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Abstract

Core body temperature (t_b) of market-size male broilers (46 ± 3 d; 2.8 ± 0.1 kg; Ross × Ross breed) was continuously measured by telemetry during acute, 90- to 240-min exposures to 18 thermally challenging conditions. The thermal conditions consisted of 18 factorial combinations of three dry-bulb air temperatures (t_{db}; 35°C, 38°C, and 41°C), two dewpoint temperatures (t_{dp}; 19.4°C and 26.1°C), and three air velocities (V; 0.2, 0.7, and 1.2 m s^{-1}). Based on t_b rise after 90-min exposures to the thermal conditions, a temperature-humidity-velocity index (THVI) was developed to delineate the synergistic effects of the thermal components on the birds, having the form of THVI = $(0.85t_{db} + 0.15t_{wb}) \times V^{-0.058}$, where t_{wb} = wet-bulb temperature. The homeostasis state of the bird was classified as normal, alert, danger, or emergency, which correspond to a t_b rise threshold of 1.0°C, 2.5°C, 4.0°C, or > 4.0°C, respectively. These different homeostasis states were functionally and graphically expressed in terms of THVI and exposure time. For example, if the broilers were acutely exposed to a thermal condition for 90 min, then the THVI threshold for the normal, alert, danger, and emergency state would be about 35°C, 38°C, 40°C, and >40°C, respectively. If the exposure duration was increased to 120 min, the THVI threshold would drop to 34°C, 37°C, 38°C, and >38°C, respectively. The results of this study serve as a scientific basis for making management decisions and risk assessment associated with market-size broiler production and handling under thermally challenging conditions.

Keywords

Body temperature, Heat stress, Telemetry, Temperature humidity index (THI), Temperature humidity velocity index (THVI), Thermoregulation

Comments

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ACUTE SYNERGISTIC EFFECTS OF AIR TEMPERATURE, HUMIDITY, AND VELOCITY ON HOMEOSTASIS OF MARKET–SIZE BROILERS

X. Tao, H. Xin

ABSTRACT. *Core body temperature (t_b) of market–size male broilers (46 ±3 d; 2.8 ±0.1 kg; Ross × Ross breed) was continuously measured by telemetry during acute, 90– to 240–min exposures to 18 thermally challenging conditions. The thermal conditions consisted of 18 factorial combinations of three dry–bulb air temperatures (t_{db}; 35°C, 38°C, and 41°C), two dewpoint temperatures (t_{dp}; 19.4°C and 26.1°C), and three air velocities (V; 0.2, 0.7, and 1.2 m s^{-1}). Based on t_b rise after 90–min exposures to the thermal conditions, a temperature–humidity–velocity index (THVI) was developed to delineate the synergistic effects of the thermal components on the birds, having the form of $THVI = (0.85t_{db} + 0.15t_{wb}) \times V^{-0.058}$, where t_{wb} = wet–bulb temperature. The homeostasis state of the bird was classified as normal, alert, danger, or emergency, which correspond to a t_b rise threshold of 1.0°C, 2.5°C, 4.0°C, or >4.0°C, respectively. These different homeostasis states were functionally and graphically expressed in terms of THVI and exposure time. For example, if the broilers were acutely exposed to a thermal condition for 90 min, then the THVI threshold for the normal, alert, danger, and emergency state would be about 35°C, 38°C, 40°C, and >40°C, respectively. If the exposure duration was increased to 120 min, the THVI threshold would drop to 34°C, 37°C, 38°C, and >38°C, respectively. The results of this study serve as a scientific basis for making management decisions and risk assessment associated with market–size broiler production and handling under thermally challenging conditions.*

Keywords. *Body temperature, Heat stress, Telemetry, Temperature humidity index (THI), Temperature humidity velocity index (THVI), Thermoregulation.*

Poultry are homeothermic. When the effective environmental temperature (EET) is within the thermoneutral zone (TNZ), core body temperature (t_b) of adult chickens is maintained between 41.2°C and 42.2°C by thermoregulatory mechanisms with minimal effort. When EET rises above TNZ, biophysical defense mechanisms against heat challenge, such as reduced energy intake, come into play. If the thermoregulation mechanism is insufficient to maintain homeothermy, t_b begins to rise and eventually leads to death from heat exhaustion. Acute thermal stress can cause significant economic losses.

Effective environmental temperature is the result of integrating the environmental factors, including dry–bulb temperature (t_{db}), humidity, air velocity (V), solar radiation, and precipitation. For confinement production, radiant exchange and precipitation generally are negligible, but humidity and air velocity may be significant factors. High humidity can aggravate the adverse effect of high temperature (Steinbach, 1971) because animals increasingly rely on latent heat loss with rising temperature. Air velocity plays an important role in heat relief for certain housing schemes, such as tunnel ventilation.

To assess the effects of thermal conditions on farm animals, certain environmental indices based on animal physiological status and/or production performance have been documented. Among them, the temperature and humidity index (THI), a linear combination of dry–bulb and wet–bulb temperature (t_{db}, t_{wb}), is most popular and has been developed for various species, including cows (Bianca, 1962; Kabuga, 1992; Cargill and Stewart, 1966), pigs (Ingram, 1965), laying hens (Egbunike, 1979; Zulovich and DeShazer, 1990), hen turkeys (Xin et al., 1992), and tom turkeys (Brown–Brandl et al., 1997). Other indices such as black globe humidity index (BGHI) for dairy cows (Buffington et al., 1981; Yamamoto et al., 1994), heat stress intensity (HSI) for swine (Axaopoulos et al., 1992), and tympanic temperature as a thermal index for swine (Eigenberg et al., 1995) also have been investigated to delineate thermal effects on animals.

THI equations describe the relative importance of t_{db} and t_{wb} for the species based on physiological parameters (e.g., t_b, respiration rate, or pulse rate), heat production, or production performance (e.g., milk production, egg production, or weight gain). In doing so, relative weighting factors are

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assigned to t_{db} and t_{wb}. The following t_{db} and t_{wb} weighing factors have been reported in the literature for various species: 0.65 and 0.35 for swine, 0.35 and 0.65 for cattle, 0.60 and 0.40 for laying hens, 0.74 and 0.26 for hen turkeys, and 0.64 and 0.36 for tom turkeys. It is clear that considerable differences exist in the weighing factors among species. Gates et al. (1995) used the THI of laying hens to assess broiler production in response to heat stress for lack of information on THI for broilers.

Although THI reveals the relative importance of t_{db} and t_{wb} for animals, it fails to integrate the important effect of V, which has become a typical venue to alleviate heat challenges in modern animal production facilities such as tunnel–ventilated houses. This is especially the case with broiler production. Information is also lacking with regard to the effect of acute thermal challenges by simultaneous existence of t_{db}, t_{wb}, and V on the homeostasis of broilers, as may be encountered during production or live–haul operation of market–size broilers. Therefore, the objectives of this study were: (1) To investigate the relative importance of air temperature, humidity, and velocity on homeostasis of market–size broilers by developing a temperature–humidity–velocity index (THVI) during acute heat exposures; and (2) based on the homeostatic responses of the birds, to define the exposure–time dependent thresholds of THVI as normal, alert, danger, and emergency states. Such information will aid development of management strategies and risk assessment to enhance animal well–being and increase production profit.

MATERIALS AND METHODS

EXPERIMENTAL BIRDS

Male broiler chickens (Ross × Ross breed) at 46 ±3 d of age (2782 ±128 g body mass) were used in this study. Day–old chicks were procured from a local broiler hatchery in six sequencing batches (for bird age consistency during trials) and were raised at the Poultry Research Farm of Iowa State University. At 39 d of age (2277 ±211 g), the birds were transported to the Livestock Environment and Animal Physiology Laboratory II (LEAP Lab II). Upon arrival, the birds were housed in one of the environment–controlled rooms, where they were acclimated for at least 3 d at thermoneutral condition of 21°C ±1.1°C t_{db} and 40% ±5% RH. The birds were provided with free access to feed and water and a photoperiod of 23 L:1 D (11:00 to 12:00 p.m. dark) with a fluorescent illumination intensity of about 15 lux at the bird level. Testing of exposure to the thermal conditions began when the birds were 42 d old, and the trials lasted 6 to 7 d per batch.

THERMAL ENVIRONMENTS EXPOSED

One of the environment–controlled rooms of the LEAP II lab was used as the testing room, and another was used as the acclimation/holding room. The testing room contained a wind tunnel (1.10 W × 2.45 L × 0.69 H m) that circulated air within the room. Temperature and relative humidity (RH) of the testing room were controlled, according to the measured values in the animal–occupied zone (AOZ), within ±0.3°C and ±2% of the respective target values. Air velocity in the AOZ was achieved by operating a variable–speed fan. Yanagi et al. (2002a) and Tao and Xin (2003) provide detailed descriptions of the measurement and control system for the testing room. The AOZ, holding two individually caged birds, was preconditioned to the designed thermal condition before the experimental broilers were moved in.

Three levels of t_{db} (35°C, 38°C, and 41°C), two levels of dewpoint temperature (t_{dp}; 19.4°C and 26.1°C) and three levels of V (0.2, 0.7, and 1.2 m s^{-1}) were chosen to form 18 factorial combinations of the thermal conditions. The variable levels were selected to reflect the potential thermally challenging situations that can be encountered during commercial production. Four replications/birds were conducted over time for each thermal condition, totaling 72 trials. In general, the trial duration for the 35°C, 38°C, and 41°C conditions was 240, 180, and 120 min, respectively. The different durations for the different thermal conditions arose from the different rates of body temperature (t_b) rise to the treatments. The duration was maximized to the extent possible while minimizing the occurrence of fatal heat exhaustion of the birds. In other words, once the bird was detected to experience intolerable heat stress, by either visual inspection (video surveillance) or magnitude of t_b rise, it was removed from the exposure.

CORE BODY TEMPERATURE MEASUREMENT

Core body temperature (t_b) of the broilers was measured with a telemetric system at 20 s intervals throughout the trial exposures. The telemetric system consisted of ingestible t_b sensors (±0.1°C accuracy; 262 or 300 kHz frequency), an omnidirectional L–shaped antenna, an 8–channel receiver (4 channels per frequency; Model 8000), and the companion software (ThermoDot 2000, HQI, Palmetto, Fla.). The ingestible t_b sensor (1.2 to 1.4 dia. × 2.5 to 2.8 L cm) was fed to the chicken in the acclimation room, and gentle strokes were applied to the crop to facilitate the sensor to slide down the tract and reach the gizzard quickly. A lower–than–normal t_b (<40.6°C; Anderson, 1977) would signify that the sensor was still in the crop. The t_b was measured for at least 0.5 h before the bird was transferred to the testing room, and the average t_b of this period served as the baseline t_b value for the bird. After each test, the broiler was sacrificed by cervical dislocation (approved by IACUC, Iowa State University), and the sensor was retrieved from the gizzard and reused if its condition permitted. The t_b sensors had a lifespan ranging from 3 to 7 d once put into operation.

DATA ANALYSIS

As previously stated, each trial lasted 90 to 240 min. Thus, to compare the effect of all the treatments, t_b rise (Δt_b) during the first 90–min exposure, denoted $\Delta t_{b(90)}$, was used in the development of THI and THVI models. Analysis of variance (ANOVA) was performed on the $\Delta t_{b(90)}$ data (SAS, 2001) to determine the effects of the thermal variables at 0.05 and 0.01 significance levels.

To develop the THI model, weighting factors for t_{db} and t_{wb}, x and $(1 - x)$, were varied from 0.0 to 1.0, and the correlation coefficient (γ) between the prospective THI and $\Delta t_{b(90)}$ was determined. The weighting factors that led to the maximum γ were selected and used in the final THI equation. Analysis of interactions on t_{db} × V, t_{dp} × V, and t_{db} × t_{dp} × V proved negative. Hence, the THI equation was developed using the pooled $\Delta t_{b(90)}$ data for all three V levels. Once the

Table 1. Summary of body temperature rise and mortality of market–size broilers (2.8 ±0.1 kg) during acute exposure to the experimental thermal conditions (mean ±standard deviation of four replications).

t_{db} (°C)	t_{dp} (°C)	V (m s^{-1})	$\Delta t_{b(90)}$ (°C)	$\Delta t_{b(\text{end})}$ (°C)	$\Delta t_{b(\max)}$ (°C)	Exposure Time (min)	Mortality (%)	Body Mass (g)
35	19.4	0.2	1.5 ± 0.6	2.5 ±0.8	2.6 ±0.8	224 ±33	0	2788 ±48
		0.7	1.0 ± 0.2	1.6 ±1.0	1.7 ±0.9	230 ±14	0	2729 ±193
		1.2	0.5 ± 0.3	0.3 ±0.4	0.7 ±0.3	228 ±11	0	2745 ±74
	26.1	0.2	2.3 ± 0.3	5.0 ±0.1	5.0 ±0.1	194 ±31	100	2736 ±60
		0.7	1.2 ± 0.5	1.7 ±0.4	1.7 ±0.4	230 ±16	0	2835 ±126
		1.2	1.0 ± 0.1	0.9 ±0.1	1.1 ±0.1	218 ±20	0	2770 ±139
38	19.4	0.2	2.3 ± 0.8	4.1 ±1.4	4.1 ±1.4	174 ±26	50	2708 ±147
		0.7	2.0 ± 0.6	4.0 ±1.2	4.5 ±0.7	164 ±29	50	2887 ±114
		1.2	1.5 ± 0.4	2.8 ±1.1	2.8 ±1.0	188 ±16	0	2743 ±114
	26.1	0.2	3.0 ± 0.4	5.2 ±0.5	5.2 ±0.5	143 ±9	100	2730 ±98
		0.7	2.9 ± 0.6	4.7 ±0.6	4.7 ±0.6	152 ±21	75	2824 ±147
		1.2	1.7 ± 0.6	2.8 ±1.6	2.8 ±1.6	188 ±21	25	2781 ±170
41	19.4	0.2	3.9 ± 0.6	4.5 ±0.2	4.5 ±0.4	119 ±32	100	2749 ±88
		0.7	3.7 ± 0.9	4.8 ±0.2	4.8 ±0.2	106 ±19	75	2778 ±99
		1.2	3.4 ± 1.3	4.1 ±1.0	4.1 ±1.2	119 ±25	50	2705 ±136
	26.1	0.2	4.3 ± 0.8	4.9 ±0.2	5.0 ±0.3	104 ±15	100	2888 ±132
		0.7	4.1 ± 0.9	4.6 ±0.5	4.6 ±0.5	100 ±30	75	2862 ±225
		1.2	4.1 ± 0.9	4.7 ±0.4	4.7 ±0.5	102 ±27	75	2824 ±124

t_{db}, t_{dp}, and V = dry–bulb temperature, dewpoint temperature, and velocity of air, respectively.
$\Delta t_{b(90)}$ = body temperature rise during first 90 min.
$\Delta t_{b(\text{end})}$ = body temperature rise at the end of the exposure period.
$\Delta t_{b(\max)}$ = maximum body temperature rise of the bird during the entire exposure period.
Exposure time = the actual period that the trial birds stayed in the testing room.

THI equation was obtained, THVI was derived by incorporating the effect of V on $\Delta t_{b(90)}$ for a given THI, followed by regression analysis.

The magnitude of Δt_b reflects the degree or state of homeostasis of the broilers. For instance, whenever Δt_b exceeds 4°C to 5°C, fatality becomes imminent. Based on the behavior and mortality data of this study and of previous studies on laying hens from this lab (Chepete and Xin, 2000; Yanagi et al., 2002b), the following thresholds of Δt_b were proposed to represent the homeostasis states of normal, alert, danger, and emergency, respectively: $\Delta t_b \leq 1.0$, $1.0 < \Delta t_b \leq 2.5$, $2.5 < \Delta t_b \leq 4.0$, and $\Delta t_b > 4.0$°C. For a given THVI value, the exposure time required to reach the Δt_b threshold of 1.0°C, 2.5°C, or 4.0°C was expressed in equation and graphical forms.

Table 2. Results of ANOVA between body temperature rise and the thermal factors.

Source	DF	SS	MS	F Value	Pr > F
B	3	0.98	0.33	0.66	0.578
t_{db}	2	87.69	43.85	88.97	<0.0001
t_{dp}	1	3.21	3.21	6.51	0.014
V	2	11.54	5.77	11.70	<0.0001
$t_{db} \times$ V	4	0.50	0.25	0.51	0.607
$t_{dp} \times$ V	2	1.51	0.38	0.77	0.55
$t_{db} \times t_{dp}$	2	0.29	0.15	0.30	0.74
$t_{db} \times t_{dp} \times$ V	4	1.00	0.25	0.51	0.73

B = block.
t_{db} = dry bulb temperature.
t_{dp} = dewpoint temperature.
V = air velocity.

RESULTS AND DISCUSSION

EFFECTS OF THERMAL FACTORS ON BODY TEMPERATURE RISE

Table 1 summarizes the data on body temperature rise (Δt_b) of the broilers under the experimental thermal conditions. The effects of the thermal variables on Δt_b and their interactions are shown by the ANOVA results listed in table 2. The effects of t_{db} and V on Δt_b were highly significant ($P < 0.01$), while the effect of t_{dp} also was significant but at a lesser degree ($P < 0.05$). No interactions were detected between any two or three of the thermal factors. Hence, data could be pooled when determining the main effect of a specific thermal factor. The pooled temporal t_b profiles over the three V levels are shown in figure 1. As expected, Δt_b increased at a faster rate under the combinations of higher t_{db} and/or higher t_{dp}. The higher t_{dp}, or more humid condition, aggravated the adverse effect of t_{db}, whereas V lessened the t_{db} effect to some degree, as reflected by the negative correlation coefficient (γ) shown in table 3.

THE THI EQUATION

The t_{db} weighting factor (x) was varied from 0 to 1 at increments of 0.1, with the concomitant t_{wb} weighting factor ($1 - x$) varying from 1 to 0. The γ values between the prospective THI and Δt_b were calculated for different t_{db} weighting factors, as shown in figure 2. A regression equation was further developed to describe the functional relationship between x and γ:

$$\gamma = -07995x^2 + 1.3546x + 0.4169 \quad (R^2 = 0.823) \qquad (1)$$

Taking the derivative of equation 1 with respect to x and equating it to zero yielded the x value that led to the maximum γ, namely:

$$\frac{d\gamma}{dx} = -1.599x + 1.3546 = 0$$

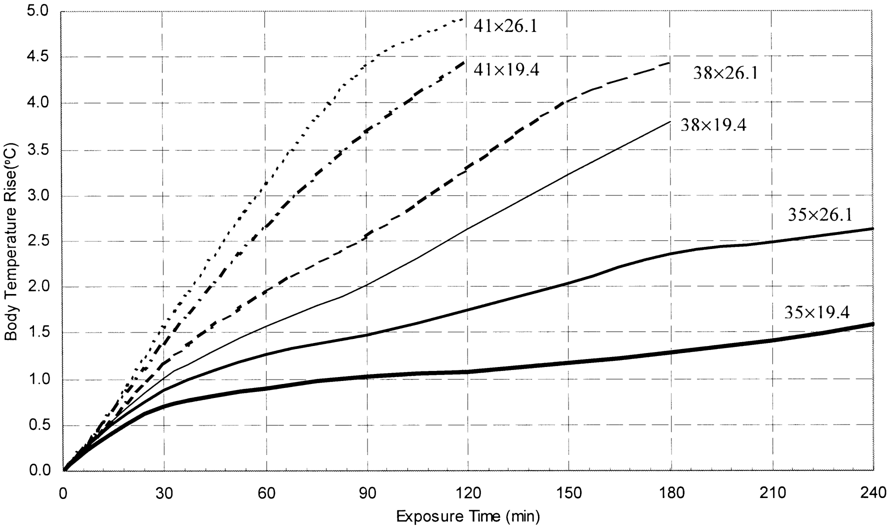

Figure 1. Body temperature rise of 2.8 kg broilers during the course of acute exposure to various dry–bulb (t_{db}) and dewpoint (t_{dp}) temperature combinations that were averaged over air velocities of 0.2, 0.7, and 1.2 m s^{-1}. The legends are t_{db} × t_{dp} (in °C).

Table 3. Correlation coefficient (γ) between body temperature rise and dry–bulb temperature (t_{db}), dewpoint temperature (t_{dp}), and air velocity (V) (N = 71).

	Thermal Factors		
Variable	t_{db}	t_{dp}	V
γ	0.81	0.16	–0.29
P (H_0: $\gamma = 0$)	<0.0001	0.1880	0.0138

$$x = 0.847 \approx 0.85$$

Therefore, the t_{db} and t_{wb} weighting factors were 0.85 and 0.15, respectively; and the resultant THI equation for the broilers for V ranging from 0.2 to 1.2 m s^{-1} had the following form:

$$\mathrm{THI} = 0.85t_{db} + 0.15t_{wb} \qquad (2)$$

Equation 2 reveals that t_{db} has far greater impact on the homeostasis, or Δt_b, of the broilers than t_{wb}. Lack of sweat glands and the relatively small surface area–to–volume ratio of these market–size broilers (as compared with smaller birds) may have contributed to their relatively lower dependence on t_{wb}, or humidity. In comparison, the perception of these broilers of the temperature and humidity component is closer to that of hen turkeys (0.74 and 0.26) than to other species that had been reported in the literature. However, it should be noted that the hen turkey study (Xin et al., 1992) was carried out under calm conditions of V < 0.2 m s^{-1}. The average higher V of 0.7 m s^{-1} used in the current study could have contributed to the shift of weight toward the t_{db} term.

The relationship between the THI and the pooled mean $\Delta t_{b(90)}$ over the three V levels of 0.2, 0.7, and 1.2 m s^{-1} was further quantified as:

$$\Delta t_{b(90\ \mathrm{pooled})} = (0.51 \times \mathrm{THI}) - 15.90\ (R^2 = 0.90) \qquad (3)$$

The $\Delta t_{b(90)}$ values calculated from equation 3 were used for the development of THVI.

THE THVI EQUATION

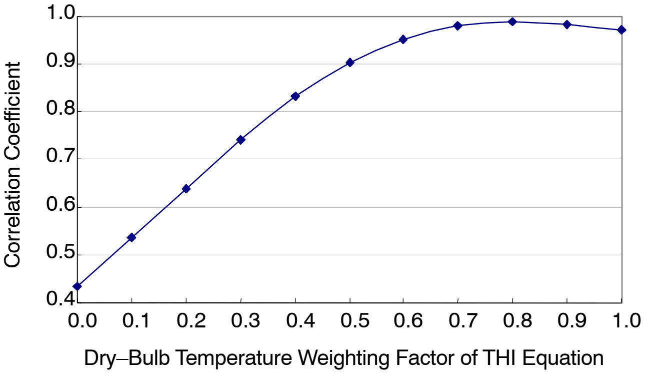

Figure 2. Relationship of correlation coefficient to THI resulting from different dry–bulb temperature weighting factors that delineate body temperature rise of 2.8 kg broilers after 90 min acute exposure to the experimental thermal conditions of this study.

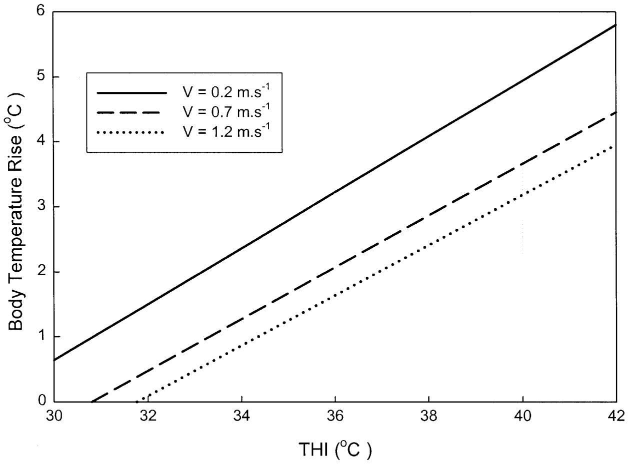

Figure 3. Body temperature rise of 2.8 kg broiler chickens after 90 min acute exposure to various values of temperature and humidity index (THI) at V = 0.2, 0.7, and 1.2 m s^{-1}.

As shown by the results in table 1, significant differences existed among the V levels. The pooled $\Delta t_{b(90)}$ with respect to V was 2.9°C, 2.5°C, and 2.0°C for V = 0.2, 0.7, and 1.2 m s^{-1}, respectively. For a given THI value, there were three Δt_b values at V = 0.2, 0.7, or 1.2 m s^{-1}, which deviated from the pooled mean, $\Delta t_{b(90\ \mathrm{pooled})}$. The effects of V on Δt_b were

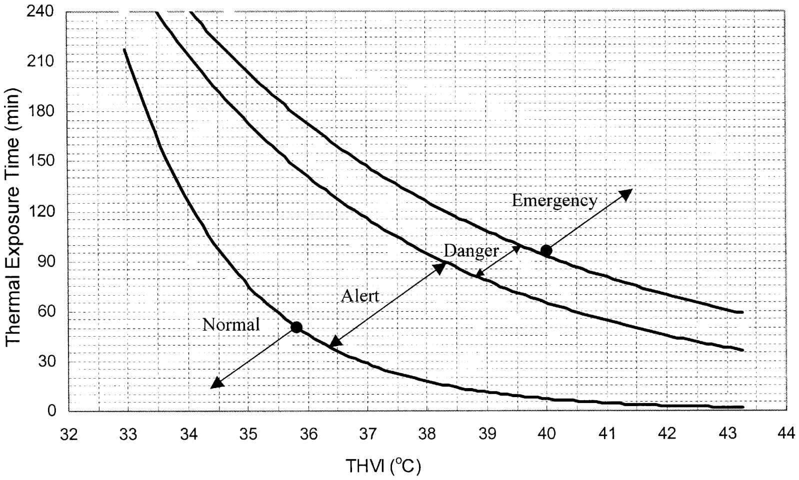

Figure 4. The zone of homeostasis of 2.8 kg broiler chickens subjected to acute thermal exposure. The thresholds of body temperature rise for the normal, alert, danger, and emergency states were defined as 1.0°C, 2.5°C, 4.0°C, and >4.0°C, respectively.

accounted for by incorporating V into THI, leading to the development of THVI. Because of the nonlinear nature of the effect of V on heat dissipation and thus homeostasis of the bird, the asymptotic function THVI = THI × V^n was considered. Performing logarithmic transformation of the equation and regression analysis of transformed $\Delta t_{b(90)}$, corresponding THI and V (72 sets of data), gave rise to the exponent $n = -0.058$ (±0.018 SE). Therefore, the THVI equation had the following form:

$$\text{THVI} = (0.85t_{db} + 0.15t_{wb}) \times V^{-0.058}\ (0.2 \leq V \leq 1.2) \quad (4)$$

The relationship between $\Delta t_{b(90)}$ and THVI from equation 4 was further expressed as:

$$\Delta t_{b(90)} = 0.39 \times \text{THVI} - 12.22\ (R^2 = 0.847) \quad (5)$$

$\Delta t_{b(90)}$ as a function of THI for V = 0.2, 0.7, or 1.2 m s^{-1} is shown in figure 3.

Zones of Homeostasis

Based on the predetermined Δt_b thresholds of 1.0°C, 2.5°C, 4.0°C, and >4.0°C for normal, alert, danger, and emergency states of homeostasis, respectively, the THVI values and their associated exposure times (ET, min) for the bird to reach each Δt_b threshold were extracted from the dynamic t_b profiles (similar to those shown in fig. 1) under the 18 thermal conditions. Regression analysis of ET vs. THVI resulted in the following functional relationships:

For $\Delta t_b = 1.0$°C:

$$\text{ET} = 2 \times 10^{29} \times \text{THVI}^{-17.68}\ (R^2 = 0.88) \quad (6)$$

For $\Delta t_b = 2.5$°C:

$$\text{ET} = 4 \times 10^{13} \times \text{THVI}^{-7.38}\ (R^2 = 0.81) \quad (7)$$

For $\Delta t_b = 4.0$°C:

$$\text{ET} = 3 \times 10^{11} \times \text{THVI}^{-5.91}\ (R^2 = 0.87) \quad (8)$$

Graphical representation of the homeostasis zones is shown in figure 4. This information provides a quantitative measure for assessing the thermoregulation effort required of the bird at various stages of an acute thermal exposure, and therefore the degree of risk in economic loss caused by potential acute heat stress. Such information is of value not only during production of broilers but, perhaps more importantly, during live–haul transportation or abattoir holding of market–size broilers. For ease of practical use, THVI values corresponding to various thermal conditions are listed in table 4. These THVI values can be used in conjunction with figure 4 for homeostasis assessment.

Conclusions

A temperature–humidity–velocity index (THVI) for market–size broilers (2.8 ±0.1 kg) was developed that integrates the effects of air temperature, humidity, and air velocity on the homeostasis of the birds. The THVI has the form THVI = $(0.85t_{db} + 0.15t_{db}) \times V^{-0.058}$, which describes the acute responses of core body temperature rise (Δt_b) of the birds to thermal conditions of 35°C to 41°C dry–bulb temperature, 19.4°C to 26.1°C dewpoint temperature, and 0.2 to 1.2 m s^{-1} air velocity. The state of homeostasis of the bird was classified as normal, alert, danger, or emergency with the corresponding Δt_b threshold of 1.0°C, 2.5°C, 4.0°C, or >4.0°C, respectively. The acute exposure time taken for the bird to reach the Δt_b threshold for a given THVI condition was expressed functionally and graphically. These results delineate the sensitivity of broilers to thermal challenges and provide a quantitative guideline for making management decisions and risk assessment to ensure bird well–being and to minimize heat–related production losses.

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Table 4. Temperature–humidity–velocity index (THVI) values for 2.8 kg broiler chickens acutely exposed to various thermal conditions.

V (m s^{-1})	t_{db} (°C)	t_{wb} (°C)	RH (%)	THVI (ºC)	V (m s^{-1})	t_{db} (°C)	t_{wb} (°C)	RH (%)	THVI (°C)	V (m s^{-1})	t_{db} (°C)	t_{wb} (°C)	RH (%)	THVI (°C)
0.2	35	25	45	36.9	0.6	35	25	45	34.5	1.0	35	25	45	33.5
0.2	35	26	50	37.1	0.6	35	26	50	34.7	1.0	35	26	50	33.7
0.2	35	27	55	37.2	0.6	35	27	55	34.9	1.0	35	27	55	33.8
0.2	35	28	59	37.4	0.6	35	28	59	35.0	1.0	35	28	59	34.0
0.2	35	29	65	37.6	0.6	35	29	65	35.2	1.0	35	29	65	34.1
0.2	37	25	39	38.8	0.6	37	25	39	36.3	1.0	37	25	39	35.2
0.2	37	26	43	38.9	0.6	37	26	43	36.5	1.0	37	26	43	35.4
0.2	37	27	47	39.1	0.6	37	27	47	36.6	1.0	37	27	47	35.5
0.2	37	28	51	39.3	0.6	37	28	51	36.8	1.0	37	28	51	35.7
0.2	37	29	56	39.4	0.6	37	29	56	36.9	1.0	37	29	56	35.8
0.2	39	25	33	40.6	0.6	39	25	33	38.0	1.0	39	25	33	36.9
0.2	39	26	36	40.8	0.6	39	26	36	38.2	1.0	39	26	36	37.1
0.2	39	27	40	41.0	0.6	39	27	40	38.4	1.0	39	27	40	37.2
0.2	39	28	44	41.1	0.6	39	28	44	38.5	1.0	39	28	44	37.4
0.2	39	29	48	41.3	0.6	39	29	48	38.7	1.0	39	29	48	37.5
0.2	41	25	28	42.5	0.6	41	25	28	39.8	1.0	41	25	28	38.6
0.2	41	26	31	42.7	0.6	41	26	31	40.0	1.0	41	26	31	38.8
0.2	41	27	35	42.8	0.6	41	27	35	40.1	1.0	41	27	35	38.9
0.2	41	28	38	43.0	0.6	41	28	38	40.3	1.0	41	28	38	39.1
0.2	41	29	42	43.2	0.6	41	29	42	40.4	1.0	41	29	42	39.2
0.4	35	25	45	35.4	0.8	35	25	45	34.0	1.2	35	25	45	33.1
0.4	35	26	50	35.6	0.8	35	26	50	34.1	1.2	35	26	50	33.3
0.4	35	27	55	35.7	0.8	35	27	55	34.3	1.2	35	27	55	33.4
0.4	35	28	59	35.9	0.8	35	28	59	34.4	1.2	35	28	59	33.6
0.4	35	29	65	36.0	0.8	35	29	65	34.6	1.2	35	29	65	33.7
0.4	37	25	39	37.2	0.8	37	25	39	35.7	1.2	37	25	39	34.8
0.4	37	26	43	37.3	0.8	37	26	43	35.8	1.2	37	26	43	35.0
0.4	37	27	47	37.5	0.8	37	27	47	36.0	1.2	37	27	47	35.1
0.4	37	28	51	37.7	0.8	37	28	51	36.1	1.2	37	28	51	35.3
0.4	37	29	56	37.8	0.8	37	29	56	36.3	1.2	37	29	56	35.4
0.4	39	25	33	39.0	0.8	39	25	33	37.4	1.2	39	25	33	36.5
0.4	39	26	36	39.1	0.8	39	26	36	37.5	1.2	39	26	36	36.6
0.4	39	27	40	39.3	0.8	39	27	40	37.7	1.2	39	27	40	36.8
0.4	39	28	44	39.5	0.8	39	28	44	37.9	1.2	39	28	44	36.9
0.4	39	29	48	39.6	0.8	39	29	48	38.0	1.2	39	29	48	37.1
0.4	41	25	28	40.8	0.8	41	25	28	39.1	1.2	41	25	28	38.2
0.4	41	26	31	40.9	0.8	41	26	31	39.3	1.2	41	26	31	38.3
0.4	41	27	35	41.1	0.8	41	27	35	39.4	1.2	41	27	35	38.5
0.4	41	28	38	41.3	0.8	41	28	38	39.6	1.2	41	28	38	38.6
0.4	41	29	42	41.4	0.8	41	29	42	39.7	1.2	41	29	42	38.8

V = air velocity.
t_{db} = dry–bulb temperature.
t_{wb} = wet–bulb temperature.
RH= relative humidity.

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