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Effect of Roof Insulation Materials on Broiler Housing Heat Exchange During Summer and Winter Seasons in Southeastern Botswana

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ABSTRACT

A study was conducted to investigate the effects of three different roof insulation treatments, namely, Thatch grass (TH), Envirotuff (EN) and Alucushion (AL) on conductive heat flux exchange (HFE) when compared to that without roof insulation (Control, CT) during summer and winter seasons in southeastern Botswana. Each treatment was replicated three times. Black globe temperatures and outdoor air velocity were measured hourly during the two seasons. Data measured during two of the hottest and two of the coldest months were averaged hourly to obtain diurnal patterns and were used in the calculations of HFEs. Data was analysed using the ANOVA procedure in Statistical Analysis System and the means compared using Turkey's multiple comparisons procedure. In summer, the daytime average hourly HFE values were significantly ($p<0.05$) lower in TH (2.2±2.1), EN (2.0±2.0) and AL (1.9±2.1) than 15.9±2.1W/m^2 in CT. The HFE values at night were also significantly lower for TH (-1.6±2.7), EN (-1.6±2.7) and AL (-1.4±2.7) than -13.7±2.7 W/m^2 in CT. In winter, the HFE were significantly lower in TH (4.9±2.4), EN (4.8±2.4) and AL (4.5±2.4) than 36.8±2.4 W/m^2 in CT. Correspondingly, the values at night were also significantly lower in TH (-2.4±2.2), EN (-2.1±2.2) and AL (-1.9±2.2) than -15.3±2.2 W/m^2 in CT. During summer, cooling is required for 12 hours per day while in winter, heating is required for 17 hours per day. Further studies are required on cost-benefit analyses of insulating roofs of broiler houses in Botswana.

Keywords: Botswana, Broiler, heat transfer, insulation, poultry housing.

INTRODUCTION

Botswana lies in the sub-tropical region (17 and 27^{o}S latitude and 20 and 30^{o}E longitude) and the mean minimum and maximum temperatures in the eastern part range between 4 to 19^{o}C and 22 to 33^{o}C, respectively, while relative humidity range from 28 to 47% (Chepete, 2008). High ambient temperatures and solar radiation heat transmitted through building envelopes result in extreme heat loads in sub-tropical regions. 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.

Almost all small scale broiler houses in Botswana lack supplementary cooling and heating systems to mitigate the high heat load and cold in the houses during the hot and cold seasons (Chepete and Tsheko, 2006; Chepete *et al.*, 2005). Chepete and Tsheko (2006) reported that 60% of conductive heat gain in broiler houses was achieved through the uninsulated roof, while 30% was through the wall. If the roofs are insulated, a significant reduction in conductive heat gain could be achieved which could help maintain better indoor temperatures. Hence, the objectives of this study were to (a) quantify the average hourly conductive heat flux exchanges in summer and winter seasons; (b) determine the average number of hours in a day required for either heating or cooling and; (c) determine the magnitude of conductive heat exchange reduction due to the use of roof insulation in southeastern Botswana.

MATERIALS AND METHODS

Treatments

A total of twelve small experimental houses each measuring 1.6m L × 0.7m W × 0.4m H were fabricated. They resembled the conventional small scale broiler houses commonly used in Botswana as described by Chepete and Tsheko (2006). The floor of each house was made of masonry bricks to resemble the concrete floor. They were then anchored to the ground with wires to prevent uplift by wind. Their walls were made of 3mm thick plywood board with thermal conductivity of 1.3 $W \cdot m^{-1} \cdot K^{-1}$ at 25°C and were roofed with corrugated iron sheets.

Three insulation materials (treatments), each replicated three times, were placed 5cm beneath the corrugated roof sheets. The first treatment involved a single sheet of Envirotuff 201 insulation (EN). The EN was made of three layers of woven aluminum foil. The second was a single sheet of single-sided fire retardant Alucushion® (AL). The AL was manufactured by a continuous lamination process of low density polyethylene and aluminum foil with sealed bubbles of air between the two outer laminates. The third was thatch grass (*Eragrostis pallens*) (TH) in which the grass phytomers were compacted by hand to 3cm thickness before placing. The fourth was the Control (CT) with no roof insulation.

Measurements and data collection

The experimental houses were placed in an open field free from obstructions and randomly laid in a 6 × 2 array with a separation distance of 1.5m between and within a row. Hourly measurements of black globe temperatures (BGTs) and air velocity were done during winter (May to August 2007) and summer (October 2007 to March 2008) using data loggers. Within each house, indoor BGTs were measured using precision temperature sensors (model PT907, Pace Scientific Inc. Mooresville, NC. USA) connected to data loggers (model XR5-SE, Pace Scientific, Inc., Mooresville, NC. USA). A single similar BGT sensor was placed outside to record the ambient air temperature. The black globes were made of 150mm diameter copper sphere with the outer surface painted black. The temperature sensor was then inserted and secured midway into each black globe. The BGT was used instead of the regular air temperature because it integrates air temperature, solar radiation and air movement to give a temperature that indicates what an animal would actually "feel". The ambient air velocity was measured using HOBO SWCA smart sensor (model 7911, Onset Instruments, MA. USA) connected to a HOBO weather station data logger (model H21-001, Onset instruments, MA. USA). The data were periodically downloaded into the computer for analysis.

Determination of conductive heat flux exchange

The standard steady state heat transfer analysis through a composite material was used in the calculation of heat exchanges through the roof. The analysis resulted in an equation of the form:

$$Q = \frac{T_1 - T_2}{R_1 + R_2 + R_3 + R_4 + R_5} \qquad [1]$$

where:
Q = conductive heat flux exchange through the roof, W/m^2; T_1 and T_2 are outdoor and indoor BGTs, °C; R_1 through R_5 = heat flow resistance values (R-values) through the roof structure as defined in Table 1. For the CT, R_3 and R_4 were set to zero. Thus, a positive value of Q indicated heat gain into the house while a negative value indicated heat loss from the house.

Table 1: The thermal resistance values (R-values) for air and roof components

Component	R-value (m^{2}K/W)
[1]R_1, the outside air film over the roof sheets	Dependent on air velocity and it ranged from 0.04 to 0.11 for 3 m/s to still air, respectively.
[1]R_2, the corrugated iron roof sheet	0.11
[1]R_3, the air in the attic space	1.09
[2]R_4, the insulation material	0.8, 0.99 and 0.77 for EN, AL and TH, respectively.
[1]R_5, the air inside the house	0.11

[1]Values obtained from Bengtsson and Whitaker (1988); [2]R-value for EN and AL were obtained from the manufacturer specification while that for TH was obtained from Bengtsson and Whitaker (1988).

Data handling

Two hottest months in summer and two coldest months in winter were selected and their data used in the analysis in order to represent the worst case scenarios in each season. The data were averaged on hourly basis and presented as a single 24-hour (diurnal) record for each season. These data were then used to calculate the diurnal heat flux exchanges using equation [1].

Data analysis

The raw data summaries and calculations of heat fluxes were performed using Microsoft Excel 2007 spreadsheet. The data was analysed using the ANOVA procedure of Statistical Analysis System (SAS) (SAS, 2008) and the treatment means in each season were compared using Turkey's multiple comparisons procedure.

RESULTS AND DISCUSSIONS

Summer

The hottest months during the measurement period were December and January. The outdoor temperature (BGT_o) averaged 33.4±2.4°C and 19.2±0.7°C during the daytime and night time, respectively. The air velocity averaged 1.9±0.2m/s and 0.9±0.1m/s during the day and night, respectively.

Table 2 shows the average indoor temperatures, heat flux exchanges and percent heat exchange reduction across the four treatments during the summer season. The data were partitioned into daytime (5:00 AM to 7:00 PM inclusive) and night time (8:00 PM to 4:00 AM inclusive) values.

There was no significant difference ($P>0.05$) in the BGT_i among all the treatments during the day or at night. This was possibly caused by the small air volume in the experimental houses. It is expected that when real houses are monitored, temperature differences may be observed due to larger air volume and larger mass of the structural components involved in heat transfer. There was significant difference ($P<0.05$) in the heat exchange rate between the insulated houses when compared to the CT. This showed that the use of insulation was important in reducing the heat transfer. With reference to the CT, the insulation materials reduced the heat exchange rate by 623 to 737% (or 6.2 to 7.4 times lower than CT value) and 756 to 879% (or 7.6 to 8.8 times lower than CT value) during the day and night, respectively. However, no significant difference ($P>0.05$) was observed among the heat exchange rates of the insulated houses indicating that these materials effectively reduced heat exchange to similar extent. Both the EN and AL are commonly used in industrial roof insulation while TH grass is commonly used in roofing huts in rural areas in Botswana. The choice of using EN or AL would largely be determined by cost, availability, and ease of installation. TH grass is often readily available and affordable but its commercial usage is limited by it being a fire hazard and having lower durability.

Table 2: The average indoor temperatures, heat flux exchanges and percent heat exchange reduction during the summer season in southeastern Botswana

	Treatments			
Variable	**Thatch**	**Envirotuff**	**Alucushion**	**Control**
	Day time (5:00 AM to 7:00 PM)			
BGT_i (°C)	28.6±1.2 ^{a}	28.9±1.2 ^{a}	28.9±1.2 ^{a}	28.9±1.2 ^{a}
HFE (W/m^2)	2.2±2.1 ^{a}	2.0±2.0 ^{a}	1.9±2.1 ^{a}	15.9±2.1 ^{b}
% HFE red.	623	695	737	
	Night time (8:00 PM to 4:00 AM)			
BGT_i (°C)	22.6±1.6 ^{a}	22.6±1.6 ^{a}	22.6±1.6 ^{a}	22.7±1.6 ^{a}
HFE (W/m^2)	-1.6±2.7 ^{a}	-1.6±2.7 ^{a}	-1.4±2.7 ^{a}	-13.7±2.7 ^{b}
% HFE red.	756	756	879	

BGT_i = internal black globe temperature, HFE = heat flux exchange, HFE red. = heat flux exchange reduction with reference to the Control. Means with the same letter along a row are not significantly different (P>0.05).

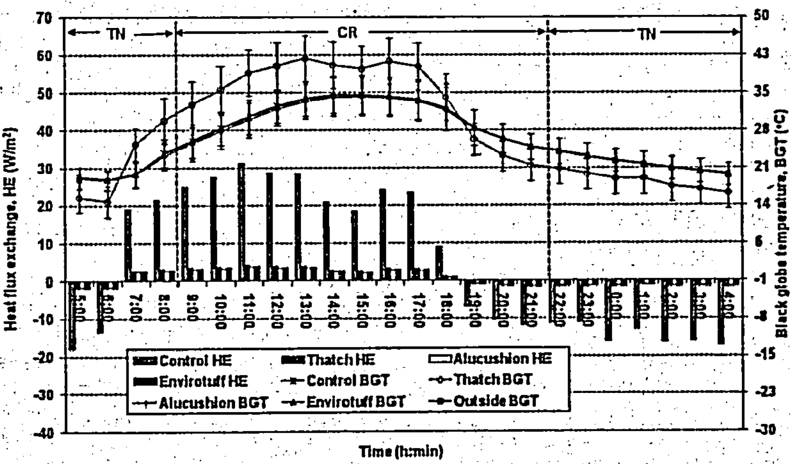

Figure 1: Average diurnal heat flux exchanges and the corresponding black globe temperatures in summer in southeastern Botswana. TN = thermoneutral temperature, CR = cooling would be required.

Figure 1 shows the average dynamic temperature and heat flux exchange profiles during the summer period. The heat exchange rates during the day were higher than those at night due to larger temperature differences between the inside and outside conditions during the day when compared to those during the night. The thermoneutral temperature (TN) for broilers range from 24°C (at 8 days of age) to 18°C at slaughter age (Okelo *et al.*, 2003). This meant that when BGT_i was below 18°C, heating would be required and when it was above 24°C, cooling would be required. From figure 1, the BGT_i among the treatments ranged from 24.9 to 35.1°C averaging 31.0±0.5°C between 9:00 AM and 9:00 PM. Cooling would thus be required for 12 hours per day or for 50% of the time each day in order to lower the temperature to within TN where the birds would be comfortable. If cooling is not effected, the birds may become heat stressed, which may cause the birds to reduce feed intake (Tao and Xin, 2003) and consequently have reduced feed efficiency (Okelo *et al.*, 2003) and lower body weight gain (Yalcin *et al.* 1997). Mortality rates and time to reach market weight may also be increased (Muiruri and Harrison, 1991). Since cooling systems are not usually installed in small scale broiler houses in Botswana, there is complete reliance on cooling by natural ventilation. But, with daytime wind speed averaging 1.9±0.2 m/s, it may not be adequate to effectively assist in cooling. During calm days, the indoor conditions could be more stressful to the housed birds due to excessive indoor heat buildup. The building type, structure, heat capacitance effect and other heating loads such as equipment and animals, directly affect the magnitudes of heating and cooling loads (Zhang *et al.*, 2000).

Both heat gains and heat losses were experienced and were significantly higher ($P<0.05$) in the CT when compared to the other treatments with roof insulation. Banhazi *et al.* (2008) reported that building type and wall insulation type accounted for 11% of variation in internal temperature of pig houses in Australia. For 12 hours of each day, the BGT_i was within the TN zone and this occurred at night as the outside air cooled down. In summer, cooling would thus be the main operation to undertake during the day in order to attain TN conditions and would be required for 12 hours per day. Such information is needed in the estimation of cooling costs as well as in the selection of the suitable cooling equipment.

Winter

The coldest months during the monitoring period were June and July. The outdoor BGT averaged 25.7±2.8°C and 6.5±1.0°C during the daytime and night time, respectively. The air velocity averaged 1.6±0.3m/s and 0.4±0.1m/s during the day and night, respectively.

Table 3 shows the average BGT_i, heat flux exchanges and percent heat exchange reduction across the four treatments during the winter season. The data were partitioned into daytime (7:00 AM to 5:00 PM inclusive) and night time (6:00 PM to 6:00 AM inclusive) values. Similar to the summer season, the BGT_i were not significantly different ($P>0.05$) among the treatments during the day or at night.

Compared to the CT treatment, the insulated houses reduced heat exchange by 651 to 718% (or 6.5 to 7.2 times lower than CT value) and 538 to 705% (or 5.4 to 7.1 times lower than CT value) during the day and night, respectively. This showed that the use of insulation was important in reducing the conductive heat transfer. Heat is lost from a broiler house primarily by conduction and convection through the ceiling and walls or with warm air exhausted through the ventilation system (Flood *et al.*, 1998).

Table 3: The average indoor temperatures, heat flux exchanges and percent heat exchange reduction during the winter season in southeastern Botswana

Variable	Treatments			
	Thatch	Envirotuff	Alucushion	Control
Day time (7:00 AM to 5:00 PM)				
IT (°C)	17.6±1.4^a	17.8±1.4^a	17.6±1.4^a	17.8±1.4^a
HFE (W/m^2)	4.9±2.4^a	4.8±2.4^a	4.5±2.4^a	36.8±2.4^b
% HFE red.	651	667	718	
Night time (6:00 PM to 6:00 AM)				
IT (°C)	11.6±1.3^a	11.0±1.3^a	10.8±1.3^a	10.3±1.3^a
HFE (W/m^2)	-2.4±2.2^a	-2.1±2.2^a	-1.9±2.2^a	-15.3±2.2^b
% HFE red.	538	629	705	

IT = internal temperature, HFE = heat flux exchange, HFE red. = heat flux exchange reduction with reference to the Control. Means with the same letter along a row are not significantly different (P>0.05).

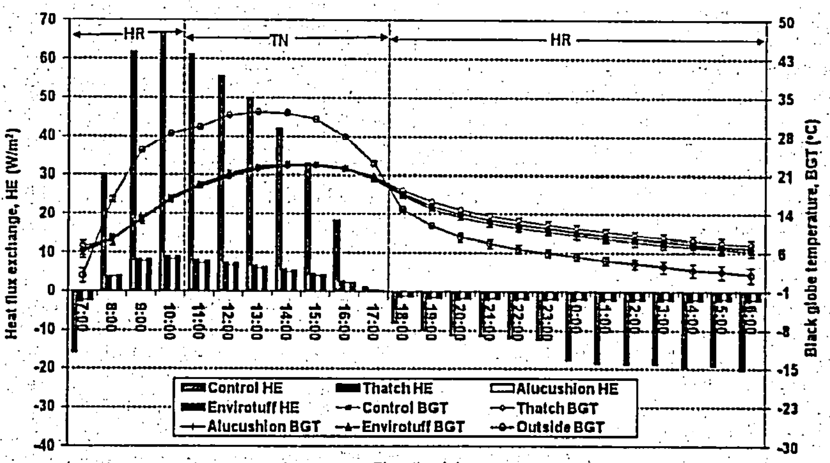

Figure 2: Average diurnal heat flux exchanges and the corresponding black globe temperatures in winter in southeastern Botswana. TN = thermoneutral temperature, HR = heating would be required.

Figure 2 shows the average dynamic BGT$_i$ and heat flux exchange profiles during the winter period. The daytime BGT$_i$ in the treatments averaged about 8.0°C below the

BGT_o resulting in the houses gaining heat. At night, the BGT_i averaged about 4.5°C above BGT_o resulting in heat loss from the houses. Banhazi *et al.* (2008) reported that the external temperature accounts for 67% of the variation in internal temperature while 33% is controlled by manipulating the engineering features of naturally ventilated buildings in Australia.

From 6:00 PM to 10:00 AM, the BGT_i in all the treatments were below TN and ranged from 6.4 to 17.5°C averaging 11.0±0.4°C. Thus heating would be required during this period, which amounts to 71% of the time daily. If heating is not effected, the birds may become cold stressed which may cause the birds to increase feed intake in order to produce more heat to keep warm at the expense of meat production. Consequently, the growth rate would be reduced and the time to reach market weight and expenditure on feed would increase. Under controlled environment, heating costs could contribute to more than 70% of the total energy bill during the heating seasons (Zhang *et al.*, 2000). Both heat gains and losses were experienced from 6:00 PM and 10:00 AM and were significantly higher ($P<0.05$) in the CT than in the other treatments.

The BGT_i was within TN zone 29% of the time or for 7 hours per day in all the treatments between 11:00 AM and 5:00 PM. This was a result of solar heat gain and heat buildup in the houses as the day progressed. In winter, heating would be the main operation to undertake especially at night and would be required for about 17 hours per day. Estimation of the heating costs requires such information as well as selection of the most economic heating system.

CONCLUSIONS

All roof insulations had similar effect on conductive heat flux exchange (HFE) and promoted lower HFE when compared to houses with no roof insulation during both the summer and winter seasons. Cooling is required in the summer season while heating is required in the winter season to attain suitable indoor temperature for the housed birds. A cost-benefit analyses study is needed to determine the effect of roof insulation on broiler profitability in Botswana.

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