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Field Evaluation of a Sprinkling System for Cooling Commercial Laying Hens in Iowa

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Keywords

Egg production, Heat stress, Partial surface wetting, Air quality, Autocorrelation analysis

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

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Keywords. *Egg production, Heat stress, Partial surface wetting, Air quality, Autocorrelation analysis.*

Commercial cage layer houses in the Midwest are traditionally not equipped with evaporative cooling systems such as found in poultry facilities in the southern United States. Instead, summer cooling is limited to increasing ventilation rate through the houses (10~12 m^3/h or 6~7 cfm per bird max). The weeklong heat wave [temperature peaked at 46°C (110°F)] sweeping across the Midwest in July 1995 took a death toll of more than 1.8 million laying hens — nearly 10% of the total hens in stock in Iowa alone. Compounding the disastrous losses were the reduced egg production and egg quality for the survived birds and the burden to dispose of the mortality. Without supplemental cooling, air passing through a poultry house will be at least 1~3°C (2~5°F) warmer than the incoming air as the result of sensible heat generation by the birds. When the ambient temperature is higher than the normal body temperature of the birds [41°C (106°F)], the animals will actually gain heat from the environment. The rate of heat gain will accelerate with higher ventilation rates and thus air velocity (Timmons and Hillman, 1993), which leads to quicker heat prostration of the birds. The increasing frequency of occasional but costly heat wave incidents prompts the need for alternative, cost–effective cooling methods for typical layer facilities in the Midwest. An effective cooling system that can be retrofitted into existing houses as well as installed in new facilities would be particularly desirable.

Cooling animals by sprinkling water over their surface has been used extensively by the swine and cattle industries (MWPS, 1983; Bucklin et al., 1991). However, its application to poultry cooling has been limited (Wilson and Hillerman, 1952; Berry et al., 1990). Chepete and Xin (2000) conducted laboratory studies to evaluate the efficacy of cooling laying hens by intermittently sprinkling water onto the head and appendages of hens, and concluded that the method was effective for heat stress relief. For a detailed review of literature on typical cooling methods and thermoregulation of poultry, refer to Chepete (1999) and Chepete and Xin (2000).

The objective of this study was to assess the efficacy of the partial surface sprinkling method for cooling laying hens in a commercial high–rise layer house, as judged by comparative data on egg production, body temperature, and the environmental conditions between the treatment and control.

Materials and Methods

The Experimental Layer House

A commercial high–rise layer house located in Central Iowa was used as the experimental house. The layer house measured 14 × 130 m (46 × 426 ft) with an east–west orientation and held 73,400 Hy–Line W–77 hens (64 weeks old) at the start of the experiment. A schematic cross–section of the house is shown in figure 1. The hens were distributed in five A–frame type cage rows and four decks within a row. The house used continuous, manually adjustable perimeter slot inlets along both sidewalls of the birds level. Twenty–six single–speed exhaust fans of 1.2 m (48 in.) in diameter were

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located in the sidewalls of the lower/manure storage level. The number of fans in operation and hence ventilation rate of the house was a function of air temperature and was controlled by an automatic environmental controller. Based on the airflow capacity of the fans at static pressure of 30 Pa (0.12 in. H_2O) – 9.4 m^3/s (19,900 cfm) per fan, the maximum ventilation rate with the 26 fans was estimated to be 244 m^3/s (517,400 cfm; 7 CFM/bird). Consultation with the cooperating commercial company indicated that there was no location effect on the interior environment of the building. Thus, the south half of the house was randomly chosen as the treatment side and the north half as the control side (fig. 1). Partition of the same house into treatment and control eliminated potential effects that could be caused by building (e.g., ventilation) and production (e.g., bird age) variations among different houses.

THE SPRINKLING SYSTEM

For the treatment half–house, 41 low–pressure (276 kPa, 40 psi) sprinklers were equally spaced at 3 m (10 ft) apart in each aisle (i.e., between cage rows) (fig. 1). The sprinklers were located 2.4 m (8 ft) above the aisle floor. Each sprinkler had a rated water output of 2.1 mL/s (2 gal/h). The sprinklers were controlled to operate 10 s every 10 min when the inside temperature (T_i) exceeded 32°C (90°F), amounting to 0.86–L (0.23–gal) water output per aisle per sprinkling session. Initially 15–s operation sessions were tried, but they caused excessive floor wetness in the aisle. Consequently the duration was reduced to 10 s. No relative humidity (RH) control of the system operation was used in this study. The cost of the system was about $0.05/bird.

TEST SCHEDULE AND MEASUREMENT VARIABLES

The test began on 24 June 1998 when the hens were 64 weeks old and data collection continued until 30 September 1998 when the hens were 77.5 weeks old. However, molting started on 26 June 1998. Egg production was restored to normal level by 28 August 1998. Hence, egg production data during the period of 28 August to 30 September 1998 was used in the analysis.

The measured environmental variables included inside and outside air temperature, RH, NH_3, dust concentration, and airflow pattern (see fig. 1 for measurement locations). The temperature and RH were measured using portable electronic temperature/RH loggers with an accuracy of 0.2°C (0.36°F) and 3%, respectively (HoboPro Series Temp/RH logger, Onset Computer Corp., Bourne, Mass.).

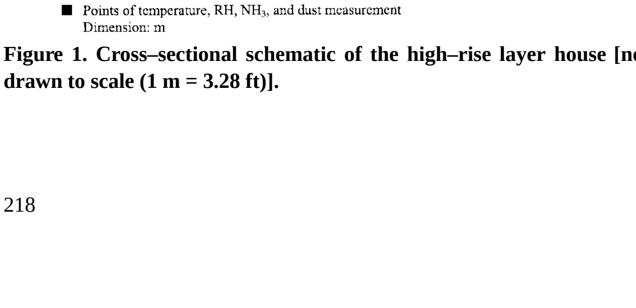

Figure 1. Cross–sectional schematic of the high–rise layer house [not drawn to scale (1 m = 3.28 ft)].

The measurements were taken at 1–min intervals and stored as 10–min averages. Temperature and humidity index (THI) was derived using the THI equation for layers (Zulovich and DeShazer, 1990):

$$THI = 0.6\ T_{db} + 0.4\ T_{wb} \qquad (1)$$

where

T_{db} = Dry–bulb temperature (°C)

T_{wb} = Wet–bulb temperature (°C)

The level of respirable dust (0.5 to 5 μm) was sampled using a portable, programmable laser particle counter (PLPC) (Model 237A, Met One, Grants Pass, Ore.). The PLPC had four measurement ranges of the particle size – 0.5 to 0.7, 0.7 to 1.0, 1.0 to 5.0, and >5.0 μm and used 47 mL/s (0.1 cfm) sampling airflow rate. Each sampling lasted for 1 min, sufficient time for two air exchanges of the house assuming complete air mixing. Measurement of dust concentration change between sprinklings was attempted using 1–min samples, starting 20 s after a sprinkling. The difference in dust level between aisles was also used to help evaluating the spatial distribution of the ventilation air. Aerial ammonia (NH_3) level was measured using gas detector tubes (0–20 ppm range) and a sampling pump (model 8014–400A, Matheson – Kitagawa, Joliet, Ill.). It was measured at 4–h intervals in aisle 2 and 5 (fig. 1) on 19 August 1998. Airflow pattern was visualized using a theatrical fogging machine (model Rosco1000, Rosco Laboratories, Inc., Port Chester, N.Y.). Air velocity distribution was measured with a hot wire anemometer (model MPM 4100, Solomat Neotronics, Norwalk, Conn.). Rectal temperature of randomly selected treatment and control birds was taken from each deck (four birds per deck) in aisle 2 (control) and aisle 5 (treatment) during the period of 12–13 August 1998. A rectum thermometer (0.1°C accuracy) (Model 8525–00 Digi–Sense, Cole–Parmer Instrument Co., Vernon Hills, Ill.) was used to perform the measurement every 4 h throughout the 1–day period (10:00, 14:00, 18:00, 22:00, 02:00, and 06:00 h). The same measurement was repeated for the same birds in the top and bottom decks during the period of 19–20 August 1998.

One concern about the sprinkling practice was that water droplets might fall on the eggs, although majority of the egg production and collection would have been completed prior to the hottest part of the day. The water droplets might reduce the cuticle protection of the eggshell. To investigate this potential side effect, 24 egg samples in each regimen were collected from the egg belts (6 eggs from each deck) during the operational period of the sprinkling system and brought to an Iowa State University laboratory where they were stored in a refrigerator [4°C (39°F)] until the time of analysis. The refrigerated shell eggs were equilibrated at room temperature [21°C (70°F)] for 4 h and then dipped in a blue lake dye solution [0.25% (w/v) blue lake dye in 0.1% Triton X–10] for 3 min and then drained for 5 min at room temperature. The eggs were placed on egg flats, wrapped with aluminum foils, and then incubated for 24 h at 25°C (77°F) in a humidified incubator. After removal from the incubator, the eggs were washed with warm tap water and the surface of eggshell was blotted dry with paper towels. This step prevented false identification of dye penetration into eggshell. The eggs were cracked open and the blue spots inside of eggshell membrane, if present, were examined and counted.

Analysis of variance or paired t–test in the Microsoft Excel® spreadsheet program was used to evaluate the effect of sprinkling on egg production, rectal temperature, and the environment. Moreover, autocorrelation analysis of the daily egg production of the treatment and control hens for the period of 28 August to 30 September 1998 was performed to examine how the thermal history might affect the current egg production. The autocorrelation coefficient, $R_{(\tau)}$, was calculated as:

$$R_{(\tau)} = \frac{\sum_{t=\tau}^{n}[x_{(t)} - \overline{x}][x_{(t-\tau+1)} - \overline{x}]}{\sum_{t=1}^{n}[x_{(t)} - \overline{x}]^2} \quad (2)$$

where

τ = time lag (day)

$x_{(t)}$ = egg production on t^{th} day

$\overline{x}$ = average egg production for the (n–day) time period

Results and Discussion

Environmental Conditions

Thermal Environment

There were 17 hot days [i.e., $T_i > 32°C$ (90°F)] during the testing period of 18 August to 30 September 1998. The daily maximum temperatures (T_{max}) and the coincident RH of the 17 hot days are listed in table 1. No significant difference in the overall average T_{max} was detected between the treatment and control during the hot days ($P > 0.05$), although the treatment half house tended to be slightly cooler. However, a significant difference in T_{max} between the treatment [33.6°C (92.5°F)] and control [34.2°C (93.6°F)] was detected for six hot days in September ($P < 0.05$). Hence, sprinkling could appreciably reduce peak temperature. The average coincident RH for both treatment and control was identical at 47%. The daily average inside and outside air temperatures are shown in figure 2, with no significant difference between the treatment and control. The same was true with the daily average THI values between the treatment and control.

Table 1. Daily maximum temperature and RH during the hot days in August and September 1998.

Date of 1998	Maximum Temperature (°C)[a] Treatment	Control	Outside	Coincident RH (%) Treatment	Control	Outside
18 Aug.	31.9	32.0	33.9	68	68	64
19Aug.	32.6	33.2	34.8	71	68	65
20 Aug.	33.8	34.1	36.9	58	57	53
22 Aug.	32.6	33.2	34.7	59	59	58
23 Aug.	33.6	34.1	36.3	50	52	44
28 Aug.	32.8	31.3	30.6	49	52	48
29 Aug.	32.9	32.2	32.2	47	41	40
4 Sept.	32.1	31.5	31.6	40	41	39
5 Sept.	31.7	32.7	32.7	58	55	51
6 Sept.	34.1	34.6	35.6	54	52	49
10 Sept.	31.9	32.4	31.3	31	29	30
11 Sept.	33.3	34.0	33.4	24	23	21
12 Sept.	34.3	34.9	34.4	33	31	30
13 Sept.	33.3	34.0	33.9	38	37	37
19 Sept.	33.4	34.1	33.8	33	33	32
25 Sept.	32.2	31.9	30.5	50	54	57
26 Sept.	33.6	33.8	33.3	44	42	40
Average	32.9	33.2	33.5	47	47	45

[a] Conversion of °C to °F: °F = 1.8 × °C + 32

Airflow Pattern

Airflow transfers heat and mass and thus its pattern greatly influences the spatial distribution of air quality. Figure 3 depicts the airflow pattern of the layer house. The incoming air jet flowed along the ceiling and dropped at the symmetrical plane of row 3. Air in aisles 1, 2, 5, and 6 was somewhat stagnant, leading to a less desirable air quality in these regions, as shown below by the distribution of dust concentration.

Dust and Ammonia Levels

The level of respirable dust (i.e., aerodynamic diameter less than 5 μm) in the house ranged from 30 to 500 particles per mL of air (8.5×10^5 to 1.4×10^7 particles/ft^3) during the experimental period. The wide range of dust was primarily attributable to feeding activity and light switching on and off. Specifically, the level of respirable dust increased 5 to 6 folds during dark to light transitions. Sprinkling tended to reduce the dust level, particularly right after the application, but the results were not consistent. The inconsistent suppression of dust by the sprinkling was speculated to arise from different bird activity level during the course because ventilation rate was at the maximum. Since respirable dust behaves as a passive scalar and it is transported by airflow, its distribution reflects the airflow pattern. During sprinkling on 19 August

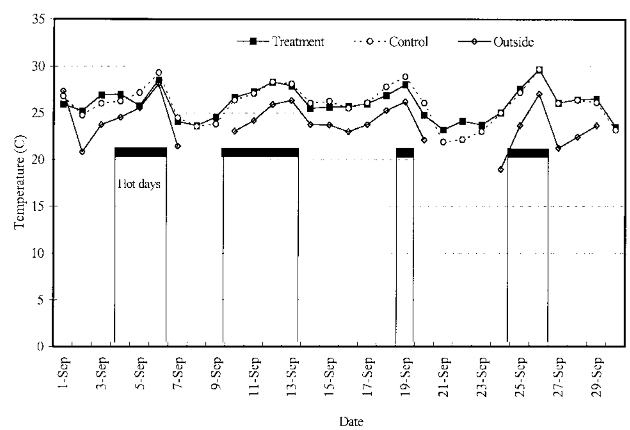

Figure 2. Daily average outside and inside temperatures during September 1998.

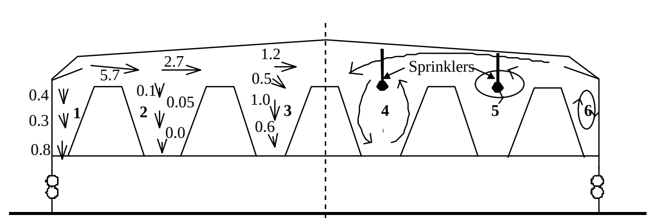

Figure 3. Airflow pattern and velocity profile of the experimental layer house (1 m/s = 197 ft/min).

1998, average respirable dust levels over 60 min for aisles 2 and 3 were 408±54 and 300±26 particles per mL of air, respectively. The 34% higher dust concentration in aisle 2 than in aisle 3 ($P < 0.01$) confirmed the relatively stagnant air in aisle 2, as revealed by the direct measurement of airflow pattern. There was no significant difference between treatment and control in aerial NH_3 concentration that averaged about 5 ppm. The high ventilation rate was presumably responsible for the low NH_3 level.

Egg Production and Quality

Daily egg production (per 1000 hens housed) for the treatment and control during the period of 28 August to 30 September 1998 is shown in figure 4. The average egg production (per 1000 hens housed) by deck location during the same period is summarized in table 2. There was significant difference in egg production between the treatment and the control ($P < 0.01$). Overall, egg production of the treatment birds was 2.6% greater than that of the control birds, 724 versus 705 eggs per 1000 hens housed. As can be noted in table 2, egg production was deck–location dependent, with hens in the third deck from the top producing the most eggs. The difference in egg production between the treatment and control birds occurred at the upper two decks. This result indicated that hens in the upper two decks benefited more from the sprinkling than those in the lower two decks. This outcome implied that hens at the bottom two decks did not receive as much sprinkling as those in the upper two decks. Therefore, future work is needed to improve distribution of the water sprinkling by reconfiguration of the nozzles, different locations of the nozzle line, or both.

Figure 5 shows the autocorrelation coefficient $R_{(\tau)}$ of daily egg production for both the treatment and control birds. The profiles of $R_{(\tau)}$ were quite distinctive for the two regimens. It is interesting to note that present egg production of the control hens had quite a high autocorrelation (0.60) with that of six days ago. Does this mean that an acute exposure of hens to heat stress would bear a 6–d post exposure effect on their egg production? Unfortunately, data from the present study were not sufficient to adequately address this question because of the uncontrolled climatic changes and thus environmental conditions in the layer house. This issue would be better addressed using a series of experiments with controlled environmental conditions. Nevertheless, this result indicates that autocorrelation analysis may prove a useful tool for quantifying the impact of thermal history on hen productivity. Understanding this thermal impact could lead to the development of intelligent management decisions or environment control strategies that will help the hens recover from heat stress. The unique environmental control strategy based on thermal history of the birds (i.e., the time–integrated variable or TIV control) to improve the environment control quality as proposed by Timmons et al. (1995) is an excellent example of such efforts.

Results of the cuticle status examination revealed no penetration of the dye through the eggshell. Thus, sprinkling as used in the current study showed no adverse effect on the integrity of the eggshell.

Table 2. Egg production per 1000 hens housed by deck location during the period of 28 August to 30 September 1998 (n = 33).

	Deck[a, b]				
	Top	Second	Third	Bottom	Average
Treatment	697 (29)[a]	746 (29)[c]	748 (27)[c]	707 (40)[a]	724 (29)[c]
Control	660 (34)[b]	726 (32)[d]	739 (30)[c,d]	695 (39)[a]	705 (31)

[a] Column and row means with different superscript letters were significantly different ($P < 0.05$).
[b] Values in parenthesis were standard deviation.
[c] Overall egg production for treatment and control was significantly different ($P < 0.01$).

Rectal Temperature

During the period of 19 and 20 August 1998 when sprinkling was in operation part of the time [when $T_i > 32°C$ (90°F)], rectal temperatures of the treatment and control birds were sampled at 4–h intervals for a 24–h period and the results are listed in table 3. During the intermittent sprinkling period from 14:30 to 18:00 h, a significant difference in rectal temperature was found at the top deck between the treatment and control hens at 18:00 h ($P < 0.05$). This coincided with the significant difference in egg production between the top decks (table 2). However, there was no significant difference in daily average rectal temperature between the treatment [41.5°C (106.7°F)] and control [41.6°C (106.8°F)]. The benefit of intermittent sprinkling on reducing body temperature rise had been shown previously in our

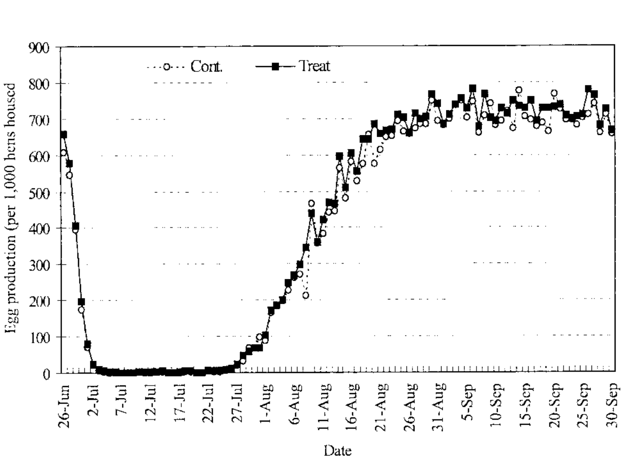

Figure 4. Daily egg production of the laying hens subjected to the treatment (intermittent sprinkling of water) and control (no sprinkling) in the same house during the period of 26 June and 30 September 1998 or 64 to 78 weeks old.

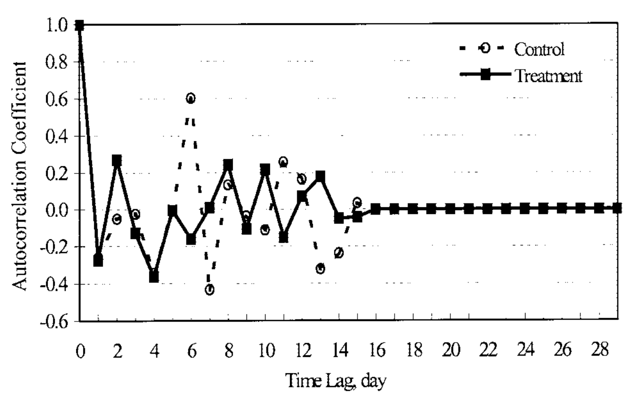

Figure 5. Autocorrelation coefficient of egg production for treatment and control.

controlled–hot [40°C (104°F)] environment laboratory tests (Chepete and Xin, 2000). The ambient temperatures experienced during this field test were not severe enough to show the full merit of the cooling system.

Although only anecdotal, management personnel of the farm indicated that it was clear that hens in the treatment half were more comfortable than those in the control half during hot days.

CONCLUSIONS

The efficacy of an economical, low–pressure sprinkling system for cooling commercial laying hens in high–rise houses was evaluated in a commercial laying house in Iowa. The results indicated:

- Intermittent sprinkling of water when inside temperature exceeded 32°C (90°F) improved overall egg production by 2.6% ($P < 0.05$). The system benefited hens in the upper decks more than those in the lower decks, improving egg production by 5.6% for hens in the top deck of the treatment as compared with those of the control.
- No adverse effect of the sprinkling was observed concerning the integrity of eggshell cuticles.
- The intermittent sprinkling had some positive effects in reducing peak temperature of the house.
- Autocorrelation analysis provided useful insight toward the impact of thermal exposure history of the hens on their subsequent egg production response.

Table 3. Rectal temperature (°C) of the hens.

		Time of Day (h)[b, c]								
Top Deck[a]		10:00	14:00	18:00	22:00	2:00	6:00	10:00	14:00	Avg.
Trt	Mean	41.1	41.7	41.8	41.3	41.1	41.5	41.3	41.6	41.4
	SE	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	
Ctrl	Mean	41.3	41.5	42.1	41.3	41.2	41.4	41.3	41.8	41.5
	SE	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	
Bottom Deck										
Trt	Mean	41.5	41.8	42.1	41.4	41.0	41.4	41.4	41.8	41.5
	SE	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.1	
Ctrl	Mean	41.6	41.6	42.0	41.6	41.2	41.5	41.5	41.9	41.6
	SE	0.2	0.1	0.3	0.1	0.1	0.2	0.1	0.1	
Trt Average		41.3	41.7	41.9	41.3	41.1	41.4	41.3	41.7	41.5
Ctrl Average		41.4	41.6	42.1	41.5	41.2	41.5	41.4	41.8	41.6

[a] Trt = treatment; Ctrl = control; n = four birds per deck.
[b] Intermittent sprinkling was in operation from 14:30 to 18:00 h.
[c] Significant difference was detected at 18:00 h between the treatment and control hens for the top decks ($P < 0.05$).

FUTURE WORK NEEDS

Work is needed to improve the distribution of water sprinkling among the decks. Future work should also be conducted to optimize operation and water output of the sprinkling system as a function of the environmental conditions, i.e., temperature, RH, and possibly air velocity levels in the house.

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