COOLING BROILER CHICKENS BY SURFACE WETTING: INDOOR THERMAL ENVIRONMENT, WATER USAGE, AND BIRD PERFORMANCE

Y. Liang, G. T. Tabler, T. A. Costello, I. L. Berry, S. E. Watkins, Y. V. Thaxton

ABSTRACT. *A surface-wetting cooling system was evaluated and compared to a conventional evaporative cooling system in commercial, tunnel-ventilated broiler houses during five flocks in summer months over three years. Surface wetting (accomplished using low pressure sprinklers, SPRK) and a conventional evaporative pad cooling system (PAD) were employed in adjacent houses at the University of Arkansas Applied Broiler Research Farm. With SPRK, overhead sprinklers were spaced evenly 6 m apart and 1.2 to 2.4 m above the litter surface and were intermittently operated to apply controlled volumes of large water droplets onto the birds. The SPRK house had substantially higher air temperature but lower relative humidity compared to the PAD house during critical supplemental cooling periods. During a 2-day heat stress period, the core body temperatures of birds in the SPRK house were similar to those of birds in the PAD house. The bird live weight and livability were not significantly different between SPRK and PAD with feed conversion being better in the SPRK treatment. No correlations were found between daily mortality and either daily maximum ambient temperature or flock age, indicating both cooling systems were effective in relieving heat stress of broiler chickens. Apparently, the evaporation of sprinkled water from the bird's surface, benefiting from favorable convective conditions (intrinsically high air velocity of tunnel ventilation) and lower relative humidity, was able to compensate for higher temperatures measured in the SPRK house. Final litter moisture conditions were not significantly different. Due to the nature of the water delivery, cooling water usage per bird basis in SPRK was significantly less than that used by PAD (water in SPRK averaged 33% of that used in PAD). This represents a major opportunity for water conservation in broiler production.*

Keywords. *Poultry, Heat stress, Surface wetting, Sprinkler, Cooling, Broiler, Water consumption.*

Higher air velocities achieved in tunnel-ventilated broiler houses are important in alleviating heat stress of broiler chickens by increasing sensible heat loss (Simmons et al., 1997; Dozier et al., 2006). Most commercial broiler houses in the United States are equipped with a combination of tunnel ventilation and evaporative cooling systems, including evaporative pads (fan-and-pad), fogging, or low-pressure misting systems. Fan-and-pad systems typically have two sections of cellulose-type, evaporative cooling pads at summer ventilation inlets, one on each sidewall. Their use is popular in tunnel-ventilated broiler houses due to the potentially high cooling efficiency; however, they require a large amount of water to cool the air due to high air exchange rates in summer ventilation. Many producers are concerned about the availability and cost of water to operate the system. Other indirect cooling systems-either low-pressure misting (water pressure of at least 1050 kPa, 150 psi) or high pressure fogging (water pressure up to 6,900 kPa, 1,000 psi)-produce a fine mist of droplets in the ambient indoor air. Water evaporates rapidly before reaching the birds, which cools the air inside the house (Timmons and Baughman, 1983; Bottcher et al., 1991). Misting systems are characterized by lower initial installation costs, but smaller temperature reduction of inside air compared to fan-and-pad systems. Conventional misting systems commonly use multi-stage or timer functions to control the amount of water added to a house; nevertheless, they often provide too much water at one time of day, or insufficient water at other times (Simmons and Lott, 1997). Evaporative cooling systems inevitably cause elevated humidity levels of inside air. Higher humidity is counterproductive to the bird's natural ability to cool itself by evaporative heat loss through its respiration mechanism (Genc and Portier, 2005), especially for modern broilers with a higher metabolic rate.

More direct cooling can be achieved by sprinkling the surface of livestock or poultry with coarse water droplets

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and evaporation occurs locally on the animal (Wolfenson et al., 2001), assuming there is sufficient air velocity to support the evaporation. With sprinkler cooling, indirect cooling of the indoor air also occurs to a lesser extent due to evaporation of water from wetted surfaces other than that of the animal, such as the floor or equipment. Sprinklers have been used effectively by dairy and beef cattle producers (Morrison et al., 1981; Turner et al., 1992; Gaughan and Tait, 2005). Harp and Huhnke (1991) evaluated a drip cooling system and a wetted-pad evaporative cooling system in farrowing houses, and found no significant difference between cooling methods in piglet weight gain, percentage of piglets weaned, or sow weight loss. However, respiration rates were lower for drip cooling methods when wet-bulb depression was low.

Application of surface wetting to cool chickens has been limited. Chepete and Xin (2000) conducted laboratory studies to evaluate the efficiency of cooling laying hens in cages by intermittently sprinkling water onto the head and appendages of hens, and concluded that the method was effective for heat stress relief. The cooling water requirements of partial surface wetting for caged laying hens were field tested (Ikeguchi and Xin, 2001) and further optimized (Yanagi et al., 2002; Tao and Xin, 2003a). Mutaf et al. (2008) reported significant reduction in core body temperatures, head and dorsal surface temperatures of laying hens that received sprinkling compared to those that did not, under thermal conditions ranging from 31.3°C to 36.0°C. Webb and King (1984) reported that thermal resistance of plumage of chickens was approximately halved when feathers were wet.

Surface wetting as a direct cooling method for heat stress relief of broiler chickens was tested on a 1,500-bird summer flock in a mechanically ventilated room, and compared with a curtain-sided room with natural ventilation (Berry et al., 1990). The results showed lower mortality under sprinkler cooling than non-sprinkler treatment. In subsequent broiler cooling studies, a sprinkler system was installed and used in one of four commercial houses at the University of Arkansas Applied Broiler Research Farm (ABRF) from 1995 to 2005 (Tabler et al., 2008). During this period, the farm had two experimental, curtain-sided tunnel-ventilated houses with two sections of tunnel air inlets on the same wall (south) and average tunnel air speed lower than 2.0 m/s (400 fpm). One of the two tunnel-ventilated houses used sprinklers for cooling and the other used cooling pads. During 17 summer flocks, cooling water use by the sprinkler house was consistently less (85% less on average) than the other experimental tunnel house that used cooling pads. The ABRF was later renovated (2006) into solid-sidewall houses with tunnel ventilation, drop ceilings and evaporative cooling systems (all four houses). At renovation, the use of the sprinkling system was discontinued in order to adopt the cooling system (pad-and-fan) prevalent in the industry.

Municipal water or water pumped from private wells that is used in pad-and-fan systems is not only a production cost, but also represents consumption of a finite resource. Many broiler farms operate from wells that may become flow-limited or expensive to pump due to declining groundwater levels. Drilling multiple separate wells by producers to meet integrator's specifications can be a significant expense. Pumping energy consumption and costs are proportional to volumetric water usage and depth to water table. Cooling system water conservation therefore is a worthwhile goal that could reduce peak water demand, costs, energy use, and groundwater depletion. It was from the perspective of water conservation that we renewed our interest in sprinkler cooling.

The objective of this study was to test the effectiveness of the surface wetting method by an overhead sprinkler system in cooling broilers in a tunnel-ventilated commercial broiler facility in the Southern region of the United States during summer conditions. Flock livability, average market weight, feed conversion efficiency, cooling water usage, litter moisture contents, the environmental conditions of the houses, and the core body temperatures of birds under the sprinkler system (SPRK) or the traditional evaporative cooling system (PAD) were evaluated.

Experimental Sprinkler System Operating Algorithm

The goal of the sprinkler cooling system design was to intermittently apply a targeted volume of water on the feather/skin surface to meet the cooling needs of the chickens under the given ambient conditions. Evaporation of sprinkled water from the body surface provides a mechanism of cooling to supplement normal convective and respiratory heat loss. This cooling mechanism mimics sweating-a process that human, horses, pigs, and other animals utilize but chickens do not (they have no sweat glands). For this cooling mechanism to be effective, sufficient airflow is needed to prevent moisture accumulation in the boundary layer air, thereby maintaining a humidity gradient for evaporation from the animal surface to the surrounding air (Berman, 2008).

Although we recognized that air velocity is an important component of thermal comfort for broilers under hot weather conditions, we did not intend to alter the fan controls or air velocities (ranging from 2.5 to 3.0 m s^{-1}) normally attained during cooling stages in commercial tunnel-ventilated houses. Based upon earlier experiences (e.g., Berry et al., 1990), we assumed that these velocities would be sufficient to evaporate the controlled masses of sprinkled water. Failure of this assumption would be evidenced by observations of excessive litter moisture, which was monitored in the present study. Therefore, the control strategy for the water sprinkling was based upon making an estimate of the water needed to provide the supplemental cooling for the given ambient conditions and the size of the bird, and did not include air velocity as a control parameter.

The original algorithm used in the study conducted by Berry et al. (1990) was based on experimental data from Reece and Lott (1982) that indicated sensible heat production at a constant air temperature of 26.7°C (80°F) averaged 3.2 W kg^{-1} (5 Btu h^{-1} lb^{-1}) live body weight (BW) for broilers between 0.45 and 1.82 kg BW. Sensible heat transfer between the exposed chicken surfaces and the surrounding air was estimated to decrease linearly from 3.2 to 0.0 W kg^{-1} as air temperature increases from 26.7°C to 33°C (92°F). As sensible heat loss decreases with rising ambient temperature, the increasing supplemental cooling requirement (needed to maintain homeostasis) was estimated as:

$$H_l = \max\left(0, \frac{3.2 \times (t_A - 26.7)}{(t_S - 26.7)}\right) \quad (1)$$

where

H_l = supplemental cooling requirement (W kg^{-1} BW)

t_A = measured room air temperature (°C)

t_S = average temperature of chicken surfaces exposed to sprinkling (°C).

Total heat loss was thus maintained by increasing the latent heat dissipation by applying water at rates proportional to the temperature rise above 26.7°C. A t_S value of 33°C, determined by direct measurement with an infrared radiometer, was used by Berry et al. (1990) in the original algorithm. This value compares to the measured surface temperatures (i.e., 32°C to 38°C) of partially sprinkled laying hens under heat stress conditions of up to 38°C ambient temperatures and up to 1.2 m s^{-1} air velocity in a study conducted by Yanagi et al. (2002). Mutaf et al. (2008) reported that the head and dorsal temperatures of partially sprinkled laying hens were between 28°C and 32°C under ambient temperatures of 33°C and 36°C.

Based on historical trends in chicken metabolism (Xin et al., 2001), we adjusted the design water application rate in the present study by changing the coefficient of 3.2 W kg^{-1} (5 Btu h^{-1} lb^{-1}) in equation 1 to 5.7 W kg^{-1} (9 Btu h^{-1} lb^{-1}). In addition, an empirical BW factor was added in the formula to increase the sprinkling rate for larger birds to account for crowding of birds near harvest under high stocking densities often used in modern commercial production. This resulted in higher specific latent heat demands for heavier birds than lighter birds (fig. 1). The t_S value of 33°C was unchanged. The updated algorithm was:

$$H_l = \max\left(0, \frac{5.7 \times \left(t_A + 16.7 \times \frac{BW}{BW + 1.6} - 35.6\right)}{(t_S - 26.7)}\right) \quad (2)$$

where

BW = calculated chicken body mass as a function of age (kg bird^{-1}).

The increased cooling requirement associated with the updated algorithm is illustrated in figure 1, which shows increased H_l at higher air temperatures and bird mass.

Based on the computed H_l, the sprinkling rate was computed by dividing the target cooling requirement by the latent heat of vaporization of water, and adjusting for total chicken mass:

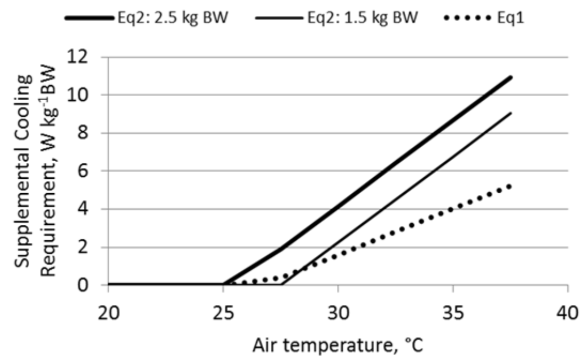

Figure 1. Supplemental cooling requirements calculated from equations 1 or 2.

$$Q_{SPRK} = \frac{H_l}{h_{fg}} \cdot BW \cdot n \quad (3)$$

where

Q_{SPRK} = sprinkler spray rate (mL s^{-1})

h_{fg} = heat of vaporization at 30°C (i.e., 2,430 J g^{-1} water)

n = number of birds in the house (bird).

Body weight was estimated daily in the control program using a regression equation that we developed based on growth rates observed at the ABRF (data not shown), with the bird age as input. Alternative implementation of the algorithm could employ real-time bird scales or other empirical relationships.

Materials and Methods

Broiler Houses

Experiments were conducted at the University of Arkansas ABRF, which had four commercial-scale broiler houses each measuring 12×121 m (40×400 ft), located west of Fayetteville, Arkansas. All houses were equipped with solid sidewalls, dropped ceilings, tunnel ventilation and evaporative pad cooling. The following equipment were installed: eight, 1.27 m belt-drive tunnel fans located at the west end; four, 0.9 m direct-drive exhaust fans on the north sidewalls; two sections of re-circulating evaporative cooling pads (dimension of 21 m × 1.2 m × 15 cm), one on each sidewall on the east end. Air velocity with all tunnel fans in operation averaged 2.5 m s^{-1} (500 fpm). The sprinkler system was installed in spring 2009 in House 2 (SPRK). The adjacent house (House 1) operated as conventional PAD system when supplemental cooling was needed.

Tunnel Ventilation

The ventilation system was operated to conform to the guidelines of the poultry integrator, who supplied the temperature and ventilation settings installed onto the environmental controllers. Temperature set points of both houses were 34.0°C, 29.8°C, 27.8°C, 25.4°C, 20.4°C, 18.4°C, and 17.2°C on Day 0, 7, 14, 21, 28, 35, and 42, respectively. Based on a daily set point T, the controller would turn on the subsequent stages of tunnel fan(s) when the house T increased in increments of 0.6°C or 1.1°C (1°F or 2°F). Houses transitioned to tunnel ventilation just before the fourth tunnel fan was called into operation (at 3.9°C from setpoint). During the transitional period (usually 1 to 2 min), all sidewall inlets were closed, and sidewall and tunnel fans were turned off to allow the tunnel inlet curtains to progressively open. Once the tunnel inlet curtains had opened, the controller would activate the correct number of tunnel fans (minimum of four), until all eight tunnel fans were in operation (6°C above setpoint).

Evaporative Cooling System

Evaporative cooling pads were programmed at 7°C above daily setpoint T, staged after the last tunnel ventilation fan. Evaporative cooling was programmed to allow operation from 9 a.m. to 9 p.m. Occasionally, the program in the controller was changed to allow evaporative cooling pads to operate prior to the 7th tunnel ventilation fan when birds were younger than 4 weeks old under extremely hot conditions.

Sprinkler System

The experimental SPRK system consisted of 63 nozzles [a nominal flow rate of 0.027 L s^{-1} (26 gph at 172 kPa) per nozzle, Antelco, Vari-Rotor Spray™, Australia] configured in three rows (two side rows above the feed lines and a mid-row). Nozzles were plumbed into lines of PVC pipes (2.0 cm ID, ¾ in. nominal diameter) parallel to the ridge-line, and winched from the ceiling support structure to accommodate the live haul and clean out crews. The nozzles were evenly spaced at 5.7 m apart and lines were adjusted to a height of about 2.1 m above the litter surface in the mid-row and about 1.2 m above the litter surface in the side rows when the system was in use. The three rows of nozzles were separated at mid-point along the house length, creating six 58-m long lines. Six solenoid valves controlled the lines of sprinklers, allowing each line to be activated sequentially (each group having 20 or 21 nozzles). Spraying was activated intermittently every 10 min. The spray on-time, corresponding to the 10-min interval, was calculated by equation 3. Air temperatures (T) were measured by a thermocouple sensor, installed in the center of the house and shielded from water drops by aluminum foil. A data measurement and control module (CR10, Campbell Scientific, Logan, Utah) recorded the T and activated relays when spray was needed. Sprinkler operation was allowed only between 9 a.m. and 9 p.m. Sprinkler operation was independent of the tunnel fan stages discussed above.

Test Schedule and Measurement Methods

Cooling methods were evaluated for five summer flocks, with market dates of 29 June 2009 (Trial 1), 2 September 2009 (Trial 2), 16 July 2010 (Trial 3), 10 September 2010 (Trial 4), and 12 September 2011 (Trial 5). Each house received 20,100 chicks on average and birds were marketed between 45 and 50 d. Sprinkling was disallowed before 21 d of age to avoid wetting litter due to small floor coverage by young birds. The evaporative cooling capability in SPRK house was disabled after 21 d for the five trials. Before d 21, pads of both houses were occasionally used to gently tamper the air during extreme hot conditions.

Bird Performance

Bird performance data, including individual bird weight, livability, feed consumption, drinking and cooling water consumption (separate meters on cool-cell system and sprinkler system), were collected daily for each house during all flocks. Individual bird weight was automatically measured by two platform scales in each house. Both cumulative mortality and daily average mortality from flock age 34 days until harvest were reported.

Ambient Environment Conditions

The environmental variables of inside and outside air T and relative humidity (RH) were measured using portable data loggers (HOBO U-10, Onset Computer Corp., Bourne, Mass.). Three loggers were installed inside each house. One logger was placed at the air entrance of tunnel inlet, and two were placed on the waterline cables with one at 60 m house length, and one close to the tunnel fan end of the house. Measurements were taken at 15-min intervals, starting from 22 d of age. Outside dry bulb and dew point temperatures were monitored by an on-farm weather station (Onset Computer Corp., Bourne, Mass.). Sprinkling events in the SPRK house were automatically recorded by a data logger (CR10, Campbell Scientific, Logan, Utah) that also controlled the sprinkler operation.

Litter Moisture Contents

Litter samples from all four houses were taken on the same day immediately after the flocks were harvested for determination of moisture content (MC) in Trials 1 to 4 in 2009 and 2010. Three composite litter samples-near the evaporative cooling pad, house middle, and tunnel fan area-were collected from each house. Litter MCs were determined by oven drying at 105°C for 24 h.

Body Temperature

Core body temperatures (CBT) of a sample of chickens were measured on 15-16 August 2012 using miniature temperature data loggers (DS1922L, Maxim, Sunnyvale, Calif.), which had a published accuracy of ±0.5°C and resolution of 0.0625°C. Loggers were fed to randomly-selected birds at 37 d of age, and recovered from the gizzard by sacrificing the birds three days later. Instrumented birds were selected from two areas within each house. Each house was divided length-wise into four quarters by migration fences-a typical practice in commercial tunnel ventilated houses to avoid areas of over-crowding. Each quarter held approximately equal numbers of birds. Seven birds from the quarter having the tunnel inlets of the house (Inlet quarter) and eight birds from the quarter having the tunnel fans of the house (Exhaust quarter) were instrumented for the measurement. Three or four of the seven or eight birds were males, with the others females. Birds were randomly caught, sexed, weighed, fed the sensors, tagged by wing tags, painted with small amount of black spray paint along the back, and released to the same quarter of the house. The logger was placed behind the tongue in the month so that the bird could swallow it with ease, per the method described by Brown-Brandl et al. (2003). Bird weights at the time of sensor placement were taken using a portable electronic scale. Core body temperatures were recorded at 5-min interval over the 2-d measurement period. Temperature and RH of Inlet and Exhaust quarters of all houses were recorded every 5 min (HOBO U-10, Onset Computer Corp., Bourne, Mass). All procedures were approved by the Animal Care and Use Committee at the University of Arkansas Division of Agriculture, Agricultural Experimental Station.

Data Analysis and Statistical Procedure

Two days (days 38-39) of CBT data from birds of both sexes from two locations in the two houses were analyzed. Hourly CBT was averaged from the 5-min observations and were analyzed using a repeated measures analysis with the PROC MIXED procedure (SAS 9.2, 2010), with hour as a repeated factor. Means were separated using Fisher's LSD and significance was considered at $P \leq 0.05$.

Temperature-humidity index (THI), a parameter typically used to represent heat stress exposure of animals, was calculated using the equation developed for conventionally-cooled broilers by Tao and Xin (2003b):

$$THI_b = 0.85\times T_{db} + 0.15\times T_{wb} \qquad (4)$$

where
THI_b = THI for broilers (°C),
T_{db} = ambient indoor dry bulb temperature (°C),
T_{wb} = ambient indoor wet bulb temperature (°C).

Other THI equations for poultry (layers and turkeys) have been developed (Zulovich and DeShazer, 1990; Xin et al., 1992; Brown-Brandl et al., 1997), but not used in this study due to different genetics, metabolism, and body conformation of broilers, layers, and turkeys.

The daily mortality after day 34 and daily cooling water usage of SPRK versus PAD were analyzed using a paired sample t-test (JMP 9.0). Mortality after day 34 was chosen to evaluate cooling system effectiveness because it is during this period that birds are most vulnerable to heat stress. During later stages of the grow out cycle, some mortality occurs at even moderate temperatures due to rapid increases in body weight and density (bird weight per unit area of floor space, Timmons and Gates, 1989) and other factors such as disease. Temperature, RH, and corresponding THIs during supplemental cooling periods (typically between 12 p.m. to 6 p.m.) were also analyzed using similar paired t-tests. The T and RH data collected on days when the maximum outside THIs were below 26°C were removed from the dataset as "moderate days" prior to conducting the paired sample t-test. Purswell et al. (2012) reported reduced broiler production performance under controlled calm conditions with THI of 26°C compared to 20.8°C. In commercial facilities, depending on the programmed set points, evaporative cooling tends to run in extended periods when house T is above 27°C (81°F). The effects of cooling systems on feed conversion, average market weight, cooling water per bird, drinking water per bird, and final litter MC were analyzed using one-way ANOVA (JMP 9.0).

The daily mortality rates and daily cooling water usage of PAD and SPRK treatments from five trials were analyzed for correlation with the daily maximum outside T and flock age (JMP 9.0). The flock age for cooling water usage was between 22 and 50 d, while that for mortality was between 34 and 50 d. Daily mortality and daily cooling water usage were fitted to the following regression equations:

$$M_d = b_0 + b_1 * T_{max,d} + b_2 * age \qquad (5)$$

$$W_d = b_3 + b_4 * T_{max,d} + b_5 * age \qquad (6)$$

where
M_d = daily mortality from each flock per house (bird day^{-1}),
W_d = daily cooling water usage per bird per day (L bird^{-1} day^{-1}),
$T_{max,d}$ = daily maximum outside temperature (°C),
age = flock age (d),
b_0, b_1.. b_5 = regression parameters.

Results and Discussion

Environmental Conditions

The summer of 2009 was a relatively mild but humid season, while summers of 2010 and 2011 were both hot and relatively dry (table 1). Representative T and RH inside and outside the houses in August 2010 are shown in figure 2. Temperatures in the PAD house were as much as 6°C lower than that of SPRK for extended period during day time, while the RHs in the PAD house were as much as 20% higher than those observed in the SPRK house. Temperatures in the SPRK house were slightly lower than outside temperatures during the peak hours of the day (fig. 2).

Paired sample t-tests of interior dry bulb T (T_{db}) during the 6-h periods (noon to 6 p.m.) of the five summer flocks showed that the SPRK house was warmer than the PAD house when supplemental cooling was used (table 2). However, corresponding dew point Ts in the SPRK house were below those of the PAD house (table 2). This indicated that air inside the SPRK house was drier during supplemental cooling periods. The THI values observed in the SPRK house were higher than those of the PAD house ($P<0.0001$).

Sprinkler Operation

The onset and duration of sprinkler operation and water application rates varied based on bird BW and interior T_{db}. Based on a 10-min interval, figure 3 shows that the spray duration yielded by the algorithm increased with increasing interior T_{db} and increasing broiler body mass.

Table 1. Number of days that the daily outside maximum temperature exceeded 30°C, 33°C, or 35°C during July and August of 2009, 2010, and 2011. Also, average daily maximum temperature for each period.

	2009	2010	2011
T_{max} (°C)	Days Exceeding T_{max} in July-August		
30	35	55	60
33	10	26	46
35	3	17	36
	Daily Average T_{max} (°C)		
	29.8	33.2	35.6

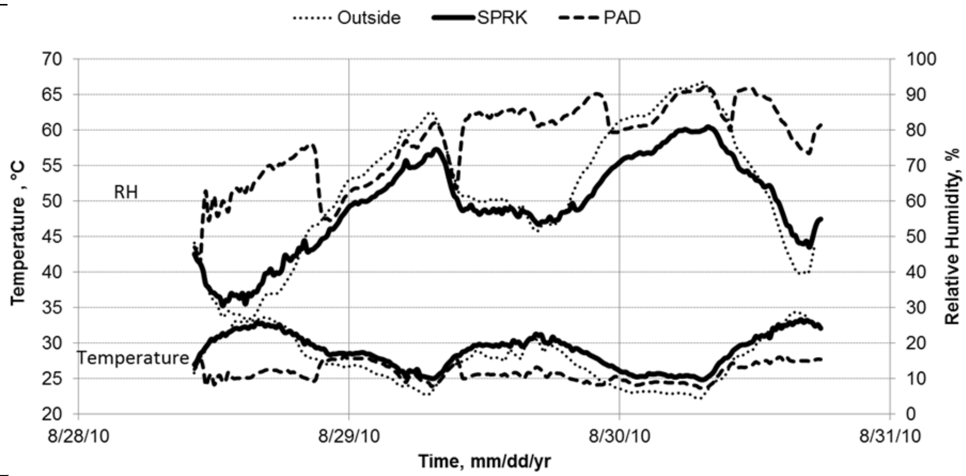

Figure 2. Outside temperature and relative humidity (RH), and temperature and RH observed inside the SPRK and PAD houses.

Table 2. Mean dry bulb temperature (T_{db}), dew point temperature (T_{dp}), and Temperature - Humidity Index (THI) over 6-h periods (12 p.m. to 6 p.m.) during the five trials for the SPRK and PAD houses.

	Dry Bulb Temperature					Dew Point Temperature					Temperature-humidity Index [a]				
Trial	T_{dbSPRK}	T_{dbPAD}	Mean Difference ±Stderr	t value	P> |t|	T_{dpSPRK}	T_{dpPAD}	Mean Difference ±Stderr	t value	P> |t|	$T_{THISPRK}$	T_{THIPAD}	Mean Difference ±Stderr	t value	P> |t|
1	30.4	27.8	2.6 ±0.03	87.0	<0.0001	22.7	24.0	-1.3±0.02	56.0	<0.0001	29.6	27.3	2.2 ±0.03	85.4	<0.0001
2	30.1	27.3	2.7 ±0.03	79.0	<0.0001	21.1	22.6	-1.5±0.03	45.5	<0.0001	29.1	26.8	2.3 ±0.03	78.8	<0.0001
3	31.3	28.9	2.5 ±0.04	59.1	<0.0001	23.2	24.2	-1.0 ±0.04	28.6	<0.0001	30.5	28.3	2.1 ±0.04	59.1	<0.0001
4	31.7	28.4	3.4 ±0.06	56.9	<0.0001	18.0	20.2	-2.2±0.04	57.4	<0.0001	30.3	27.5	2.8 ±0.05	55.5	<0.0001
5	32.3	30.0	2.4 ±0.03	70.0	<0.0001	21.0	21.5	-0.5±0.05	9.5	<0.0001	31.0	29.0	1.9 ±0.03	66.9	<0.0001

[a] THI = $0.85*T_{db} + 0.15*T_{wb}$.

Figure 4 shows an example of the actual hourly cooling water usage by SPRK system on two separate days with different thermal conditions. The SPRK system used 230 L h^{-1} of water during the peak hour when the interior T_{db} reached 36°C on 23 August 2010, when flock age was 31 d. On 6 September 2010, even though the air was cooler (32°C), more water was used by SPRK (330 L h^{-1} of water) because birds were older and heavier. Daily cooling water totaled 107 and 145 mL d^{-1} $bird^{-1}$ for ages 31 and 45, respectively. In comparison, daily cooling water usage from PAD house was 436 and 353 mL d^{-1} $bird^{-1}$, respectively, for the corresponding two days. The PAD house used more cooling water on the earlier (hotter) day due to lower outside RH associated with higher T_{db}.

CORE BODY TEMPERATURE

No mortality occurred to the instrumented birds before miniature sensor retrieval. Instrument failure in two of the 30 birds reduced the number of observations included in the analysis. The dynamic trend in bird CBT is illustrated in figure 5, showing representative CBT from two male birds (one in each house) at Exhaust quarter and the corresponding interior T_{db}. During the 6-h period, the THI ranged from 25.8°C and 30.8°C, showing a general trend of higher values in the Exhaust quarter than those in the Inlet quarter of the houses (table 3).

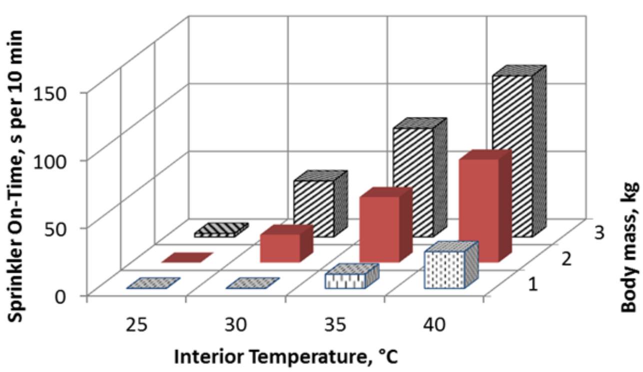

Figure 3. The relationship of spray duration of every 10-min interval, the interior dry bulb temperature, and broiler body mass.

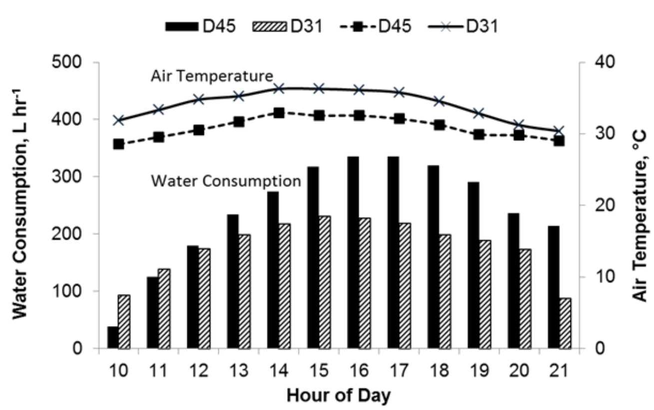

Figure 4. Hourly water sprinkling rates in SPRK on 23 August vs. 6 September 2010 (flock age 31 vs. 45 d) and their corresponding hourly average interior dry bulb temperatures (flock sold on 10 September 2010).

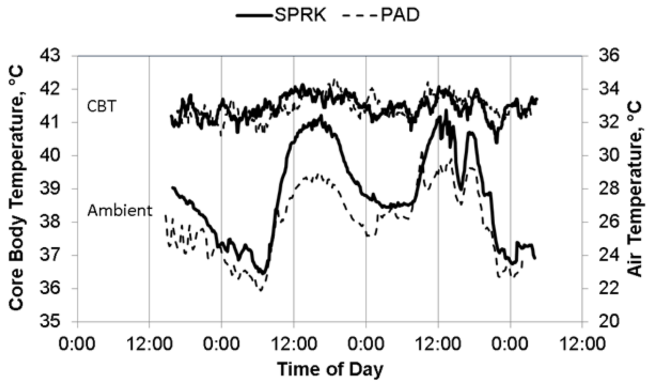

Figure 5. Representative core body temperature (CBT) of two instrumented male birds located in the exhaust quarters (one in each house) and corresponding dry bulb temperature.

Core body temperatures of birds from both days were pooled together (table 4) due to the fact that no differences were found between days. No significant differences of CBT were found between SPRK and PAD treatments (P= 0.11). Core body temperatures of males and females were not significantly different (P= 0.58), although males were heavier (2417 ±25 g) than females (2079 ±25 g) (P < 0.0001). Core body temperatures of birds in the Inlet quarter were not different from those in Exhaust quarter (table 4, P =0.52).

Higher THI values in SPRK house showed that birds in SPRK house were disadvantaged when considered using a conventional quantification of the microclimate. However, the fact that CBT and mortality for the SPRK birds (reported later) did not increase with the higher THI indicated that birds did not respond to the THI alone, but as well to the supplemental cooling mechanism. The auxiliary cooling by surface wetting provided an additional heat release mechanism, replacing the loss of sensible heat dissipation due to hot weather. The THI algorithm given in Tao and Xin (2003b) may not serve as an appropriate heat stress indicator for birds having access to surface wetting cooling mechanism and/or higher velocities typical in tunnel-ventilated broiler houses. Water evaporation on the chicken surface under the favorable convective conditions of tunnel ventilation, combined with lower RH, may have compensated for the higher T_{db} in the SPRK house so birds were able to maintain thermal homeostasis.

MORTALITY AND BIRD PERFORMANCE

Daily mortalities (after day 34) from the PAD and SPRK houses of each summer flock were analyzed using a paired sample t-test (table 5). Daily mortality in the SPRK and PAD houses in Trials 1 and 2 were not significantly different. However, the SPRK house had higher mortality than the PAD house in Trial 3 (P=0.013), while the PAD house had higher mortality than the SPRK house in Trials 4 and 5 (P=0.005 and 0.035). Daily mortality of all five flocks in SPRK and PAD treatments were not different (with P=0.052). Cumulative mortality rates (per flock) averaged 2.6% and 2.4% over five summer flocks in the PAD and SPRK houses, respectively, which were comparable with other field observations (Feddes et al., 2002; Liang et al., 2013). Bird market weights were not significantly different among houses in the SPRK or PAD treatments, while feed conversion ratios (feed: weight gain) in the SPRK house were better than those in the PAD house (P=0.02, table 6). Drinking water on per bird basis were not significantly different (P=0.70).

Daily mortality (after day 34) was not correlated with either daily maximum ambient temperature, or bird age in either of the cooling methods (P =0.85, SPRK; P = 0.37, PAD; data not shown). This indicated that the totally enclosed, tunnel-ventilated broiler houses using either PAD or SPRK systems were effective in reducing bird loss due to heat stress.

COOLING WATER USAGE

Sprinkler cooling used 67% less water than that was used in a conventional evaporative cooling system over three summers (table 6). The amounts of cooling water usage per day in SPRK treatment were significantly lower than those in PAD treatment (table 7, P<0.001). On a per

Table 3. Mean dry bulb temperature (T_{db}), relative humidity (RH) and Temperature - Humidity Index (THI) during 6 h (12 p.m. to 6 p.m.) for outside and inside conditions recorded during CBT testing (15 and 16 August 2012).

		Day 1			Day 2		
House	Quarter	T (°C)	RH (%)	THI[a] (°C)	T (°C)	RH (%)	THI[a] (°C)
Outside		32.7	43.3	31.3	31.8	53.2	30.6
PAD	Inlet	26.6	66.5	25.8	26.7	72.3	26.1
PAD	Exhaust	28.5	76.5	28.0	28.7	80.0	28.2
SPRK	Inlet	30.2	50.2	28.8	29.4	61.9	28.5
SPRK	Exhaust	31.7	62.3	30.8	30.7	70.2	30.0

[a] THI = $0.85*T_{db} + 0.15*T_{wb}$.

Table 4. Mean (±standard error) CBT from 12 pm to 6 pm of birds of 38 and 39 days of age in the Inlet and Exhaust quarters under two cooling treatments in the 12 × 122 m broiler houses, and average BW (15 and 16 August 2012).

		Male			Female		
House	Quarter	n	BW (g)[a]	CBT (°C)	n	BW (g) [a]	CBT (°C)
PAD	Inlet	4	2513 ±87 [a]	41.70 ±0.04 [a]	2	1948 ±81 [ac]	41.80±0.06 [a]
PAD	Exhaust	3	2503 ±75 [a]	41.76 ±0.05 [a]	4	2070 ±57 [bc]	41.63 ±0.04 [a]
SPRK	Inlet	3	2374 ±87 [a]	41.78 ±0.05 [a]	4	2206 ±57 [b]	41.77 ±0.05 [a]
SPRK	Exhaust	4	2371 ±75 [a]	41.97 ±0.04 [a]	4	2036 ±57 [bc]	41.88 ±0.04 [a]

[a] Body weights at the time of sensor installation at 37 days of age.
[a-c] Means followed by the same superscript letters are not significantly different (P>0.05).

Table 5. Mean and standard error of daily mortality between day 34 and market age and the paired sample t-tests of five flocks under PAD and SPRK cooling systems.

	Daily Mortality (birds day^{-1})				
Trial	SPRK	PAD	Mean Difference ±Stderr	t_value	P> |t|
1	12.0	14.5	-2.54 ±1.875	-1.357	0.204
2	8.4	10.7	-2.27 ±1.720	-1.318	0.209
3	15.4	12.2	3.15 ±1.085	2.906	0.013
4	5.4	8.0	-2.56 ±0.785	-3.264	0.005
5	7.6	9.1	-1.50 ±0.635	-2.360	0.035
Combined	9.4	10.6	-1.20 ±0.606	-1.983	0.052

Table 6. Average live market weights, feed conversion (feed:weight gain), cooling and drinking water per bird and final litter moisture contents (MC) of five summer flocks under PAD and SPRK cooling systems.

Item	Live Market Weight (kg)	Feed Conversion	Cooling Water, (L bird^{-1})	Drinking Water (L bird^{-1})	Litter MC [a] (%)
SPRK	2.65 ±0.11	1.86 ±0.014 [a]	1.8 ±0.52 [a]	9.8 ±0.44	34.0 ±2.84
PAD	2.68 ±0.10	1.92 ±0.014 [b]	6.1 ±0.52 [b]	9.5 ±0.44	36.0 ±2.84
P value	0.84	0.02	P<0.001	0.70	0.64

[a] Litter moisture contents were analyzed from litter samples collected at the end of the first four trials.

a-b Levels marked by different letter were significantly different (P<0.05).

Table 7. Mean (±standard error) of daily cooling water used (mL bird^{-1} day^{-1}) by evaporative (PAD) and sprinkler cooling (SPRK) systems and the paired sample t-tests.

	Cooling Water Use (mL bird^{-1} day^{-1})				
Trial	SPRK	PAD	Mean Difference ±Stderr	t_value	P> |t|
1	132	262	-130 ±13	-9.7	<0.0001
2	22	196	-174 ±12	-14.6	<0.0001
3	71	188	-117 ±11	-10.4	<0.0001
4	73	261	-188 ±20	-9.3	<0.0001
5	96	232	-136 ±11	-12.1	<0.0001
Combined	84	255	-170 ±9.5	-17.9	<0.0001

bird basis, SPRK used an average of 8.4 mL water bird^{-1} h^{-1}, under a daily maximum outside T range of 26°C to 37°C and bird age between 35 and 50 d. By comparison, in a partial surface-wetting laboratory study (Yanagi et al., 2002), 10-mL spray water was applied to an adult laying hen every 30 to 10 min under thermal environments that varied between 26.7°C and 41°C and air velocity between 0.2 and 1.2 m s^{-1}. The higher rates applied by Yanagi et al. (2002) may have been necessitated by the more extreme heat stress that was imposed. It may also suggest that sprinkled water was utilized more efficiently in a high-density commercial production house than the laboratory condition involving wetting and cooling of a single bird at a time.

To explore the relationship between cooling water use and maximum daily outside T and flock age, multiple regression models were fitted for both systems (eqs. 7 and 8; P<0.0001, fig. 6). The regression models were not meant to be predictive for operational purposes (especially given that the actual control algorithms for both systems were based upon nonlinear functions of the dynamic inside conditions). Instead they allow a gross comparison of cooling water usage by the two cooling systems based upon extrinsic parameters. The reason that cooling water usage in PAD treatment was a function of flock age was due to the programmed set points decreasing as birds grew, which demanded a longer cooling period per day at older flock ages under similar thermal conditions.

$$\text{PAD: } W_{pd\_d} = -0.931\ (\pm 0.106) + 0.029\ (\pm 0.0027) * T_{max,d} + 0.0079\ (\pm 0.0011) * D\ (D > 22\text{ day})\ (R^2 = 0.55) \quad (7)$$

$$\text{SPRK: } W_{sp\_d} = -0.753\ (\pm 0.065) + 0.019\ (\pm 0.0017) * T_{max,d} + 0.0072\ (\pm 0.0006) * D\ (D > 22\text{ day})\ (R^2 = 0.65) \quad (8)$$

where

W_{pd_d}, W_{sp_d} = daily cooling water usage by PAD or SPRK systems (L bird^{-1} day^{-1}),

$T_{max,d}$ = daily maximum outside temperature (°C).

The dramatic difference in sprinkler water usage for birds of different ages (fig. 7) indicates that the algorithm was sensitive to body mass and adjusted sprinkling rates accordingly to meet higher cooling needs of heavier birds while avoiding over-application for younger birds. By evaporating water from the chicken surface, overhead sprinkler systems were effective in providing a supplemental cooling mechanism as inside T_{db} approached body

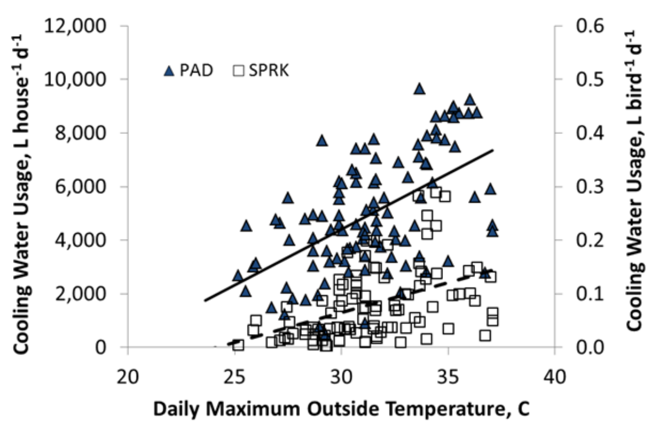

Figure 6. Daily cooling water usage as a function of ambient temperatures in sprinkler (SPRK) and evaporative cooling (PAD) houses.

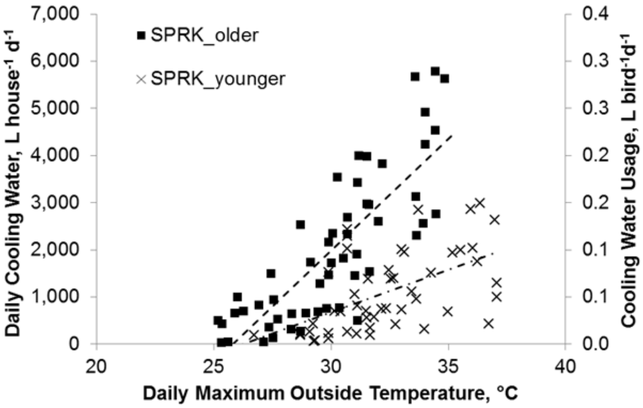

Figure 7. Daily cooling water usage of SPRK treatment as a function of ambient temperature for birds younger than 35 day (SPRK_younger) or older than 35 day (SPRK_older).

temperature. This method of local evaporation relied on the inherently high air speeds under tunnel ventilation, and avoided large RH increase associated with conventional evaporative cooling. Cooling water was substantially reduced at younger flock ages (<35 days).

LITTER MOISTURE CONTENTS

Average litter moisture contents at the end of growout cycles were shown in table 6. Litter MC in the SPRK house were not significantly different from those in the PAD house (P=0.64). One might expect that the SPRK system would create a wetter litter condition than the PAD system. Litter inevitably received sprinkled water from the overhead sprinkler systems. However, the drier air and the higher temperature in SPRK house may have contributed to the equivalent litter moisture conditions in present study. The fact that SPRK litter MC was not a problem is indicative of some success in designing a control algorithm to add only the needed water to surfaces that could be evaporated.

COSTS AND MAINTENANCE

Growers who experience water shortage or high water costs may be interested in the sprinkler cooling system. Adoption of alternate sprinkler cooling will affect capital and operating costs for growers. In terms of gross cost estimates at the time of this writing, the capital cost of a sprinkler system (for the house size used in this study) was estimated to be $4,000. Estimated cost for a 6-in. pad, recirculating evaporative cooling system was $15,000. Some growers may opt to install both systems to achieve redundancy. Operating costs (utility water bill or well water pumping and treatment costs) would be greatly reduced for the SPRK system that will use much less water. Maintenance for the SPRK used in this study was minimal. Although we have not actually experienced nozzle plugging, other growers may need occasional cleaning of sprinkler nozzles depending on the type of nozzles and water quality on the farm. Paper elements in the pad system need regular cleaning and replacement after extended period.

CONCLUSION

An alternative method of cooling broiler chickens in tunnel-ventilated houses was evaluated during five summer flocks at a commercial broiler farm in Northwest Arkansas in 2009, 2010, and 2011, with body temperature recorded for a short period in 2012. Core body temperatures of birds raised under two different cooling mechanisms were not significantly different, although thermal conditions in the houses were different, characterized by hotter and drier environment in a SPRK house compared to a PAD house. Bird livability and market live weights from SPRK and PAD houses were not significantly different, while feed conversion from the SPRK treatment was better than that from the PAD house. Sprinkler cooling used 67% less cooling water than PAD. Final litter moisture contents from the SPRK house were not significantly different from the PAD cooling house. Sprinkling achieved satisfactory bird cooling by targeting the surface wetting of birds using a controlled amount of water. The study indicated that an intermittently operated surface wetting method in tunnel ventilated houses was able to compensate for indoor ambient temperatures up to 35°C in cooling floor-raised broiler chickens up to 2.5 kg.

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REFERENCES

Berman, A. (2008). Increasing heat stress relief produced by coupled coat wetting and forced ventilation. *J. Dairy Sci., 91(12)*, 4571-4578. doi:http://dx.doi.org/10.3168/jds.2008-1175

Berry, I. L., Costello, T. A., & Benz, R. (1990). Cooling broiler chickens by surface wetting. ASAE Paper No. 90-4024. St. Joseph, Mich.: ASAE.

Bottcher, R. W., Baughman, G. R., Gates, R. S., & Timmons, M. B. (1991). Characterizing efficiency of misting systems for poultry. *Trans. ASAE*, 32(2), 586-590. doi:http://dx.doi.org/10.13031/2013.31703

Brown-Brandl, T. M., Beck, M. M., Schulte, D. D., Parkhurst, A. M., & DeShazer, J. A. (1997). Temperature humidity index for growing tom turkeys. *Trans. ASABE, 40*(1), 203-209. doi: :http://dx.doi.org/10.13031/2013.21246

Brown-Brandl, T. M., Yanagi, T., Xin, J. H., Gates, R. S., Bucklin, R. A., & Ross, G. S. (2003). A new telemetry system for measuring core body temperature in livestock and poultry. *Applied Eng. in Agric., 19*(5), 583-589. doi: http://dx.doi.org/10.13031/2013.15316

Chepete, H. J., & Xin, H. (2000). Alleviating heat stress of laying hens by intermittently partial surface cooling. *Trans. ASAE, 43*(4), 965-971. doi:http://dx.doi.org/10.13031/2013.2993

Dozier, W. A., Purswell, J. L., & Branton, S. L. (2006). Growth responses of male broilers subjected to high air velocity for either twelve or twenty-four hours from thirty-seven to fifty-one days of age. *J. Appl. Poult. Res., 15*, (3)362-366.

Feddes, J. J., Emmanuel, E. J., & Zuidhof, M. J. (2002). Broiler performance, body weight variance, feed and water intake, and carcass quality at different stocking densities. *Poultry Sci., 81*, (6)774-779.

Gaughan, J. B., & Tait, L. A. (2005). Effectiveness of evaporative cooling of beef cattle housed in confinement. In *Proc. of the VII International Livestock Environment Symposium.* St Joseph, Mich.: ASAE.

Genc, L., & Portier, K. M. (2005). Sensible and latent heat productions from broilers in laboratory conditions. *Turkish J. Vet. Anim. Sci., 29*, (3) 635-643.

Harp, S. L., & Huhnke, R. L. (1991). Drip vs. wetted-pad evaporative cooling of farrowing houses in Oklahoma. *Applied Eng. in Agric., 7*(4), 461-464. doi:http://dx.doi.org/10.13031/2013.26246

Ikeguchi, A., & Xin, H. (2001). Field evaluation of a sprinkling system for cooling commercial laying hens in Iowa. *Applied Eng. in Agric., 17*(2), 217-221. doi:http://dx.doi.org/10.13031/2013.5457

JMP Pro. (2010). *User's Guide Version 9.0.0.* Cary, N.C.: SAS Institute, Inc.

Liang, Y., Kidd, M., Watkins, S., & Tabler, G. (2013). Effect of commercial broiler house retrofit: A 4-year study of live performance. *J. of Appl. Poul. Res., 22*(2), 211-216. doi:http://dx.doi.org/10.3382/japr.2012-00601

Morrison, S. R., Prokop, M., & Lofgreen, G. (1981). Sprinkling cattle for heat stress relief: Activation temperature, duration of sprinkling and pen area sprinkled. *Trans. ASAE, 24*(5), 1299-1300. doi:http://dx.doi.org/10.13031/2013.34438

Mutaf, S., Kahraman, N. S., & Firat, M. Z. (2008). Surface wetting and its effect on body and surface temperatures of domestic laying hens at different thermal conditions. *Poultry Sci., 87*, (12) 2441-2450. doi:http://dx.doi.org/10.3382/ps.2007-00391

Purswell, J. L., III, W. A., Olanrewaju, H., Davis, J. D., Xin, H., & Gates, R. S. (2012). Effect of temperature-humidity index on live performance in broiler chickens grown from 49 to 63 days of age. In *Proc. of the Ninth International Livestock Environment Symposium, Valencia, Spain.* St. Joseph, Mich.: ASABE.

Reece, F. N., & Lott, B. D. (1982). Heat and moisture production of broiler chickens. In *Proc. Second Int'l Livestock Environment Symp* (pp. 330-337). St. Joseph, Mich.: ASAE.

SAS. (2010). *SAS User's Guide Version 9.2.* Cary, N.C.: SAS Institute, Inc.

Simmons, J. D., & Lott, B. D. (1997). Computer-controlled fogging. *Applied Eng. in Agric., 13*(4), 525-530. doi:http://dx.doi.org/10.13031/2013.21628

Simmons, J. D., Lott, B. D., & May, J. D. (1997). Heat loss from broiler chickens subjected to various air speeds and ambient temperatures. *Applied Eng. in Agric., 13*(5), 665-669. doi:http://dx.doi.org/10.13031/2013.21645

Tabler, G. T., Berry, I. L., Liang, Y., Costello, T. A., & Xin, H. (2008). Cooling broiler chickens by direct sprinkling. *Avian Advice, 10*(4), 10-15.

Tao, X., & Xin, H. (2003). Acute synergistic effects of air temperature, humidity, and velocity on homeostasis of market-size broilers. *Trans. ASAE, 46*(2), 491-497.

Tao, X., & Xin, H. (2003). Surface wetting and its optimization to cool broiler chickens. *Trans. ASAE, 46*(2), 483-490.

Timmons, M. B., & Baughman, G. R. (1983). Experimental evaluation of poultry mist-fog systems. *Trans. ASAE, 26*(1), 207-210. doi:http://dx.doi.org/10.13031/2013.33905

Timmons, M., & Gates, R. (1989). Temperature dependent efficacy of evaporative cooling for broilers. *Appl. Eng. in Agric., 5*(2), 215-224. doi:http://dx.doi.org/10.13031/2013.26505

Turner, L. W., Chastain, J. P., Hemken, R. W., Gates, R. S., & Crist, W. L. (1992). heat stress in dairy cows through sprinkler and fan cooling. *Applied Eng. in Agric., 8*(2), 251-256. doi:http://dx.doi.org/10.13031/2013.26061

Webb, D., & King, J. R. (1984). Effects of wetting on insulation of bird and mammal coats. *J. Thermal Biology, 9*(3), 189-191. doi:http://dx.doi.org/10.1016/0306-4565(84)90020-2

Wolfenson, D., Bachrach, D., Maman, M., Graber, Y., & Rozenboim, I. (2001). Evaporative cooling of ventral regions of the skin in heat-stressed laying hens. *Poultry Sci., 80*, 958-964.

Xin, H., Berry, I. L., Tabler, G. T., & Costello, T. A. (2001). Heat and moisture production of poultry and their housing systems: Broilers. *Trans. ASAE, 44*(6), 1851-1857. doi:http://dx.doi.org/10.13031/2013.7023

Xin, H., DeShazer, J. A., & Beck, M. M. (1992). Responses of prefasted growing turkeys to acute heat exposure. *Trans. ASAE, 35*(1), 315-318. doi:http://dx.doi.org/10.13031/2013.28605

Yanagi, T. J., Xin, H., & Gates, R. S. (2002). Optimization of partial surface wetting to cool caged laying hens. *Trans. ASAE, 45*(4), 1091-1100. doi:http://dx.doi.org/10.13031/2013.9942

Zulovich, J. M., & DeShazer, J. A. (1990). Estimating egg production declines at high environmental temperatures and humidities. ASAE Paper No. 90-4021. St. Joseph, Mich: ASAE.