due to gravity,H -differencebetween inlet and outlet m, T<sub>i</sub>. Inlet air temperature k, T<sub>o</sub> .Outlet air temperature k,ΔT= T<sub>o</sub> -T<sub>i</sub>,V- air exchange rate m<sup>3</sup> s<sup>-1</sup>,N - Number of animals,n- Number ofbuilding surfaces, q -Heat output per animal,ρ - Density of air 1.2 kg m<sup>3</sup>,C<sub>p</sub>specific heat capacity of air, 1010 jkg<sup>-1</sup>K<sup>-1</sup>,A<sub>s</sub> - Surface area of a particular room surface (floor, roof) m<sup>2</sup>,U<sub>s</sub> .Thermal transmittance of particular building surface (floor,roof).

The design expert software was used to establish relationship within solar radiation, trombe wall surface temperatures and the optimal brooder envelope temperatures.The appropriate brooding temperatures for day old chicks is 34<sup>0</sup>C while at 28 days of age required temperature range is 21-24<sup>0</sup>C.The parameters considered for the computation of the relationship were; SolarRadiation, brooder temperatures and inlet temperature (ambient temperatures) while the output was Trombe wall surface temperature.The Box-Behnken design led to 3 levels with 5 centre points as shown in table 2 below.

**2.3 Set up for relation relationship within solar radiation, trombe wall surface temperatures and thebrooder temperatures.**

Table 2: Box-Behnken design for solar radiation, brooder temperature and brooder inlet temperature as factors and Trombe wall surface temperature as response.

		Factor 1	Factor 2	Factor 3	Response
Std	Run	A:Solar Radiation	B:Brooder Room Temp	C:Brooder Inlet Temp	Trombe wall o/s Temp
		Wh/m <sup>2</sup> /day	<sup>0</sup> C	<sup>0</sup> C	<sup>0</sup> C
11	1	590	24	26	
4	2	640	34	21	
3	3	540	34	21	
9	4	590	24	16	
17	5	590	29	21	
14	6	590	29	21	
1	7	540	24	21	
13	8	590	29	21	
10	9	590	34	16	
12	10	590	34	26	
15	11	590	29	21	
2	12	640	24	21	
5	13	540	29	16	
16	14	590	29	21	
7	15	540	29	26	

8	16	640	29	26	
6	17	640	29	16	

**III. RESULTS AND DISCUSSION**

**3.1 Wall surface temperatures for various time of the day**

The glazed brooder surface temperature for all the months of the year for wall thickness of 100,150,225 and 300mm were generated. However, for this study a wall thickness of 150 mm was considered because this is the commonly moulded brick size and used for construction of farm structures in the locality, secondly the resultant surface temperatures throughout the year were above the regular brooding temperatures. Hence regulation of the brooder surface temperatures can be done to achieve the appropriate

brooder envelope temperatures when the 150 mm trombe wall is used for brooding.

The resultant glazed brooder surface temperatures for the 150 mm brick wall were 77°C to 85°C. In view of the appropriate brooding temperatures for day old chicks being 34°C while at 28 days of age required temperature range is 21-24°C. Consequently, the trombe wall can be used to optimally regulate brooder temperatures. Figure 1 shows the brooder surface temperatures for the month of March for various wall thickness with variation in ambient temperatures.

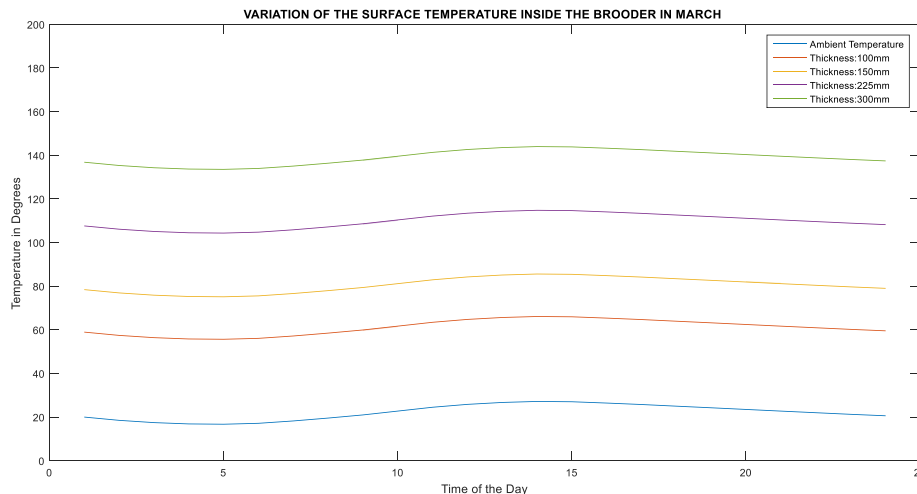


Fig. 1. Surface for various wall thickness for different time of the day

**3.2 Relationship within solar radiation, the optimal brooder envelope temperatures and inlet brooder temperature.**

The solar radiation, the optimal brooder envelope temperatures and inlet brooder temperatures sampled for

study were; Solar radiation 640, 590, and 540Wh/m<sup>2</sup>/day, brooder envelope temperature 24, 29 and 34 °C, brooder inlet temperature-16, 21 and 26 °C. The study yielded surface temperature 47.623°C to 63.480°C as outlined in table 3.

Table.3: Trombe wall surface temperature

Std	Run	Factor 1 A:Solar Radiation Wh/m <sup>2</sup> /day	Factor 2 B:Brooder Room Temp °C	Factor 3 C:Brooder Inlet Temp °C	Response Trombe wall o/s Temp °C
11	1	590	24	26	60.552
4	2	640	34	21	58.480
3	3	540	34	21	52.623
9	4	590	24	16	50.552
17	5	590	29	21	55.552
14	6	590	29	21	55.552

1	7	540	24	21	52.623
13	8	590	29	21	55.552
10	9	590	34	16	60.552
12	10	590	34	26	60.552
15	11	590	29	21	55.552
2	12	640	24	21	58.480
5	13	540	29	16	47.623
16	14	590	29	21	55.552
7	15	540	29	26	57.623
8	16	640	29	26	63.480
6	17	640	29	16	53.480

The analyses showed a linear relationship amongst solar radiation, trombe wall surface temperatures and the optimal brooding temperatures as shown in tables 4 to 10 and summarized in equation (7).

Table 4: Model summary -test of equation type.

Response	2	Tr wall o/s Temp	Transform:	None	
Summary (detailed tables shown below)					
	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	0.0005		0.6762	0.4556	Suggested
2FI	0.1954		0.7313	0.1636	
Quadratic	0.2375		0.7825	-0.5225	
Cubic			1.0000		Aliased

Table 5: Model summary –Sum of squares

Sequential Model Sum of Squares [Type I]					
	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob> F
Mean vs Total	53578.89	1	53578.89		
Linear vs Mean	193.61	3	64.54	12.14	0.0005
2FI vs Linear	25.00	3	8.33	1.89	0.1954
Quadratic vs 2FI	19.12	3	6.37	1.78	0.2375
Cubic vs Quadratic	25.00	3	8.33		
Residual	0.000	4	0.000		
Total	53841.62	17	3167.15		

Table 6: Model summary- Lack of fit tests

Lack of Fit Tests					
	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob> F
Linear	69.12	9	7.68		
2FI	44.12	6	7.35		
Quadratic	25.00	3	8.33		
Cubic	0.000	0			
Pure Error	0.000	4	0.000		

Table 7: Model summary

Model Summary Statistics						
	Std.		Adjusted	Predicted		
Source	Dev.	R-Squared	R-Squared	R-Squared	PRESS	
Linear	2.31	0.7369	0.6762	0.4556	143.02	Suggested
2FI	2.10	0.8321	0.7313	0.1636	219.76	
Quadratic	1.89	0.9048	0.7825	-0.5225	400.00	
Cubic	0.000	1.0000	1.0000		+	Aliased

Table 8: Analysis of variance for surface wall temperatures

ANOVA for Response Surface Linear model						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		Mean	F	p-value	
Source	Square	df	Square	Value	Prob> F	
Model	193.61	3	64.54	12.14	0.0005	significant
A-Solar Radiation	68.61	1	68.61	12.90	0.0033	
B-Brooder Room Temp	12.50	1	12.50	2.35	0.1492	
C-Brooder Inlet Temp	112.50	1	112.50	21.16	0.0005	
Residual	69.12	13	5.32			
Lack of Fit	69.12	9	7.68			
Pure Error	0.000	4	0.000			
Cor Total	262.73	16				

Table 9- Standard deviation

Std. Dev.	2.31	R-Squared	0.7369
Mean	56.14	Adj R-Squared	0.6762
C.V. %	4.11	Pred R-Squared	0.4556
PRESS	143.02	Adeq Precision	11.942
-2 Log Likelihood	72.09	BIC	83.42
		AICc	83.42

Table 10: Equation of the model

	Coefficient		Standard	95% CI	95% CI	
Factor	Estimate	df	Error	Low	High	VIF
Intercept	56.14	1	0.56	54.93	57.35	
A-Solar Radiation	2.93	1	0.82	1.17	4.69	1.00
B-Brooder Room Temp	1.25	1	0.82	-0.51	3.01	1.00
C-Brooder Inlet Temp	3.75	1	0.82	1.99	5.51	1.00

**Final equation interms of coded factors**

Trombe wall surface temperature = 56.14 +2.93\*A +1.25\*B +3.75\*C ..... (7)

Where A- Solar radiation, B-Brooder room temperature and C-Brooder inlet temperature

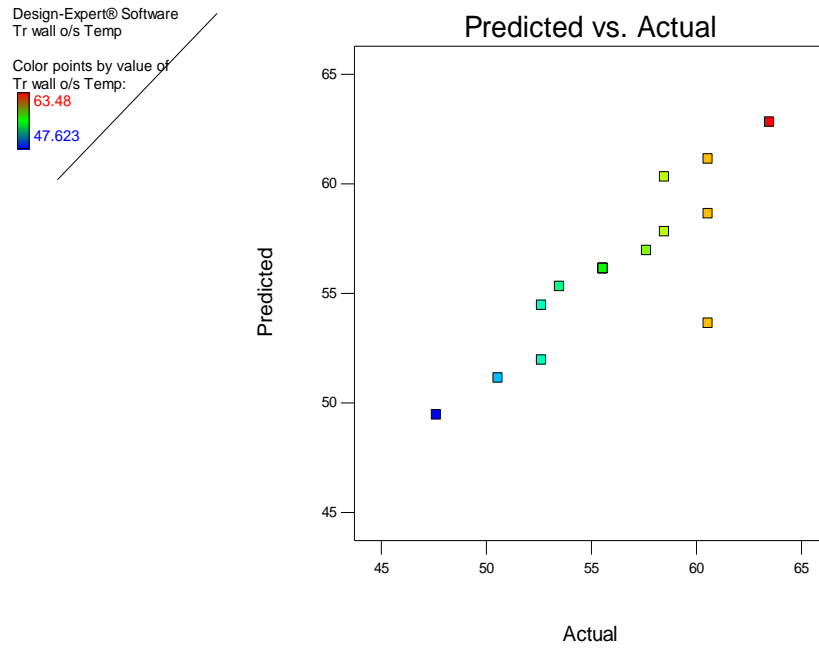


Fig.2. Relationship between actual and predicted figures

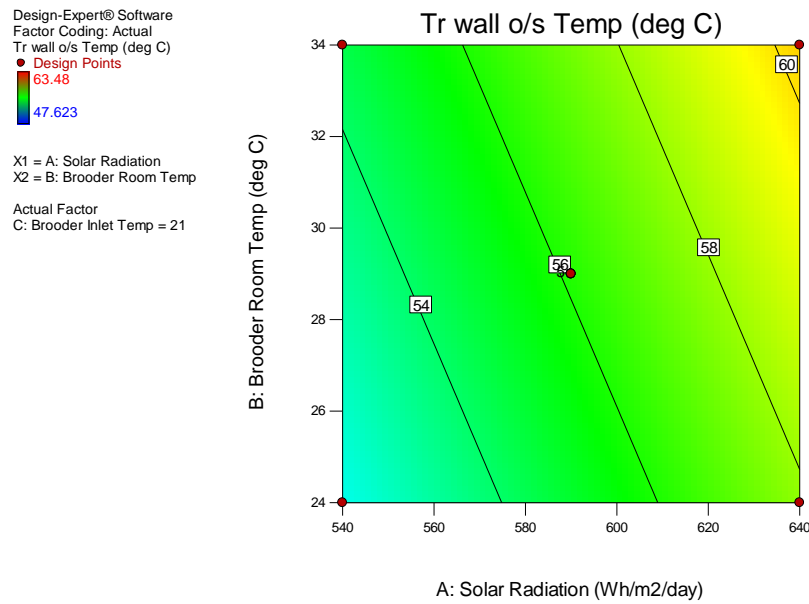


Fig 3. Contour of Solar radiation, Brooder & wall temp

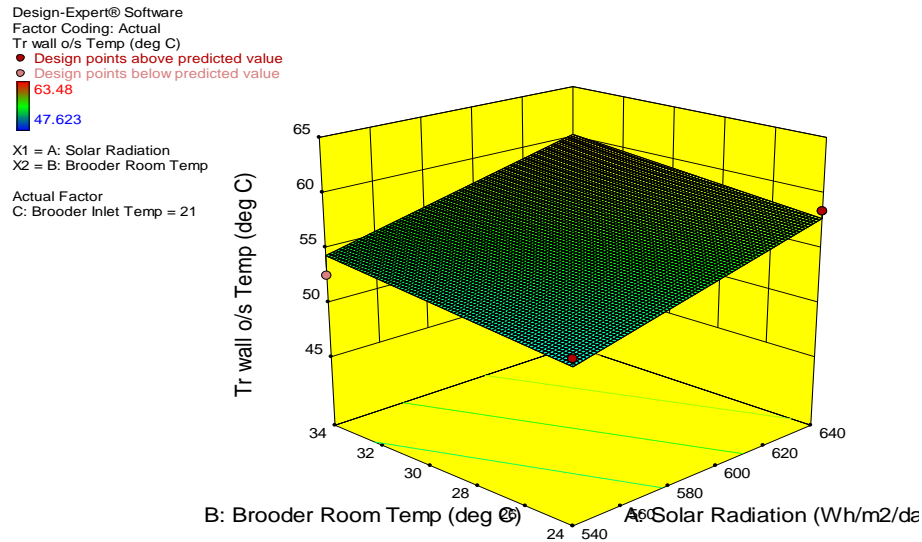


Fig. 4. 3-D for Solar radiation, Brooder temperature and brooder wall surface temperature.

#### IV. CONCLUSION

A brooder constructed of a brick trombe wall and wooden slatted floor can be used to raise chicks since the internal brooder temperatures developed by simulation were within the optimal brooding temperatures for chicken i.e 24 °C to 34 °C. There is a linear relationship amongst solar radiation, trombe wall surface temperatures and the optimal brooding temperatures. Thus, Trombe wall surface temperature =  $56.14 + 2.93 \times \text{solar radiation} + 1.25 \times \text{brooder room temperature} + 3.75 \times \text{brooder inlet temperature}$ .

#### REFERENCES

- [1] Ahiaba U.V., Nwakonobi T.U., Obitta S.E. (2015). Development and Evaluation of a Passive Solar System for Poultry Egg Incubation. International Journal of Engineering Research and General Science Volume 3, Issue 6, November-December, 2015 ISSN 2091-2730. [www.ijergs.org](http://www.ijergs.org)
- [2] Ahmed M. Abdel-Ghany, Toyoki Kozai (2005): Dynamic modeling of the environment in a naturally ventilated, fog-cooled greenhouse. Renewable Energy 31 (2006) 1521-1539. [www.sciencedirect.com](http://www.sciencedirect.com)
- [3] Berg, C.A. (1976). "Potential for Energy Conservation in Industry". *Annual Review of Energy*. 1: 519 – 534
- [4] Demeke S. (2007): Suitability of hay-box brooding technology to rural household poultry production system. *Livestock Research for Rural Development*. Volume 19, Article #3. <http://www.lrrd.org/lrrd19/1/deme19003.htm>
- [5] Fairchild B. (2012). Environmental Factors to Control When Brooding Chicks. UGA Cooperative Extension Bulletin 1287
- [6] Iqbal, M. 1983. *Introduction to Solar Radiation*. Academy Press: New York, NY. 215-275.
- [7] Kugonza D.R., Kyarisiima C. C. and Iisa A., (2008) Indigenous chicken flocks of Eastern Uganda: Productivity, management and strategies for better performance. *Livestock Research for Rural Development*. 20(9) 2008. Department of Animal Science, Makerere University, Kampala, Uganda. [donkugonza@agric.mak.ac.ug](mailto:donkugonza@agric.mak.ac.ug)
- [8] Okonkwo W.I. (1998) "Solar Energy Chick Brooding Technology" In Energy Commission of Nigeria. *Rural Energy Needs and Five Supply Technology* pp 58-71.
- [9] Nwanya A. C., (2012). Comparative evaluation of small scale passive solar brooder system for poultry brooding. *Continental J. Applied Sciences* 7 (1): 7 - 13, 2012 © Wilolud Journals, 2012, ISSN: 1597 – 9928. <http://www.wiloludjournal.com>
- [10] Szokolay S.V. (2004), *Introduction to Architectural Science: The Basis of Sustainable Design*, Elsevier, Oxford Great Britain.
- [11] Wachira, M.A., Mail S.K., Munyasi J.W., Nzioka M., Mwangi D. M., P. Kaguthi P, and Kithome J. Uptake of improved technologies through dissemination by indigenous chicken service providers in southern rangelands of Kenya