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Research Article

Sensible and Latent Heat Productions from Broilers in Laboratory Conditions

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Abstract: Heat production from chickens and other resources inside the broiler house is a major problem for the broiler industry. Temperature and relative humidity (RH) as well as airflow and broiler physiology directly affect heat production in broiler houses. This study was carried out under laboratory conditions to determine heat production for male broilers. In the laboratory experiment, 108 broilers were used to determine the influence of different temperature-humidity combinations on the physiological response of 2.0 to 2.3 kg broilers during the 40 min test. In the laboratory experiment, three dry bulb (DB) temperatures (25 °C, 30 °C, and 35 °C) and three RHs (50%, 70%, and 90%) were used in a block design with four replications, 3 birds per test. DB and wet bulb (WB) temperatures of air entering and exiting the chamber were measured. Before and after each test, body temperatures were measured to control the stress level, and sensible heat production (SHP) and latent heat production (LHP) were calculated based on DB and WB temperatures.

It was found that SHP decreased when the temperature and humidity combination increased. When initial DB temperature was 24.8 ± 0.2 °C and RH was 71%, SHP and LHP were 2.1 ± 0.3 W/kg and 4.0 ± 0.4 W/kg respectively. Increasing RH 50% to 86%, decreased the LHP from 5.7 ± 0.6 to 3.0 ± 1.0 W/kg at the 24.8 °C. Latent heat production increased as DB temperature increased at 50% and 70% RH. At 90% RH, latent heat loss was zero for both 30 and 35 °C. Results also showed that broiler body temperature difference (BTD) increased when initial dry bulb (IDB) and initial relative humidity (IRH) combinations increased

Key Words: Heat production, sensible heat, latent heat, broiler, temperature, relative humidity.

Laboratuar Şartlarında Etlik Piliçlerin Üretiği Hissedilebilir ve Gizli Isı

Özet: Etlik piliç üretiminin ana problemlerinden biri hiç kuşkuşuz tavuklardan ve diğer kaynaklardan kümes ortamına katılan ısıdır. Sıcaklık ve oransal nem oranının yanında hava akımının ve etçil tavukların fizyolojisi ise ısı üretimi üzerinde doğrudan etkili diğer kaynaklardır. Bu çalışma laboratuar koşullarında etlik piliçlerden ortama yayılan ısının belirlenmesi için yapılmıştır. Bu çalışmada, 108 adet 2.0 ile 2.3 kg ağırlığındaki etlik piliçlerin farklı sıcaklık ve oransal nem oranlarına karşı gösterdikleri fizyolojik tepkileri belirlenmeye çalışılarak ısı üretiminin ölçülmesi amaçlanmıştır.

Laboratuar koşullarında her deney için üç tavuk, üç değişik kuru sıcaklık değeri (25 °C, 30 °C, ve 35 °C) ve üç değişik oransal nem oranları (% 50, % 70, ve % 90) kullanılarak blok düzende dört tekrarla 40 dakika boyunca denemeye tabi tutulmuşlardır. Kuru ve yaş sıcaklık değerleri kafese girişte ve çıkışta okunmuştur. Ayrıca tavukların vücut sıcaklıkları hem deney öncesi hem sonrası ölçülmüştür. Hissedilebilir ve gizli sıcaklık kuru ve ıslak sıcaklıklar kullanılarak hesaplanmıştır.

Çalışma sonuçları kuru sıcaklık ve nem oranı azaldığında hissedilebilir sıcaklıktada azalma olduğunu göstermiştir. Kafes girişindeki kuru sıcaklık 24,8 ± 0,2 °C ve oransal nem oranı % 71 olduğunda hissedilebilir ısı 2,1 ± 0,3 W/kg, gizli ısı ise 4,0 ± 0,4 W/kg olarak hesaplanmıştır. 24,8 °C de oransal nem % 50 den % 80'e yükseldiğinde gizli ısı miktarıda 5,7 ± 0,6 den 3,0 ± 1,0 W/kg'a düştüğü gözlenmiştir. % 50 ve % 70'lik oransal nem oranlarında gizli sıcaklık diye de tanımlanan havadaki su buharının miktarındaki değişikliklerden ve su buharındaki formasyon değişikliklerinden doğan gizli ısı oranındaki artış kuru sıcaklıklarda meydana gelen artışla doğru orantılı olduğu görülmüştür. Bununla beraber % 90 oransal nem ve 30 °C ve 35 °C sıcaklıklarda gizli ısı kaybına rastlanmamıştır.

Sonuçlar göstermiştirki başlangıç kuru sıcaklık ve oransal nem miktarı arttığında vücut sıcaklık değişimi (BTD) da buna bağlı olarak artmaktadır.

Anahtar Sözcükler: Isı üretimi, hissedilebilir ısı, gizli ısı, broyler, sıcaklık, oransal nem

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Introduction

Heat-stress is an important problem in the poultry industry, with yearly economic losses in the United States in the range of hundreds of millions of dollars (1,2). Heat stress not only causes bird loss, but in less severe cases, also causes slower and less efficient growth of birds, resulting in high feed costs (3). An estimate of the physiological response of broilers to high temperatures is needed to better understand the impacts of heat stress. This improved understanding will help in three main areas: improved production, animal welfare, and design of facilities (4-6).

The Temperature-Humidity Index (THI) has been used to assess effects of hot, semi-humid, and humid environments on human and animals. The THI indicates human and animal response to temperature and humidity and the relative importance of the sensible and latent thermal components (7). Generally, THI is expressed as a weighted sum of dry bulb (DB) and wet bulb (WB) temperatures. THIs usually are based on rectal temperature, respiratory rate or heart rate response to temperature and humidity combinations.

Homeothermy is the ability of an animal to maintain a relatively constant core body temperature independent of external environmental conditions. Domestic animals are homeothermic which means they maintain a nearly constant core body temperature (3,8). To achieve thermal balance, animals closely balance heat added to the body with the heat dissipated from the body, as shown in equation 1.

Heat loss ± Accumulation = Heat gain + Heat produced (1)

If the body temperature falls below the norm, then a condition of hypothermy develops. If the body temperature increases above the norm then the state is called hyperthermy (3,9).

Many researchers have studied temperature and humidity effects on animals and humans. Any equation developed for predicting heat stress from temperature and humidity is referred to as a THI. There have been numerous THIs developed for different purposes: human (10), dairy cattle (11,12), beef cattle (13), swine (14), laying hens (15), turkey hens (16), and tom turkeys (4). Advance information about sensible heat production (SHP) and latent heat production (LHP) and their relationship to heat stress can be found in references (7,17,18).

Although the problem of heat stress in livestock has been studied since the 18th century, there is disagreement among researchers regarding the best method of livestock design (6,7,17). The biggest problem in designing livestock is matching different environmental regions to the physiological differences among animals (19). Based on the information available in the literature, it would be expected that SHP will decrease with increasing dry bulb temperature, and body weight (5,7,17). When the dry bulb increases and the wet bulb decreases, LHP reaches its maximum (3). At high air temperature and high RH combinations, animals and humans cannot exhaust the latent and sensible heat from their body to the environments. The specific objective of this study was to determine the critical SHP and LHP for broilers. This is done using an environmental chamber that allows quantative measurements of broiler response to varying temperatures and relative humidity.

Materials and Methods

Broilers

A total of 1000 chickens were donated by Gold Kist Hatchery, Live Oak, FL, USA, and raised at the University of Florida. At the appropriate weight, birds were taken from a flock housed at the University of Florida poultry farm. The house temperature was between 23 and 27 °C during the growing period. For this study, 108 birds were randomly selected from the original 1000 birds and immediately weighed. After a 10 to 20 hour stay in the house, birds were moved to an acclimation chamber. Birds waited between 1-7 hours in the acclimation chamber. Feeding of broilers was same as in poultry farm at University of Florida. At the start of each trial, the birds were weighed again for final records. Three broilers were used for each of nine trials. Each trail was replicated 4 times. All trials were conducted using 5.5-6 week old broilers at 2.0 to 2.3 kg (2). Each trial was started 30-50 minutes after the birds were placed in the environmental chamber to allow the environmental chamber to reach equilibrium at the target temperature and RH and for the bird to become accustomed to this environment.

Environmental chambers

A direct calorimetry system was used. The environmental chamber consisted of a pair of nested boxes, input and output airflow thermocouples for WB and DB temperature measurements and a data acquisition system. (Figure 1). The environmental chambers consisted of a small box nested within a separately constructed large box. The inner box had outside dimensions of 0.5 m wide, 0.8 m long and 0.5 m high, with a volume 0.2 m^3. The outer box, with outside dimensions of 0.7m wide, 1.0m long, and 0.6 m high. Both boxes were constructed using half-inch thick plywood (Figure 1). The tops of the chambers were constructed of Plexiglas to provide light and allow inspection of its interior. An aluminum tray on the floor collected manure. For ease of moving and for transfer of animals, one end wall of the chamber had a 30 cm by 50 cm door. The small box had holes in both inlet and outlet sidewalls to provide air movement (Figure 1).

Air Conditioner System

The temperature in the chamber was controlled by a heater-cooler-fan attached to the air inlet (Figure 2). This heater-cooler-fan system had an ice bath to control the dew point temperature; a heater allowed setting of the desired dry bulb temperature.

The system had two pumps and two fans to provide appropriate airflow, to recycle the water inside the

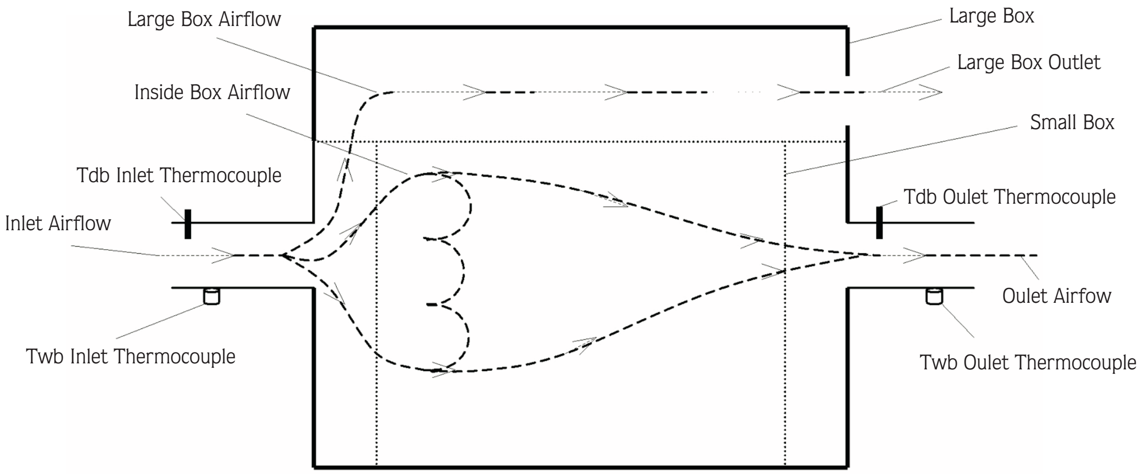

Figure 1. Environment chamber side cross section. Tdb: Temperature dry bulb, Twb: Temperature wet bulb.

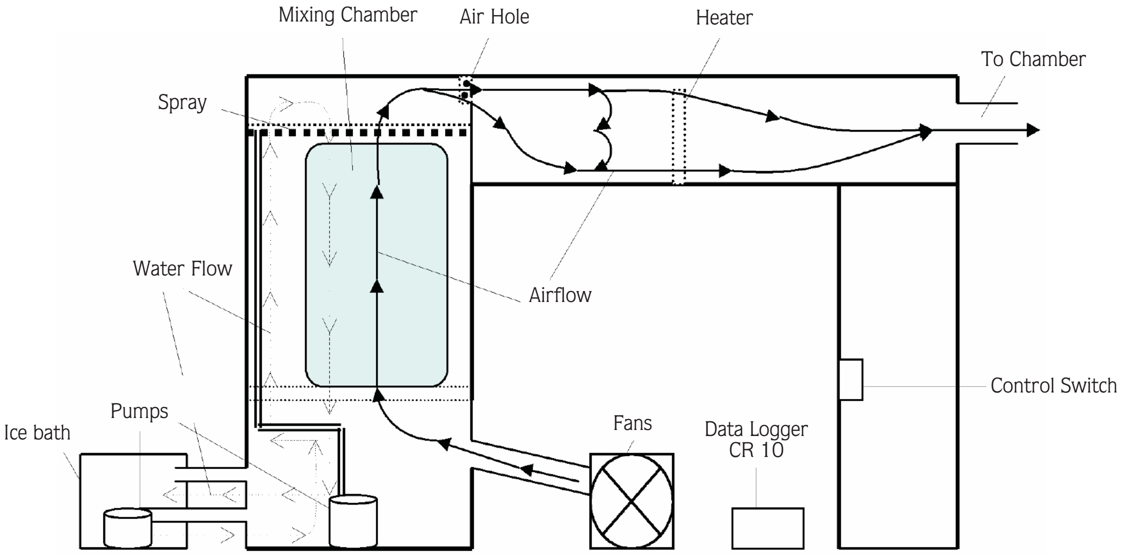

Figure 2. Air conditioner system.

evaporative cooler, and to carry the cold water into the evaporative cooler (Figure 2). The ice bath utilized an ice and water mix. The system worked as a humidifier and dehumidifier.

A commercial available Filocell evaporative cooler was used (Figure 2). A Filocell is the system constructed of multiple wire lines that enhances the surface area of water droplett in the humidifier. The system obtaines cold water from the ice bath that contains a mixture of ice and water. When the temperature reaches the desired value for the Filocell, a solenoid valve opens and allows cold-water flow into the Filocell. Cold water or hot water was added by hand to reach the equilibrium point.

Experimental settings and Determination of SHP and LHP:

The experimental settings (Table 1) used were chosen to represent temperatures and humidities expected under field conditions. DB temperature, WB temperature, the Filocell temperature, air velocity, and body temperatures were continuously recorded during each 40-min trial.

SHP and LHP were calculated based on the DB and the WB temperatures using equations 2 and 3 (20).

$$SHP = \frac{M * C_p * (T_{db2} - T_{db1})}{TB_w} \qquad (2)$$

where, SHP is sensible heat production (W/kg), M is mass ventilation rate (kg/s), C_p is specific heat of air (J/kg °C), T_{db1} is initial dry bulb temperature (°C), and T_{db2} is final dry bulb temperature (°C), TBw is total body weight (kg).

$$LHP = \left(\frac{(Q*(W_i - W_o)/v)*2430000}{TBw}\right) \qquad (3)$$

where LHP (W/kg) is latent heat production, Q is ventilation rate for moisture (m^3/s), W_i is humidity ratio of inside air (kg water/kg air), W_o is the humidity ratio of outside air (kg water/kg air), v is the specific volume of air (m^3/kg), 2430000 is the latent heat vaporization of water (k J/kg water), and TBw is total body weight (kg).

Mass ventilation rate was calculated based on the air volumetric airflow rate by equation (4).

$$M = Q/v \qquad (4)$$

where M is the Mass ventilation rate (kg/s), Q is the volumetric airflow rate (m^3/s), and n is the specific volume of air (m^3/kg). Volumetric airflow rate was calculated based on the air velocity and outlet area using equation (5).

$$Q = V * A \qquad (5)$$

Where Q is the volumetric airflow rate (m^3/s), V is air velocity (m/s), and A is outlet area (m^2).

Data Acquisition

The data acquisition system consisted of a computer, a data logger used as a measurement and control module (CR10) (21) a manual thermocouple reader, and a portable anemometer. The CR10 was used to collect the inlet and outlet dry bulb (DB) temperature, Filocell temperature, and inlet and outlet wet bulb (WB) temperatures. The computer was used to collect the data stored by the CR10 and to display the real time data.

The system was run for times ranging from 0.5 to 5 hours with an empty environmental chamber in order to reach the environmental setting. Air velocity was read every 10 minutes. Thermocouples were located in air inlets and outlets and acted as DB and WB thermometers.

Table 1. State points for 25, 30, 35 °C and relative humidities.

# of Replications	V m/s	Birds per replication	Inlet dry bulb °C	Inlet wet bulb °C	Inlet Humidity °C	Total Birds
4	1.05	3	24.6	18.3	50	12
4	0.95	3	24.5	21.1	71	12
4	0.95	3	25	23.3	86	12
4	0.95	3	29.6	22.8	56	12
4	0.95	3	29.8	25.3	70	12
4	0.95	3	30.4	28.8	90	12
4	0.95	3	34.5	25.5	52	12
4	0.95	3	35.1	31.1	72	12
4	0.95	3	35.4	32.2	80	12

Copper-Constant Thermocouples ("Type T") with a temperature accuracy of 0.3 °C were connected to data logger channels of the CR10. The thermocouples were calibrated with a mercury thermometer with an accuracy of 1 °C.

Body Temperature

In order to control the stress level, an electronic temperature transmitter, developed for use by astronauts, was used to monitor body temperature in one bird before and after each experiment. The transmitter was swallowed by the birds before each test, with the transmitter becoming lodged in the bird's crop or gizzard. The transmitter was covered by a hard plastic material to protect the electronic parts from body enzymes and gizzard pressure. Once the bird was placed in the chamber, a radio receiver connected to the data logger recorded body temperature for the duration of the trial.

For each experiment, a complete calibration of the system was conducted. The thermocouples used to measure the DB and WB temperature were calibrated manually with an aspirated psychrometer. Temperatures were read by the aspirated psychrometer inside the test room, at the chamber outlet, and at the outlet air. After all measurement and calculation, results were comparing with Simmons et al. (18), Reece and Lott (7) and Gates et al. (17).

Results

In general, SHP decreased with temperature and humidity increases. When initial DB temperature was 24.8 ± 0.2 °C and RH was 71%, SHP and LHP were 2.1 ± 0.3 W/kg and 4.0 ± 0.4 W/kg respectively. Increasing the RH from 50% to 86%, decreased the LHP from 5.7 ± 0.6 to 3.0 ± 1.0 W/kg at the 24.8 °C (Figure 3).

The SHP, LHP, and total heat production (THP) per kilogram of live weight was calculated in this study for broilers, 2.0 to 2.3 kg, at temperatures of 25, 30, and 35 °C (Table 2). At constant temperature, SHP decreased as RH increase. SHP decreased from 2.1 ± 0.4 W/kg to

Table 2. SHP and LHP observed in different studies

%RH	21 °C	25 °C	29 °C	30 °C	32 °C	35 °C
38			S SHP = 2.7 LHP = 4.0			
45					S SHP = 2.0 LHP = 4.5	
50		LG SHP = 2.1 LHP = 5.7		LG SHP = 1.3 LHP = 4.4		LG SHP = 0.0 LHP = 6.2
52						S SHP = 1.3 LHP = 5.5
63	RL SHP = 2.5 LHP = 5.0 G SHP = 3.7 LHP = 2.8	RL SHP = 2.7 LHP = 6.1 G SHP = 3.7 LHP = 4.5				
70		LG SHP = 2.1 LHP = 4.0		LG SHP = 1.3 LHP = 4.8		LG SHP = 0.0 LHP = 0.0
90		LG SHP = 2.3 LHP = 3.0		LG SHP = 1.7 LHP = 0.0		LG SHP = 0.0 LHP = 0.0

RL = Reece and Lott, (1982).
G = Gates et al., (1993).
S = Simmon et al., (1997).
LG = Genc (1999).

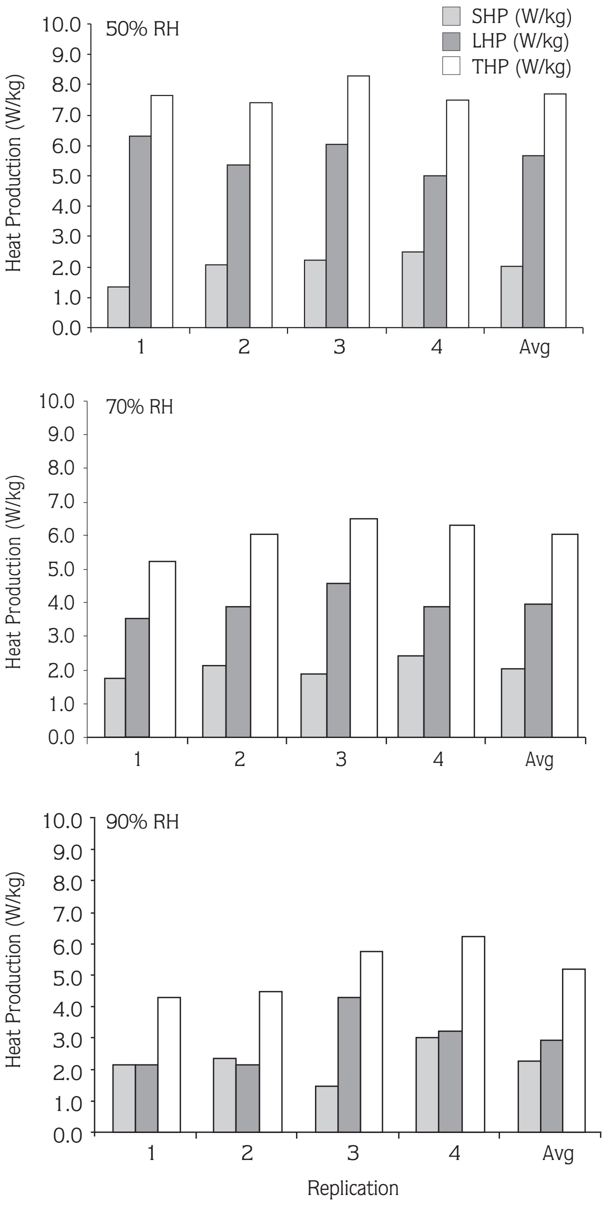

Figure 3. Heat production at 25 °C and different relative humidities.

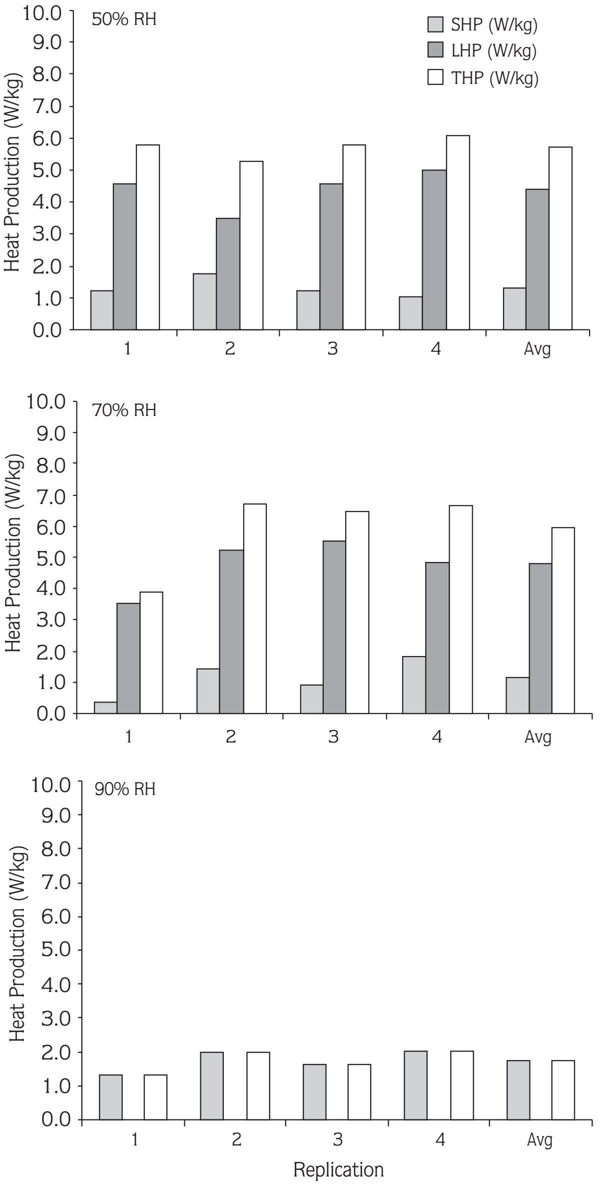

Figure 4. Heat production at 30 °C and different relative humidities.

1.3 ± 0.3 W/kg when RH was constant and DB temperature ranged from 24.8 ± 0.2 to 29.7 ± 0.2. At 25 °C SHP increased 10% (2.1 ± 0.1 to 2.3 ± 0.6) when RH increased from 50% to 86%. A thirty percent increase was observed for SHP when RH increased from 56% to 90% at 30 °C. There were no SHP at 35 °C and all RH combinations (50%, 70%, and 90%) (Figures 3, 4, and 5). LHP decreased from 5.7 ± 0.6 W/kg to 4.4 ± 0.3 W/kg when RH was constant and DB temperature ranged from 24.8 ± 0.2 to 29.7 ± 0.2. At 25 °C, LHP decreased from 5.7 ± 0.6 W/kg to 3.0 ± 1.0 W/kg when RH increased from 50% to 90% (Figure 6).

There was no LHP at 30 °C and 90% RH. LHP was the highest level, 6.2 ± 0.3 W/kg, at highest DB temperature and lowest RH combinations (35 °C and 50%) (Figure 5). After 35 °C and 72% RH, LHP were not observed.

Before and after each experiment, initial dry bulb (IDB), initial wet bulb (IWB), final dry bulb (FDB), final wet bulb (FWB), initial relative humidity (IRH) and final

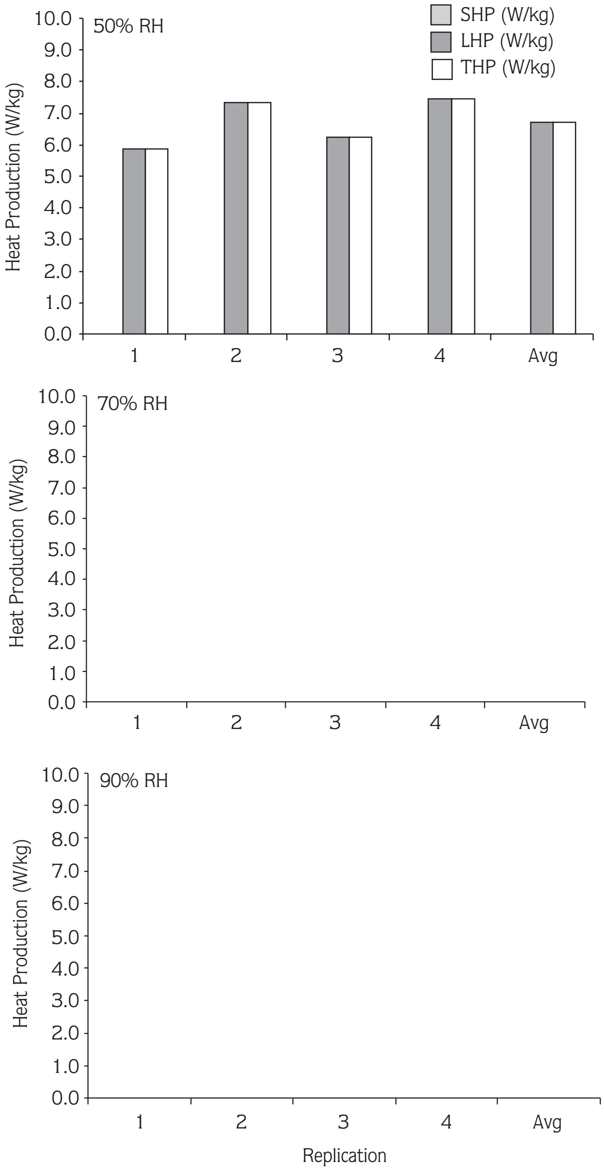

Figure 5. Heat production at 35 °C and different relative humidities.

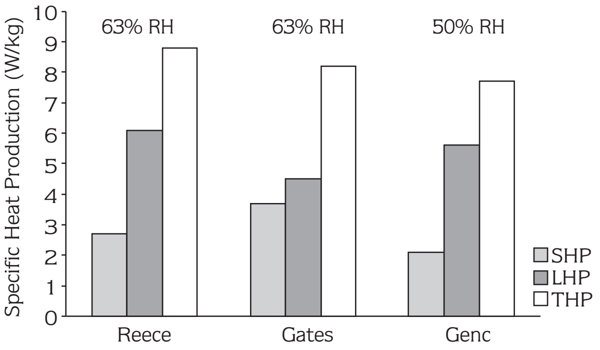

Figure 6. Heat production SHP, LHP, and THP for 25 °C and different % RH. Reece: Reece and Lott (7) and Gates: Gates et al. (17).

relative humidity (FRH) were recorded and BTs were measured (Table 3). As dry bulb temperature increased, core BT, and LHP increased. As the DB temperature increased, SHP decreased (Table 4). Results showed that body temperature difference (BTD) increased when IDB and IRH combinations increased. At the 25 °C and low RH (50%), BTD was negative (Table 3). At the same temperature 25 °C and 50% RH combinations, BTD between the initial and final body temperature was –0.5 °C. When IRH increased from 50% to 70%, BTD still was negative (-0.3 °C), but higher than 50% RH and 25 °C. Increasing the RH from 70% to 90% increased the BTD by an average of 0.3 °C. This relationship was the same for all temperature and RH combinations in this study (Table 3).

In this study, birds were comfortable at the 25 °C and 50% RH, 70% RH and 90% RH environmental settings. At 25 °C and 50% RH, and 25 °C and 70% RH, tests birds' BT decreased. At the 35 °C and 50% RH, 35°C and 70% RH, and 35 °C and 90% RH, BT increased (Table 3).

Body temperature differences before the trial and after the trial increased three fold when DB and RH increased from 25 °C and 50% to 35 °C and 90% RH. Body temperature differences before and after trials were negative at the 25 °C and 50% environmental settings, implying that broilers lost more heat than they produced. Body temperature increased as total heat loses decreased at the 35 °C and 90% RH (Table 3) environmental setting. Beyond this setting, bird mortality is highly probable, especially if these conditions persist for an extended period.

Discussions

Heat production for three studies in addition to this one are summarized in Table 1. In this study, SHP was observed to be less than were found in other studies, but LHP was very similar. All of these studies were run at similar temperature and RH combinations. At 29 °C DB temperature and 38% RH, Simmons et al. (18) found 2.7 W/kg SHP and 4.0 W/kg LHP for broilers aged 40 days or more. At 32°C DB and 45% RH, they also

Table 3. Body temperature differences at different temperatures versus relative humidities

IDB (°C)	IWB (°C)	FDB (°C)	FWB (°C)	IRH (%)	FRH (%)	BTD (°C)
24.5	20.3	25.8	20.2	68	60	-1
25.0	17.4	26.1	19.5	50	54	-0.5
24.7	17.6	25.7	19.1	50	52	-0.2
24.8	18.0	25.9	19.2	52	54	-0.2
25.0	21.0	25.8	22.3	70	74	*
24.4	20.4	25.7	21.9	70	72	-0.7
24.4	21.2	25.7	22.5	73	76	-0.3
25.2	21.9	26.7	23.3	70	76	0.2
25.4	23.8	26.5	25.2	84	90	*
25.5	23.8	27.0	25.8	90	91	0.2
25.5	23.3	26.3	24.7	84	88	0.2
25.1	23.3	27.2	25.6	86	89	0.5
29.2	22.8	30.1	23.8	58	60	0.6
29.4	22.9	30.0	23.5	56	58	0.2
29.7	22.5	30.1	22.5	56	58	0.5
30.5	22.8	30.9	22.8	54	56	1.3
29.7	26.1	30.0	26.5	75	77	*
29.7	25.3	30.7	27.0	70	75	0.4
30.0	25.0	30.7	26.0	67	70	0.7
29.9	25.2	31.1	26.5	68	70	1.1
30.2	28.4	31.1	29.3	89	88	0.6
30.1	29.3	31.5	28.7	94	81	0.8
30.3	28.9	31.5	27.8	90	75	0.9
30.4	28.4	31.8	28.1	86	78	1.7
35.3	26.3	33.7	29.7	50	62	1.3
35.4	26.0	34.8	29.5	48	58	1.6
33.9	26.0	32.9	26.9	54	70	1.2
34.0	26.0	33.5	29.0	54	72	1.3
34.5	30.1	34.4	30.1	72	73	0.6
35.1	30.2	34.2	29.8	70	70	1.3
35.9	30.6	34.6	29.9	72	70	2.0
34.9	30.3	34.6	29.7	72	70	2.5
35.4	33.1	35.1	32.3	85	84	1.3
35.4	33.1	35.1	32.5	85	82	1.7
35.7	32.6	34.6	32.2	77	85	2.3
35.1	31.1	34.7	31.5	75	86	2.4

*Data were not collected.

calculated 2.0 W/kg SHP and 4.5 W/kg LHP, which correlate well with the results for 30 °C DB temperature and 50% RH (1.3 W/kg and 4.4 W/kg) in this study. Hhighest LHP and lowest SHP in all studies were found at the 35 °C DB temperature and 50% RH.

For 2.0 kg broilers, Reece and Lott (7) estimated SHP at 2.9 W/kg at the 26.7 °C for 63% RH and 0.04 m^3/s airflow rate. In the same study, LHP was measuredat 5 W/kg, similar to this study if one accounts for the difference in airflow between the two studies. In this study the airflow rate at 0.0076 m^3/s was lower than in Reece and Lott (7). In the study by Gates et al. (17), heat and moisture production for modern broilers gave similar results as reported by Reece and Lott (7).

Reece and Lott (7) and Gates et al (17) and this study all measured heat production at 25 °C 63% RH. Figure 6 shows that estimated SHP in this study (2.1 W/kg) that was 0.6 W/kg less than that observed by Reece and Lott (7) and 1.6 W/kg less than for Gates et al. (17). LHP was found to be 5.7 W/kg, which was 1.2 W/kg more than observed in Gates et al., (17) and 0.4 W/kg less than that of Reece and Lott (7).

Brown-Brandl et al. (5) found that at ambient conditions of 38.4 °C, 83% RH, and 37.7 °C, 83% RH, maximum moisture production occurred for the 15 week- old and 21 week-old turkeys. In this study, when ambient conditions were 35 °C and 90% RH, there was no sensible loss and latent heat production occurred. Brown-Brandl (4) suggested that above this temperature and humidity condition, the birds could not longer increase their moisture production to increase heat loss. In this study, for 2.0 and 2.3 kg broilers, moisture production was the highest at the lowest RH and highest DB temperature (35 °C and 50% RH) (Figure 5). When the RH ratio increased, moisture production decreased. At 35 °C and 75% RH, birds could not lose sensible heat, but they still could lose latent heat to their environment. At 35 °C and 90% RH, neither sensible or latent heat (Figure 5) loss was observed.

SHP, LHP, and THP were calculated using differences between the air inlet and air outlet temperatures. The DB temperature difference between the inlet and outlet decreased as inlet DB and RH increased, and the WB temperature difference between the air inlet and air outlet increased as the inlet RH decreased. SHP, LHP, and THP were calculated depending on this change. Sensible heat loss decreased as DB increased for all relative humidities. Latent heat loss decreased as RH increased for all dry bulb temperatures. Latent heat losses increased as DB increased for 50% and 70% RH. At 90% RH, latent heat lost was zero at 30 °C and 35 °C.

Previous heat production results Reece and Lott (7) and Gates et al. (17) were found to be adequate for SHP, LHP, and THP for broilers. These two studies and this study have almost the same results for heat production in laboratory experiments.

This study confirmed and extended knowledge on heat loss in broilers. Knowedge of critical SHP, LHP, and THP under laboratory conditions will help reduce broiler mortality in broiler houses. Work is still needed to validate these results under field conditions.

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