Effectiveness of a Novel Method to Reduce Heat Stress in Broilers: A Cool Roost System

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Abstract. *Effective and economical techniques to minimize production losses that result from heat stress are important in the broiler industry. Zone cooling, as opposed to whole-house cooling, during hot weather may be effective in relieving heat stress. The present studies seek to determine the effectiveness of such a practice. Two flocks (1 and 2) were raised sequentially for 42 days. Studies were analyzed separately, and when the results of the two studies were consistent, a combined analysis was completed and reported. Means comparison tests were completed on production parameters at harvest (day 42). Cool roost birds showed greater live weight and roost use, lower mortality, and lower feed-to-gain ratios than ambient roost and floor birds, respectively. The parts yield analysis showed that wing weight was greater in the floor-raised birds than in either the cool roost or ambient roost raised birds in flock 1. In flock 2, the cool roost birds showed a greater breast meat weight than the ambient roost birds. The cool roost system appeared to be more efficient at relieving heat stress at temperatures below 30°C than at temperatures above 30°C. Heat loss through the feet of birds ranged between 0.65 and 5.09 watts per bird during week 6 in either flock (chamber air temperature varied from 29°C to 37°C). Moisture condensation on the cool roost system did not significantly increase the litter moisture content in the cool roost treatment beyond that of the ambient roost system.*

Keywords. *Broilers, Cooling poultry, Heat stress, Poultry, Roost systems.*

Typically, the summer season in the southern broiler-producing areas of the U.S. is characterized by hot ambient temperatures, above the zone of neutrality (18.3°C to 23.9°C) for the chickens (Sturkie, 2000). Hot ambient temperatures characteristically reduce feed intake, growth rates, and feed efficiency in growing broilers (Reece and Lott, 1983). When broilers are exposed to high temperatures for extended periods, mortality rates (Muiruri and Harrison, 1991) and the time to reach market weight are increased (Deaton et al., 1978). The broiler industry employs mixing fans, tunnel ventilation, and evaporative cooling to reduce heat stress (Carr, 2003). When outside atmospheric temperatures are above 29.5°C, increasing air circulation in the broiler house may not be the best solution, and misting increases humidity levels. High humidity and high temperature are conducive to the cultivation of pathogenic microorganisms and spread of disease (Rose, 1997).

In their natural habitats, heat stress is averted in many species of birds by selection of cooler microclimates. Many bird species living in hot climates dissipate heat by spending long periods of time in water (Murrish, 1970; Kilgore and Schmidt-Nielsen, 1975). The effectiveness of microclimate selection with respect to maintenance of body temperature in hot environments has led to the investigation of management systems employing zone cooling as opposed to whole-house cooling. Reilly and Harrison (1984) found that conductive heat transfer from the feet of laying hens to a thermally controlled perch helped relieve heat stress. This study explored temperature controlled perches for relieving heat stress in broilers.

Objectives

Objectives of this research were to determine the effectiveness of providing a cool roost system in a hot ambient environment on: (1) heat transfer through the feet of birds to a cool roost system, (2) roost use, and (3) broiler performance based on live weight, feed-to-gain ratio, drinking water consumption, and carcass yield of parts based on ready-to-cook weights.

Materials and Methods

Facility Description

Data were obtained from two flocks of commercial broilers reared consecutively to market age in the same

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facility. The flocks were raised during the summer months, when high ambient temperature and heat stress were expected to occur. Cooling in the cool roost system was initiated when birds were 3 weeks old in each flock. The research was conducted in the Poultry Environmental Research Facility at the University of Maryland's Lower Eastern Shore Research and Education Center in Princess Anne, Maryland. Nine chambers were available for the studies. Five hundred one-day-old, straight run, mixed sex, commercially available broilers were placed in each chamber (density of 13.4 birds/m^2) and fed a commercial broiler ration *ad libitum* throughout each study. The company that supplied the birds determined the feeding program. The research facility was of pole and panel construction with eighteen 6.1 × 6.1 m independent windowless chambers. Chambers were positioned nine to each side of the house and separated by a 1.5 m wide hallway. Each chamber had its own feeding, water, and ventilation systems.

Two nipple drinker lines positioned 1.2 m from the wall parallel to the diagonal of the chambers and with nipples 20.3 cm apart, for a total of 36 nipples per chamber, were used to provide drinking water *ad libitum* throughout the study (fig. 1). Drinking water consisted of tap water provided at ambient temperature for all treatments. A feed line and feeders were located midway between the two nipple drinker lines for each chamber. The feed line consisted of a 70 kg feed bin and seven 30 cm diameter feed pans and one control pan (a total of eight pans) to operate the feeding system. An auger system in the feed line was used to distribute feed from the 70 kg feed bins to the 30 cm feed pans (see fig. 1). Weighed feed was distributed to the 70 kg feed bins in each chamber by an overhead auger system running the length of the nine chambers. The amount of feed added to a chamber was recorded at each addition.

Continuous lighting was provided by two 100 W incandescent lamps located over the feed line and two 25 W incandescent lamps in the other two corners of each chamber. To provide air exchange, each chamber was equipped with a 26.6 cm diameter centrifugal fan and a 42.5 cm diameter direct-drive axial-flow fan. The larger fan was thermostatically controlled by a thermostat located 40 cm off the floor. The thermostat was set 2.5°C above the desired chamber temperature. The air inlet was located at the ceiling (with the option of directing the airflow across the ceiling or down the wall) along the hallway side of the chamber. Roost inlet and outlet water temperatures in the cool roost chambers and ambient air temperatures in all chambers, respectively, were logged using a Multipoint Recorder/Logger (MRL) data acquisition system (model MRL-25/48-PD-RC-64-DS-96IKL-RD/-Y, Esterline Angus Instrument Corp., Indianapolis, Ind.) that was interfaced with a Campbell Scientific data logger (model CR7X, Campbell Scientific, Inc., Logan, Utah).

A volume-measuring device tapped into the water distribution line was used to measure the amount of drinking water used in each chamber. The water volume measuring device consisted of a Plexiglas reservoir, a short and a long liquid level control electrode (corresponding to the upper and lower liquid levels, respectively), a solenoid-operated valve, and a circuit board designed to regulate the opening and closing of the valve. The valve closed when the water level rose to the tip of the short electrode. A digital counter registered one count for each operation (one opening and closing) of the valve. The volume of water between the two levels was determined by calibration. Calibration showed that the greatest error was 1.6% (i.e., about ±10 mL) for the water measurement.

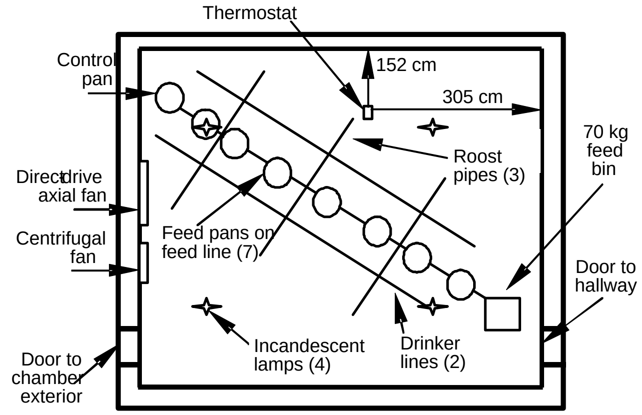

Figure 1. Chamber layout showing lighting, ventilation, roost, feeding, and watering systems in a chamber used in the studies. Light bulbs were located 1.5 m from the nearest wall.

Cool Roost

The cool roost system (COOL-R) consisted of three black iron pipes (4.57 m length, 3.8 cm diameter) that were held in place by wood supports with slots for pipe positioning and security. The pipe length was selected to allow approximately 150 birds to be on the roost at one time. Data from work at Illinois suggested that no more than 150 birds (out of the approximately 500 in each chamber) would use the roost at any one time (Harrison, 1997).

Cooling in the roost system was accomplished by maintaining a constant flow of cooled water through the pipes and discharging it to the chamber exterior. Type T thermocouple probes (part number TMTSS-125G-12, Omega Engineering, Inc., Stamford, Conn.) tapped into the inlet and outlet ends of each pipe and connected to the Esterline data acquisition system in a parallel circuit arrangement were used to measure the average inlet and outlet water temperature, respectively, of the cool roost. The inlet water temperature ranged between 20°C and 25°C, while the outlet temperatures were between 30°C and 34°C and up to 36°C on the warmest days. Orifices (0.5 mm diameter) were positioned near the inlet end of each pipe to restrict water flow. The water flow rate through the roost system was measured three times a day using a 1000 mL measuring cylinder and a stopwatch. Volume was measured over at least one minute. The measurements were taken at 8:00 a.m., 12:00 p.m., and 5:00 p.m. Two air-cooled Elkay chillers (model ER 10-1B, Elkay Manufacturing Co., Oak Brook, Ill.) with a capacity of 9.5 L/h of 10°C water installed in a series arrangement were used to supply cool water to the roost system. All pipes carrying cool water from the chillers to cool roost system were insulated. In order to estimate the cool roost outlet temperature without birds, the ambient air temperature in every cool roost chamber was gradually increased in 5°C increments over the range of environmental temperatures expected during the study period (about 18°C to 40°C). Ambient air temperature and cool roost water temperatures were recorded and used to obtain a regression equation for the estimation of roost outlet water temperature without birds.

The heat transfer through the birds' feet was estimated using a model (eq. 1) developed by Hillman et al. (1985). Heat loss through the feet of the roosting birds to the cool roost systems was measured hourly over the last four days of studies 1 and 2:

$$Q = m_p c_p (T_{in} - T_{out}) - m_p c_p (T_{in} - T_{bout})$$
$$= m_p c_p (T_{bout} - T_{out}) \quad (1)$$

where

- Q = heat loss from the feet of birds (W)
- m_p = mass flow of water through the roost (g/sec)
- c_p = specific heat capacity of water (4.1855 J/g °C at 29°C, 1 atm)
- T_{in} = temperature of water entering the roost (°C)
- T_{out} = temperature of water exiting the roost without birds (°C)
- T_{bout} = temperature of water exiting the roost with birds (°C).

Ambient Roost

A roost system similar to the cool roost but without cool water flowing through it was provided for each chamber assigned to the ambient roost treatment (AMB-R). Roost temperature was not controlled.

Floor Birds

The FLOOR treatment consisted of chambers without a roost system.

Response Variables

Litter Moisture Content

Litter moisture content determination was carried out once per week from day 28 until harvest in each study. About 100 g composite litter samples from ambient and cool roost chambers and from chambers without a roost system (floor birds) were collected in clear polythene bags and sealed to preserve the moisture in the litter. Twenty to 30 g samples of litter were placed in a crucible and weighed. Samples were then oven dried for a period of 12 h at 101°C. Crucibles and their contents were then re-weighed to determine the dried weight of the litter samples. Wet and dry weights were used to compute litter moisture content (wet basis).

Live Weight

To estimate the mean live weight in a chamber; three separate representative samples of 25 birds were weighed at 6 weeks of age using an electronic scale (model FS300S, Sartorius North America, Inc., Edgewood, N.Y.), and the data were manually recorded. Weight data were used to compute the mean chamber live weight in kg/bird.

To select a representative sample of birds, an expandable fence was set across a corner of the room to fence off about 75 to 100 birds. The fence was moved toward the corner to crowd the birds. Twenty-five birds were taken from the penned-in area, placed on the scale, and weighed. These birds were released to the larger section of the chamber so they would not be weighed again. A second sample followed by a third sample of 25 birds was taken from the penned-in area, weighed, and released. Because the penned-in area contained a random group of birds from the entire pen and most of the penned-in birds were used for samples, these bird samples were accurate representatives of the population.

Cumulative Mortality

The percentage cumulative mortality in each chamber was computed based on the number of birds (500 day-old chicks) on day 1 in each chamber. The number of dead birds (there was no culling) in a chamber (mortality) was recorded daily. Percent cumulative mortality at 6 weeks was obtained by dividing cumulative number of dead birds in a chamber by the initial number of live birds multiplied by 100.

Feed-to-Gain Ratio

The feed-to-gain ratio for each chamber was determined at 6 weeks of age by dividing the cumulative amount of feed consumed at 6 weeks by the estimated total weight of live birds. The estimated total weight of birds in each chamber was obtained by multiplying estimated mean weight per bird in the chamber by the number of live birds in the chamber at 6 weeks of age.

Cumulative Water Use

Cumulative drinking water use in each chamber (L/bird) was obtained by dividing total water use (L) in each chamber at 6 weeks by total number of live birds in the chamber.

Carcass Yield

Ten male broilers were selected from each pen, slaughtered, and processed. Carcasses were then cut into parts, and the weight of the parts was recorded. Weight of the various parts was used to determine if there were treatment effects on parts yield.

Roost Use

Roost use in COOL-R and AMB-R chambers was observed each day from day 21 until harvest (the time the COOL-R was activated) from a location in the chamber near the doorway to the hallway without agitating the birds. The total number of birds sitting on the roost was observed once each hour for the hours of 3:00, 4:00, and 5:00 p.m., respectively, when the greatest heat stress was anticipated. The percent roost use in each chamber was computed by dividing the total number of birds using the roost by the total number of live birds left in the chamber after accounting for mortality and then multiplying by 100. Livability, the number of live birds in a chamber at any specific time, was used to calculate the percent of birds using the roost.

Statistical Methods

Experimental Design and Treatment Structure

Heat stress intervention treatments were identified as cool roost (COOL-R), ambient roost (AMB-R), and a control consisting of chambers without a roost system, floor birds (FLOOR). A completely randomized design was used with each treatment randomly assigned to three chambers.

Statistical Procedures

The linear mixed model procedure of SAS (Littell et al., 1996; SAS, 1998) was used to analyze the data. The experiment was repeated, and each study (studies 1 and 2) was a completely randomized design with three replicate chambers per treatment (Sokal and Rohlf, 1996). The two studies were analyzed separately, and when the results of the two studies were statistically the same, a combined analysis was completed and reported (Mead, 1994).

For the analysis of bird weights, feed-to-gain ratio, water consumption, cumulative mortality, and parts yield, the fixed portion of the mixed model contained treatment effects, and the residual was defined as random for the individual study analyses. For the analyses combining studies, the random portion of the model also included study and study by treatment interaction.

For litter moisture, the data included repeated measures over time; therefore, in addition to the above, day and day by treatment were also included as fixed effects. The random portion of the model included chamber within treatment and the residual error. The repeated measures features of the mixed procedure were used to fit the residuals, and goodness-of-fit statistics were used to identify a variance/covariance structure that adequately represented the repeated measures. The combined analysis included the same fixed effects, but the random sources of variation were study, chambers within study and treatment, and the residual variance.

An analysis was carried out of the heat flow between the birds and the cool roost system for the last four days of both studies. One of these days, day 38, for flock 2 was identified as a high-heat day and the other three days (days 39 through 41) were classified as low-heat days based on ambient air temperature in the chambers. The fixed portion of the model included day, hour, and hour by day. Random sources of variation were chamber, chamber by day, and the residual variance. The repeated measures features of the mixed procedure were used to fit the hourly data within days, and goodness-of-fit statistics were used to identify a variance/covariance structure that adequately represented the repeated measures.

Contrasts were used to test the main effects of roost system and roost temperature and their interaction. For all analyses, the residuals were examined for evidence of a lack of homogeneity of variances and for non-normality. The residuals were judged to be adequately normal; however, in some cases, homogeneity of variance was not satisfactory. In these cases, residual variance was partitioned into two or more residual variances, and goodness-of-fit statistics were used to identify a residual variance structure that adequately represented the variance of the residuals.

Results and Discussion

The summer of the study was characterized by low heat stress activity, with ambient air temperatures remaining below 32°C for much of the production periods. Chamber temperatures were 30°C to 34°C during days 32 to 41 in flock 1; in flock 2, chamber temperatures were between 34°C and 38°C during the same production period.

Calibration of Cool Roost

A roost inlet temperature of 10°C was not achieved in all cases due to thermal heat gain to the cool water pipes from ambient air and walls and loss of chiller efficiency due to overload (the chiller operated at a flow rate of 25 L/h instead of the specified 9.5 L/h at 10°C). The increased flow through the chillers ensured that the roost temperature was cool but not so cold as to injure the chicken's feet. Equation 2 was obtained by linear regression using the calibration data (fig. 2). Equation 2 was used to estimate roost exit water temperatures without birds (T_{out}):

$$T_{out} = (0.89)T_{amb} - 0.65 \quad (2)$$

$$S_{xy} = 0.061$$

$$R^2 = 0.98$$

where

T_{out} = roost outlet water temperature without birds (°C)

T_{amb} = ambient air temperature (°C)

S_{xy} = 0.061, the standard deviation from the regression line (°C).

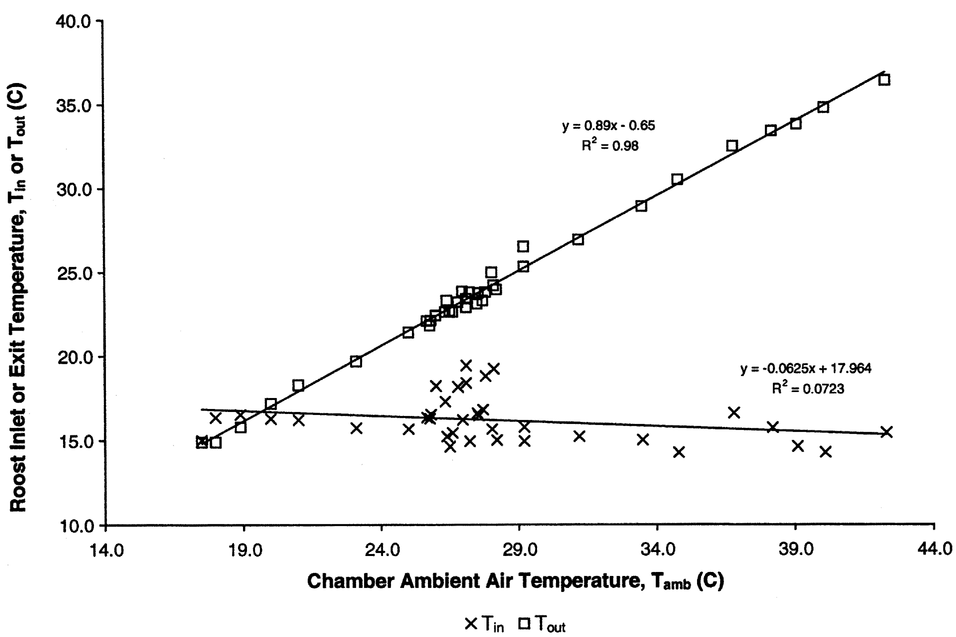

Figure 2. Roost calibration curve used to estimate roost exit temperature without birds (T_{out}).

HEAT TRANSFER AND ROOST USE

In flock 1, day by hour interaction was not significant at $\alpha = 0.05$ ($p = 0.994$), indicating that heat loss patterns during the last four days were similar; therefore, the days were not classified as high- or low-heat days. In flock 2, however, day 38 showed a higher daily maximum ambient temperature than the rest of the days, 39 through 41, and was therefore classified as a high-heat day. The rest of the days were classified as low-heat days. Day by hour interaction was significant ($p = 0.009$) in flock 2. Regression equations (eqs. 3 and 4, respectively) were obtained to relate heat loss to ambient air temperature for low- and high-heat days, respectively, in flock 2:

$$HL_{low} = 476 - 10(T_{amb}) \tag{3}$$

where HL_{low} is the heat loss through feet of birds to a cool roost system on a low-heat day (watts per chamber).

$$HL_{high} = 363 - 10(T_{amb}) \tag{4}$$

where HL_{high} is the heat loss through feet of birds to a cool roost system on a high-heat day (watts per chamber).

The thermal efficiency of the cool roost system in removing heat from the birds' feet decreased as the ambient air temperature increased. Lower heat losses observed during higher ambient air temperatures indicate a decrease in thermal efficiency and was a result of higher T_{bout} temperatures at the higher T_{amb} periods.

Heat loss through the feet of birds to the cool roost system was caused by the temperature difference between birds' feet and the cool roost surface. The downward sloping portions of the heat loss plots in figures 3 and 4 may be explained as follows. Total convective heat loss from birds' feet in a chamber was progressively reduced as ambient air temperature (T_{amb}) increased. Equation 1 simplifies to $Q = m_p c_p(T_{bout} - T_{out})$. T_{out}, and T_{bout} increased as T_{amb} increased. However, T_{bout} increased at a slower rate than T_{out}, resulting in Q being progressively smaller as T_{amb} increased. T_{bout} might have been influenced by the roost use patterns, because the number of birds using the roost system did not increase directly as the ambient air temperature increased. It was speculated that the upward sloping portions of the plots were due to more birds using the roost system in the latter part of the day, thereby reversing the rate of heat loss from a negative to a positive value. Convective heat loss rates from the birds to the COOL-R system ranging from 0.65 to 5.09 watts per bird were achieved during the warmest period of production, which occurred in the last week of production in both studies. This rate (conductive heat transfer) of heat loss was in agreement with rates reported by Rose (1997) of 0.7 watts per bird for a day-old chick to 8 watts per bird for a well feathered laying hen. These results suggest that the cool roost system was more efficient at ambient temperatures below 30°C than at temperatures above 30°C (figs. 3 and 4).

Birds tended to show greater use of either roost systems (cool or ambient) at higher temperatures than at lower temperatures. Figures 5 and 6 show the percent of live birds in the chamber using the COOL-R or the AMB-R systems. As an example, for flock 1 on day 38, an average of 54 birds (11%) were observed to be using the cool roost system, and 22 birds (5%) were using the ambient roost system during the afternoon. This is a statistically significant difference at $p = 0.0001$. In flock 2, an average of 59 birds were observed to be using the cool roost system, as compared to an average of 27 birds using the ambient roost system during the same production period. This difference is also statistically significant with a $p = 0.0002$ (figs. 5 and 6). Cooling of the roost systems was started at 21 days of age and maintained until harvest. These results suggest that birds responded to higher environmental temperatures in flock 2 with greater roost use in order to alleviate heat stress through conductive cooling of their feet.

On the hottest days, up to 73 birds occupied the COOL-R system. Thus, a considerable amount of the roost area was covered with chicken feet. This would have reduced the transfer of heat from the air to the cool water in the roost pipes. No attempt was made to adjust the heat loss due to the

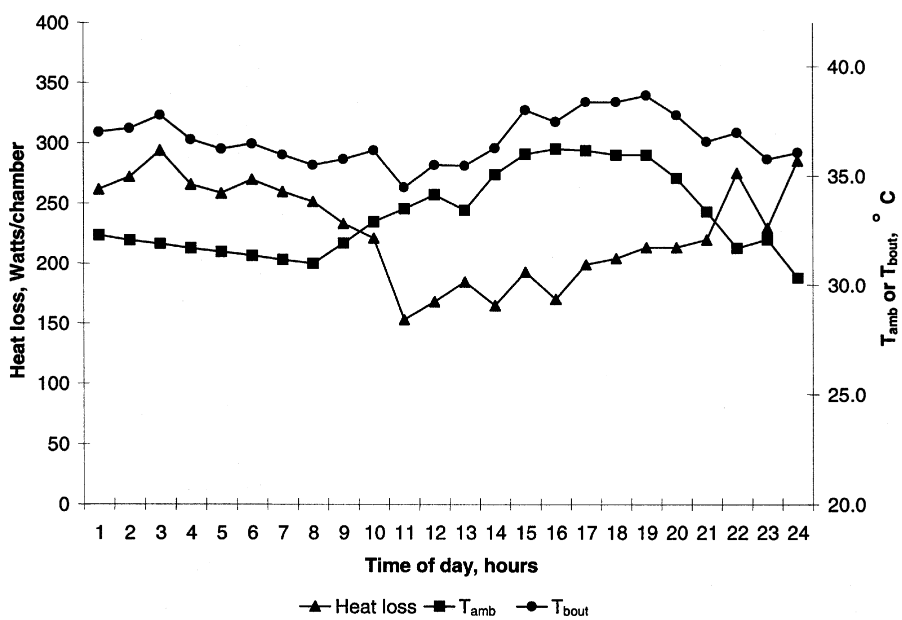

Figure 3. Plot of day 39 average heat lost through birds' feet to the cool roost system and corresponding ambient air temperature (T_{amb}) and cool roost water exit temperature (T_{bout}) in flock 2.

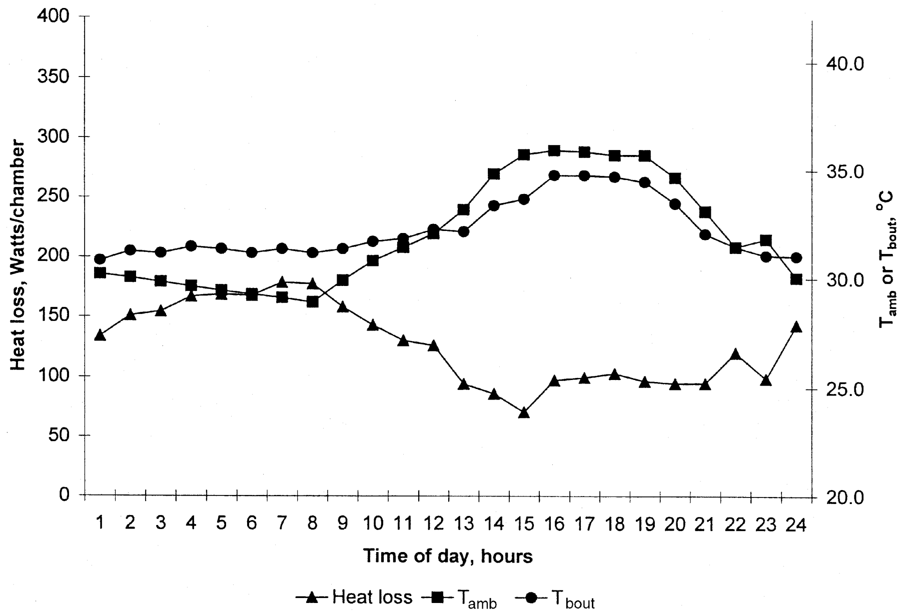

Figure 4. Plot of day 40 average heat loss through birds' feet to the cool roost system and corresponding ambient air (T_{amb}) and cool roost water exit temperature (T_{bout}) in flock 2.

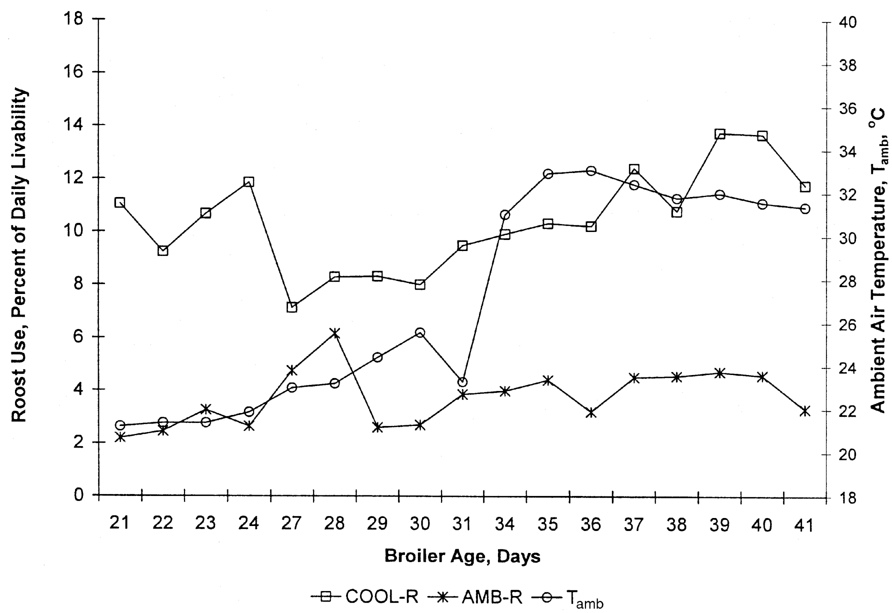

Figure 5. Roost use as a percentage of daily livability in flock 1. Average roost use for the hours of 3:00, 4:00, and 5:00 p.m. was used in the plots. Corresponding ambient air temperature (T_{amb}) is shown.

chicken feet covering part of the pipes in the calculations used to develop figures 3 and 4. Thus, the heat loss values shown in figures 3 and 4 are probably slightly lower than actually occurred.

Litter Moisture Content

Litter moisture contents in all the three treatments were not significantly different from one another at $\alpha = 0.05$ (table 1). The litter moisture content observed in the studies was within the normal range, 25% to 35% for a typical well-managed broiler house (Butcher and Miles, 1996). Although light condensation was observed on the surface of the cool roost system pipes, the condensate did not drip enough to cause an appreciable increase in litter moisture content in COOL-R (table 1).

Live Weight

COOL-R birds showed a significantly higher live weight than AMB-R birds ($p = 0.032$), but FLOOR birds live weight was not different from either COOL-R or AMB-R birds (table 2).

The improved live weight of COOL-R birds may be attributed to the heat loss to the cool roost system through the feet of the birds (heat stress relief) during periods when ambient air temperatures were above the thermoneutral range of birds of a given age. One could speculate that the

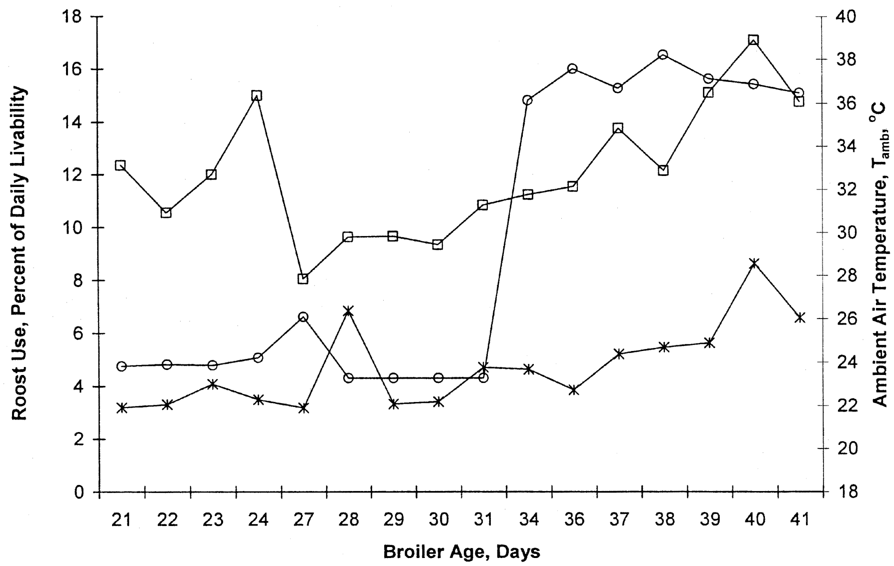

Figure 6. Roost use as a percent age of daily livability in flock 2. Average roost use for the hours of 3:00, 4:00, and 5:00 p.m. was used in the plots. Corresponding ambient air temperature (T_{amb}) is shown.

Table 1. Summary of litter moisture content results: AMB-R = ambient roost, COOL-R = cool roost, and FLOOR = floor birds (control).

Treatment	Liter Moisture Content (%, w.b.) (mean ±SE)
AMB-R	30.4 ±2.76
COOL-R	30.5 ±2.75
FLOOR	30.8 ±2.75

high mortality in flock 2 (table 3) changed the bird density and resulted in better growth. However, 57% to 97% of flock 2 mortality occurred on day 40, one day prior to harvest. Thus, the density differences lasted less than two days and should therefore have little effect on the results.

Cumulative Mortality

COOL-R birds showed lower cumulative mortality at harvest than AMB-R or FLOOR birds in flock 1, but these differences were not significant a α = 0.05 (table 2). In flock 2, when ambient temperatures were higher, COOL-R birds showed significantly lower cumulative mortality than FLOOR birds (p = 0.029). Although COOL-R birds showed lower cumulative mortality than AMB-R birds, and FLOOR birds showed lower cumulative mortality than AMB-R birds, these differences were not significant (table 2). Because investment in broiler feed represents a significant portion of the production cost, feed fed to birds that die prior to harvest is wasted and is an economic loss. The closer the birds are to harvest when they die, the greater the economic loss because they have consumed more feed.

Table 2 shows that the mortalities in flock 2 were much higher than in flock 1. This is due to excessive temperatures experienced on day 39 in flock 2, up to 39°C. The birds were not acclimated to high temperatures, as the high temperature occurred without slowly increasing temperatures. Table 3 shows the total mortality and the mortality on day 40 for each treatment in both flocks 1 and 2. Table 3 makes it clear that by far the majority of mortalities in flock 2 occurred on day 40, one day after the highest temperatures were experienced.

Feed-to-Gain Ratio

Numerically, COOL-R birds showed the lowest feed-to-gain ratio when compared to AMB-R or FLOOR birds (table 2). Differences in feed-to-gain ratio (FGR) values between the treatments were not significant at α = 0.05. Because feed is the most costly item in the production of broilers, efficient feed utilization, as represented by lower FGR values, can be of considerable economic importance to the broiler grower (Vest, 1999).

Table 2. Mean day 42 production performance data, standard errors, and t-test probabilities for selected comparisons. Three replications per treatment. Data for all variables in flocks 1 and 2 were analyzed separately; when the results were consistent, a combined analysis was completed. Results of separate analyses for cumulative mortality are reported.

	Weight (kg/bird) (mean ±SE)	Cumulative Mortality (%) Study 1 (mean ±SE)	Cumulative Mortality (%) Study 2 (mean ±SE)	Feed-to-Gain Ratio (kg feed/kg bird) (mean ±SE)	Cumulative Water Use (L/bird) (mean ±SE)
Treatment					
COOL-R	2.02 ±0.021	3 ±0.4	15 ±4.2	1.9 ±0.25	6.6 ±0.73
AMB-R	1.94 ±0.025	4 ±0.9	38 ±12.8	2.1 ±0.25	7.0 ±0.83
FLOOR	1.96 ±0.040	4 ±0.9	30 ±4.2	2.1 ±0.25	7.4 ±0.77
Comparisons					
COOL-R vs. AMB-R	0.032	0.309	0.205	0.360	0.480
COOL-R vs. FLOOR	0.179	0.512	0.029	0.310	0.151
AMB-R vs. FLOOR	0.669	0.765	0.601	0.921	0.518

Table 3. Bird mortality in studies 1 and 2.

Study	Chamber	Treatment	Total Mortality for Duration of Study	Mortality on Day 40	% Total Mortality Occurring on Day 40
1	8	FLOOR	9	0	0
1	9	FLOOR	15	0	0
1	18	FLOOR	23	0	0
1	2	COOL-R	18	0	0
1	5	COOL-R	12	0	0
1	10	COOL-R	9	0	0
1	4	AMB-R	11	0	0
1	6	AMB-4	22	0	0
1	16	AMB-R	29	0	0
2	8	FLOOR	133	104	78
2	9	FLOOR	178	159	89
2	18	FLOOR	140	116	83
2	2	COOL-R	72	41	57
2	5	COOL-R	108	94	87
2	10	COOL-R	53	38	72
2	4	AMB-R	171	152	89
2	6	AMB-R	314	304	97
2	16	AMB-R	92	74	79

Cumulative Water Use

Numerically, FLOOR birds showed the greatest cumulative water use, followed by the AMB-R and COOL-R birds, but these difference were not statistically significant at $\alpha = 0.05$ (table 2). Broilers consume more water during hot weather in order to balance an increase in water loss by the lungs that accompanies panting under heat stress conditions (Butcher and Miles, 1990).

Carcass Yield

FLOOR birds showed greater wing weight than AMB-R or COOL-R birds, respectively, in flock 1 ($p < 0.001$, $\alpha = 0.05$). There were no other significant differences in carcass yield of breast, thigh, drum, or back among the three treatments in flock 1 (table 4). Table 5 contains mean parts yield analysis and selected means comparisons for flock 2. COOL-R birds showed 8% greater breast weight than AMB-R birds in flock 2 ($p = 0.039$, $\alpha = 0.05$). The heat stress relief techniques employed in these studies appeared to have improved carcass breast weight of birds in flock 2, but not other parts. Carcass composition is mostly influenced by genetics, although nutrition, sex, and environmental conditions also play a role (Leeson, 2000). It was concluded that providing the cool roost system to birds under environmental conditions experienced in flock 2 was beneficial in improving breast weight of birds.

Conclusions

The following conclusions can be drawn from this study:

- The cool roost system produced significantly higher live bird weights than the ambient roost system, probably due to reduced heat stress for the broilers.
- Flock 2 showed much higher mortality rates than flock 1 because the last four days of flock 2 had very high ambient temperatures.
- The cool roost system had significantly less mortality than the floor treatment in flock 2.
- There were no significant differences found in feed-to-gain ratio (FGR), litter moisture content, or cumulative water use between any of the treatments.
- The cool roost system appeared to be thermally more efficient in alleviating heat stress at lower temperatures (below 30°C) than at higher temperatures (above 30°C) due to a combination of ambient temperature and the roost use patterns of birds during hot weather. Heat loss rates ranging from 0.65 to 5.09 watts per bird were achieved during the warmest period of production.

Table 4. Summary of carcass yield for AMB-R, COOL-R, and FLOOR at harvest in flock 1.

	Breast (g)		Thigh (g)		Drum (g)		Wings (g)		Back (g)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Treatment										
AMB-R	471	18.5	258	18.5	213	18.5	189	18.5	242	18.5
COOL-R	494	19.1	277	19.5	222	19.5	183	19.1	240	19.1
FLOOR	486	18.5	272	18.5	220	18.5	287	18.5	254	18.5
Comparisons - Probability values ($\alpha = 0.05$)										
COOL-R vs. AMB-R	0.381		0.473		0.738		0.838		0.937	
COOL-R vs. FLOOR	0.775		0.848		0.964		<0.001		0.596	
AMB-R vs. FLOOR	0.548		0.593		0.769		<0.001		0.647	

Table 5. Summary of carcass yield for AMB-R, COOL-R, and FLOOR at harvest in flock 2.

	Breast (g)		Thigh (g)		Drum (g)		Wings (g)		Back (g)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Treatment										
AMB-R	507	13.6	249	13.6	213	13.6	167	13.6	215	13.6
COOL-R	547	13.6	271	13.6	226	13.6	182	13.6	252	13.6
FLOOR	528	13.6	261	13.6	215	13.6	168	13.6	239	13.6
Comparisons - Probability values ($\alpha = 0.05$)										
COOL-R vs. AMB-R	0.039		0.257		0.474		0.444		0.060	
COOL-R vs. FLOOR	0.327		0.598		0.558		0.488		0.507	
AMB-R vs. FLOOR	0.274		0.544		0.895		0.924		0.221	

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