Hot and Cold Weather Heat Load Dynamics of Uninsulated Broiler House in Botswana

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ABSTRACT

Most poultry houses in Botswana are naturally ventilated and not insulated despite the long hot summer periods. A study was conducted to quantify the diurnal heat load patterns in a conventional small scale broiler house during the hot and cold weather conditions. The values were partitioned into day and night and expressed as heat fluxes based on floor area. Environmental parameters were measured over a year. These included indoor and outdoor temperature and relative humidity, wind speed and direction, solar radiation, and surface temperatures of the wall and roof materials. Data loggers were used to collect and store data every hour and were periodically downloaded for analysis. The months of February and June were the hottest and coldest, respectively. Hence, data collected during these months were used in the analysis as they represented the weather extremes. During the hot weather, the heat gain, heat loss, and heat stored ranged from -1.5 to 1303.9, 10.1 to 29.8, and -12.5 to 1274.0 Wm^{-2} averaging 703.2, 18.9 and 684.3 Wm^{-2}, respectively, during the day. The corresponding values at night were -6.8 to 17.3, 9.9 to 12.1 and, -16.7 to 6.5 Wm^{-2} averaging 5.9, 10.6, and -4.7 Wm^{-2}. During the cold weather, the heat gain, heat loss, and heat stored ranged from 57.5 to 975.4, -3.1 to 6.8, and 58.6 to 970.9 Wm^{-2} averaging 549.8, 2.4 and 547.4 Wm^{-2}, respectively, during the day. The corresponding values at night were 27.2 to 47.0, -5.3 to -0.5 and, 28.1 to 52.0 Wm^{-2} averaging 39.2, -2.8, and 42.0 Wm^{-2}. During the day, heat gain through the roof was 120% higher than that through the wall during the hot period and 86% higher during the cold period. Natural ventilation by wind was more dominant in summer while thermal buoyancy was more dominant in winter. The data indicates a need to modify the existing structural design such that the intense heat load transmission into the house in summer will be reduced which otherwise cause heat stress to the birds and reduce their productive potential. Further, the housing structure should retain the indoor heat during winter.

Keywords: Heat gain, heat loss, heat storage, broiler, solar radiation, natural ventilation.

1. INTRODUCTION

High ambient temperatures and solar radiation heat transmitted through building envelopes result in extreme heat loads in sub-tropical regions (Magoko and Gustafsson, 1994). This problem is compounded by excessive animal heat loads causing heat stress on the animals which consequently result in reduced animal production, performance, impaired welfare and degradation of the environment for workers (Aradas *et al*., 2005; Zhang *et al*., 2001; North, 1984). Poultry houses in the tropics are often inadequately insulated against solar radiation. Increased ventilation, use of reflecting building surfaces and building materials with high heat storage capabilities, and improved insulation are some of the means of reducing the heat loads in the tropics (Magoko and Gustafsson, 1994). Guidelines for summer ventilation in animal houses that have been developed for temperate regions (CIGR, 1989) do not consider high heat loads from solar radiation in poorly insulated houses in the tropics.

Most poultry houses in Botswana (17^o and 27^o South latitudes and 20^o and 30^o East longitudes) are not insulated despite the long hot summer periods. Ventilation is predominantly natural where it is generated by thermal buoyancy and wind (Nääs *et al.*, 1998). Thermal buoyancy is important on still days. When the temperature difference between inside and outside air conditions is small, the convection produced by wind moving through the openings is the dominant mode of natural ventilation in hot weather. Properly sized wall openings, angle of incidence of the wind, and wind velocity are critical for effective operation of structures ventilated by wind (Nääs *et al*., 1998; Verlinde *et al*., 1998). Work has not been done in Botswana to assess the performance of the conventional small scale broiler houses despite reports of heat stress by producers. Thus, there is need to quantify the dynamics of heat loads in these houses and consequently design a suitable structure that would improve bird comfort. Hence, the objectives of this study are to quantify the diurnal heat load patterns in the conventional broiler house during hot and cold weather conditions and partition the values between day and night.

2. MATERIALS AND METHODS

2.1 Broiler House Description

A small scale broiler house at the Botswana College of Agriculture was monitored in this study. Table 1 summarizes its size and thermal characteristics.

Table 1. Size and thermal characteristics of the broiler house monitored

Building Component	Length (m)	Width (m)	Height (m)	Slope (degrees)	U-value ($Wm^{-2}K^{-1}$)	α	ε
Dwarf side wall	16.0	0.11	0.7	90	3.45	0.4	0.9
Eave height			2.4				
End wall		7.6	3.4	90	3.5	0.4	0.9
Floor	16.0	7.6					
Ridge vent	16.0	0.45					
Summer side wall opening	15.0		1.7				
Winter side wall opening	15.0		0.17				
South-facing roof	16.8	5.3		14	3.85	0.53	0.25
North-facing roof	16.8	4.2		8	3.85	0.53	0.25
End wall characteristic length	3.4						
Dwarf side wall characteristic length	0.7						
South-facing roof characteristic length	5.3						
North-facing roof characteristic length	4.2						

No supplemental heating or cooling throughout. Lighting with 3 fluorescent light bulbs at 58W each. Ventilation was natural all-year-round. α = absorption coefficient for solar radiation; ε = thermal radiation emmitance of the surface.

2.2 Environmental Parameter Measurements

The indoor temperature and relative humidity (RH) was measured using Hobo Pro temperature and RH data logger (Model H08-032-08) placed in the middle of the house at 1.0 m above the floor. A similar data logger was used to measure outdoor temperature and RH placed 2.0 m above the ground near the sidewall opening. The indoor black globe temperature was measured using PT 510 platinum RTD temperature sensor inserted mid way into a 12 cm diameter black toilet float placed in the middle of the house at 1.0 m above the floor. The wind speed and direction was measured using Hobo SWCA smart sensor (Model 7911) connected to a Hobo weather station data logger (Model H21-001) placed on the broiler house roof top at a height of 4.6 m above the ground surface. At the same location was a pyranometer (Model LP PYRA 03) for measuring solar radiation intensity. The inside and outside surface temperatures of the walls were measured using PT510 platinum RTD temperature sensors connected to XR5 data logger (Model XR5-8A-SE). The sensors were placed in the middle and mid-height of each of the four walls (two end walls facing East-West and two side walls facing North-South). All the instruments were obtained from AWR Smith Process Instrumentation CC, Randburg, South Africa. The average value of each parameter was recorded every hour in the data loggers and downloaded periodically for analysis. The measurement period was from January to December 2005.

2.3 Data Handling and Analysis

The all-year-round data were analyzed to determine the hottest and coldest months. The average data for these months were used in the analysis as they represented the weather extremes. Before analysis, the data were inspected to remove outliers and averages calculated for each hour for the entire month to obtain diurnal patterns. The calculations of heat gain, loss and storage were performed using the foregoing equations and expressed as fluxes based on floor area.

2.3.1 Heat Gains

There was no supplemental heating in the house during the study. Hence, three modes of heat sources were considered.

2.3.1.1 Sensible Heat Gain from the Birds, Q_s: Total heat production (THP, $Wbird^{-1}$) of the broilers was estimated using equation [1].

$$THP = 10M^{0.75} \qquad \text{(CIGR, 1999)} \qquad [1]$$

Typically for small scale producers in Botswana, about 1500 birds are reared per house with birds attaining average live body mass (M) of 1.5 kg per bird at slaughter. To obtain THP in Wm^{-2} of floor area, equation [1] was multiplied by 1500 birds divided by floor area (121.6 m^2). THP was reduced by 25% (Xin *et al.*, 1996) for night time calculations to account for reduced bird activity.

To obtain sensible heat production (SHP) of the birds, data on THP and SHP as functions of indoor temperature for broilers published in CIGR handbook (1999) were used and SHP was expressed as percentage of THP (% SHP of THP) at various temperatures. Regression models were developed using these data to obtain relationships between % SHP of THP and indoor temperatures. The selected indoor temperatures were representative of those recorded in this study and were 22 to 37^o C for hot season and 7 to 26^o C for cold season. Temperatures in the CIGR handbook ranged from 10 to 40^o C. The % SHPs were calculated for each mean temperature recorded. Then, the calculated THP was multiplied by the corresponding % SHP of THP to obtain the SHP values. The regression models developed are:

For hot period with indoor black globe temperatures (t_i) of 22 to 37^o C,

$$\%\ SHP\ of\ THP = -0.1488 t_i^2 + 6.6428 t_i - 18.485 \qquad R^2 = 0.9981 \qquad [2]$$

For cold period with t_i of 10 to 26^o C,

$$\%\ SHP\ of\ THP = -0.0202 t_i^2 + 0.4464 t_i + 55.255 \qquad R^2 = 0.9944 \qquad [3]$$

For equation [3], there were five data points where temperatures were below 10^{o}C (ranged from 7 to 9^o C). To be conservative, the % SHP of THP at 10^o C was 58% and was used in the calculation of SHP for all the five data points. Thus, for both hot and cold periods,

$$SHP = \frac{\%\ SHP\ of\ THP}{100} \times THP \qquad [4]$$

2.3.1.2 Sensible Heat Gain from Electrical Source, Q_m: Fluorescent lights were the only sources of electrical heat and these add 20% more heat than the installed wattage due to power required to operate the ballasts. Equation [5] was used to quantify the heat flux.

$$Q_m = \frac{1.2 R_w \cdot N}{A_f} \qquad [5]$$

where R_w and N are rated wattage and total number of fluorescent light bulbs, respectively; A_f is floor area, m^2. At night, Q_m was 0.

2.3.1.3 Solar Heat Gain, Q_{so}: Due to high solar radiation intensity in Botswana, the sol-air temperature approach was used to quantify heat gains via the roof and wall using equation [6].

$$Q_{so} = \frac{h_c \cdot A_c \cdot (t_{sa} - t_s)}{A_f} \qquad [6]$$

where Q_{so} = solar heat gain through the component (wall or roof), Wm^{-2}; A_c = surface area of component, m^2; t_{sa} = sol-air temperature of component; t_s = surface temperature of component, ^{o}C; h_c = convective heat transfer coefficient of component, Wm^{-2}K^{-1}. The h_c factors were determined using standard equations presented in ASHRAE (2001).

The sol-air temperature or effective outside temperature of the various surfaces were calculated using equation [7].

$$t_{sa} = t_o + \left[\frac{\alpha I - 6\varepsilon \cos\phi (10 - \Omega)}{h_c} \right] \qquad [7]$$

where α = absorption coefficient for solar radiation ; I = solar radiation intensity, Wm^{-2}; ε = thermal radiation emittance of the surface; ϕ = angle of inclination of the surface; Ω = cloud cover and clear sky conditions were assumed in this study.

The overall heat gain was the sum of [4], [5], and [6].

2.4.2 Heat Losses

The heat losses were considered through the wall and roof, slab floor, and ventilation air.

2.3.2.1 Heat Loss Through the Structural Components (wall or roof), Q_c: It was calculated as

$$Q_c = \frac{\sum_c (UA)_c \cdot (t_i - t_o)}{A_f} \qquad [8]$$

where U = overall unit area thermal conductance of component, $Wm^{-2}K^{-1}$, A = area of structural component, m^2; c = path of heat transfer which may be wall or roof component.

2.3.2.2 Heat Exchange with the Slab Floor, Q_f: It was calculated as

$$Q_f = FP \cdot (t_i - t_o) \qquad [9]$$

where P = building perimeter, m; F = an experimentally determined perimeter heat loss factor, $Wm^{-1}K^{-1}$. Values of F for an uninsulated and unheated slab floor on grade range between 1.4 and 1.6 $Wm^{-1}K^{-1}$, depending on the severity of the winter (Albright, 1990). In this study, an F value of 1.4 $Wm^{-1}K^{-1}$ was used.

2.3.2.3 Sensible Heat Contained in the Ventilation Air (Q_v): Natural ventilation is determined by wind effects and thermal buoyancy. Thus, heat loss due to wind-induced ventilation (Q_{vw}) and thermal buoyancy (Q_{vt}) were considered. These were added by quadrature to give Q_v. The sensible heat contained in the ventilation air entering the house was assumed to be equal to that leaving the house. The difference between these air streams is the heat lost from the house and was calculated as

$$Q_v = \frac{C_p \cdot \rho \cdot \dot{V}_{tot} \cdot (t_i - t_o)}{A_f} \qquad [10]$$

where; C_p = specific heat of moist air, $Jkg^{-1}K^{-1}$; ρ = air density, kgm^{-3}; $\dot{V}_{tot}$ = the sum of volumetric air flow rate due to wind and thermal buoyancy, m^3s^{-1}.

The C_p and ρ were calculated using standard equations presented in ASHRAE (2001). The wind-induced and thermal buoyancy-induced ventilation rates approximately add through quadrature.

$$\dot{V}_{tot} = \left(\dot{V}^2_{wind} + \dot{V}^2_{thermal}\right)^{0.5} \qquad \text{(Albright, 1990)} \qquad [11]$$

Due to difficulty in estimation of the coefficients required in the pressure coefficient method used to estimate ventilation produced by wind, the empirical expression was used to predict the flow through the sidewall opening as a function of wind velocity and opening effectiveness.

$$\dot{V}_{wind} = E \cdot A_o \cdot V \qquad \text{(ASHRAE, 2001)} \qquad [12]$$

where E = ventilation opening effectiveness; A_o = area of ventilation inlet opening, m^2; V = wind velocity, ms^{-1}.

The ventilation opening effectiveness values used were 0.60, 0.5, 0.35, 0.30, and 0.25 for wind directions 85 to 90, 70 to 85, 50 to 70, 30 to 50, and 10 to 30^o to the openings, respectively (Nääs *et al*., 1998).

Wind velocity was measured at 4.6 m above the ground. The midpoint of the ventilation opening from the ground was 1.6 m which was regarded to be close to 2 m. Then, a logarithmic equation of wind speed profile was used to determine the equivalent wind speed through the ventilation opening.

$$V_2 = V_z \frac{4.87}{\ln(67.8z - 5.42)} \qquad \text{(Allen \textit{et al}., 1998)} \qquad [13]$$

where V_2 = wind speed at 2 m above the ground; V_z = measured wind speed at z m above the ground surface; z = height of measurement above the ground surface, m.

Volumetric air flow rate due to thermal buoyancy was calculated as

$$\dot{V}_{thermal} = C_D A_o \left[2g\Delta H_{NPL}(T_i - T_o)/T_i\right]^{0.5} \qquad \text{(ASHRAE, 2001)} \qquad [14]$$

where C_D = discharge coefficient of opening which accounts for all viscous effects such as surface drag and interfacial mixing; g = gravitational constant, 9.81 ms^{-2}; ΔH_{NPL} = distance between the midpoint of the sidewall opening and the Neutral Pressure Level (NPL) or ridge vent, m; T_i and T_o = inside and outside air temperatures, ^oK.

For summer conditions, openings were fully open and C_D of 0.65 was used as the flow was assumed to be unidirectional with no mixing. During winter, sidewall curtains were 90% closed and the ridge vent remained fully open. The inside air was warmed by the heat from the birds and air would rise and escape through the ridge vent resulting in fresh air entering the house from both sidewall openings. This may result in interfacial mixing of the air and C_D was calculated as

$$C_D = 0.40 + 0.0045|T_i - T_o| \qquad \text{(Kiel and Wilson, 1986)} \qquad [15]$$

The sidewall and ridge vent openings were not equal and had ratios of 3.5 and 2.8 in summer and winter, respectively. As a result, the ventilation rates determined with equation [14] were increased by 36 and 33% in summer and winter, respectively. The percent increases were determined using data presented in ASHRAE (2001) which depicts the relationship between ratio of outlet to inlet area or vice versa and percent increase.

The overall heat loss was the sum of [8], [9], and [10].

2.3.2 Heat Storage

The amount of heat stored was calculated as

$$Heat\ stored = Total\ heat\ gain - Total\ heat\ loss \qquad [16]$$

3. RESULTS AND DISCUSSIONS

3.1 Hot Weather Conditions

The month of February was the hottest and its data were used to represent the hot period.

3.1.1 Environmental Conditions

Figure 1 shows the environmental conditions inside and outside the broiler house during the hot weather conditions.

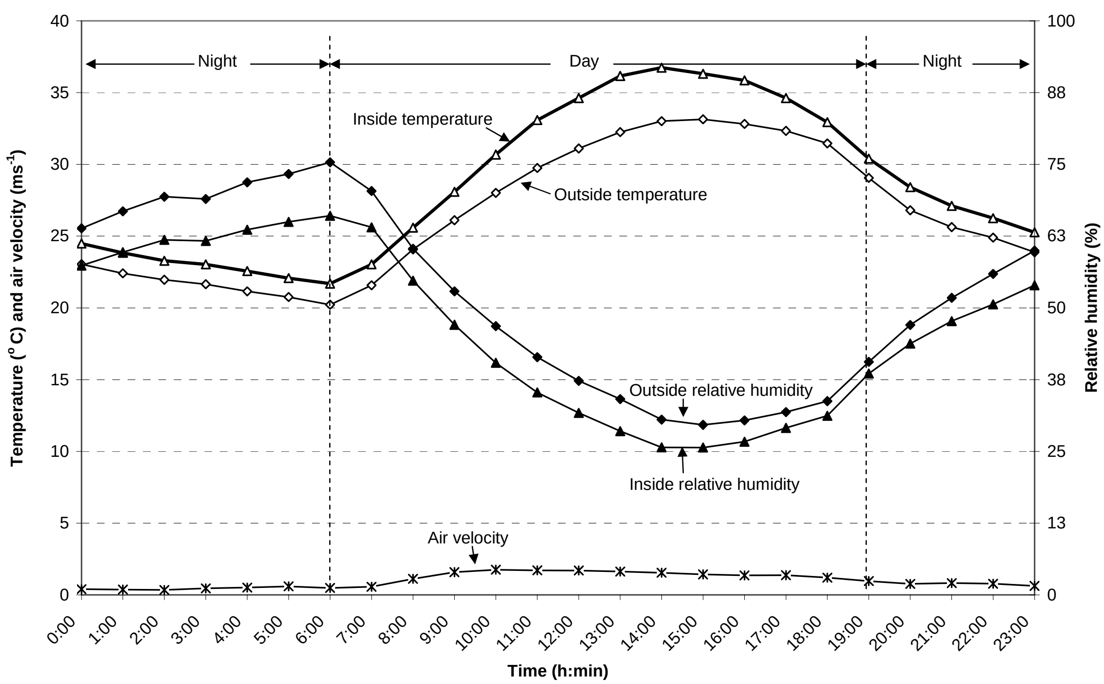

Figure 1. Diurnal environmental conditions during the hot weather

The inside temperature and RH ranged from 21.7 to 36.7^{o} C and 26 to 66%, respectively. The corresponding outside temperature and RH ranged from 20.2 to 33.0^{o} C and 30 to 75%, respectively. The inside temperature was consistently higher than outside temperature due to high solar heat and absorption during the day by building elements and other objects in the house resulting in heat dispersion from the house at night. Air velocity ranged from 0.3 to 1.8 ms^{-1}, averaging 1.0 m^{s-1}.

3.1.2 Conductive Heat Gains

Table 2 shows the mean day, night, and time-weighted average (TWA) heat gains and losses during the hot weather. The largest solar heat gain was through the uninsulated roof (435.1 Wm^{-2}) followed by that through the uninsulated wall (197.6 Wm^{-2}) during the day. Heat gain through the roof alone constituted 60% of total heat gain during the day while the wall constituted 30%. This is consistent with findings by Liberati and Zappavigna (2001) who reported that among the elements that constitute the building's housing, the covering is the part that has greatest effect on thermal exchanges both regarding solar energy in the day and night dispersion. At night, the negative heat gain through the roof and wall was caused by the surface temperatures being higher than the sol-air temperature resulting in heat loss from the house. The heat gains were -52.2 and -8.1 Wm^{-2} through the roof and wall, respectively.

Table 2. Heat gains, heat losses and heat stored (Wm^{-2}) during the hot weather

Period	**Heat gains**					**Heat losses**					***Heat**
	Roof	**Wall**	**Birds**	**Lights**	*Total*	**Roof**	**Wall**	**Floor**	**Vent.**	*Total*	**Stored**
Night (n=11hrs)	-52.2	-8.1	66.1	0.0	*5.9*	7.1	2.6	0.8	0.06	*10.6*	-4.7
SEM	1.7	0.5	2.3	0.0	*2.5*	0.1	0.1	0.0	0.00	*0.2*	
Day (n=13 hrs)	435.1	197.6	68.9	1.6	*703.2*	12.6	4.7	1.4	0.34	*18.9*	684.3
SEM	84.4	41.9	4.9	0.1	*124.8*	0.5	1.3	0.1	0.06	*2.0*	
TWA	211.7	103.3	67.6	0.9	*383.6*	10.1	3.7	1.1	0.21	*15.1*	368.5

TWA = Time-weighted average; Vent. = Convective heat loss via ventilation air; *Heat stored = total heat gains - total heat losses
SEM = Standard error of the mean

The rate of heat flow depends on the amount of temperature difference and the thermal conductivity of the material. The temperature difference between the roof surface and indoor air ranged from 1.8 to 27.1 and 2.3 to 4.1^{o} C during the day and night, respectively. For the wall, the corresponding temperature differences were 1.1 to 10.2 and 1.8 to 3.7^{o} C. The roof was made of thin zinc-coated corrugated iron sheets which have high thermal conductivity of 116 $Wm^{-1}K^{-1}$ at 27^{o} C when compared to the wall made of hollow 110 mm concrete blocks at 1.1 $Wm^{-1}K^{-1}$ at 27^{o} C (Incropera and DeWitt, 1996). Hence, the rate of heat flow through the roof was higher than that through the wall.

Liberati and Zappavigna (2001) suggested that research directed for improving thermal performance of housing structures should concentrate on the roof. Amendola *et al*. (2001) recommended the use of roof insulation mainly to reduce the effects of solar radiation in already built housing to reduce heat stress on the animals which may lower their productive potential. Further, the authors reported 3 to 8% mortality in broilers reared in house with roof insulation with10 to 22 $birdsm^{-2}$ whereas those reared in a house without roof insulation recorded mortality of 7 to 14% at similar bird density. They also reported production per unit area of 20 to 38 kgm^{-2} compared to 19 to 36 kg/m^2. These effects were attributed to heat stress. Chepete *et al.* (2005) reported mortality of 4 to 9% and production per unit area of 23 to 29 kgm^{-2} for Cobb broilers reared in uninsulated naturally ventilated houses at 12 $birdsm^{-2}$ density.

Where possible, an auxiliary cooling system would help reduce the heat load for the housed animals to remain comfortable. The roof overhang was 0.5 m from the wall. Larger roof overhangs cast large shadows which cools the air before it enters the house (El Boushy and van Marle, 1978).

3.1.3 Heat Gains from Birds and Lights

The estimated sensible heat load from the birds was 68.9 and 66.1 Wm^{-2} during the day and night, respectively. Thus, the birds contributed 10% of the total heat gain during the day. At night, the birds were the only source of sensible heat in the house which may have contributed to elevated indoor night temperatures (Figure 1). The lights only contributed 0.2% to total heat gain during the day.

3.1.4 Conductive Heat Losses

The heat loss during the day was higher through the roof (12.6 Wm^{-2}) than through the wall (4.7 Wm^{-2}) and was 7.1 and 2.6 Wm^{-2} at night, respectively. The amount of conductive heat loss is largely determined by the temperature difference between indoor and outdoor temperatures. The differences ranged from 1.3 to 3.9 and 1.3 to 1.6^{o} C during the day and night, respectively. Thus, larger heat losses were experienced during the day than at night. During the day, the heat loss was not sufficient to offset the heat gains resulting in high heat storage which averaged 684.3 Wm^{-2}. The consequent dispersion of the stored heat may have resulted in elevated indoor temperature (Figure 1) which could potentially stress the birds especially during the day. Deaton *et al.* (1968) reported a significant decrease in body weight of 5-week old broilers when exposed to dry bulb temperature above 26.7^{o} C for half an hour or more. In this study, indoor temperatures from 0900 h to 1900 h ranged between 28.1 and 36.7^{o} C. The lowest heat loss was experienced through the floor probably due to insulation provided by the wood shavings and other objects like feeders and drinkers.

3.1.5 Heat Loss through Ventilation Air

Natural ventilation is determined by wind effects and thermal buoyancy (Verlinde *et al.,* 1998). The wind speed ranged from 0.5 to 1.8 and 0.3 to 0.8 ms^{-1} during the day and night, respectively. This correspondingly resulted in wind-induced ventilation rates of 3.6 to 24.1 and 2.2 to 6.0 m^3s^{-1}. The angles of incidence of the wind were 40 to 90 and 3 to 48^{o} during the day and night, respectively. The wind speed and orientation of the building with respect to the prevailing wind direction greatly affect air flow through the house (Verlinde *et al.,* 1998). The ventilation opening effectiveness is higher (0.60) for incident wind directions of 90^{o} or closer and lower (0.25) for those below 30^{o}. Thus, for the same wind speed, the highest air flow rate is experienced when the wind direction is perpendicular to the ventilation opening than at other angles. Thermal buoyancy-induced ventilation rates were 2.5 to 4.3 and 2.5 to 2.8 m^3s^{-1} during the day and night, respectively. The corresponding temperature differences were 1.3 to 3.9 and 1.3 to 1.6^o C during the day and night. Generally, wind-induced ventilation was more dominant than thermal buoyancy-induced ventilation during the hot period. ASHRAE (2001) reports that wind speeds higher than 0.75 ms^{-1} produce greater ventilation than does thermal buoyancy with temperature difference of 3^o K.

The combined wind and thermal buoyancy ventilation rates were 4.5 to 24.3 m^3s^{-1} (averaging 14.3 m^3s^{-1}) and 3.4 to 6.5 m^3s^{-1} (averaging 5.0 m^3s^{-1}) during the day and night, respectively. This resulted in an overall heat loss of 0.06 to 0.71 Wm^{-2} (averaging 0.34 Wm^{-2}) and 0.04 to 0.09 Wm^{-2} (averaging 0.06 Wm^{-2}) during the day and night, respectively (Table 2). The low wind speed and temperature difference may have caused this low heat loss values.

Under controlled environment, the maximum bird-level ventilation rate of 6.0 $m^3hr^{-1}kg^{-1}$ is recommended (Ross breeder Ltd, 1995). In this study, the time weighted average ventilation rate at 2 m height was 16.1 $m^3hr^{-1}kg^{-1}$. The ventilation rate in this study was higher and appears to indicate over-ventilation. However, this may not be the case because the recommended values have been developed in regions of lower solar heating with insulated poultry houses. High solar heating and lack of insulation of poultry houses in Botswana requires higher ventilation rates to remove excess heat in summer. The high indoor temperatures (Figure 1) suggest that the ventilation rate experienced was not sufficient to keep the temperatures comfortable. Perhaps this may be attributed to structural design particularly size of opening, height of dwarf wall, roof pitch and orientation relative to predominant wind direction. There is need to cool the air before it enters the house and insulate the roof and / or walls (El Boushy and van Marle, 1978).

3.1.6 Overall House Thermal Performance

Figure 2 shows the dynamic heat gain, loss and storage. During the day, the heat gain, heat loss, and heat stored ranged from -1.5 to 1303.9, 10.1 to 29.8, and -12.5 to 1274.0 Wm^{-2}, respectively. The corresponding values at night were -6.8 to 17.3, 9.9 to 12.1 and, -16.7 to 6.5 Wm^{-2}.

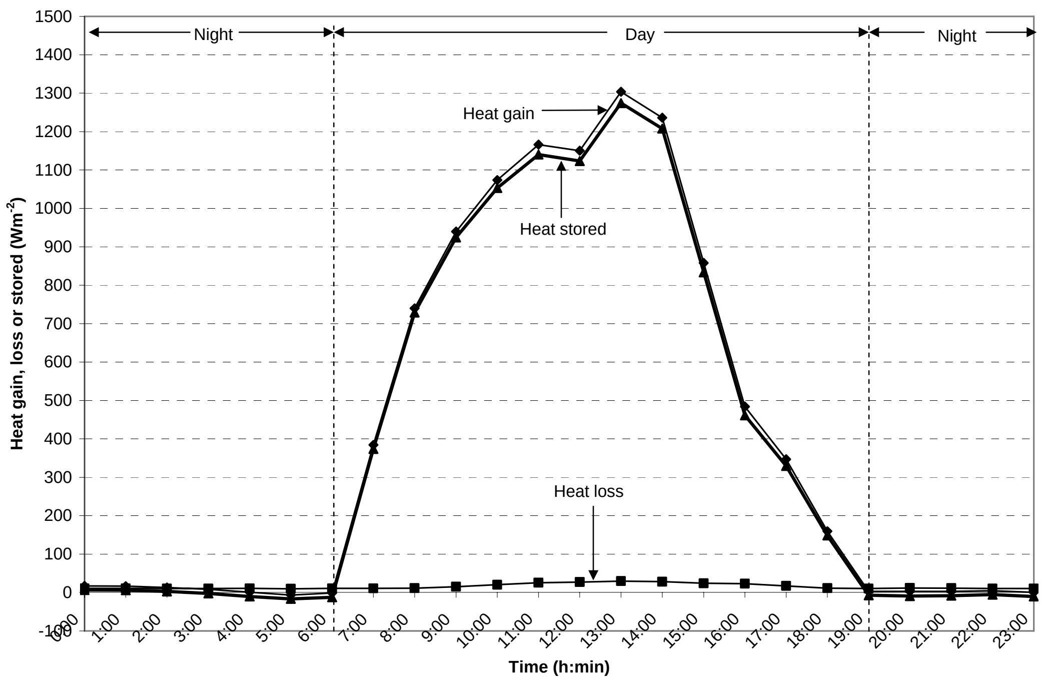

Figure 2. Diurnal heat gain, heat loss and heat stored during the hot weather

3.2 Cold Weather Conditions

The month of June was the coldest and its data were used to represent the cold period.

3.2.1 Environmental Conditions

Figure 3 shows the environmental conditions inside and outside the broiler house during the cold period. The inside temperature and RH ranged from 7.4 to 26.0^{o} C and 22 to 72%, respectively. The corresponding outside temperature and RH ranged from 7.3 to 25.2^{o} C and 22 to 80%, respectively. The temperature difference between inside and outside was higher between 1800 h

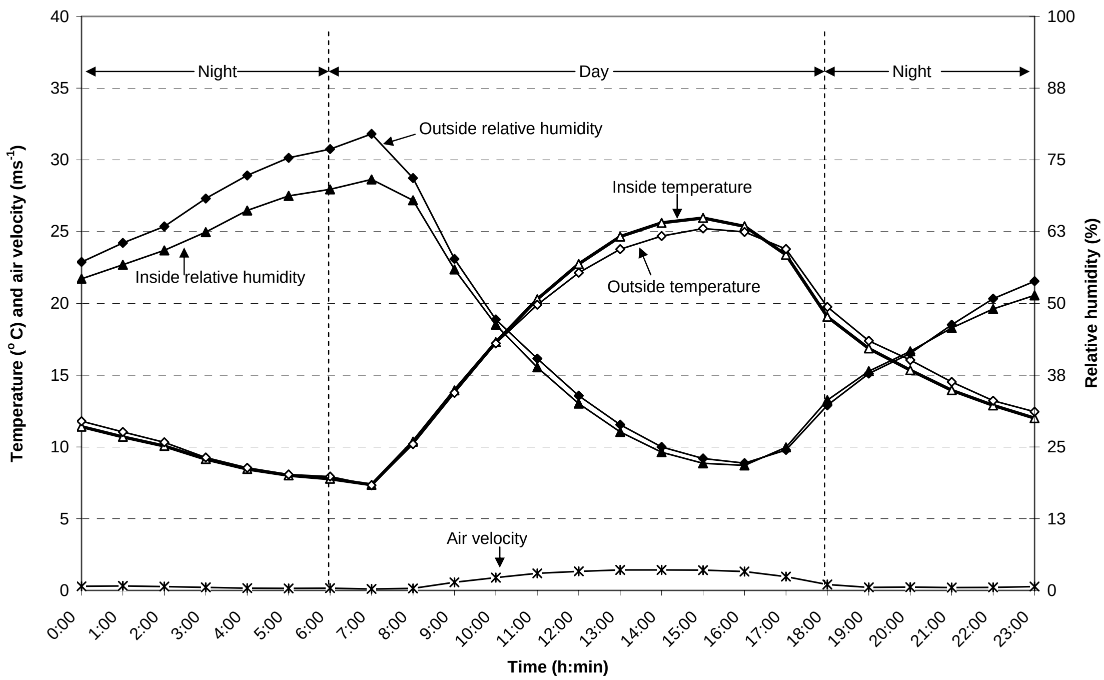

Figure 3. Diurnal environmental conditions during the cold weather

and 0100 h and were similar between 0200 h and 0600 h. This may have been caused by the sensible heat generation from the birds at night (averaging 72.1 Wm^{-2}) which accumulated in the house and gave rise to indoor temperature by the early hours of the morning. Air velocity ranged from 0.1 to 1.4 ms^{-1}, averaging 0.6 ms^{-1}.

3.2.2 Conductive Heat Gains

Table 3 shows the mean day, night, and time-weighted average (TWA) heat gains and losses during the cold weather. The trends of solar heat gain through the roof and wall are similar to that reported in the hot weather. The total heat gain through the roof was higher (295.8 Wm^{-2}) than that gained through the wall structure (159.3 Wm^{-2}) during the day. Thus, 50% of total sensible heat gain was through the roof and 30% through the wall. Compared to the hot weather period, the magnitudes of the heat gains are lower largely because of reduced solar heating as the temperature differences between the roof or wall surfaces and indoor temperatures are quite comparable. The temperature differences for the roof ranged from 2.6 to 20.8 and 2.8 to 4.9^{o} C during the day and night, respectively. Correspondingly, the differences for the wall ranged from 0.2 to 6.7 and 0.1 to 3.9^{o} C. The solar radiation ranged from 66.9 to 1035.6 and 6.8 to 624.8 Wm^{-2} during the hot and cold weather periods, respectively. The heat gains were much higher than losses leading to a substantial amount of heat storage in the house which averaged 547.4 Wm^{-2} during the day. However, the dispersion of the stored heat was not sufficient to maintain a 24 to 25^{o} C thermoneutral temperature suitable for 1.5 kg broilers (Cobb Broiler Management Guide, 2004). The indoor temperature ranged from 7.4 to 22.7 and 24.6 to 25.4^o C from 1700 to 1200 and 1300 to 1600 hrs, respectively. Thus, the birds were in a cold environment most of the time.

Table 3. Heat gains, heat losses and heat stored (Wm^{-2}) during the cold weather

Period	**Heat gains**					**Heat losses**					***Heat**
	Roof	**Wall**	**Birds**	**Lights**	*Total*	**Roof**	**Wall**	**Floor**	**Vent.**	*Total*	**Stored**
Night (n=12hrs)	-30.3	-2.5	72.1	0.0	*39.2*	-1.9	-0.7	-0.2	-0.002	*-2.8*	42.0
SEM	2.3	0.6	0.1	0.0	*1.9*	0.1	0.3	0.0	0.000	*0.5*	
Day (n=12 hrs)	295.8	159.3	92.9	1.7	*549.8*	1.6	0.6	0.2	0.004	*2.4*	547.4
SEM	64.9	36.1	0.9	0.0	*99.8*	0.2	0.6	0.1	0.000	*0.9*	
TWA	132.8	78.4	82.5	0.9	*294.5*	-0.1	-0.1	0.0	0.001	*-0.2*	294.7

TWA = Time-weighted average; Vent. = Convective heat loss via ventilation air; *Heat stored = total heat gains - total heat losses
SEM = Standard error of the mean

This indicates a need to incorporate a heating system to augment the sun and birds as the major sensible heat sources as well as roof and wall insulation to help retain the heat (El Boushy and van Marle, 1978).

At night, the negative heat gains through the roof and wall were caused by the surface temperatures of the elements being higher than the sol-air temperatures resulting in heat loss from the house.

3.2.3 Heat Gains from Birds and Lights

During the day, the birds produced 92.9 Wm^{-2} of sensible heat which reduced to 72.1 Wm^{-2} at night due to reduced physical activity of the birds (Xin *et al*., 1996). This represents 20% contribution to total heat gain during the day while the lights contributed 0.3%.

3.2.4 Conductive Heat Losses

The total heat loss during the day was 1.6 and 0.6 Wm^{-2} through the roof and wall, respectively. Correspondingly, the losses at night were -1.9 and -0.7 Wm^{-2}. The indoor and outdoor temperature differences were small (Figure 3) resulting in very low conductive heat losses. The differences were 0 to 0.9 and 0.1 to 0.7^o C during the day and night, respectively. These differences are comparable and resulted in losses which are close in magnitude (Table 3). The heat losses at night were negative because the outdoor temperatures were higher than those for indoor resulting in heat gain into the house. Little heat exchange occurred through the floor as earlier explained.

3.2.5 Heat Loss through Ventilation Air

The wind speed ranged from 0.1 to 1.4 and 0.1 to 0.4 ms^{-1} during the day and night, respectively. This correspondingly resulted in wind-induced ventilation rates of 0.1 to 2.0 and 0.1 to 0.4 m^3s^{-1}. In Botswana, the wind speeds are lower in winter than in summer. The angles of incidence of the wind were 19 to 88 and 7 to 56^o during the day and night, respectively. The reasons earlier advanced about the effect of prevailing wind direction on wind speed are true even in winter conditions. Thermal buoyancy-induced ventilation rates ranged from 0.1 to 0.5 m^3s^{-1} during the day and night. The corresponding temperature differences were 0.0 to 0.9 and 0.1 to 0.7^o C during the day and night and are comparable. Thermal buoyancy-induced ventilation was higher than wind-induced ventilation 80% of the time at night when air velocity was lower than during the day. This is in agreement with Boulard *et al.* (1998) who reported that the relative importance of thermal buoyancy and wind forces depends on the ratio between wind velocity and the root of the inside outside temperature difference ($V/\Delta T^{0.5}$). When the wind is low, this ratio is small and the buoyancy forces are important.

The combined wind and thermal buoyancy ventilation rates were 0.1 to 2.1 m^3s^{-1} (averaging 1.0 m^3s^{-1}) and 0.2 to 0.6 m^3s^{-1} (averaging 0.4 m^3s^{-1}) during the day and night, respectively. The resultant overall heat losses were negligible (Table 3) probably due to low wind speed and small temperature differences between indoor and outdoor air. The minimum ventilation rate of 0.6 $m^3hr^{-1}kg^{-1}$ is recommended under controlled environment (Ross breeder Ltd, 1995). In this study, the time weighted average ventilation rate was 1.1 $m^3hr^{-1}kg^{-1}$. The higher ventilation rate may have positively contributed in removing aerial pollutants and excess moisture that condensed on the underside of the roof sheets due to lack of insulation, especially at night.

3.2.6 Overall House Thermal Performance

Figure 4 shows the dynamic heat gain, loss and storage. Due to low magnitude of heat loss, the heat gain and heat stored overlap. During the day, the heat gain, heat loss, and heat stored ranged from 57.5 to 975.4, -3.1 to 6.8, and 58.6 to 970.9 Wm^{-2}, respectively. The corresponding values at night were 27.2 to 47.0, -5.3 to -0.5 and 28.1 to 52.0 Wm^{-2}.

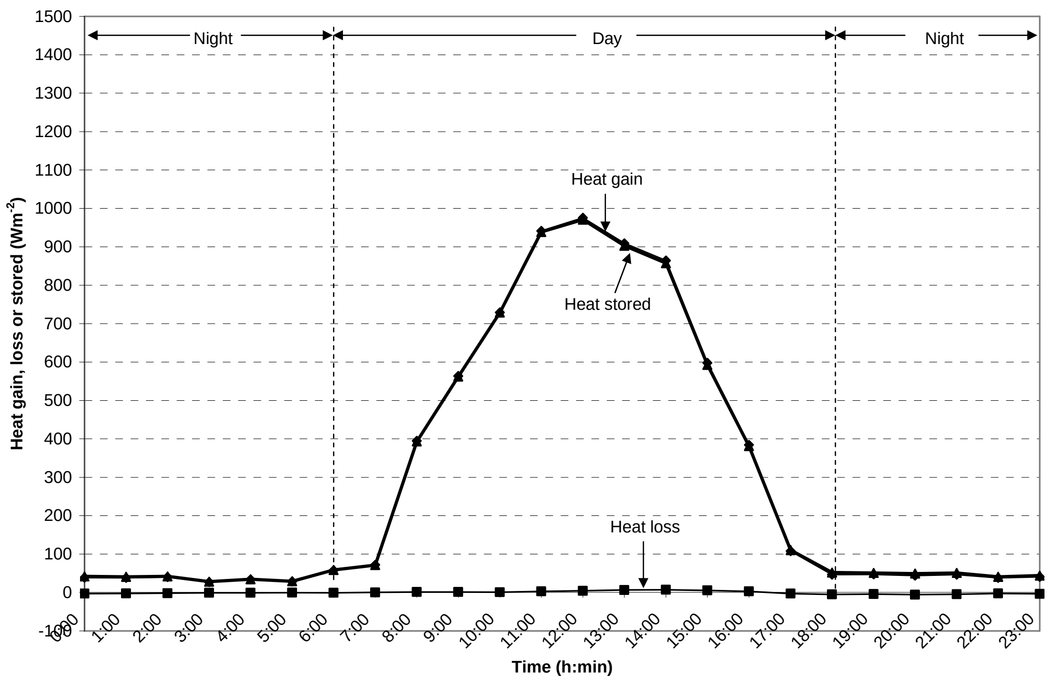

Figure 4. Diurnal heat gain, heat loss and heat stored during the cold weather

3. CONCLUSIONS

- The diurnal heat load patterns in the conventional small scale broiler house during the hot and cold weather conditions have been established. Further, their daytime and nighttime values have been quantified.
- During the hot weather, heat gain, heat loss, and heat stored ranged from -1.5 to 1303.9, 10.1 to 29.8, and -12.5 to 1274.0 Wm^{-2} averaging 703.2, 18.9 and 684.3 Wm^{-2}, respectively, during the day. The corresponding values at night were -6.8 to 17.3, 9.9 to 12.1 and, -16.7 to 6.5 Wm^{-2} averaging 5.9, 10.6, and -4.7 Wm^{-2}.
- During the cold weather, heat gain, heat loss, and heat stored ranged from 57.5 to 975.4, -3.1 to 6.8, and 58.6 to 970.9 Wm^{-2} averaging 549.8, 2.4 and 547.4 Wm^{-2}, respectively, during the day. The corresponding values at night were 27.2 to 47.0, -5.3 to -0.5 and, 28.1 to 52.0 Wm^{-2} averaging 39.2, -2.8, and 42.0 Wm^{-2}.
- During the day, heat gain through the roof was 120% higher than that through the wall during the hot period and 86% higher during the cold period.

Though the data used were collected over a single year period, they are quite indicative of a need to insulate and perhaps redesign the broiler houses to reduce heat load in summer and retain heat in winter.

5. RECOMMENDATIONS

Data collected over a longer period (at least 10 years) should be used in the analysis. Due to high solar heat load in Botswana, the poultry housing structures should be designed such that they do not gain too much heat in summer, retain heat in winter and, maximize natural ventilation especially in summer. Affordable auxiliary cooling and heating systems may be of benefit during adverse weather if retrofitted into existing buildings.

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