Direct surface wetting sprinkler system to reduce the use of evaporative cooling pads in meat chicken production: indoor thermal environment, water usage, litter moisture content, live market weights, and mortalities

Mark W. Dunlop[1] and Jim McAuley

Department of Agriculture and Fisheries, Queensland Government, Toowoomba Qld 4350, Australia

ABSTRACT An overhead sprinkler system that directly applies water onto meat chickens in tunnel ventilated houses was evaluated and compared with a conventional evaporative cooling pad system at 2 commercial farms in south-eastern Queensland, Australia. The sprinkler system was used to reduce the use of evaporative cooling pads as the primary cooling system but not replace evaporative cooling pads altogether. The sprinkler system used low water pressure and comprised evenly spaced sprinklers and a programmable controller. Water was applied intermittently based on house temperature and a temperature program that was related to bird age. The study was conducted over 6 sequential grow-outs during a 1-year period. Air temperature, relative humidity, litter moisture content, cooling water usage, live market weight, and mortality were assessed during the study. The effect of sprinklers on these measured parameters was complicated by interactions with farm, batch, bird age, and time of day. We found that, in general, houses with combined sprinkler and evaporative cooling pad systems used less water, while having similar litter moisture content, live market weight, and mortality compared with control houses that were fitted with conventional evaporative cooling pads. When evaporative cooling was required, sprinkler houses had warmer air temperature but lower relative humidity than the control houses. Bird comfort due to the direct cooling effect of water evaporating off the birds was not directly assessed during this study but was inferred from thermal camera images and from live weight and mortality data. This was the first study in Australia involving this sprinkler system, and we suggest that the sprinkler system design and operation may require some adaptation to better suit Australian poultry house design and climatic conditions, including the need for additional sprinklers to improve coverage, lower set-point temperatures, and altering sprinkler spacing to suit ceiling baffle curtains (if fitted).

Key words: broiler, poultry, sprinkler, water efficiency, relative humidity

2021 Poultry Science 100:101078
https://doi.org/10.1016/j.psj.2021.101078

INTRODUCTION

Chickens raised intensively for their meat are grown out in specially designed and operated poultry houses. These houses have evolved over several decades and are now commonly equipped with sophisticated ventilation and evaporative cooling systems that are designed to remove the substantial amount of heat that is produced by the chickens as they metabolize high-energy feed. Evaporative cooling pad systems are found on many modern poultry houses and are used when mechanical ventilation alone cannot provide sufficient cooling. When correctly designed and operated, evaporative cooling pads are effective in reducing the temperature of air entering the poultry house, but the evaporation of water and cooling of the air substantially increases the relative humidity (Xin et al., 1994; Liang et al., 2014). Such high values of relative humidity negatively affect the ability for meat chickens to dissipate heat during hot weather (Tao and Xin, 2003a), which they primarily achieve through respiratory evaporation (Lin et al., 2005; Hillman, 2009). High relative humidity is also recognized as one of the multifactorial factors that negatively affects litter quality (Payne, 1967; Weaver and Meijerhof, 1991; Dunlop et al., 2016) and, by association, influences health and welfare outcomes (Jones et al., 2005; Shepherd and

---

Received January 12, 2021.

Accepted February 11, 2021.

[1] Corresponding author: mark.dunlop@daf.qld.gov.au

Table 1. Date ranges and maximum duration for each of the grow-out cycles during the study.

	Farm A		Farm B	
Grow-out	Date range (d/m/y)	Duration of grow-out (d)	Date range[1] (d/m/y)	Duration of grow-out (d)[2]
1	28/11/2016–13/1/2017	47	13/10/2016–12/12/2016	51–56
2	25/1/2017–15/3/2017	49	16/12/2016–8/2/2017	49–52
3	28/3/2017–17/5/2017	50	20/2/2017–12/4/2017	48–50
4	25/5/2017–13/7/2017	49	21/4/2017–14/6/2017	48–53
5	27/7/2017–14/9/2017	49	3/7/2017–24/8/2017	50–52
6	28/9/2017–16/11/2017	49	5/9/2017–30/10/2017	48–53

[1] Not all houses had birds placed on the indicated start day, due to operational requirements.
[2] A range of values indicates that each house was grown to a different bird age within this range.

Fairchild, 2010; de Jong et al., 2012; de Jong et al., 2014; Taira et al., 2014; Kaukonen et al., 2016).

Directly applying water onto poultry using sprinkler systems, which partially wet the birds with intermittent applications using low pressure and coarse droplets, have previously been tried in tunnel-ventilated poultry houses and been shown to provide effective cooling and relief of heat stress (Chepete and Xin, 2000; Ikeguchi and Xin, 2001; Tao and Xin, 2003b; Tabler et al., 2008; Liang et al., 2014; Liang et al., 2020), while reducing (although not significantly) airborne respirable and inhalable dust fractions (Williams Ischer et al., 2017). These sprinkler systems use less water and are less likely to cause high relative humidity that is normally associated with use of evaporative cooling pads (Tabler et al., 2008; Liang et al., 2014; Liang et al., 2020).

The objective of this study was to evaluate the effect of a sprinkler system on indoor thermal environment, cooling water usage, litter conditions, and live market weights in tunnel-ventilated meat chicken houses. To the best of our knowledge, this is the first time that an intermittently operating sprinkler system has been evaluated in Australia. There was a need to gain a practical understanding of how well this technology could be incorporated into poultry production due to local building design features (e.g., ceiling baffles), weather, and production practices (e.g., flock thinning) that may not be common where sprinkler technology has previously been tested. Being the first research trial of this cooling system in Australia, configuration and adjustments to the system occurred during the trial period and operational parameters may not have been optimal. The focus of this research trial was litter conditions and water usage; future trials are required to measure more of the production- and welfare-related performance measures.

MATERIALS AND METHODS

Experimental Conditions

This study was conducted at 2 farms (A and B) in south-eastern Queensland, Australia, for 6 grow-out

Table 2. Specifications of the tunnel-ventilated poultry houses used in this study.

Parameter	Farm A	Farm B
Number of houses included in study	2 (1 house had the sprinkler system installed to complement the pre-existing evaporative cooling system; 1 house had only the pre-existing evaporative cooling system).	4 (2 houses had the sprinkler system installed to complement the pre-existing evaporative cooling system; 2 houses had only the pre-existing evaporative cooling system).
Birds placed per house in each grow-out	40,000	25,400 to 25,800
Bird pickup schedule	Approximately 20,000 birds harvested on d 34–35 with balance harvested on d 47–50.	3–4 harvesting events of 2,500 to 12,000 birds between d 28 and 56 depending on market requirements.
House dimensions (L x W) (m)	154 × 15.3	113 × 13.7
Wall height (m)	2.7	2.4
Roof apex height (m)	4.3	4.1
House construction	Insulated metal roof with steel trusses. Solid, insulated walls. 145 wall inlet vents (each 0.55 m wide), 28 m of evaporative cooling pad on each side of the house, with insulated tilting tunnel-ventilation inlets.	Spray foam–insulated metal roof with steel trusses; curtain side walls (curtains remained closed during the grow-out); 62 wall inlet vents (each 1.2 m wide); 22 m of evaporative cooling pad on each side of the house with tunnel inlets closed with a curtain.
Design ventilation rate (m^3/s)	145	92
Calculated maximum tunnel air speed (m/s)	3.5	3.0
Litter management	Fresh pine shavings placed in one half of the house for brooding; and reused litter from the previous grow-out in the rest of the house. At the end of each grow-out, the end of the house that started with reused litter was cleaned out.	Fresh hardwood sawdust at the start of each grow-out. All litter removed at the end of each grow-out.
Ceiling baffles (height above ground, m)	2.7 (baffles spaced 8.1 m apart for 117 m in the end of the house nearest the tunnel-ventilation fans, such that 36 m of the house near the evaporative cooling-pads had no baffle curtains)	2.2 (baffles spaced every 7.2 m).

Table 3. Specifications of the sprinkler systems used in this study.

Parameter	Farm A	Farm B
Sprinkler system	Weeden Environments (Ontario, Canada) WSS-6 sprinkler controller (24 VAC, 50 Hz) with temperature sensors, 275 kPa (40 PSI) pressure regulator, stainless steel filter, solenoids, sprinklers, and flexible droppers as supplied.	
Sprinkler mode	Activity promotion and cooling	
Description of sprinkler layout	Rows of sprinklers (n = 2) were installed along the ceiling, 3.6 m from the walls (outer lines). A third line was installed mid-way during the study and positioned along the ceiling in the middle of the house (center line). Each sprinkler rows adjacent to the wall had 26 sprinkler nozzles installed at 6 m intervals. The mid-house row had 20 sprinkler nozzles spaced at 6 m intervals in a section of the house that had no ceiling baffles and at 8.1 m spacing so that each sprinkler was positioned equally spaced between ceiling baffles. 25 mm PVC (class 12) pipe was installed and supported between ceiling trusses by attaching to 4 mm stainless steel cable.	2 rows were installed along the ceiling, 3.5 m from the wall. 25 mm PVC (class 12) pipe was installed and supported between ceiling trusses by attaching to 4 mm stainless steel cable. Sprinklers nozzles were installed at 6 m intervals.
Number of sprinklers per house	72	36
Sprinkler flowrate	1.3 L/min (14 L applied to the house during each 10 s activity promotion and 28 L each 20 s cooling application)	1.3 L/min (7 L applied to the house during each 10 s activity promotion and 14 L each 20 s cooling application)
Installed sprinkler height (m)	2 rows adjacent walls: 2.3 Mid-house row: 3.4	2 rows adjacent walls: 1.8
Sprinkler zoning	Zone 1 (outer lines) and Zone 3 (center line) – back of the house (brooding end) nearest the tunnel fans Zone 2 (outer lines) and Zone 4 – front of the house nearest evaporative cooling-pads Zones 1 and 3 shared a temperature sensor. Zones 2 and 4 shared a temperature sensor. Temperature sensors were positioned near bird level and approximately in the center of each zone.	Zone 1 – front of house nearest evaporative cooling-pads Zone 2 – back of house (brooding end) nearest the tunnel fans Each zone had an independent temperature sensor positioned near bird level and approximately in the center of each zone.

cycles from October 2016 until November 2017 (Table 1). Dimensions and specifications of the tunnel-ventilated poultry houses were different at each of the farms (Table 2), but were typical of houses used for growing-out meat chickens in Australia. At farm A, 2 houses were used in the study and at farm B, 4 houses were used in the study. At each farm, half of the houses were unmodified and managed in a conventional manner (hereafter referred to as "control houses"). The remaining houses ("sprinkler houses") had a sprinkler system installed to complement the pre-existing evaporative cooling pad system. The evaporative cooling pad system remained operational in all houses. However, operational settings for the cooling pads were modified in the sprinkler houses by increasing the temperature at which the cooling pads would be operated (to approximately 27°C–35°C depending on the bird age), so that the sprinkler system would be used to replace low levels of evaporative cooling.

Sprinkler System

A low-pressure sprinkler system (Weeden Environments, Ontario, Canada; specifications summarized in Table 3) was installed in selected houses at both farms in accordance with the manufacturer's recommendations (Figure 1) and programmed to operate in "activity promotion" and "cooling" modes (Figure 2). Activity promotion mode used a timer to apply water at regular intervals after day 14 of the grow-out (and was limited to a range of hours on each day, usually during daylight) whereas cooling mode enabled the sprinkler controller to automatically activate the sprinklers for a longer duration and more frequently in response to elevated temperatures, but only after d 21 of the grow-out. Usage of the sprinkler system differed between the farms (Table 4). Settings were altered by the farm managers in response to their perception of bird thermal comfort and environmental conditions, including litter condition (Table 5). The main temperature set-point was altered daily, typically decreasing during the grow-out (Table 6).

The sprinkler controller was installed near the ventilation computer to facilitate easy access for altering settings. Each sprinkler house was divided into 2 zones: (1) front of the house nearest the evaporative cooling pads; and (2) back of the house nearest the tunnel-ventilation fans. Each house zone had a temperature sensor to control the cooling mode, which was installed centrally in the zone and close to bird height on height-adjustable supports suspended from the ceiling. Sprinklers installed in each zone were activated by an electronic solenoid valve that was controlled by the sprinkler control system in response to the temperature sensor in that zone. For activity promotion mode, the controller activated the zones sequentially during each scheduled activity event.

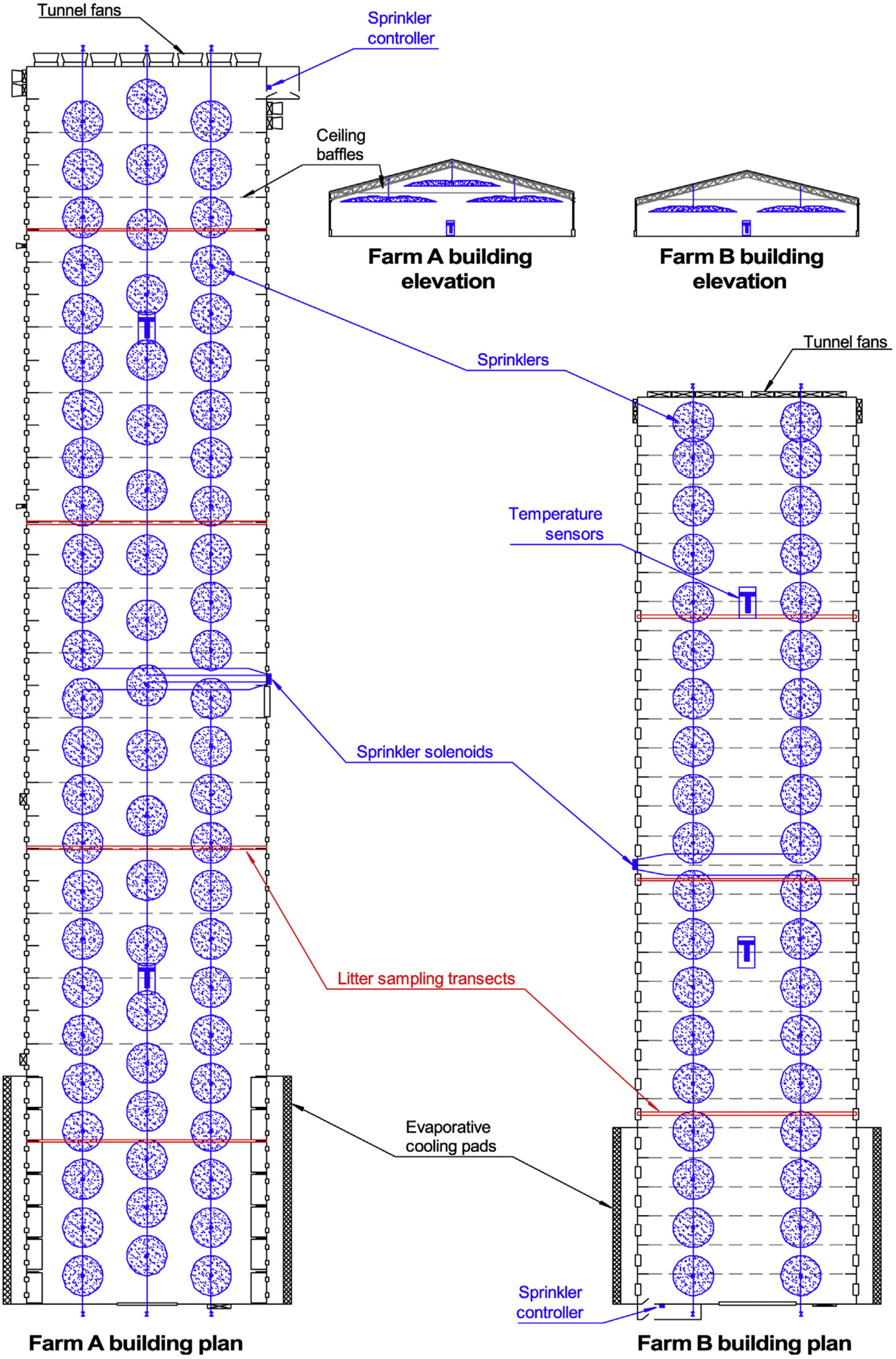

Figure 1. Schematic of poultry houses, sprinkler system layouts, and litter sampling positions used in this study (note: circles surrounding the sprinklers are not intended to show spray patterns, coverage or overlap; and building length:width ratio is drawn at 1:2).

Measurements

In-house temperature and relative humidity were monitored in the control and sprinkler houses using sensors (model 114 temperature/humidity sensor, dol-sensors, Denmark) that were co-located with the sprinkler controller temperature sensors (one sensor in each sprinkler zone, in each house). An additional temperature/humidity sensor was installed outside the houses to enable monitoring of ambient conditions. Water usage by the sprinkler system and evaporative cooling systems were monitored using water meters fitted with an electrical

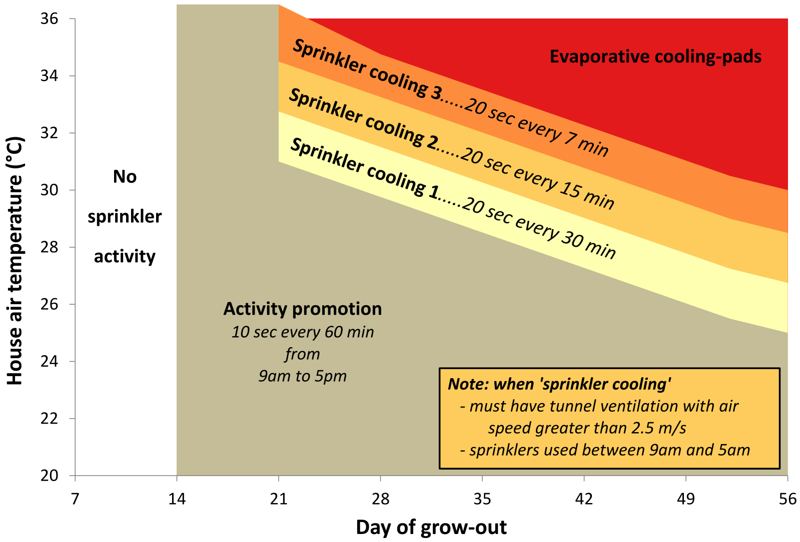

Figure 2. Example of a program used for the sprinkler system (note that activation of the evaporative cooling pads is controlled by the pre-existing ventilation controller).

pulse output (1 pulse = 1 L). The temperature/humidity sensors and water meter were connected to a data logging system (SPOKEdata model Analogue/SD-12/Pulse, Pacific Data Systems, Brisbane, Australia), with data reported at 15 min intervals. Ad hoc thermal images were taken with a thermal camera (model T6400, FLIR Systems, Sweden) to observe the temporal and spatial dynamics of the cooling effect after sprinkler operation.

Litter moisture content was measured using litter that was subsampled from each house on approximately 4 occasions during each grow-out: the day before any sprinkler use (0–21 d); before flock thinning (22–35 d); after flock thinning (36–44 d); and the end of the flock (45–53 d). Litter was collected from predesignated transects (Figure 1; 4 in each house at farm A, and 3 at farm B) that were approximately equally spaced along the length of the house. In each transect, approximately 30 subsamples of litter, each 50 mL, were collected from the top 1–2 cm of the litter surface using a trowel or scoop and mixed well in a bucket. From this bucket, a 250 mL composite subsample was placed in a plastic jar and transported to a laboratory for moisture content analysis. In addition to the composite litter sample for each transect, single grab-samples were also collected from the top 1–2 cm of the litter surface that appeared to be the driest and wettest in each transect. Samples were placed in preweighed foil dishes and dried in an oven (model 8150, Contherm, Hutt City, New Zealand) at 65°C for 48 h to determine the moisture content. Only composite litter samples were included in the statistical analysis, with the grab-samples being used only for describing the range of moisture content.

Live market weight data (flock average) was collated from farm and processor records, which were measured at weekly intervals on the farm and on each occasion when birds were collected for slaughter. Data were analyzed in terms of measured live market weights.

Statistical Analysis

Depending on the data type and structure, general linear models or restricted maximum likelihood were used to analyze the data in Genstat (2016). Random effects were the farms and houses, which were split for in-house location, grow-outs, and age classes within grow-outs. The variance components were restricted to not permit negative estimates. The fixed effects were the sprinkler treatment (applied at the house level), grow-outs, and age classes along with all interactions. Residual plots were used to check the assumptions of homogeneous variances and low skewness, and log-transformation applied as needed. Initial analyses investigated response patterns using splines and nonlinear regressions fitted over ages within grow-outs.

Table 4. Summary of days during grow-outs when the sprinkler system was used.

	Farm A		Farm B	
Grow-out	Activity promotion	Cooling	Activity promotion	Cooling
1	14–end	21–end	14–end	21–end
2	14–end	21–end	14–end	19–end
3	14–end	21–end	14–24	21–24
4	14–end	21–end	14–30, 48–end	Off
5	14–end	21–end	43–end	43-end
6	14–end	21–end	Off	13–30

Table 5. Sprinkler controller settings as recommended by the manufacturer and as applied at the study farms.

Setting	Manufacturer recommended	Farm A	Farm B
Activity promotion mode			
Start day[4]	14	14	14 (or not used)
Daily start time	09:00	07:00–08:00	06:00–11:00
Daily end time	18:00	18:00	14:00–22:00
Application duration (s)	10	7–10	5–13
Idle time[1] (min)	60	60–90	30–60
Cooling mode			
Start day[4]	21	21	13[2]–43
Daily start time	09:00	06:00–10:00	08:00–09:00
Daily end time	22:00	22:00	19:00–24:00
Cooling levels			
1. Main set-point (°C)—Refer to Table 6			
1. Application duration (s)	20	20	10–20
1. Idle time[1] (min)	30	20–30	10–30
2. Relative offset[3] (°C)	2.0	1.0–2.0	1.3–2.5
2. Application duration (s)	20	20	15–20
2. Idle time[1] (min)	15	15	7–15
3. Relative offset[3] (°C)	4.0	3.0–4.0	2.7–3.5
3. Application duration (s)	20	20	20
3. Idle time[1] (min)	7	7	5–7

[1] Between sprinkler applications.
[2] Used during heat wave in when evaporative cooling malfunctioned.
[3] From main set-point.
[4] Refer to Table 4.

RESULTS AND DISCUSSION

Sprinkler System Installation and Operation

The sprinkler system must be operated in conjunction with the ventilation and evaporative cooling system. Owing to this study being the first time that this type of sprinkler system has been used in Australia, it must be recognized that the operation of the sprinkler system may not have been optimal, and will have influenced results in this study. Additional on-farm use at multiple farms and under different weather conditions will be necessary to improve consistency with operation of the system. We suggest that operation of the system should be further optimized before future studies are conducted.

Table 6. Main cooling set-point temperature (°C) used in the sprinkler system (note cooling is not normally recommended before day 21).

Day of grow-out	Manufacturer recommended	Farm A	Farm B
21	31.0	31.0–31.7	31.5–33.5
22	30.9	31.0–31.7	31.5–33.5
23	30.7	31.0–31.7	31.0–32.0
24	30.6	31.0–31.2	31.0–32.0
25	30.4	30.3–31.0	31.0–31.5
26	30.3	29.6–30.6	31.0–31.5
27	30.1	29.0–30.2	31.0–31.5
28	30.0	28.5–30.0	31.0–31.5
29	29.9	28.2–29.8	31.0–31.5
30	29.7	27.9–29.6	31.0–31.5
31	29.6	27.5–29.6	30.5–31.0
32	29.4	27.3–29.0	29.5–30.5
33	29.3	27.0–28.9	29.5–30.5
34	29.1	26.7–28.7	29.0–30.5
35	29.0	25.5–28.5	29.0–30.0
36	28.9	25.2–28.3	28.6–30.0
37	28.7	25.0–28.1	28.6–30.0
38	28.6	24.0–28.0	28.6–29.8
39	28.4	24.0–27.8	28.4–29.8
40	28.3	24.0–27.6	27.0–29.8
41	28.1	24.0–27.5	27.0–29.8
42	28.0	24.0–27.4	27.0–29.0
43	27.9	24.0–27.3	26.0–29.0
44	27.7	24.0–27.1	26.0–29.0
45	27.6	24.0–27.0	26.0–28.8
46	27.4	23.0–26.8	26.0–28.8
47	27.3	23.0–26.7	26.0–28.8
48	27.1	23.0–26.5	26.0–28.8
49	27.0	23.0–26.5	26.0–28.8
>49	26.7 → 24.7	23.0–26.5	25.5–28.8

Farm managers adjusted ventilation, evaporative cooling pad and sprinkler settings after discussions with the research team based on their perceptions on bird thermal comfort and litter conditions. In general, farm managers used lower cooling temperature set-points, especially during summer, to activate the sprinklers at lower temperatures and more frequently than was initially recommended by the manufacturer (Tables 4–6). During winter, however, the farm managers tended to use relatively warmer set points for cooling. Activity promotion and cooling modes were used consistently at farm A (Table 4), but were used less consistently at farm B due to the manager addressing local issues (heat waves; and damp litter that occurred due to a number of factors that rarely included the use of the sprinklers).

Two rows of sprinklers were initially installed in each of the sprinkler-houses. Following observations with a thermal imaging camera (Figure 3) that sprinkler spray patterns narrowed during tunnel ventilation due to in-house air speed, the research team decided to add a third row of sprinklers in the middle of the house at farm A to improve spatial coverage. The sprinklers in the middle row were installed higher in the ceiling (so as not to interfere with litter delivery trucks) and were centrally located between ceiling baffles (Figure 1). We suggest that installing the sprinklers above the height of the ceiling baffles increased the lateral spread of the water spray

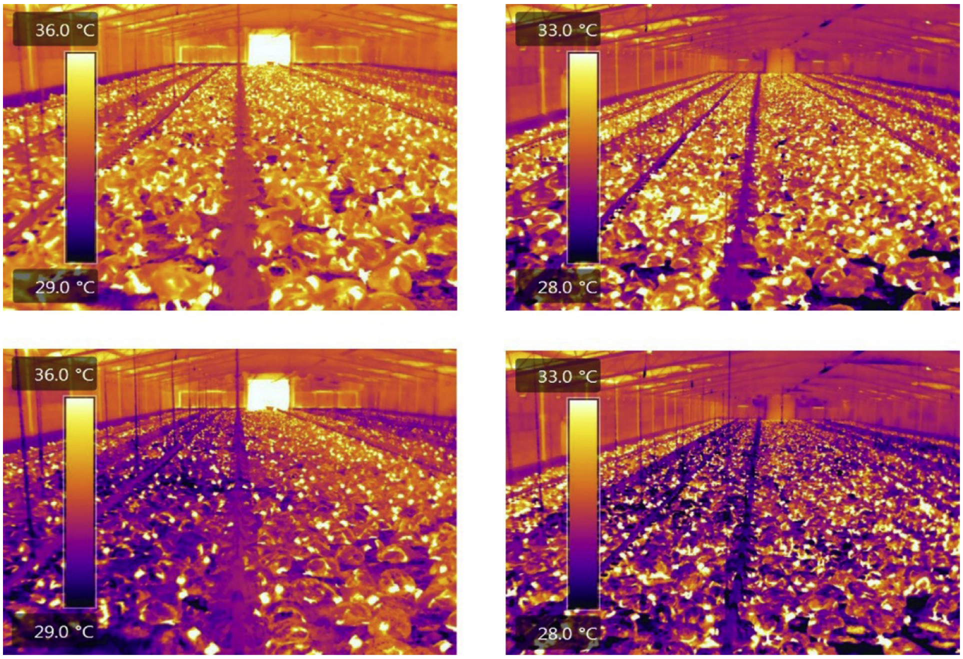

Figure 3. Thermal images before (top) and after (bottom) sprinkler operation indicating spatial uniformity of cooling effect by the sprinklers: 2 rows of sprinklers (left); and three rows of sprinklers (right).

pattern during tunnel ventilation, and should be considered in future installations when ceiling baffles are present, as it may be more beneficial than spacing the sprinklers every 6 m.

Temperature and Relative Humidity

Differences in temperature and humidity between the control houses and sprinkler houses were expected to occur only when water cooling was required, either by the evaporative cooling pads or direct surface wetting by the sprinklers. From the total number of hours included in this study, approximately 84% had no water cooling in any house, 5% had evaporative cooling pads used in the control houses with sprinklers used in the sprinkler houses, and 6% had evaporative cooling pads being used in both houses.

Temperature and relative humidity data were analyzed by including all data, and then re-analyzed by excluded data that did not involve any water cooling (restricted data). Statistical analysis revealed that effects on house temperature and relative humidity were dominated by two-way interactions between grow-out × sprinklers ($P < 0.001$), but there were also lesser two-way interactions between grow-out × day ($P < 0.001$) and grow-out × hour ($P < 0.001$) (considered to be lesser effects due to lower variance ratio statistics). The effect of sprinklers on the in-house thermal environment was consistent with a previous study by Liang et al., (2014). Dominant effects were the same regardless of whether the complete or restricted data sets were analyzed. Grow-outs occurred sequentially during a 12 mo period, and there was a slight, but inconsistent, trend during warmer seasons for differences in temperature and relative humidity to be greater between the sprinkler and control houses (with sprinkler house temperature warmer and relative humidity lower, relative to the control houses).

When no water cooling was used in either the sprinkler and control houses, temperature and relative humidity were observed to be similar in both houses (Figure 4, means for 28–35 d and 42–49 d), and coincided with mild ambient temperatures. Higher ambient temperatures coincided with the use of evaporative cooling pads in the control houses and sprinklers in the sprinkler house, during which time the greatest differences were observed between temperature (mean temperatures approximately 0.5°C–2.5°C warmer in the sprinkler house) and relative humidity (mean relative humidity approximately 3–10% lower in the sprinkler houses). Further increasing ambient temperatures resulted in the evaporative cooling pads being used in all houses, resulting in similar temperature and relative humidity conditions between the sprinkler and control houses, although mean temperature remained slightly warmer and relative humidity lower in the sprinkler house. We suggest these observed differences were likely due to cooling pads in the sprinkler houses being used less intensively when operated simultaneously with the sprinklers.

Warmer temperatures measured in the sprinkler houses should not be equated with bird comfort temperature, due to lower relative humidity as well as the direct cooling effect on the birds (Figure 3), both of which have previously been found to compensate for higher air temperature (Tao and Xin, 2003a; Tao and Xin, 2003b; Liang et al., 2014). Bird thermal comfort was assessed by experienced farm staff during routine flock inspections, with adjustments made to ventilation or sprinkler systems as required.

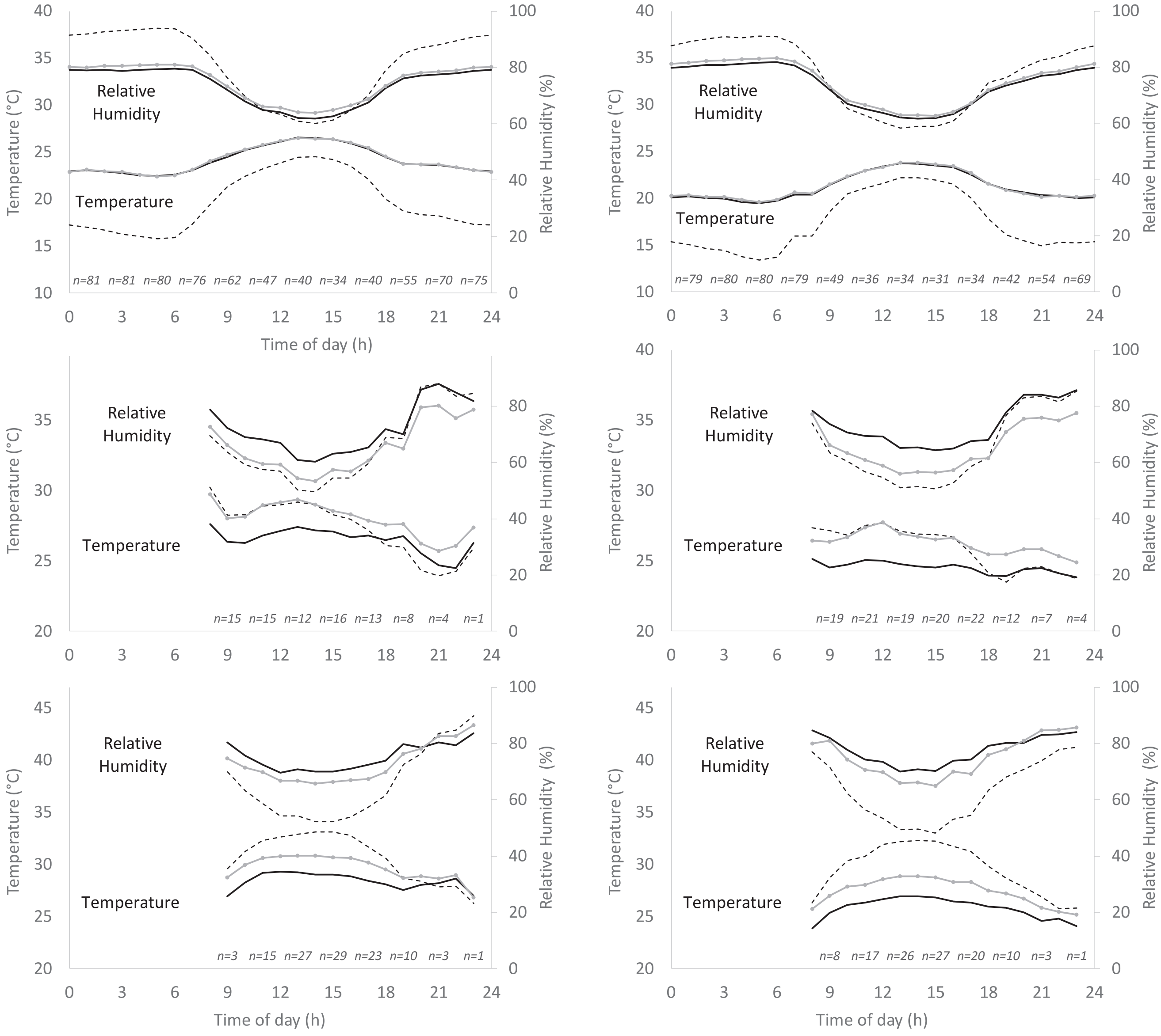

Figure 4. Mean hourly temperature and relative humidity in the control and sprinkler houses during 28 to 35 d (left) and 42 to 49 d (right) of the grow-outs—during times of no water cooling (top); when evaporative cooling was being used in the control houses and sprinklers (only) were being used in the sprinkler houses (middle); and when both control houses and sprinkler houses were using evaporative cooling (bottom). Missing hours were due to sprinklers and evaporative cooling not being used, and "n" values are the number of data points use to calculate the mean at hourly time points.

Water Used for Cooling and Activity Promotion

Cooling water usage differed ($P < 0.001$) on each farm and was dominated by a two-way interaction between grow-outs and treatments (sprinkler vs. control houses) (Table 7). Water usage at farm A showed reasonably consistent water savings in the sprinkler house compared with the control houses averaging 58% over the 6 grow-outs (individual grow-out savings ranged from 3 to 77%), whereas farm B, 1% more water was used overall in the sprinkler shed (ranged from 76% more water to 58% water saving in individual grow-outs). The water savings at farm A highlighted one of the major benefits of the sprinkler system (i.e., water savings), and were in close agreement with Liang et al., (2014) where savings of 67% were reported. It is suggested that inconsistent use of the sprinklers by the manager at farm B is likely the greatest cause for the difference, but there were other contributing factors such as differences in bird density, depopulation dates and periods of very hot weather. At farm B, in particular, short periods of very hot weather, with daily maximums reaching 30°C–35°C resulted in extensive use of evaporative cooling pads, as expected with the sprinkler system program (Figure 2), which dominated the water used in sprinkler houses.

We observed that greatest water savings associated with the sprinkler system occurred at times when sprinklers (without evaporative cooling pads) were being used in the sprinkler houses while evaporative cooling pads were being used in the control houses (Figure 5). In these situations, mean water usage in the sprinkler house was 50–100 L/h compared with 300–600 L/h in the control

Table 7. Cooling water used in the control houses and sprinkler houses (per house).

Grow-out	Water used in control houses (L)	Water used in sprinkler houses (L)[1]	Portion of water used by sprinklers (L)	Water saved in sprinkler houses (%)	Water saved in sprinkler houses (L)
Farm A					
1	110,960	55,680	19,390	50%	55,280
2[2]	214,270	78,620	30,280	63%	135,650
3	29,480	6,680	6,680	77%	22,800
4	3,350	3,250	3,160	3%	100
5	42,750	30,610	15,300	28%	12,140
6	131,010	49,820	24,230	62%	81,190
Farm A total	531,820	224,660	99,040	58%	307,160
Farm B					
1	154,320	100,460	23,490	35%	53,860
2[3]	227,100	268,560	6,060	−18%	−41460
3[4]	15,720	11,550	570	27%	4,170
4	0	340	250	-	−340
5[5]	4,900	2,070	1,230	58%	2,830
6[6]	28,090	49,350	2,790	−76%	−21260
Farm B total	430,130	432,330	34,390	−1%	−2,200
Combined summary	961,950	656,990	133,430	32%	304,960

[1] Total water used by both sprinklers and evaporative cooling pads.

[2] 47 d > 30°C including 2 d > 35°C (daily maximum ambient temperatures).

[3] 46 d > 30°C, including 20 d > 35°C (daily maximum ambient temperatures).

[4] Sprinkler not used after day 25 due to high litter moisture content in all houses.

[5] No sprinklers until day 40.

[6] No sprinklers after day 30 and sprinkler houses were depopulated 5 d after the control houses, when daily maximum temperature was >30°C, resulting in 16,270 L used in the sprinkler house evaporative cooling pads.

houses. During all periods when evaporative cooling was required in the control houses (and sprinkler houses required sprinklers, evaporative cooling pads or both), hourly cooling water usage averaged 528 L in the control houses compared with 306 L (ranging from 201 L at farm A to 427 L at farm B) in the sprinkler houses.

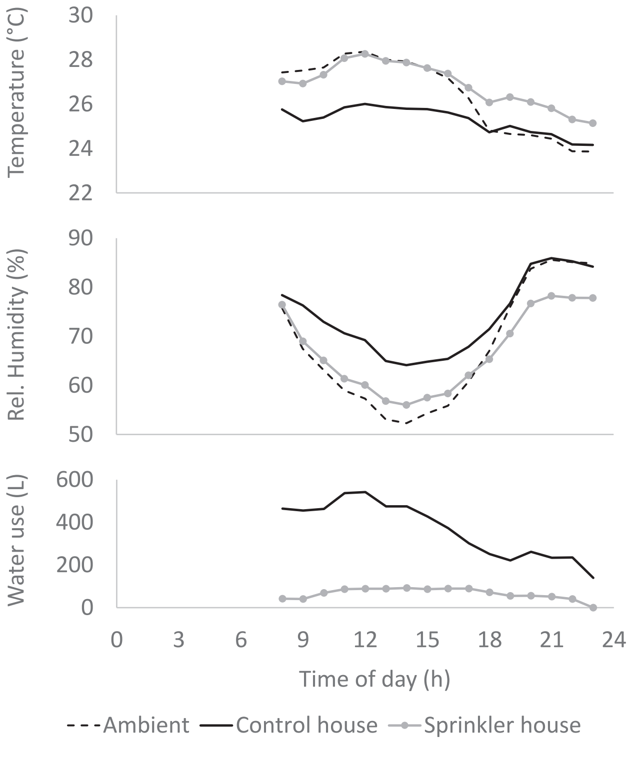

Figure 5. Mean temperature, relative humidity and water usage for usage during days 28 to 49 of the grow-outs of the grow-outs at times when evaporate cooling pads were used in the control house and sprinklers were used in the sprinkler house.

Water used for activity promotion (70 L to 140 L per house per day) contributed only a small proportion of the total water used by the sprinkler system, except during cooler months of the year when evaporative cooling requirements are minimal.

Litter Moisture

For analysis, litter samples were grouped into age classes (0–21 d, 22–35 d, 36–44 d and 45–53 d) chosen to characterize litter conditions before using the sprinklers, before flock thinning, after flock thinning, and at the end of the grow-out. Litter moisture content differed with a two-way interaction between age class × sprinklers ($P = 0.011$), with the only observable difference being slightly damper litter in the sprinkler sheds during the 36–44 d age class, after the first thinning. Moisture content also differed with a two-way interaction between grow-out × sprinklers ($P = 0.002$), with slightly drier litter in the sprinkler shed during a late-summer grow-out. There was also a weaker relationship when considering the sprinklers as a main effect ($P = 0.046$), where the mean litter moisture content was slightly lower in the sprinkler sheds (Figure 6). This result does not agree with the findings of a previous study by Liang et al., (2014) which reported no significant effect by the sprinklers on litter moisture content. While significant relationships between the sprinklers and litter moisture content were found in this study, we suggest that differences in litter moisture content between the sprinkler and control houses were relatively small and unlikely to be important from a practical point of view. In addition, farm managers would be able to change ventilation and sprinkler settings if litter conditions were seen to be

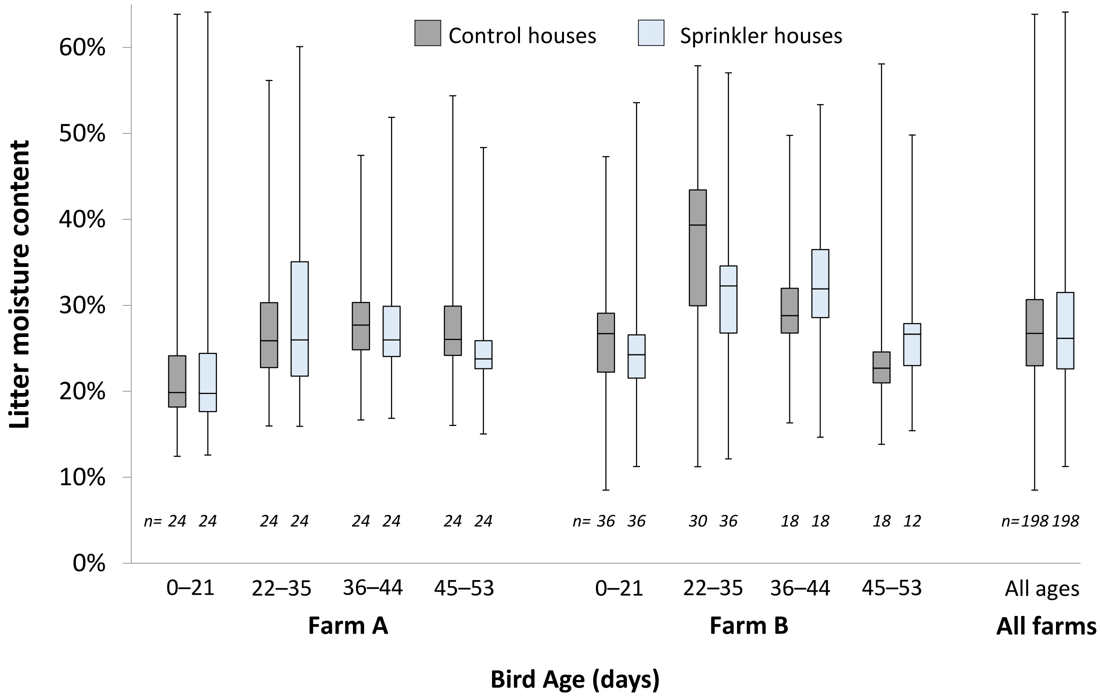

Figure 6. Litter moisture content for farm A, farm B, and combined data from both farms. Note: the center horizontal line is the median; the shaded boxes represent the range of data between the 25th and 75th percentiles; and the whiskers represent the highest and lowest values (derived from wet and dry litter grab samples); n represents the number of samples in each category.

deteriorating (either too wet or too dry). We observed a slight trend for litter to be relatively drier during warm season grow-outs and damper during cool season grow-outs, whether sprinklers were installed or not. Our trial showed that using the sprinklers during winter, which was primarily for activity promotion, did not make litter wetter. During cooler seasons, when litter moisture management may be more challenging, we suggest that growers may be able to turn off the sprinkler activity promotion mode to prevent any additional water entering the shed if they observe litter becoming wetter.

It may surprise some readers that the sprinklers did not have a more obvious effect on litter moisture content, because applying water directly toward the birds and house floor may be expected to increase moisture content. We suggest that there are a number of reasons why using sprinklers in an appropriate way did not consistently increase litter moisture content:

1. The quantity of water added to the floor (including onto the birds) by the sprinklers (median 0.07 L/m^2/day, maximum 1.04 L/m^2/day, with a maximum 0.09 L/m^2/day applied for activity promotion) is

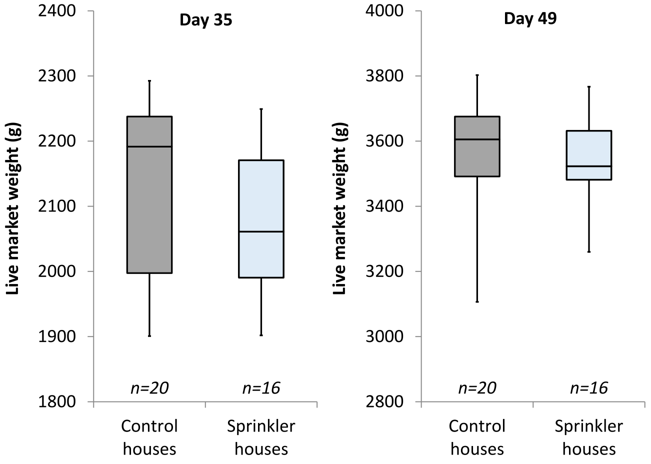

Figure 7. Live market weights at 35 d (left) and 49 d (right) in the control and sprinkler houses (data combined from farm A and farm B). Note: the center horizontal line is the median; the shaded boxes represent the range of data between the 25th and 75th percentiles; and the whiskers represent the highest and lowest values; n represents the number of samples in each category.

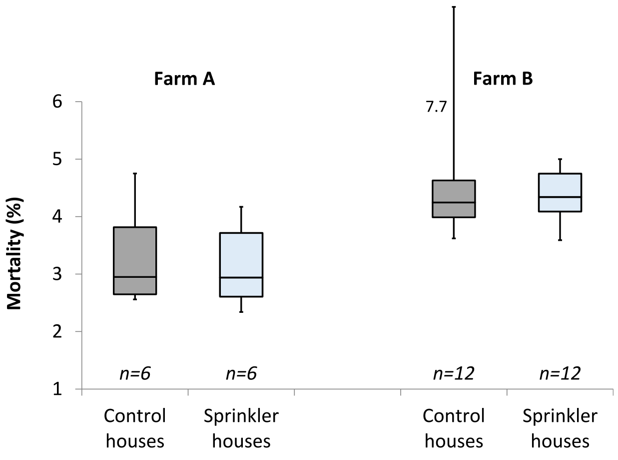

Figure 8. Mortality (average of % mortality of each flock) at farm A (left) and farm B (right). Note: the center horizontal line is the median; the shaded boxes represent the range of data between the 25th and 75th percentiles; and the whiskers represent the highest and lowest values, n represents the number of samples in each category.

generally much less than the amount of water that the birds add to litter in their excreta (estimated to be $1.6\ L/m^2/day$ to $3.3\ L/m^2/day$ (Dunlop et al., 2015)).
2. Only a portion of the water applied actually reaches the litter due to water droplets landing on the birds.
3. The sprinkler system applied greater quantities of water on warm days, when the house was operating in tunnel ventilation mode with air speed greater 2.5 m/s. These conditions are favorable for rapidly drying the water applied by the sprinklers (and also ensure the maximum evaporative cooling effect).
4. The interval between sprinkler operations is sufficient to enable the water applied during one sprinkler application to be evaporated before the after sprinkler application. Frequency of water application only increases as the temperature and air speed increases the evaporation potential in the house.

There were some situations that we suggest the sprinkler system may have contributed to a localized and temporary increase in litter moisture content. These included when the sprinklers operated frequently at the same time that evaporative cooling pads were active (where high relative humidity reduced litter drying rate); and after flock thinning (when a portion of the litter on the house floor was fully exposed). In these situations, farm managers may need to pay close attention for changing litter conditions and manage the sprinkler system and house ventilation system accordingly.

We observed that litter moisture content tended to be lower in the sprinkler houses relative the control houses at farm A, where the sprinkler system was used more consistently than at farm B (Table 4).

In general, litter moisture content is influenced by multiple factors (Dunlop et al., 2016), such as those associated with drinkers, ventilation, bird health, and litter properties, which were not able to be controlled within the scope of this study.

Live Market Weights and Mortality

No relationship was found between the live market weights of birds in the control houses and sprinkler houses ($P = 0.31$) (Figure 7). This finding was in agreement with a previous study by Liang et al., (2014).

Mortalities were different between farm A and farm B ($P < 0.001$) (mean mortality at farm A was 3.2%, and at farm B was 4.5%) but, in a similar way to live market weights, no relationship was found between mortality in the control houses and the sprinklers houses ($P = 0.31$) (Figure 8). This too was in agreement with the previous study by Liang et al., (2014). Despite there being no relationship, total mortality during the study was 5.7% lower in the sprinkler houses than in the control houses.

In conclusion, the combined use of evaporative cooling pads and a sprinkler system reduced total water usage, while having minimal practical effect on litter moisture content, live market weight, and mortality. During warm weather, sprinklers were used to delay the use of evaporative cooling pads, resulting in higher air temperature in the sprinkler house but lower relative humidity. Excessively high temperatures were avoided with the use of evaporative cooling pads in the sprinkler house. Farm managers adjusted the settings of the sprinkler and ventilation systems to effectively maintain thermal comfort and manage the house environment, evident by the measured parameters. It should be acknowledged that there is a running-in period with any new technology, and it may take multiple grow-outs to optimize the use of sprinkler systems when they are first introduced on a farm. It is recommended that future studies should be conducted under controlled conditions with a focus on feed conversion rate and quantifying bird thermal comfort.

ACKNOWLEDGMENTS

This research has been supported by funding from the AgriFutures Australia Chicken Meat Program and the Department of Agriculture and Fisheries, Queensland Government (PRJ-011502). The authors would like to thank the integrators, farm owners, managers, and staff for supporting this study. Their assistance and persistence has been greatly appreciated. The authors would also like to thank Dr. David Mayer for statistically analyzing the data.

Experimental procedures were approved by the Animal Ethics Committee of the Department of Agriculture and Fisheries, Queensland Government (approval number SA 2016/07/559).

DISCLOSURES

The authors declare no conflicts of interest for this article.

REFERENCES

Chepete, H. J., and H. Xin. 2000. Cooling laying hens by intermittent partial surface sprinkling. Trans. ASAE 43:965–971.

de Jong, I. C., J. van Harn, H. Gunnink, V. A. Hindle, and A. Lourens. 2012. Footpad dermatitis in Dutch broiler flocks: Prevalence and factors of influence. Poult. Sci. 91:1569–1574.

de Jong, I. C., H. Gunnink, and J. van Harn. 2014. Wet litter not only induces footpad dermatitis but also reduces overall welfare, technical performance, and carcass yield in broiler chickens. J. Appl. Poult. Res. 23:51–58.

Dunlop, M. W., P. J. Blackall, and R. M. Stuetz. 2015. Water addition, evaporation and water holding capacity of poultry litter. Sci. Total Environ. 538:979–985.

Dunlop, M. W., A. F. Moss, P. J. Groves, S. J. Wilkinson, R. M. Stuetz, and P. H. Selle. 2016. The multidimensional causal factors of 'wet litter' in chicken-meat production. Sci. Total Environ. 562:766–776.

Genstat. 2016. GenStat for Windows, Release 16. 1VSN International Ltd, Oxford, UK.

Hillman, P. E. 2009. In Chapter 2: Thermoregulatory Physiology in Livestock Energetics and Thermal Environmental Management. J. A. DeShazer, ed. American Society of Agricultural and Biological Engineers, St Joseph, MI.

Ikeguchi, A., and H. Xin. 2001. Field evaluation of a sprinkling system for cooling commercial laying hens in Iowa. Appl. Eng. Agric. 17:217.

Jones, T. A., C. A. Donnelly, and M. Stamp Dawkins. 2005. Environmental and management factors affecting the welfare of chickens on commercial farms in the United Kingdom and Denmark stocked at five densities. Poult. Sci. 84:1155–1165.

Kaukonen, E., M. Norring, and A. Valros. 2016. Effect of litter quality on foot pad dermatitis, hock burns and breast blisters in broiler breeders during the production period. Avian Path 45:667–673.

Liang, Y., G. T. Tabler, T. A. Costello, I. L. Berry, S. E. Watkins, and Y. V. Thaxton. 2014. Cooling broiler chickens by surface wetting: indoor thermal environment, water usage, and bird performance. Appl. Eng. Agric. 30:249–258.

Liang, Y., G. T. Tabler, and S. Dridi. 2020. Sprinkler technology improves broiler production Sustainability: from stress Alleviation to water usage Conservation: a Mini Review. Front. Vet. Sci. 77:1–8.

Lin, H., H. F. Zhang, R. Du, X. H. Gu, Z. Y. Zhang, J. Buyse, and E. Decuypere. 2005. Thermoregulation responses of broiler chickens to humidity at different ambient temperatures. II. Four weeks of age. Poult. Sci. 84:1173–1178.

Payne, C. G. 1967. Factors influencing environmental temperature and humidity in intensive broiler houses during the post-brooding period. Br. Poult. Sci. 8:101–118.

Shepherd, E. M., and B. D. Fairchild. 2010. Footpad dermatitis in poultry. Poult. Sci. 89:2043–2051.

Tabler, G. T., I. L. Berry, Y. Liang, T. A. Costello, and H. Xin. 2008. Cooling broiler chickens by direct sprinkling. Avian Advice 40:10–15.

Taira, K., T. Nagai, T. Obi, and K. Takase. 2014. Effect of litter moisture on the Development of footpad dermatitis in broiler chickens. J. Vet. Med. Sci. 76:583–586.

Tao, X., and H. Xin. 2003a. Acute synergistic effects of air temperature, humidity, and velocity on homeostasis of market-size broilers. Trans. ASAE 46:491–497.

Tao, X., and H. Xin. 2003b. Surface wetting and its optimisation to cool broiler chickens. Trans. ASAE 46:483–490.

Weaver, W. D., and R. Meijerhof. 1991. The effect of different levels of relative humidity and air movement on litter conditions, ammonia levels, growth, and carcass quality for broiler chickens. Poult. Sci. 70:746–755.

Williams Ischer, S., M. B. Farnell, G. T. Tabler, M. Moreira, P. T. O'Shaughnessy, and M. W. Nonnenmann. 2017. Evaluation of a sprinkler cooling system on inhalable dust and ammonia concentrations in broiler chicken production. J. Occup. Env. Hyg. 14:40–48.

Xin, H., I. L. Berry, G. T. Tabler, and T. L. Barton. 1994. Temperature and humidity profiles of broiler houses with experimental conventional and tunnel ventilation systems. App. Eng. Agric. 10:535–542.