# COOLING LAYING HENS BY INTERMITTENT PARTIAL SURFACE SPRINKLING

H. J. Chepete, H. Xin

**ABSTRACT.** *This study investigated the efficacy of intermittent partial surface sprinkling to cool caged layers at 20, 38, and 56 weeks of age. Ten birds were used per age group with two birds per paired trial (Experiment, Expt, and Control, Ctrl) that were subjected to an acute heat exposure of 40.0 ± 0.5°C air temperature, 45 ± 3% RH, and air velocity of 0.15 to 0.20 m/s for a maximum of 8 h. The Expt birds were sprinkled with water mist (8 mL/sprinkling session) on the head and appendages at 15-min intervals from the time when panting was observed; whereas, the Ctrl birds received no sprinkling. Continuous measurement of the rectal temperature and periodic thermographical measurement of the surface temperature of the birds were performed. The intermittent partial surface sprinkling had the following merits as compared with the control: lower body temperature rise (4.3 vs 5.7°C; $P < 0.05$), higher lethal heat load threshold (10.0 vs 6.6°C-h, $P < 0.05$), longer survival time (145 to > 480 vs 92 to 266 min), and reduced mortality (20 to 60% vs 100%). The maximum reduction in surface temperature of the head and appendages due to the sprinkling averaged 2.2°C. Under the present environmental conditions (i.e., 40°C, 45% RH, and 0.15 to 0.20 m/s), sprinkling once every 5 to 6 min would provide adequate cooling to prevent the surface temperature from rising. The concept of body heat load ($\beta$) seems to provide an effective measurement of heat tolerance of the birds under different cooling schemes.*

***Keywords.*** *Poultry, Heat stress, Evaporative cooling, Infrared thermography.*

Poultry are homeothermic in that they maintain a relatively constant body temperature in spite of wide environmental fluctuations. During heat stress the unfeathered extremities such as comb and wattles of fowl (Richards, 1971; Van Kampen, 1971; Nolan et al., 1978) or the leg (Richards, 1971; Hillman et al., 1982) are normally vasodilated. Van Kampen (1971) reported that the total surface area of the comb and the wattles accounts for about 10% of the total body surface, and consequently the head and appendages play an important role in heat dissipation.

Chickens and turkeys lack sweat glands and the capability to perspire. Thus they lose excess heat primarily by evaporating water through respiration and releasing heat from surfaces such as wattles, shanks, and unfeathered areas under wings (Carr and Carter, 1985). Research by Carter (1981) revealed that (1) the ideal temperature range for adult poultry is 21 to 26°C; (2) the effects of heat are seen at temperatures above 26°C with heat prostration normally starting to have an impact at 35°C; and (3) feed efficiency will suffer at temperatures below 21°C.

Ventilation of poultry buildings is provided by mechanical means, i.e., fans in the sidewalls or wind flowing through sidewall openings (Bottcher et al., 1995). Air movement over the birds is especially critical during hot weather when heat produced by the birds raises their body temperature (Smith and Oliver, 1971) when the birds' ability to lose heat is diminished. Increasing air velocity significantly enhances the birds' ability to dissipate heat by convection. Maintaining air temperature at or above 35°C for significant periods of time requires some temperature reduction through evaporative cooling. High wind speeds at 37.8°C or higher without evaporative cooling result in increased thermal stress (Timmons and Hillman, 1993).

Pad systems are the most expensive of the evaporative cooling systems feasible for poultry production; whereas, misting and fogging systems are much more affordable. The latter are thus the choice of many producers in the less humid regions of the United States due to lower initial and operating costs and the relative ease of installation in both new and remodeled buildings (McNeill et al., 1980). Fine mists can cause a more humid microenvironment and inhibit cooling from the surface or respiratory pathway by reducing the vapor pressure potential. Intermittent sprinkling is important to allow time for the moisture to evaporate. In humid areas, fans also are needed to increase the evaporative cooling rate and fans may not be necessary in drier areas or where natural ventilation is adequate.

In their evaluation of poultry mist-fog systems, Timmons and Baughman (1983) conjectured that the benefits obtained in these systems were primarily due to surface wetting of the bird and subsequent evaporation by heat supplied by the bird, thus increasing the heat loss of the wetted bird. They further suggested that misting type

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systems should be designed to promote the wetting of the bird instead of an attempt to mist the air of the entire house volume, thereby reducing the problem of wet litter, equipment, and/or feed. Surface or skin wetting has been used to cool swine (MWPS, 1983; Panagakis et al., 1992). Studies conducted in Florida, Kentucky, Missouri, and Israel showed that sprinkling and fan cooling systems reduced heat stress in dairy cows (Bucklin et al., 1991). Berry et al. (1990) applied surface wetting on broilers with low-volume nozzles at a flow rate of 2.82 g/min and reported reduced mortality due to heat stress. Spraying was performed no more than 30 to 50 s every 10 min for the hottest temperatures.

Infrared (IR) thermography has been used to identify the distribution of surface temperatures and thus heat for a number of animals (Clark and Stothers, 1980; Hill et al., 1980; Korhonen and Harri, 1986) and floor heating devices (Xin, 1998). Mohler and Heath (1988) concluded that the thermographic method of measuring surface temperatures reveals much more information about the control and characteristics of heat loss from a surface than does any method measuring temperature at one or a few points.

Commercial laying hen barns in Iowa are traditionally not equipped with supplemental cooling systems as compared with those in the southern United States because of the historically mild summers. Cooling of the birds in summer is limited to increased ventilation rates through the barns. A devastating week-long heat wave in July 1995 took a death toll of 1.8 million laying hens in Iowa, prompting the Iowa egg industry to explore a cost-effective cooling system that can be retrofitted into existing barns or installed in the new ones. In these commercial laying hen barns, birds usually have their heads and appendages sticking out of the cages into the aisles. Thus, upon using sprinklers installed along the aisles, the water droplets will most likely fall onto the exposed head and appendages than on the rest of the body—hence partial body surface sprinkling.

The objectives of this study were to: (1) evaluate the efficacy of partial body surface cooling of laying hens by intermittent sprinkling as measured by physiological responses of the birds; and (2) determine the application frequency of the partial body surface cooling.

## Materials and Methods

### Experimental Birds and Handling

Three groups of layers of age 20, 38, and 56 weeks were procured at different times from a local laying hen company and used in the study. Two weeks prior to procurement of each age group, the birds were kept in the commercial houses at average temperatures of 28, 27, and 26°C with corresponding RH of 68, 68, and 61% for the 20, 38, and 56-week-old birds, respectively. For each group, a total of 10 birds were used with two birds for each paired trial (Experiment, Expt, and Control, Ctrl). Birds of similar body weight were randomly selected at the farm and ground-transported (130 km) to the Livestock Environment and Animal Physiology (LEAP) Research Laboratory at Iowa State University, Ames, Iowa. The birds' combs were traced on paper for later determination of surface areas and thickness measured using a venier caliper. Upon arrival at the LEAP laboratory, the birds were placed in holding cages and given feed and water *ad libitum* for the entire experimental period. The feeding and lighting regime at the LEAP laboratory was the same as that on the farm, i.e., lights were turned on at 6:00 A.M. and off at 9:00 P.M. (15L:9D) for the 38 and 56-week-old birds and on at 5:00 A.M. and off at 9:00 P.M. with an extra 2 h of midnight feeding for the 20-week-old birds (18L:6D). The birds were held at room temperature of 24 ± 0.5°C and 55 ± 5% relative humidity (RH).

### Conditioning and Testing Chambers

One of the environmental chambers (1.8 L × 1.5 W × 2.4 H m each) in the LEAP laboratory was used to precondition the air drawn from the laboratory before being drawn further into a smaller testing chamber (61 W × 109 L × 162 H cm) that held birds during the trial (fig. 1). Both the conditioning and testing chambers were well insulated. The temperature and RH were 41 ± 1°C and 41 ± 3%, respectively, in the conditioning chamber and 40 ± 0.25°C and 45 ± 3%, respectively, in the testing chamber.

Heating of air in the conditioning chamber was achieved with two 1000 to 1500 W electrical heaters (Model T621, Rival Manufacturing Company, Kansas City, Missouri) and controlled with a fully programmable data logger and controller (Model CR10, Campbell Scientific Inc., Logan, Utah) via a temperature/RH probe (Model HMP 35C, Campbell Scientific, Inc.) located in the plenum of the testing chamber. The CR10 controller for heaters in the conditioning chamber utilized the testing chamber temperature set point of 40°C. A single humidifier and water reservoir under the wire mesh floor in the conditioning chamber helped in humidifying the air. These were refilled to full capacity each time just before the start of each trial.

Suction of hot air from the conditioning chamber into the testing chamber was achieved using a 10-cm-diameter variable-speed in-line duct blower. Two 10-cm-diameter flexible insulated ducts conveyed the hot air from the blower into the testing chamber via a "Y" PVC outlet connection from the blower (see fig. 1). Hot air entered the testing chamber from the top, with one duct blowing directly over one of the two testing chamber compartments housing either the Expt or the Ctrl bird. A PVC air distribution panel with 2.5-cm-diameter holes spaced 2.5 cm apart was placed 23 cm from the inside top of the chamber to ensure reasonably uniform air distribution and an air velocity of 0.15 to 0.20 m/s at the bird level below.

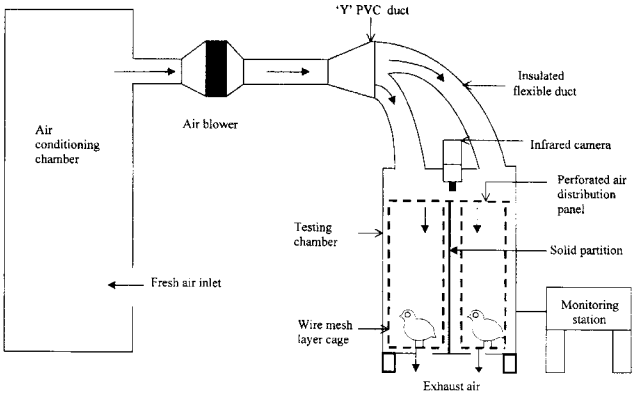



**Figure 1–Schematic representation of the experimental setup.**

The two compartments (122 H × 41 W × 46 L cm each) were divided with an opaque PVC panel from the bottom up to the air distribution panel. Each compartment housed a wire mesh cage measuring 89 H × 41 W × 46 L cm. The cages were supported 14 cm from the base. Across the middle of each compartment base were two adjustable 5-cm-diameter holes for the exhaust air. On the side of each compartment, a small window (18 L × 6 W cm) was added to observe the birds from outside, and a 3 L × 2 W-cm hole was drilled next to the window for the sprayer lance to be inserted for sprinkling.

At the center top of the testing chamber, a hole was drilled to fit an infrared (IR) camera (Model PM250, Inframetrics, North Billerica, Massachusetts). When mounted in place, the IR camera (discernable of 0.06°C) could capture images of both birds below in a single shot. The IR camera was controlled with a PC and its output was connected to a monitor. Thermal emissivity of 0.95 and background temperature of 40°C were set in the IR camera. Behavior of the birds were also monitored and videotaped using two CCD, high-speed aperture color video cameras (Panasonic WV-CP410 series) mounted in each compartment, a time lapse VCR (Model AG 6730, Panasonic Services Co.), a quad system (Model WJ 420, Panasonic Services Co.), and a TV monitor.

Nipple waterers and trough feeders were provided in each compartment to supply water and feed *ad libitum*. Illumination was provided with an 8 W fluorescent light.

### The Heat Exposure Trials

Two birds were randomly removed from the holding chamber, weighed, and randomly allocated to the treatments. Each bird had a rectal temperature probe (accuracy of 0.1°C. Model PT907, Pace Scientific, Inc., Charlotte, North Carolina) inserted into the rectum and surgically stitched onto the anus with needle and thread. A thin strip of adhesive tape was used to further secure the sensor onto the birds' tail feathers. Care was taken in handling the birds to ensure that they could still lay and defecate freely. Both birds were then kept overnight (11 to 12 h) under thermoneutrality (24°C) in the testing chamber to get acclimatized to the physical environment.

Both rectal temperature probes were connected to a pocket logger (Model XR340, Pace Scientific, Inc.) for data collection and storage. Ambient temperature and RH sensors were also placed at the bird level and connected to the same pocket logger for each bird. Fresh room air was provided throughout the acclimation period. The pocket loggers were connected to a laptop computer to monitor and record the temperature and RH readings. Sampling interval for all temperatures and RH was 20 s.

Following acclimation, at about 7:00 A.M., the heat exposure was started by turning on heaters and the humidifier in the conditioning chamber via the CR10 controller. Sprinkling of the Expt bird with tap water was started upon onset of panting and repeated every 15 min to the end of the 8 h of the trial duration or to the point of death. The Ctrl bird was not sprinkled at any time. Sprinkling was done on the head, head appendages, and neck using a 3.8-L capacity Hudson leader sprayer (Model 60071, H. D. Manufacturing Company, Hastings, Minnesota) releasing about 8 mL/sprinkling session.

The time of bird death was recorded. The birds were considered dead when no breathing movement was observed from the zoomed image on the TV monitor and looking directly through the observation window of the testing chamber. This was further verified by checking against the peak/lethal temperature point (where the birds would normally die) after the data had been downloaded.

Recording of the IR images was made at the start of the trial, just before sprinkling, just after sprinkling, and 1, 5, and 15 min after sprinkling. The next set of five images was taken after a 2-h time interval, making a maximum total of four sets of five images for each trial. Birds were videotaped for the entire trial duration or stopped only when both birds were dead. A record of behavior, physical responses, and death time of the birds was noted.

At the end of each trial, dead bird(s) were disposed of by incineration and live bird(s) were euthanized and disposed of. The holding and testing chambers were disinfected before the next batch of birds were brought in from the laying hen farm.

### Quantification of Bird Tolerance to Heat Stress

The concept of heat load ($\beta$) was used to measure the treatment effects on heat tolerance of the birds. In particular, the term lethal heat load ($\beta_l$) was introduced to define the maximum heat load that the birds could cope with before death occurs. The heat load, $\beta$, was defined as:

$$\beta = \sum_{i=1}^{N} \left| T_{b(i)} - T_{b(TN)} \right| \times \frac{\theta}{3600} \qquad (1)$$

where

$\beta$ = body heat load (°C-h)
$T_{b(i)}$ = body temperature at sampling time i
$T_{b(TN)}$ = mean body temperature under thermoneutrality (°C)
$\theta$ = sampling time interval (s) ($\theta$ = 20 s)
N = number of discrete sampling points

### Data Analysis

Analysis of variance (ANOVA) was performed to determine the differences in body temperature change and heat load tolerance within and between age groups for the Expt versus Ctrl and interaction between age and treatment. IR images were analyzed to obtain the average surface temperature and its changes for the head and appendages during the 15-min sprinkling sessions.

## Results and Discussion

### Core Body Temperatures ($T_b$)

Table 1 summarizes the responses of the laying hens exposed to heat stress. Mortality was 100% for all the Ctrl groups as compared with 20 to 60% for the Expt groups. This outcome demonstrated that sprinkling the birds with water has a positive effect on their survival under heat stress. Specifically, in the Expt group mortality was 60%, 40%, and 20%, respectively, for the 20, 38, and 56-week-old birds. The higher mortality for the younger birds could be attributed to the fact that the older birds were physiologically more heat tolerant because of less plumage cover and much larger combs and wattles (fig. 2) that

**Table 1. Summary of the responses of laying hens exposed to heat stress with or without head sprinkle cooling (Expt and Ctrl) (five birds were involved for each age group within the treatment)**

| Trt | Age (wk) | BM (kg) | | | Mortality (%) | Survival Time (min) | | Body Heat Load, β (°C-h) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Died | Lived | Combined | | Died | Lived | Died | Lived | Combined |
| Expt | 20 | 1.27 (0.06) | 1.30 (0.00) | 1.28 (0.04) | 60 | 233 (31) | > 480 | 11.1 (0.2) | 20.1 (3.5) | 14.7 (1.5) |
| | 38 | 1.59 (0.05) | 1.47 (0.08) | 1.52 (0.06) | 40 | 207 (11) | > 480 | 10.6 (1.6) | 12.1 (0.5) | 11.5 (0.9) |
| | 56 | 1.44 (0.00) | 1.52 (0.07) | 1.50 (0.05) | 20 | 145 (0) | > 480 | 5.3 (0.00) | 12.9 (2.3) | 11.3 (1.8) |
| | Overall | 1.41 (0.05)[a] | 1.45 (0.06) | 1.43 (0.05)[a] | 40 (20) | 210 (19)[a] | > 480 | 10.0 (0.6)[a] | 14.2 (2.0) | 12.5 (1.4)[a] |
| Ctrl | 20 | 1.31 (0.04) | --- | 1.31 (0.04) | 100 | 179 (22) | --- | 8.6 (0.3) | --- | 8.6 (0.3) |
| | 38 | 1.50 (0.05) | --- | 1.50 (0.05) | 100 | 113 (12) | --- | 5.4 (0.7) | --- | 5.4 (0.7) |
| | 56 | 1.51 (0.04) | --- | 1.51 (0.04) | 100 | 130 (5) | --- | 5.6 (0.3) | --- | 5.6 (0.3) |
| | Overall | 1.44 (0.04)[a] | --- | 1.44 (0.04)[a] | 100 (0) | 141 (13)[b] | --- | 6.6 (0.4)[b] | --- | 6.6 (0.4)[b] |
| | LSD | 0.10 | | 0.03 | | 37 | | 1.2 | | 2.4 |

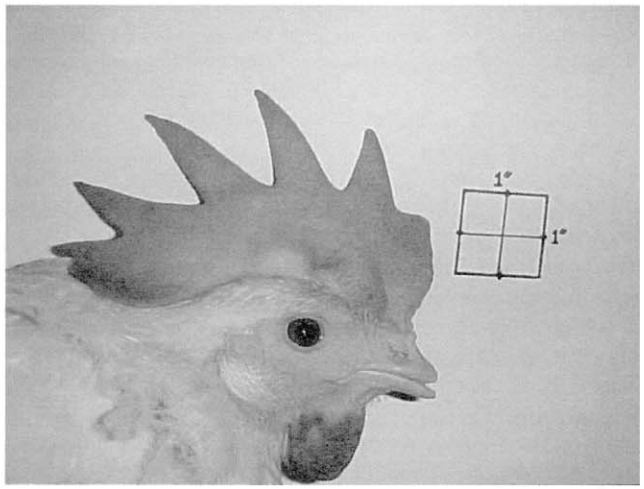
**Table 1 (continued). Summary of the responses of laying hens exposed to heat stress with or without head sprinkle cooling (Expt and Ctrl) (five birds were involved for each age group within the treatment)**

| Trt | Age (wk) | Body Temperature ($T_b$) Rise (°C) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Average | | | Maximum | | |
| | | Died | Lived | Combined | Died | Lived | Combined |
| Expt | 20 | 3.0 (0.4) | 2.5 (0.5) | 2.8 (0.3) | 6.0 (0.2) | 4.0 (0.1) | 5.2 (0.5) |
| | 38 | 3.1 (0.3) | 1.5 (0.1) | 2.1 (0.4) | 5.2 (0.1) | 3.9 (0.7) | 4.4 (0.5) |
| | 56 | 2.0 (0.0) | 1.6 (0.3) | 1.9 (0.2) | 3.4 (0.0) | 3.5 (0.5) | 3.4 (0.3) |
| | Overall | 2.8 (0.3)[a] | 1.8 (0.2) | 2.2 (0.3)[a] | 5.3 (0.1)[a] | 3.7 (0.5) | 4.3 (0.5)[a] |
| Ctrl | 20 | 3.2 (0.1) | --- | 3.2 (0.1) | 5.8 (0.2) | --- | 5.8 (0.2) |
| | 38 | 2.8 (0.1) | --- | 2.8 (0.1) | 5.8 (0.6) | --- | 5.8 (0.6) |
| | 56 | 2.6 (0.1) | --- | 2.6 (0.1) | 5.4 (0.3) | --- | 5.4 (0.3) |
| | Overall | 2.9 (0.1)[a] | --- | 2.9 (0.1)[b] | 5.7 (0.4)[a] | --- | 5.7 (0.4)[b] |
| | LSD | 0.4 | | 0.3 | 0.9 | | 0.8 |

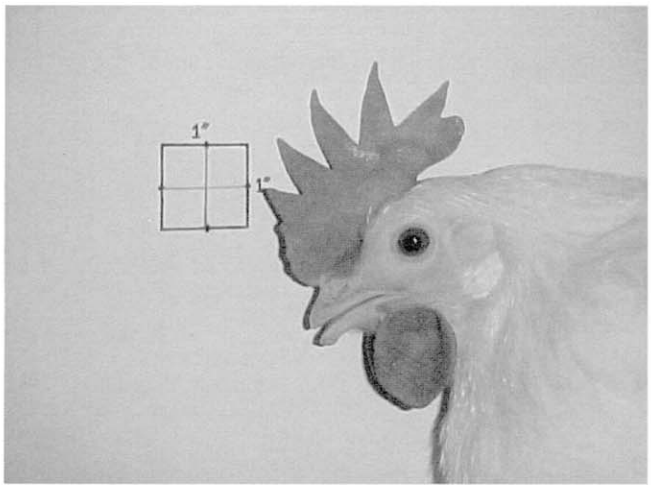
Note: Values in parentheses are standard errors of the means.
Overall column means between treatments with the same letter are not significantly different (P > 0.05).

enhanced heat loss through their surface (evaporation and sensible heat loss). On average, the combs had surface areas of 171, 227, and 252 $mm^2$ with corresponding thickness of 4.0, 4.5, and 4.0 mm for the 20, 38, and 56-week-old birds, respectively. This result was consistent with the reported increase in heat tolerance of naked-neck chickens (Cahaner et al., 1993) and that reduced feather cover are advantageous in thermoregulation at high ambient temperatures by increasing sensible heat loss (Eberhart and Washburn, 1993a; Yalcin et al., 1997).

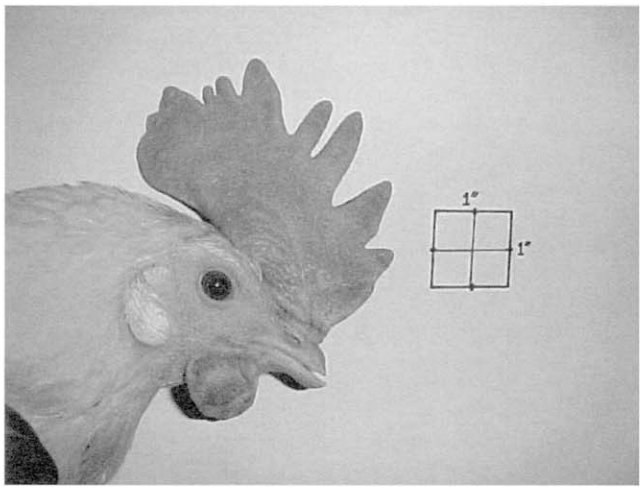
Comparison of the survival time shows that for all age groups, those that received sprinkling had a longer survival time of 145 to > 480 min as compared with 92 to 266 min for the Ctrl counterparts. This outcome provides additional evidence of the beneficial effects of the sprinkling practice. Smith and Oliver (1970) reported that hens can withstand short periods of exposure to air temperatures higher than




**(b) 38-week-old hen**




**(a) 20-week-old hen**




**(c) 56-week-old hen**

**Figure 2–Typical head appendages for the 20, 38, and 56-week-old laying hens (1 in. = 25.4 mm).**

40°C. Squibb (1959) noted that hens could withstand a temperature of 44°C for 1 h.

All the birds had a thermoneutral (TN) body temperature of 40 to 41°C, which agrees with the literature values of 40 to 43°C. The Ctrl birds showed a higher body temperature rise above the TN level (4.7 to 8.2°C) than their Expt counterparts (2.5 to 6.4°C) ($P < 0.05$). The lower body temperature rise for the Expt group could be attributed to the sprinkling effect, which enhanced heat dissipation from the birds via surface evaporation and consequently resulting in reduced body heat buildup and temperature rise. Wilson and Hillerman (1952) reported a 0.11°C reduction in body temperature over 90 min for White Leghorns kept at 31.1 to 32.8°C air temperature, with head-wetting done once for 30 s with 40 mL of water at 23.9°C.

There was no interaction between age and treatment ($P > 0.05$) for body temperature changes. Therefore, comparison of the pooled means (table 1) was conducted and significant difference ($P < 0.05$) was noted between the Expt and Ctrl for both maximum and average $T_b$ rise. The pooled mean $T_b$ rise was 2.2 and 2.9°C, and the maximum $T_b$ rise was 4.3 and 5.7°C for the Expt and Ctrl, respectively. This result also indicates the merits of sprinkling in reducing heat stress of the birds.

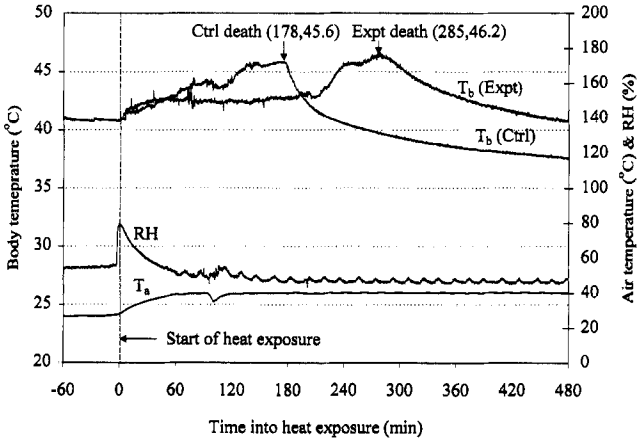
### Body Heat Load (β)

As shown by the heat load data in table 1, the Expt birds were able to tolerate more heat load as compared with the Ctrl birds, which absorbed lesser heat load by the time they died of hyperthermy. On average, the Ctrl birds had a lethal heat load ($\beta_l$) of 8.6, 5.4, and 5.6°C-h for the 20, 38, and 56-week-old birds, respectively, as compared with 11.1, 10.6, and 5.3 (only one bird) °C-h for their respective Expt counterparts. The $\beta_l$ values for the Ctrl birds suggest that the younger Ctrl birds (with lighter body mass of 1.3 kg) actually coped with the heat better than the older ones (with heavier body mass of 1.5 kg), as also evidenced by their longer survival time (179 vs 113 ~ 130 min). This outcome was speculated to arise from the lower metabolic mass ($W^{0.75}$) for the younger/lighter birds. The same younger Expt birds with smaller combs and wattles, however, apparently could not take advantage of the sprinkling cooling as well as the older birds with larger combs and wattles, as reflected by their higher mortality. The Expt birds that survived had an average β of 20.1, 12.1, and 12.9°C-h for the 20, 38, and 56-week-old birds, respectively.

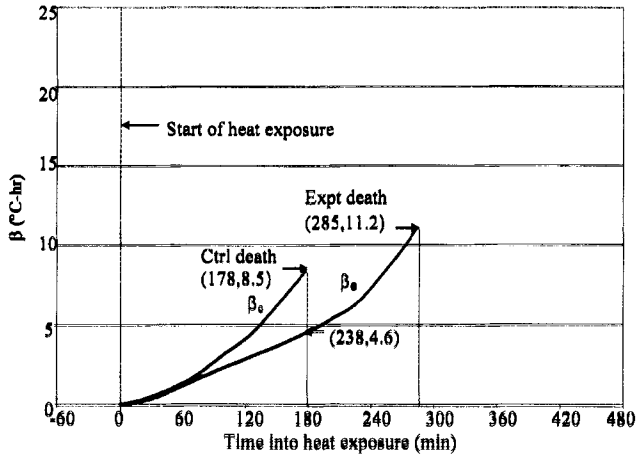
### Partition of β and $T_b$ Rise for the Expt Birds into 'Live' and 'Dead'

Table 1 further shows partitioning of the Expt birds into those that "died" and those that "lived". The Expt birds that died had an average $\beta_l$ of 10.0°C-h as compared with β of 14.2°C-h for the Expt birds that lived. $\beta_l$ averaged 11.1 and 10.6°C-h for 20 and 38-week-old birds, respectively. The birds that lived had β of 20.1, 12.1, and 12.9°C-h for the 20, 38, and 56-week-old birds, respectively. This result reveals that the younger (lighter) surviving birds retained more β compared with the older (heavier) birds.

Table 1 shows that the Expt birds that died had a higher average $T_b$ rise than the Expt birds that lived (2.8 vs 1.8°C, respectively). $T_b$ rise for the Ctrl birds (all dead) averaged




(a)




(b)

**Figure 3–Typical body temperature ($T_b$) (a), and body heat load (β) (b) profiles of 20-week-old laying hens subjected to heat exposure with or without intermittent sprinkle cooling of the head appendages (Subscript c = Ctrl; e = Expt).**

2.9°C. The dead birds had an average maximum $T_b$ rise of 6.0 and 5.2°C at 20 and 38 weeks of age, respectively. This result is consistent with the report by Moreng and Shaffner (1951) that the birds have an upper lethal body temperature of about 47.3°C (5 to 6°C above TN $T_b$). The maximum $T_b$ rise for the Expt birds was further divided into that of dead birds, 5.3°C, and that of survived birds, 3.7°C (table 1). The Ctrl birds had an overall maximum $T_b$ rise of 5.7°C.

### Dynamic Profiles of $T_b$ and β

Figure 3a shows a typical dynamic profile of $T_b$ during part of the acclimation period and the course of heat exposure while figure 3b shows β during the course of heat exposure. It can clearly be seen from figure 3a that the Ctrl and Expt birds had similar rectal temperatures during the acclimation period. It is also evident that after the start of heat exposure, both birds started to experience an increased rectal temperature. Wilson (1948) stated that change in air temperature is the most likely factor to alter $T_b$ of laying hens, particularly if it is increased above 32°C. Lethal peak $T_b$s were reached as heat production exceeded heat loss, causing $T_b$ to rise uncontrollably (Lee et al., 1945; Wilson,

1948), and then they dropped soon after the birds died. The Ctrl birds always gained heat faster and died much sooner than did the Expt birds. Figure 3b depicts that at any one time before death the Ctrl birds had a consistently higher β or heat gain. Also, the Expt birds were able to absorb considerably more β than the Ctrl counterparts due to sprinkling effect, which made them more heat tolerant.

These results demonstrate that sprinkle cooling had a positive effect in relieving the birds of heat stress through reduced rate of heat load gain that consequently reduced the rate of $T_b$ rise. Hence, the Expt birds were able to live longer. Death did come ultimately in some Expt birds as β reached lethal levels for the birds.

### Analysis of Thermographs

Both Expt and Ctrl birds had similar average surface temperatures at the start of the trials. All the Ctrl birds died prior to the second session of thermographical recording (about 165 min into the heat exposure). This short survival period was presumably attributed to the lack of cooling, which subjected the birds to heat prostration. On average, during sprinkling session no. 1 the Ctrl birds had higher average surface temperatures compared with the Expt birds in all the three age groups. This agrees with the expected effects of sprinkling in that it would reduce the surface temperature via evaporation which in turn enhance heat dissipation of the birds, consequently reducing $T_b$.

Table 2 shows that the Expt birds had an overall pooled mean surface temperature 37.0, 36.6, and 37.5°C, respectively, for the 20, 38, and 56-week-old birds just after sprinkling. Fifteen minutes after the sprinkling, the surface temperatures increased to 39.8, 39.5, and 39.7°C for the 20, 38, and 56-week-old birds, respectively.

Table 3 shows the overall pooled mean reduction in surface temperature of the head and appendages for the 20, 38, and 56-week-old birds, respectively. The largest surface temperature reduction occurred just after and 1 min after sprinkling and then reduced thereafter. The overall mean reduction in surface temperature for the 20, 38, and 56-week-old birds was, respectively, 2.1, 2.2, and 2.1°C just after sprinkling; 1.3, 1.4, and 1.4°C at 1 min after sprinkling; 0.5, 0.2, and 0.5°C at 5 min after sprinkling. By 15 min after sprinkling, the surface temperature was increased by an average of 0.7, 0.7, and 0.2°C, respectively, for the three age groups. The results thus suggest that under the present environmental conditions the sprinkling interval should be less than 15 min. A 5 to 6-min interval would be a conservative choice.

**Table 2. Changes in pooled mean surface temperature (°C) of head and appendages for the four sprinkling sessions of the Expt birds**

| Age | Time after Sprinkling (min) | | | | |
|---|---|---|---|---|---|
| (wk) | 0– | 0+ | 1 | 5 | 15 |
| 20 | 39.0 (0.5) | 37.0 (0.4) | 37.7 (0.5) | 38.6 (0.4) | 39.8 (0.4) |
| 38 | 38.7 (0.3) | 36.6 (0.3) | 37.3 (0.3) | 38.5 (0.4) | 39.5 (0.2) |
| 56 | 39.5 (0.5) | 37.5 (0.3) | 38.1 (0.5) | 39.0 (0.4) | 39.7 (0.3) |

Note: 0– = just before sprinkling.
0+ = just after sprinkling.
Values in parentheses are standard errors of the means.

**Table 3. Pooled mean change in surface temperature (°C) of head and appendages for the four sprinkling sessions of the Expt birds**

| Age | Time after Sprinkling (min) | | | |
|---|---|---|---|---|
| (wk) | 0+ | 1 | 5 | 15 |
| 20 | –2.1 (0.2) | –1.3 (0.3) | –0.4 (0.2) | 0.7 (0.2) |
| 38 | –2.2 (0.2) | –1.4 (0.3) | –0.2 (0.4) | 0.7 (0.3) |
| 56 | –2.1 (0.3) | –1.4 (0.4) | –0.5 (0.5) | 0.2 (0.5) |

Note: 0+ = just after sprinkling.
Values in parentheses are standard errors of the means.

### Behavioral Observations

The birds that lived longer or survived the trials were observed to be particularly "smarter" than other birds in terms of their behavioral response to the heat discomfort. Although most birds were restless and began flying in the chamber as temperature reached the mid 30°Cs, which compounded the $T_b$ rise. The "smarter" ones generally remained calm (minimizing restlessness or flying) and resorted to rigorous panting. They also held their wings away from their bodies as Hutchinson (1954) also had observed. Smith and Oliver (1971) demonstrated that the level of heat production of a laying hen increases with increasing body activity. The restless birds did so for about 20 to 25 min, after which they calmed down and panted rigorously with wings held away from their bodies. There was a noticeable reduction in $T_b$ in some birds after adoption of this behavior and in others the temperature kept increasing to the lethal point. Panting, which is initiated by the increase in temperature of the blood flowing to the brain (Randall, 1943), was observed to start at ambient temperatures of about 34 to 36°C, with noticeable rise in $T_b$ at about 36 to 37°C. Panting itself has been reported to generate heat (Smith and Oliver, 1971).

It was also observed that on average, by the third sprinkling session the birds would appear to "appreciate" being sprinkled as they would no longer be scared by the sprayer lance approaching their heads. In fact, some birds would even stick out their heads towards the lance after several sprinkling sessions.

All the birds were seen to start drinking water a few minutes after they started panting (and stopped roughly 15 min afterwards). Hillerman and Wilson (1955) showed that birds that consumed the most water withstood the highest temperatures, while Fox (1951) observed that survival time of fowls at high environmental temperature (42°C) was positively correlated with the persistency with which birds continued to drink.

None of the birds fed at all during the trials, which agreed with the findings by Yahav et al. (1996) that to avoid lethal increase in $T_b$, chickens minimize endogenous heat production by reducing feed intake.

## Conclusions

The efficacy of intermittent partial surface sprinkling of water to cool caged layers at 20, 38, and 56 weeks of age was investigated during an acute heat exposure to the environmental conditions of 40°C air temperature, 45% RH, and 0.15 to 0.20 m/s air velocity. The following conclusions were drawn from this study:

- Partial surface cooling by intermittent sprinkling of water is effective in relieving laying hens of heat stress in that it reduces core body temperature and head/appendages surface temperature, increases heat tolerance, and reduces mortality of the birds.

- Under the present experimental conditions, an application interval of 5 min for the partial surface sprinkling seems appropriate.
- The term body heat load ($\beta$) seems to provide an effective measurement of heat tolerance of the birds under different cooling schemes.

## REFERENCES


Berry, I. L., T. A. Castello, and R. C. Benz. 1990. Cooling broiler chickens by surface wetting. ASAE Paper No. 90-4024. St. Joseph, Mich.

Bottcher, R. W., J. Brake, G. R. Banghman, and J. R. Magura. 1995. Vertically directed mixing fans for cooling floor-raised poultry. *Applied Engineering in Agriculture* 11(4): 591–599.

Bucklin, R. A., L. W. Turner, D. K. Beede, D. R. Bray, and R. W. Hemken. 1991. Methods to relieve heat stress for dairy cows in hot, humid climates. *Applied Engineering in Agriculture* 7(2): 241-247.

Cahaner, A., D. Nader, and M. Gutman. 1993. Effects of plumage reducing naked neck (*Na*) gene on the performance of fast growing broilers at normal and high ambient temperatures. *Poultry Sci.* 72(5): 767-775.

Carr, L., and T. Carter. 1985. Housing and management of poultry in hot and cold climates. In *Stress Physiology in Livestock*, 74-108, Vol. III, Poultry. ed. M. K. Yousef. Boca Raton, Fla: CRC Press.

Carter, T. A. 1981. Hot weather management of poultry. Poultry Science and Technology Guide No. 30. Raleigh, N.C.: North Carolina State University.

Clark, R. P., and J. K. Stothers. 1980. Neonatal skin temperature distribution using infra-red color thermography. *J. Physiol.*, London 302: 323-333.

Eberhart, D. E., and K. W. Washburn. 1993a. Variation in body temperature response of naked neck and normally feathered chickens to heat stress. *Poultry Sci.* 72(8): 1385-1390.

Fox, T. W. 1951. Studies on heat tolerance in domestic fowl. *Poultry Sci.* 30(4): 477-483.

Hill, R. W., D. P. Christian, and J. H. Veghte. 1980. Pinna temperature in exercising jackrabbits, *Lepus californicas*. *J. Mammol.* 61(1): 30-38.

Hillerman, J. P., and W. O. Wilson. 1955. Acclimatization of adult chickens to environmental temperature changes. *Am. J. Physiol.* 180(3): 591-595.

Hillman, P. E., N. R. Scott, and A. van Tienhoven. 1982. Vasomotion in chicken foot: Dual innervation of arteriovenous anastomoses. *Am. J. Physiol.* 242(11): R582.

Hutchinson, J. D. 1954. Heat regulation in birds. In *Progress in the Physiology of Farm Animals*, 299-362, ed. J. Hammond. London, England: Butterworths Scientific Publ.

Korhonen, H., and M. Harri. 1986. Heat loss of farmed raccoon dogs and blue foxes as evaluated by infrared thermography and body cooling. *Comp. Biochem. Physiol.* 84A(2): 361-364.

Lee, D. H. K., E. W. Robinson, N. I. M. Yeates, and M. R. Scott. 1945. Poultry husbandry in hot climates. Experimental inquiries. *Poultry Sci.* 24(3): 195-207.

McNeill, S. G., R. L. Fehr, J. N. Walker, and R. G. Parker. 1980. Performance of evaporative coolers for mid-south gestation housing. ASAE Paper No. 80-4558. St. Joseph, Mich.: ASAE.

Mohler, F. S., and J. E. Heath. 1988. *Comparison of IR Thermography and Thermocouple Measurement of Heat Loss from Rabbit Pinna*, 389-395. Urbana, Ill.: Am. Physiology Soc.

Moreng, R. E., and C. S. Shaffner. 1951. Lethal internal temperatures for the chicken (from fertile egg to mature bird). *Poultry Sci.* 30(2): 255-266.

MWPS. 1983. *Swine Housing and Equipment Handbook*. MWPS-8. Ames, Iowa: Iowa State University.

Nolan, W. F., W. W. Weathers, and P. D. Sturkie. 1978. Thermally induced peripheral blood flow changes in chickens. *J. Appl. Physiol.* 44: 81.

Panagakis, P., S. Kyritsis, G. Papadopoulos, and D. Tambouratzis. 1992. Spray cooling of early weaned piglets: A first approach. *Applied Engineering in Agriculture* 8(1): 106-110.

Randall, W. C. 1943. Hypothermia in chickens. *Proc. Soc. Exp. Biol. Med.* 52: 240-243.

Richards, S. A. 1971. The significance of changes in the temperature of the skin and body core of the chicken in the regulation of heat loss. *J. Physiol.*, London 216(1): 1.

Smith, A. J., and J. Oliver. 1971. Some physiological effects of high environmental temperature on the laying hen. *Poultry Sci.* 50(3): 912-925.

Squibb, R. L., G. N. Wogan, and C. H. Reed. 1959. Production of White Leghorn hens subjected to high environmental temperatures with wide diurnal fluctuations. *Poultry Sci.* 38(5): 1182-1183.

Timmons, M. B., and G. R. Baughman. 1983. Experimental evaluation of poultry mist-fog systems. *Transactions of the ASAE* 26(1): 207-210.

Timmons, M. B., and P. E. Hillman. 1993. Partitional heat losses in heat stressed poultry as affected by wind speed. In *Livestock Environment IV, Proc. 4th Int. Symp.*, 265-270. St. Joseph, Mich.: ASAE.

Van Kampen, M. 1971. Some aspects of thermoregulation in the White Leghorn fowl. *Int. J. Biometeorol.* 15(2-4): 244.

Wilson, W. O. 1948. Some effects of increasing environmental temperature on pullets. *Poultry Sci.* 27(6): 813-817.

Wilson, W. O., and J. P. Hillerman. 1952. Methods of cooling laying hens with water. *Poultry Sci.* 31(5): 847-850.

Xin, H. 1998. Surface temperature distribution of commercial electrical heat mats for farrowing creep heating. In *Swine Research Report*, 115-120. Ames, Iowa: Iowa State University.

Yahav, S., A. Straschnow, I. Plavnik, and S. Hurwitz. 1996. Effects of diurnally cycling versus constant temperatures on chicken growth and food intake. *British Poultry Sci.* 37(1): 43-54.

Yalcin S., A. Testik, S. Ozkan, P. Settar, F. Celen, and A. Cahaner. 1997. Performance of naked neck and normal broilers in hot, warm, and temperate climates. *Poultry Sci.* 76(7): 930-937.