This is not a peer-reviewed article
Pp. 374-380 in Proceedings of the World Congress of Computers in Agriculture and Natural Resources (13-15, March 2002, Iguacu Falls, Brazil), eds. F.S. Zazueta and J. Xin. Publication date March 13, 2002. ASAE Publication Number 701P0301

Measurement and Control System for Studying Animal-Environment Interactions

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Abstract

An automated measurement and control system has been developed for studying physiological responses of animals to thermal environment. The controlled environmental variables include air temperature ($T_{a,SP}$ ±0.2 ºC), relative humidity (RH_{sp} ±2%), and air velocity (V_{sp} ±0.1 $m.s^{-1}$). The measured physiological variables include surface temperature using an infrared (IR) thermal imager (0.06°C sensitivity) and deep body temperature (±0.1°C) using a surgery-free, 4-channel telemetric device. The desired thermal conditions are realized by operating a small wind tunnel (V = 0 to 1.5 m s^{-1}) inside a T_a and RH-controlled environmental room (5 L × 3.5 W × 3.0 H m). Near the mid section of the wind tunnel is the animal area. Auxiliary heaters (1.5 kW max each) and humidifiers are controlled to operate in stages to achieve the target set points $T_{a,SP}$ and RH_{SP}. The IR camera is interfaced to a PC via RS232 that automatically controls the timed recording of the thermal images onto a PCMCIA memory card (40MB capacity). The real-time body temperature data are displayed on a PC monitor and saved to the PC hard drive. A programmable measurement and control data logger is used for the environmental control and measurements. A video recording (VR) system is used to record the behavior of the experimental animals. The system was used to quantify the efficacy of partial surface wetting for alleviating laying hens of heat stress under various T_a (warm to hot), vapor pressure deficit (low to high) and V (calm to drafty) conditions.

Keywords: Remote sensing, Instrumentation and Control, Heat stress, Laying hens

Introduction

Quantification of animal responses to biophysical factors, particularly in the forms of synergistic interactions, continues to be an important aspect of basic and applied research endeavors toward enhancing animal welfare and productive efficiency. The constant advancement in electronics and measurement technologies makes it increasingly feasible and affordable for researchers to establish task-specific testing facilities or measuring devices to address certain technical issues of concern that would have been formidable a few years back. The following are a few citations of the published work. Costello et al. (1991) developed an aspirated psychrometer that was particularly suitable for measuring web-bulb temperature in a dusty (e.g., poultry housing) environment. Xin et al. (1994) instrumented four commercial scale poultry houses to measure and record environmental and production variables.

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Gates et al. (1995) devised an automated body mass weighing system for growing pigs. Puma et al. (2001) developed an automated measurement and data acquisition system for studying feeding and drinking behavior of individual poultry.

One of our research topics has been to explore alternative methods for cooling poultry (Chepete and Xin, 1999, Ikeguchi and Xin, 1999). To quantify and optimize the efficacy of the cooling method(s) on heat stress relief for various climatic conditions, we need a facility that will allow us to generate such micro-environment and measure responses of the animals to the cooling method(s). It is the objective of this paper to describe the development of a test facility for precise environment control for animal research, that is of reference value to other researchers.

Materials and Methods

Control Environment Facility

This testing facility is located in the Livestock Environmental Animal Physiology Laboratory II at Iowa State University, Ames, Iowa. The facility consists of three environmental rooms, each measuring 5 L × 3.5 W × 3.0 H m. Two of the rooms are used as acclimation or holding rooms, whereas the third room is used as the testing room. All rooms have minimum degree of air temperature (T_a) control for the incoming air, and no control on relative humidity (RH). The rooms are equipped with static pressure control such that the airflow rate of the rooms and the corridor area is automatically adjusted to minimize the chance of potential cross contamination among the rooms.

Located inside the testing room is a small wind tunnel (1.10 W x 2.45 L x 0.69 H m) constructed with aluminum frame and PVC sidewalls (Fig. 1). The air straighteners are made of 0.06 Ø × 0.6 L m PVC tubes. The main body is divided into two regions: sensor region and animal region (0.33 W × 0.36 L m). The animal area is covered by a plastic film of 0.78 transmittance that allows for recording of thermographs with an infrared (IR) camera and behavioral activities of animals with a video recording system. To meet the power requirement of the testing room (heaters, humidifiers, fans, transducers and data loggers), more circuits were added to provide a total current capacity of 80@120VAC.

Measurement and Control of Environmental Variables

Environmental variables of concern include T_a, RH and air velocity (V) at the animal level inside the wind tunnel. Measurements of T_a and RH are accomplished with a thermistor T_a (±0.2°C) and capacitance RH (±3%) probe (model HMP35L, Campbell Scientific, Inc., Logan, UT) placed in the wind tunnel upstream of the animal area – sensor region (Fig. 1). V is measured with an omni-directional transducer (accuracy of 3% reading) (TSI model 8475-12, Davis Instruments, Baltimore, Md.). T_a, RH and V are sampled at 2-s intervals, and stored as 1-min averages using a programmable measurement and control module (model CR10, CSI). Fresh air is supplied to the room at T_a and RH lower than the respective target value. Heating and humidifying of air are 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 are switched by the CR10 via a 4-channel relay driver (model A21REL-12, CSI) connected to four electromagnetic 12 VAC coil relays (1 HP at 120 VAC) (see Fig.2 for a schematic representation). Two discrete control stages for heat and two stages for humidity are implemented. Each heat stage has two heaters. Stage 1 of humidification uses four humidifiers (models HD12110 and HD60001, capacity of 1.89 and 0.95 l/h, respectively, Emerson Electric Co.; models W-9H and CPM-5, capacity of 1.59 and 0.63 l/h, respectively, Bionaire). The second humidification stage has two humidifiers (models HD13003 and 4963; capacity of 2.05 and 1.89 l/h, respectively, Emerson Electric Co.). The first stage is used for maintaining a baseline value of the controlled variable, whereas the second stage is used for fine-tuning.

The same operation logic is used for both T_a and RH to achieve a specific set point ($T_{a,SP}$, RH_{sp}). For illustration purpose, control of T_a is used (Fig. 3). Heat stage 1 is activated when T_a falls below $T_{a,SP} - \Delta T_{a,1}$ and deactivated when T_a exceeds $T_{a,SP} + \Delta T_{a,1.}$ Stage 2 is activated when T_a falls below $T_{a,SP} - \Delta T_{a,2}$ and deactivated when T_a exceeds $T_{a,SP} + \Delta T_{a,2}$. The hysteresis values $\Delta T_{a,1}$ and $\Delta T_{a,2}$ were selected to balance switching frequency with control precision. Target V at animal level is achieved via manual adjustment of the variable-speed fan (model MSC-4, Phason, Inc., Winnipeg, Manitoba, Canada) of the wind tunnel. For this work 1.0 and 0.25 °C were used for $\Delta T_{a,1}$ and $\Delta T_{a,2}$, respectively; 4 and 2% for $\Delta RH_{a,1}$ and $\Delta RH_{a,2}$, respectively.

Measurement of Thermographs, Core Temperature and Behavior of Birds

Surface temperature distribution (thermograph) of the birds is measured using an IR imaging camera (0.06 ºC thermal discernibly) with a wide-angle (32°) lens (ThermaCAM PM250, FLIR Systems, N. Billerica, MA). The camera is mounted on an adjustable cantilever beam stand at 1.5 m above the animal floor area. Setup parameters of the camera, such as T_a, RH, background temperature, distance to the target, and surface emissivity of the birds (0.95) are self-explanatory. External transmissity (τ) between the camera and birds is corrected to compensate for the plastic film cover above the animal area. To perform the correction, an electrical heat mat was placed on the floor and IR images were taken without and with the plastic cover. Adjustment for τ was made until surface temperature 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 are displayed on a TV monitor and used to help the operator decide timing of applying cooling water to the birds (described later). The IR camera is connected to a PC via RS-232 port, and controlled by a Visual Basic program for setting timed recording of IR images onto a 40 MB PCMCIA memory card in the camera. The Visual Basic program also allows the operator to set all camera functions. A snapshot of the program display is shown in Fig. 4. The recorded images are subsequently analyzed with a companion program (TherMonitor 95) of the IR camera.

Body core temperature is measured with a surgery-free 4-channel (two frequencies each at 262 and 300 kHz) telemetric system (model 4000, HTI Technology Inc, Palmetto, FL). In contrast to conventional implantation of temperature transducers by surgery, the new system uses ingestible temperature pills (1.2-1.4 Ø x 2.5-2.8 L cm in dimension) that reside in the bird gizzard (Fig. 5). It usually takes 4-6 hr for the sensor pills to reach the gizzard. The longevity of the pills ranged from 3-7 d. Antennas of the telemetric system are connected to a 4-channel receiver by coaxial cable. The receiver is connected via RS232 to a PC that continuously downloads data to the hard drive using the Hyperterm program. To verify the validity of telemetry-based core temperature measurements, simultaneous recording of rectal temperature was conducted with a precision thermistor probe (0.1°C accuracy, Model PT907, Pace Scientific, Inc., Charlotte, NC). Seven paired, comparative tests were performed. Behavioral data of the birds (locomotion, drinking, or state of survival) are acquired with a video recording system. It consists of a CCD camera (Panasonic, AG-6730) above the animal area, a time-lapsed VCR (Panasonic, PV-V4520) and a TV monitor.

System Performance

The measurement and control system described above performed reasonably well. Examples of controlled T_a, RH and V profiles are presented in Figs. 6a and 6b, respectively. With four 1.5 kW heaters and the six humidifiers it is possible to achieve T_a of 35 to 41 ºC and RH of 33 to 63 % with any T_a and RH combination, which was the target range for the subsequent, planned experiment. Higher T_a and RH can be readily achieved by adding more heaters and humidifiers.

An example of body core temperature profiles obtained with the telemetric system and a rectal probe is shown in Fig. 7. The rectal probe method has two inherent drawbacks: a) the wires restrain the birds to some degree, and b) the probe occasionally gets pushed out of cloacae, causing missing or erroneous data. The telemetric system produces reasonable signals most of the time, but occasionally transmits spurious data, which is likely attributed to the antenna configuration and the distance between the animal and the antenna. Three types of antenna, i.e., loop, block, and L-shape, were tested, with the L-shape antenna proving to be most stable. The recorded body core temperature data are filtered in a spreadsheet (MS Excel) where the spurious data are removed. The resultant data agreed very well (t-test, P>0.99) with those obtained with operational rectal probe (i.e., properly inserted inside the cloacae).

Using the system, a study was performed to quantify water evaporation rate of laying hens cooled by intermittent partial surface wetting at various T_a, RH and V. Two hens at a time were subjected to the controlled environment, with one serving as control (uncooled), denoted as Ctrl; and the other as treatment (cooled), denoted as Trt. It is beyond the scope of this paper to describe the results, will be presented by Yanagi et al. (2001a,b.c). Instead, sample data are presented to illustrate the system application. Figure 8 shows core temperature profiles of Ctrl and Trt birds after filtering raw telemetric data. Figure 9 shows surface temperatures of the Ctrl and Trt birds from thermographs. Application of partial surface wetting, followed by an abrupt decline in surface temperature, was guided by visual observation of the IR images. Namely, as soon as surface temperature of Trt bird returned to nearly pre-wetting level, water was sprayed on the bird.

Closure

An automated measurement and control system has been developed for studying physiological responses of small animals to thermal environment. The system features control of air temperature (35 to 41 ± 0.2°C), relative humidity (33 to 63 ± 2 %), and velocity (0 to 1.5 ± 0.1 m/s) at animal level; and continuous, non-contact measurements of surface and core temperatures of avian species. The system can be readily extended to use in other animal research.

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Figures

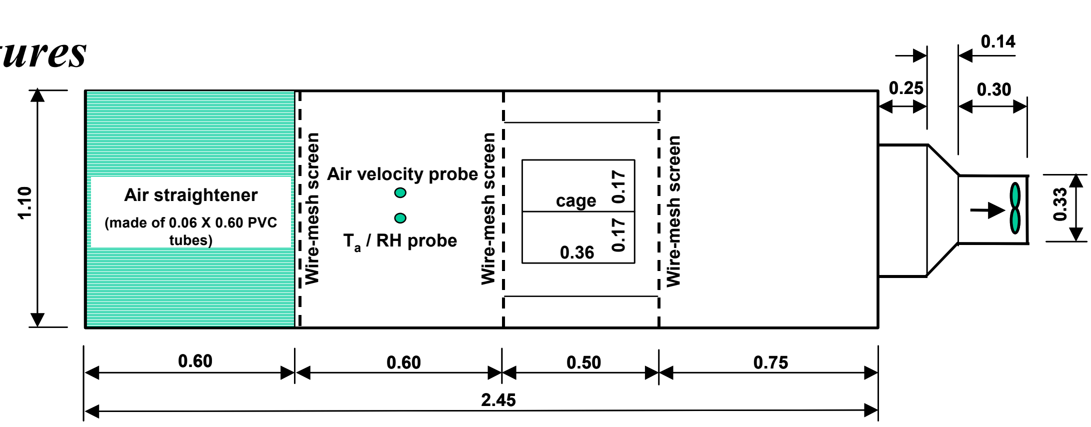

Figure 1 - Schematic top view of the experimental wind tunnel. Air flows horizontally from left to right.

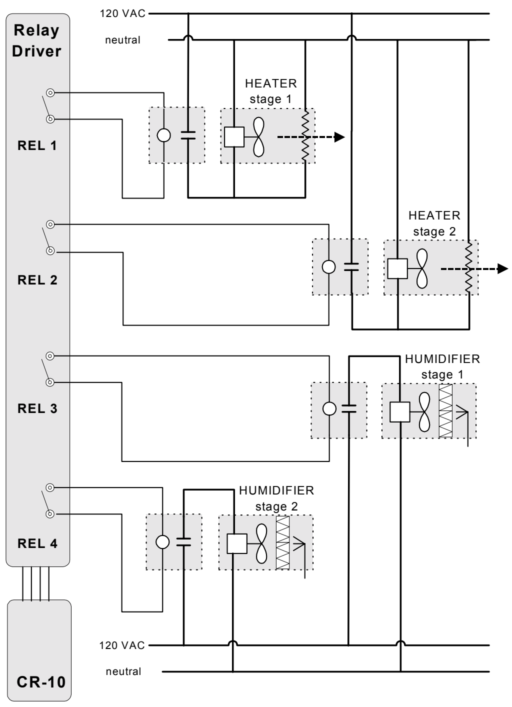

Figure 2 – Schematic of electrical connections for air temperature & RH control in the testing room.

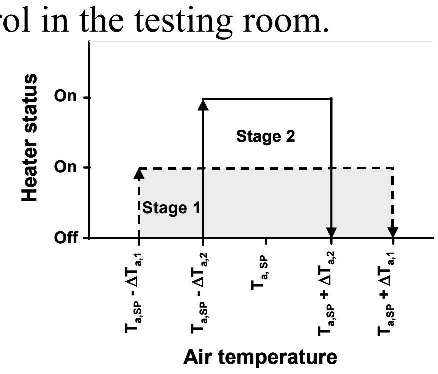

Figure 3 –Logic of T_a and RH control.

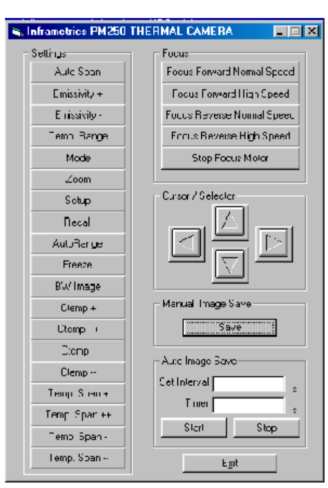

Figure 4 –Screen display of PC interface for remote control of IR camera.

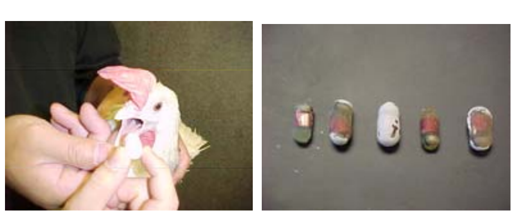

Figure 5 – Ingestion of core temperature pill and sensor appearances after 4 days of residence in bird gizzard.

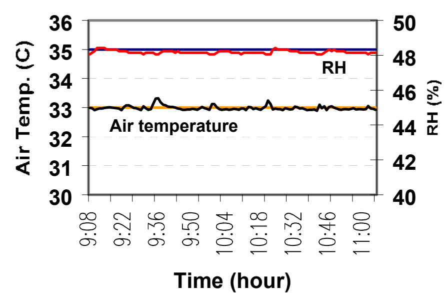

Figure 6a – Example air temperature and RH profiles as compared to set points.

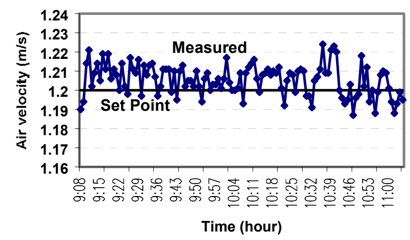

Figure 6b – Example air velocity profile.

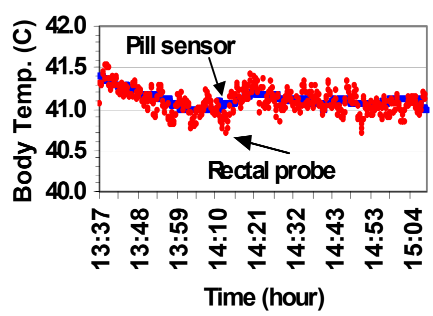

Figure 7 –Body core temperatures as measured by rectal probe vs. pill sensor.

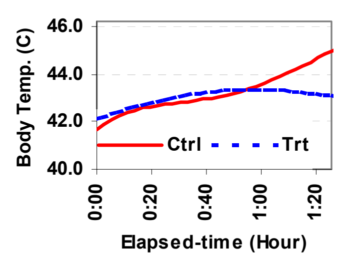

Figure 8 – Core temperature profiles of cooled (Trt) and control (Ctrl) birds.

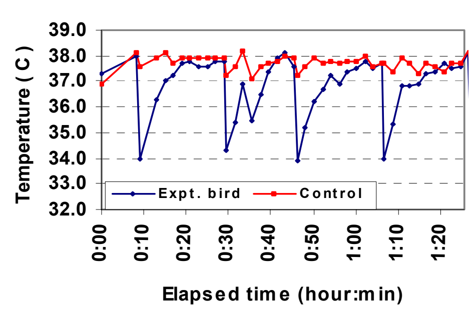

Figure 9 – Surface temperature profile of cooled (Trt) and control (Crtl) birds.