2002

A Research Facility for Studying Poultry Responses to Heat Stress and its Relief

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Abstract

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Keywords

Telemetric sensing, Thermograph, Environment control, Laying hens, Animal welfare

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

Journal Paper No. J-19473 of the Iowa Agriculture and Home Economics Experiment Station, Iowa State University, Project No. 3311. Funding for this study was provided in part by the U.S. Poultry and Egg Association and the Brazilian CAPES Foundation, and is acknowledged with gratitude.

This article is from *Applied Engineering in Agriculture* 18, no. 2 (2002): 255–260.

A Research Facility for Studying Poultry Responses to Heat Stress and its Relief

T. Yanagi, Jr., H. Xin, R. S. Gates

Abstract. *A control and measurement system was developed for studying physiological responses of poultry to thermal challenges and means of heat stress relief. The system features automatic control of air temperature and relative humidity (RH); manual setting of air velocity [±0.1 m·s^{-1} (±20 ft·min^{-1})]; and continuous recording of surface and core body temperatures of the animal. The target thermal conditions in the animal occupied zone were achieved inside a wind tunnel [0 to 1.5 m·s^{-1} (0 to 300 ft·min^{-1})] that was situated inside an environment–controlled room and re–circulated the room air. Target air temperature [±0.2°C (±0.36°F)] and RH (±2%) were achieved by controlling the auxiliary heaters and humidifiers in two stages via a programmable measurement and control module and its peripherals. Animal surface temperatures were time–recorded with an infrared thermal imager [0.06°C (0.1°F) sensitivity]. Core body temperatures [±0.1°C (0.18°F)] were collected with a surgery–free telemetric sensing unit that output the data to a PC. Moreover, a surveillance video system was used to monitor and archive animal behavior. The system has been used to quantify the responses of laying hens to various thermally challenging conditions and the efficacy of intermittent partial surface wetting in alleviating bird heat stress under these conditions.*

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Quantification of animal responses to biophysical factors and particularly their interactions remains an important aspect of research endeavors toward enhancing animal welfare and production efficiency. Constant advancements in electronics and measurement technologies have made it increasingly feasible and affordable for researchers to set up task–specific research facilities or apparatus to address technical issues of concern that would have been formidable just a few years ago. Recent work relative to measurement and data acquisition in animal environment research has been documented in the literature. Costello et al. (1991) designed and tested an aspirated psychrometer that was particularly suitable for measuring dry– and web–bulb temperatures, thus relative humidity (RH) in dusty animal housing environments. Xin et al. (1994) instrumented four commercial scale poultry houses to collect data on environmental and production variables. Gates et al. (1995) devised an automated body mass weighing system for growing pigs. Puma et al. (2001) developed an automated measurement, control, and data acquisition system for studying feeding and drinking behavior of individual poultry.

One of the recent research thrusts at Iowa State University has been to explore alternative cooling means for heat stress relief of caged layers (Chepete and Xin, 2000; Ikeguchi and Xin, 2001; Xin and Puma, 2001). One heat relief method that has demonstrated merits is intermittent partial surface (i.e., head and appendages) wetting of the birds (Chepete and Xin, 2000; Ikeguchi and Xin, 2001). The practice to date has been to apply cooling water at a fixed rate [e.g., sprinkle 10 s every 10 min when house temperature exceeds 32°C (90°F)] regardless of the severity of the climate. Such a scheme lacks optimization of system operation because water evaporation rate depends greatly on thermal conditions, i.e., air temperature (T_a), RH, and air velocity (V). A variable application rate reflecting deviation of the thermal condition from the upper critical temperature is more desirable. To quantify and optimize the variable, climate–dependent cooling water needs, a facility is needed to create the target thermal environments, determine water application rate, and measure the animals' physiological responses to the cooling scheme. Also, information is meager concerning the interactive effects of T_a, RH, and V on poultry subjected to heat challenges. The objective of this article was to describe the development and application of a testing facility that allows for conduct of such experiments.

Article was submitted for review in August 2001; approved for publication by the Structures & Environment Division of ASAE in January 2002.

Journal Paper No. J–19473 of the Iowa Agriculture and Home Economics Experiment Station, Iowa State University, Project No. 3311. Funding for this study was provided in part by the U.S. Poultry and Egg Association and the Brazilian CAPES Foundation, and is acknowledged with gratitude.

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MATERIALS AND METHODS

ENVIRONMENT CONTROL FACILITY

This testing facility was located in the Livestock Environmental Animal Physiology Laboratory II (LEAP II) at Iowa State University, Ames, Iowa. The facility consisted of three environmental rooms, each measuring 5.0 m (L) × 3.5 m (W) × 3.0 m (H) [16 ft (L) × 11 ft (W) × 10 ft (H)]. Two rooms were used as acclimation or holding rooms, whereas the third room was used as the testing room. All rooms had minimal temperature control and no RH control of the incoming air. The rooms were equipped with static pressure control such that the airflow rate of the rooms and the common corridor area was automatically adjusted to maintain a negative pressure for the corridor, minimizing the chance of potential cross–room contamination.

Situated inside the testing room was a wind tunnel, measuring 1.10 m (W) × 2.45 m (L) × 0.69 m (H) [3.6 ft (W) × 8.0 ft (L) × 2.3 ft (H)], that was constructed with aluminum frame and PVC sidewalls (fig. 1). The wind tunnel contained air straighteners that were made of 0.06–m (D) × 0.6–m (L) [0.2–ft (D) × 2–ft (L)] PVC tubes. The main body of the wind tunnel was divided into two regions: sensors region and animal region [1.1 m (W) × 0.5 m (L) or 3.6 ft (W) × 1.6 ft (L)]. The animal region was covered by a plastic film of 0.78 transmittance for acquiring infrared thermographs or surface temperatures and behavioral video images of the animals. More circuits (a total capacity of 80A at 120VAC) were added to accommodate the required heaters, humidifiers, fans, transducers, and data loggers.

MEASUREMENT AND CONTROL OF ENVIRONMENTAL VARIABLES

Environmental variables of concern included T_a, RH, and V at the animal occupied zone (AOZ) inside the wind tunnel. Air temperature and RH were measured with a thermistor temperature [±0.2°C (0.36°F)] and capacitance RH (±3%) probe (model HMP35L, Campbell Scientific, Inc., Logan, Utah) placed in the wind tunnel upstream of AOZ – sensor region (fig. 1). Air velocity was measured with an omni–directional transducer (accuracy of 3% reading) (TSI model 8475–12, Davis Instruments, Baltimore, Md.). Temperature (T_a), RH, and V were sampled at 2–s intervals, and stored as 1–min averages using a programmable measurement and control module (model CR10, CSI, Logan, Utah).

Fresh air was supplied to the testing room at T_a and RH lower than the respective target value. Ventilation rate of the testing room was reduced by blocking most of the supply and return air ducts, thereby reducing the unnecessary supplemental heat and humidification requirement. Heating and humidification of air were achieved with four 1.5–kW electric resistance heaters (model PT261, Rival Manufacturing Company, Kansas City, Mo.) and five humidifiers of various capacities. Heaters and humidifiers were switched by the CR10 via a four–channel relay driver (model A21REL–12, CSI, Logan, Utah) connected to four electromagnetic 12–VAC coil relays (1 hp at 120 VAC) (fig. 2). Two discrete control stages for T_a and two stages for RH were used. Each heating stage had a maximum power output of 3.0 kW. The first humidification stage had a water output of 5.06 $l \cdot h^{-1}$ while the second humidification stage had an output of 3.94 $l \cdot h^{-1}$. The first stage of heating and humidification provided a baseline or coarse control, whereas the second stage provided fine–tuning or refinement toward the target points.

The same logic was used for control of both T_a and RH set points ($T_{a,SP}$, RH_{sp}). Figure 3 illustrates the control logic with T_a. Heat stage 1 was activated when T_a fell below $T_{a,SP} - \Delta T_{a,1}$ and was deactivated when T_a exceeded $T_{a,SP} + \Delta T_{a,1}$. Stage 2 was activated when T_a fell below $T_{a,SP} - \Delta T_{a,2}$ and was deactivated when T_a exceeded $T_{a,SP} + \Delta T_{a,2}$. The hysteresis values $\Delta T_{a,1}$ and $\Delta T_{a,2}$ were selected to balance switching frequency with control precision. In this particular study, 1.0 and 0.25°C (1.8 and 0.45°F) were used for $\Delta T_{a,1}$ and $\Delta T_{a,2}$, respectively; and 4 and 2% used for $\Delta RH_{a,1}$ and $\Delta RH_{a,2}$, respectively. Target V at AOZ was achieved by manual adjustment of the wind tunnel variable–speed fan (model MSC–4, Phason, Inc., Winnipeg, Manitoba, Canada). The uniformity of V distribution across the wind tunnel was examined using a 3 (vertical) × 7 (horizontal), equally spaced V array in the animal area. Within the space of 150 mm (6 in.) from the sidewalls and 100 mm (4 in.) from the floor or ceiling, the V distribution had a coefficient of variation of 5% for high velocity [1.45 m/s (286 ft/min)] and 8% for low velocity [0.19 m/s (37 ft/min)].

MEASUREMENTS OF THERMOGRAPH, CORE BODY TEMPERATURE, AND BEHAVIOR

Surface temperature (T_s) distribution or thermograph of the birds was measured using an infrared (IR) imaging

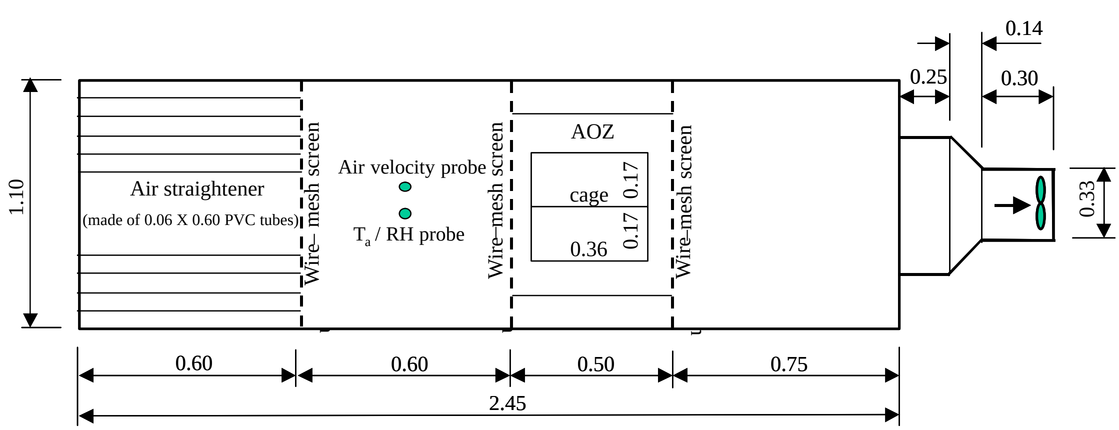

Figure 1. Schematic top view of the experimental wind tunnel. Air flows horizontally from left to right (unit of dimension: m; 1 m = 3.28 ft; AOZ = animal occupied zone).

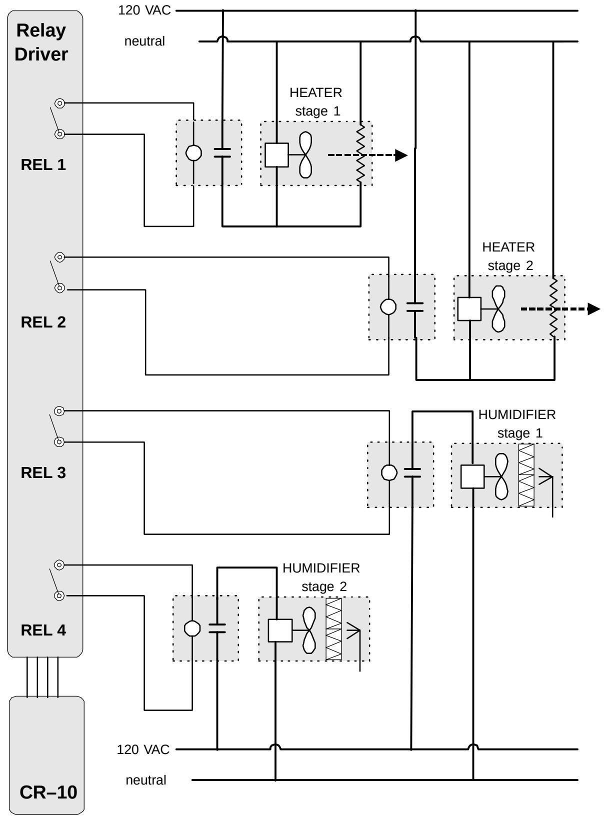

Figure 2. Schematic representation of electrical wiring for air temperature and RH control in the testing room.

camera (0.06°C thermal sensitivity) with a wide angle (32°) lens (Thermacam PM250, FLIR Systems, N. Billerica, Mass.). The camera was mounted on an adjustable cantilever beam stand at 1.5 m (5 ft) above the AOZ floor. External transmittance (τ) between the camera and the animal was corrected to compensate for the plastic film cover above the AOZ. To perform the correction, an electrical heat mat was placed on the floor and thermographs were taken without and with the plastic cover. Adjustment for τ was made until T_s readings with the presence of the film cover agreed with those without. Regression analysis revealed τ of the plastic film to be 0.78. Real–time IR images were displayed on a TV monitor and used to guide the operator in deciding the timing of cooling water application to the birds (described later). The IR camera was connected to a PC via a RS–232 serial port and controlled by a Visual Basic (VB) program. The IR images were recorded onto a 40 MB PCMCIA memory card in the IR camera. The recorded images were subsequently analyzed with a companion program (TherMonitor 95) of the IR camera.

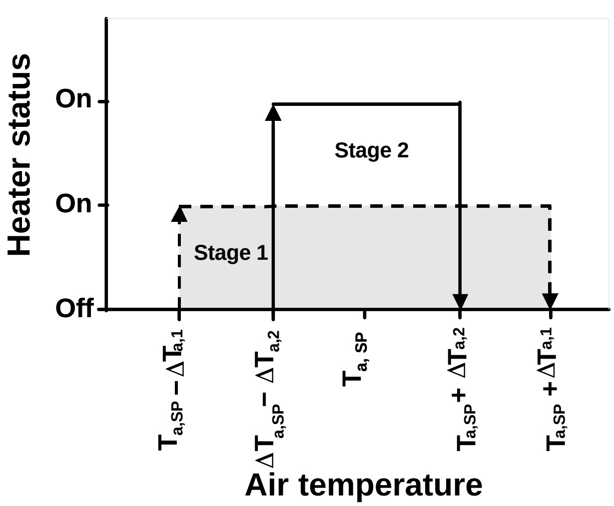

Figure 3. Graphical illustration of the control logic for T_a. The same logic applies to RH control.

Core body temperature (T_b) was measured with an experimental, non–invasive four–channel (262 and 300 kHz frequencies) telemetric system (model 4000, HTI Technology Inc, Palmetto, Fla.), as shown in figures 4a and 4b. Compared with conventional surgical implantation of temperature transmitters, the new system used ingestible temperature pills [1.2–1.4 cm (D) × 2.5–2.8 cm (L)] that resided in the bird gizzard (figs. 4c, 4d). It usually took 4 to 6 h for the T_b transmitter to reach the gizzard once swallowed. The longevity of the pills ranged from 3 to 7 days, primarily due to the life span of the battery. Extra epoxy coating was applied to the transmitters to protect the sensor circuitry from the abrasive action of the gizzard. The antennas of the telemetric system were connected to the respective channels of the receiver via coaxial cables. The receiver continuously downloaded data to the PC hard drive via RS232 serial interfacing. To verify the validity of the telemetry–based T_b measurements, simultaneous recording of rectal temperature was made with a precision thermistor probe (0.1°C accuracy, Model PT907, Pace Scientific, Inc., Charlotte, N.C.). Seven comparative tests were performed, 1 hen per test. Each test consisted of data sampled at 10–s intervals for a period of 18.5 (one test) or 28.5 (six tests) min. The testing thermal conditions used in the environmental room were: 37.8°C (100° F) and 41% RH (three tests); 32.2°C (90°F) and 52% RH (two tests); 32.2°C and 41% RH (one test); and 26.7°C (80°F) and 59% RH (one test). V of 0.2 $m \cdot s^{-1}$ (39.4 $ft \cdot min^{-1}$) was used in all tests. Core body temperature measured by both methods was compared using a paired t–test (SAS, 2001).

Behavioral data of the birds (locomotion, drinking, or state of alert) were acquired with a video recording system that consisted of a CCD camera with a high–speed aperture lens (Panasonic, WV–CP410) above the AOZ, a time–lapse VCR (Panasonic, AG–6730), and a TV monitor.

System Performance and Application

Performance

The control and measurement system described above performed well. Examples of controlled T_a, RH, and V profiles are presented in figure 5. With the 6–kW supplemental heating and 9.0–$L \cdot h^{-1}$ (2.4–$gal \cdot h^{-1}$) humidification capacities, thermal conditions of T_a = 35 to 41°C, and concomitant RH = 33 to 63% – the target values for our studies were readily achievable.

An example of T_b profiles obtained with the telemetric system and the rectal probe is shown in figure 6. The rectal probe method had three inherent drawbacks: a) the sensor wire restrains the bird's movement to a certain degree; b) the probe occasionally is pushed out of cloacae, causing erroneous data; and c) it causes considerable discomfort to the bird. The telemetric system produced reasonable

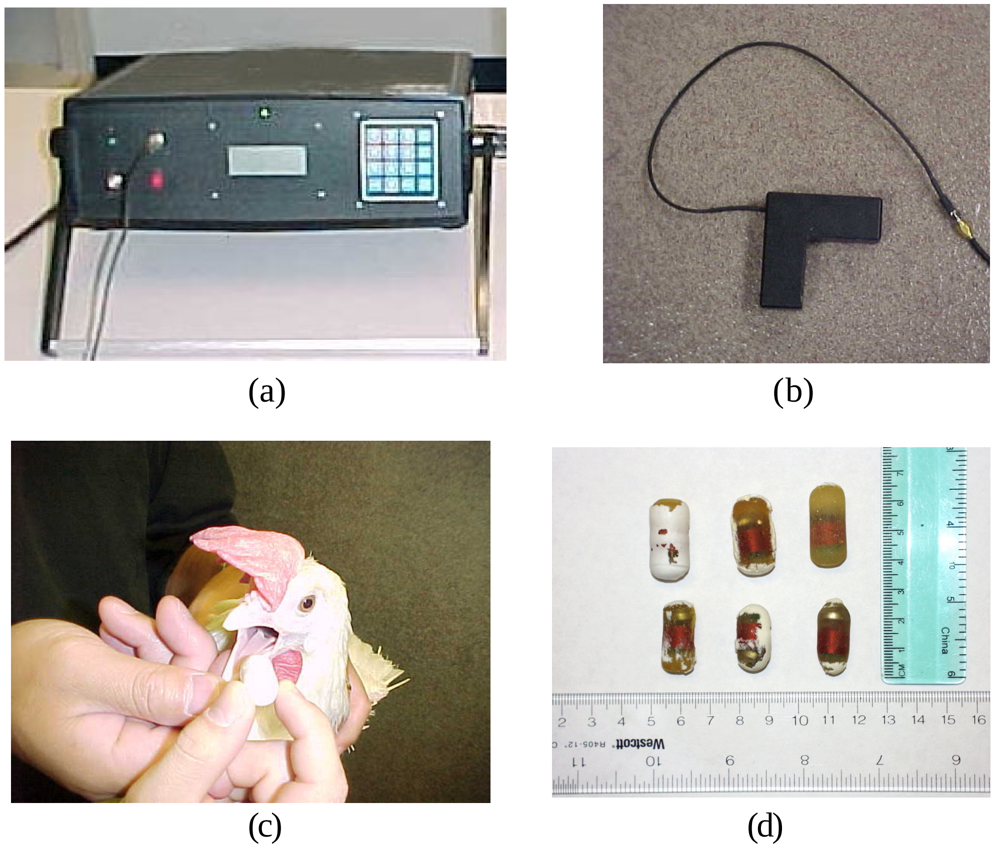

Figure 4. Telemetric body temperature measurement system: (a) 4–channel receiver, (b) L–shaped antenna, c) feeding a transmitter pill to bird, d) transmitter appearance after 1, 1, and 2 days (top), and 3, 4, and 4 days (bottom) of residence in bird gizzard.

signals most of the time, but occasionally transmitted spurious data, which was traced to the antenna configuration and the distance between the animal and the antenna. Three types of commercially available antenna, loop, block, and L–shape, were tested, with the L–shape antenna proving to be most stable. The recorded T_b raw data were filtered in an Excel spreadsheet to remove spurious data. For this particular study, the filter consisted of two steps. It started with an average of 10 consecutive, stable values. In the first step, data outside a pre–defined physiological range (e.g., from 40 to 43°C; depending on the thermal environment conditions) were eliminated. In the second step, absolute difference between the current data point (output data from first step) and the running average of 10 proceeding data points was compared to a boundary threshold of 0.25°C. If the difference was greater than the threshold, the current value was replaced with the running average; otherwise, the current value remained unchanged. The resultant data agreed well (t–test, $P > 0.99$) with those obtained when the rectal probe properly remained inside the cloacae, as shown in table 1.

Application

Using the system, a study was performed to: a) determine water evaporation rate of laying hens cooled by intermittent partial surface wetting at various T_a, RH, and V combinations; and b) quantify physiological responses of the hen to the selected thermal conditions. Two laying hens at a time were subjected to the controlled environment, with one serving as control (not cooled), denoted as *Ctrl*; and the other as treatment (cooled), denoted as *Trt*. It is beyond the

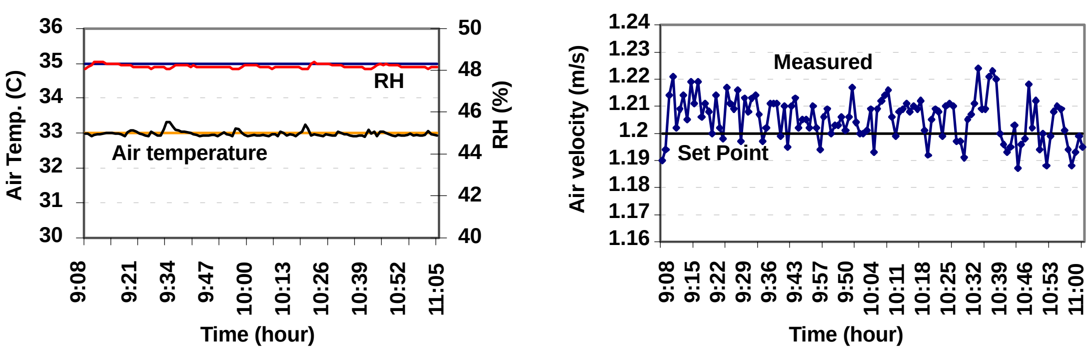

Figure 5. Examples of controlled air temperature, RH and air velocity profiles with regards to set points (unit conversion: °F = 1.8 × °C + 32).

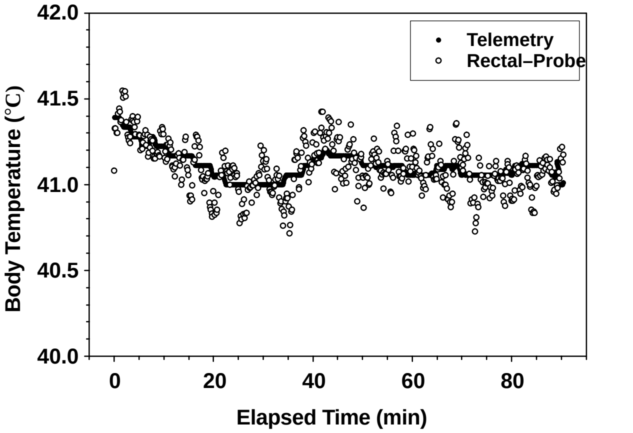

Figure 6. Example of laying hen body temperature as measured by telemetric system vs. rectal probe (unit conversion: °F = 1.8 × °C + 32).

scope of this article to describe the results in detail, which are presented by Yanagi et al. (2001a, b, c). Instead, sample data are presented to illustrate the system application. Figure 8 shows an example of T_s and T_b (after filtering) profiles of *Ctrl* and *Trt* birds. Timing of water application for the partial surface wetting was guided by visual observation of changes in the thermograph. Namely, as soon as T_s of the *Trt* bird, showing an abrupt decline immediately after a spray, returned to nearly the pre–wetting level, it was time to spray again. The goal was to prevent T_s from rising above the initial level.

With concurrently measured values of T_s, T_b, T_a, and V, and derived convective heat transfer resistance (R_a) of the surface boundary layer, mean tissue and feather thermal resistance (R_{t+f}) of the bird may be calculated as follows:

$$\frac{T_{b(i)} - T_{s(i)}}{R_{t+f(i)}} - \frac{T_{s(i)} - T_a}{R_a} = \frac{m \quad c_p}{A} \frac{\Delta T_{b(i)}}{\Delta \theta}$$

$$(i = 0,1,2,3,.....N-1)$$

$$R_{t+f} = \frac{\sum_{i=0}^{N-1} R_{t+f(i)}}{N}$$

Table 1. Comparison of mean body temperature measurements obtained with rectal probe ($T_{b,r}$) and telemetric transmitter (after filtered) ($T_{b,t}$) during each of the seven paired trials.

Trial	Environment	$T_{b,t}$ (±SE)	$T_{b,r}$ (±SE)	($T_{b,r} - T_{b,t}$) (±SE)
1	26.7°C, 59% RH	41.0 (0.010)	41.1 (0.016)	0.1 (0.0041)
2	32.2°C, 52% RH	40.7 (0.002)	40.5 (0.003)	0.2 (0.0004)
3	37.8°C, 41% RH	41.2 (0.025)	41.1 (0.037)	0.1 (0.0068)
4	32.2°C, 52% RH	41.3 (0.030)	41.3 (0.025)	0.0 (0.0009)
5	37.8°C, 41% RH	42.4 (0.3411)	42.3 (0.043)	0.1 (0.0314)
6	37.8°C, 41% RH	42.2 (0.021)	42.1 (0.035)	0.1 (0.0010)
7	32.2°C, 41% RH	42.3 (0.072)	42.3 (0.092)	0.0 (0.0060)
Overall		41.6(0.2)	41.5(0.2)	0.1(0.0)

[a] There was no significant difference in T_b values measured with both methods (P > 0.99).

where

m = mean body mass of the hen before and after heat exposure (kg)

c_p = specific heat of the body, assumed to be 4.18 J·(g·°C)$^{-1}$

A = surface area of the bird (m^2) calculated as A = 0.1067 m$^{0.705}$ (Mitchell, 1930)

N = number of measurement points considered during the exposure period

$\Delta\theta$ = time interval between measurement points (s)

Applying the above equations to data in figure 7 and the associated thermal conditions, we could obtain a mean R_{t+f} of 0.12 m^2·°C ·W^{-1} for the *Ctrl* hen. Tissue and feather thermal resistance (R_{t+f}) for avian species has been reported to range from 0.09 to 0.49 m^2·°C·W^{-1} under thermoneutrality (Wathes and Clark, 1981). The low R_{t+f} value for the current application study presumably arose from vasodilatation of the heat–challenged birds in attempt to enhance heat dissipation from the body to the environment. Figure 8 depicts the relationship of R_{t+f} to T_a for the laying hen. It

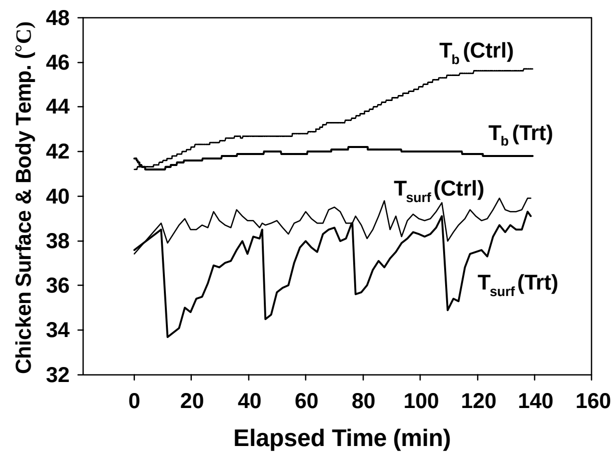

Figure 7. Example profiles of core body temperature and surface temperature of cooled (Trt) and control (Ctrl) hens subjected to 38°C air temperature, 38% RH, and 0.2 m·s^{-1} air velocity.

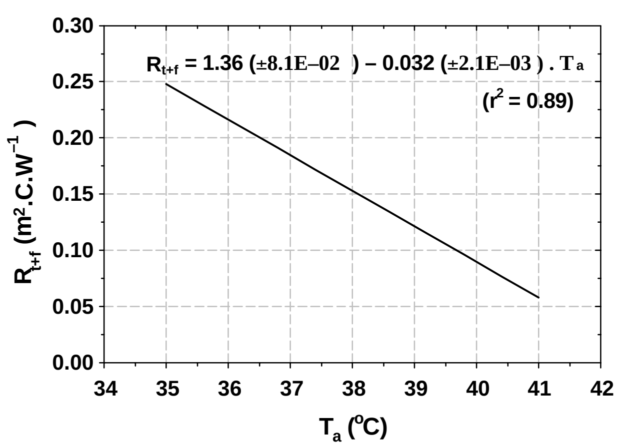

Figure 8. Thermal resistance (tissue+feather) of 34±1–week–old laying hen as a function of dry–bulb air temperature (T_a).

should be noted that, although the application study involved poultry, the system is readily expandable to accommodate other species, e.g., young pigs.

CONCLUSIONS

A control and measurement system was developed for studying interactive effects of thermal conditions on physiological responses of small animals. The system features control of air temperatures (35 to 41 ± 0.2°C), relative humidity (33 to 63 ± 2%), and velocity (0 to 1.5 ± 0.1 $m \cdot s^{-1}$) at the animal occupied zone; continuous, non–contact IR measurements of thermographs (surface temperature); and continuous, telemetric measurement of core body temperature. A study with laying hens, concerning thermoregulatory responses to heat challenge and its relief, was conducted to demonstrate application of the system.

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