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Heat and Moisture Production of Poultry and Their Housing Systems: Broilers

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Abstract
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Keywords
Environment control, Ventilation, Calorimeter, Broiler housing

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Comments
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HEAT AND MOISTURE PRODUCTION OF POULTRY AND THEIR HOUSING SYSTEMS: *BROILERS*

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ABSTRACT. *Heat and moisture production rates (HP, MP) of modern broiler chickens (Cobb strain males) raised on litter in commercial production housing were determined from extensive environmental and production data of 20 house–flocks. The flock size was 18,800 birds, with a typical growth period of 56 days. Regression equations were established that predict total, sensible and latent HP of the broiler houses over common ranges of body mass (0.4 to 3.2 kg), house temperature (20 to 32°C), relative humidity (30–80%), and photoperiod (light or dark). Specific total HP rate from this study was up to 31% higher than found elsewhere at 0.4 kg body mass, and the difference diminished as mass approached 2.3 kg. Modern broiler houses have reduced MP that presumably resulted from use of nipple drinkers as opposed to trough drinkers on which most of the literature data were based. The new HP and MP data are expected to enhance efficient design and operation of modern broiler housing ventilation systems. The results further confirm the need to systematically update literature HP and MP data for engineering practices.*

Keywords. *Environment control, Ventilation, Calorimeter, Broiler housing.*

Heat and moisture production rates (HP, MP) of animals provide the fundamental information for design and operation of housing ventilation systems. Chepete and Xin (2002) recently conducted a review of literature on HP and MP of poultry, and revealed that HP and MP data for modern poultry raised under commercial housing conditions are not adequately quantified. In addition to the effects of fast–growing, heavier meat–type broiler chickens, the prevailing use of nipple drinkers in modern housing facilities have significantly changed the amounts of litter moisture evaporated in the broiler houses (Gates et al., 1996; Xin et al., 1996). Longhouse et al. (1968) measured HP and MP of chickens in calorimeters, but depended on estimates of fecal moisture and final litter moisture to calculate the relative magnitude of latent and sensible HP (LHP, SHP) in broiler houses. Reece and Lott (1982) measured the effects of both chicken size and temperature on room HP and MP from broilers grown on litter in test chambers. However, final chicken weights at the time of their study were about 2 kg compared to 3 kg and greater in modern flocks. Moreover, open surface (i.e., trough) waterers had been used in the previous studies. A systematic updating of the literature data is therefore in order.

As a part of the overall goal to update literature HP and MP data on poultry, the objective of this study was to determine HP and MP of modern broilers grown in commercial housing. The data used for the calorimetric calculations were extracted from an energy project conducted with four new full–size broiler houses located in northwest Arkansas during 1991 to 1993.

MATERIALS AND METHODS

BROILER HOUSES

The four new broiler houses used in this study were each 12.2 m (40 ft) wide by 122 m (400 ft) long, oriented east–west, and located in northwest Arkansas. They were separated from one another by 23 m of open space to avoid cross–house ventilation interference. The houses were designed to verify energy utilization efficiency of broiler houses as affected by building insulation and ventilation types, provided that the same internal microenvironment was maintained. Two houses featured conventional cross–ventilation, summer cooling fans diagonally located on the south side, and misting foggers. The other two houses had tunnel ventilation with static pressure–controlled air inlet and evaporative cooling pads. As a result of air distribution characteristics and placement of measurement sensors, only data from the two tunnel houses were suitable and used in the determination of the HP and MP. Hence, description of the tunnel houses only is given here. The sole difference between the two tunnel houses was the structure of the building. One had a steel frame with rigid roofline insulation ($1.76\ m^2\cdot°C/W$ or R10) and the other had wooden trusses

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with loose fill ceiling insulation (3.35 $m^2 \cdot °C/W$ or R19). For complete description of the houses, refer to Berry et al. (1991) and Xin et al. (1993a,b; 1994a,b).

Continuous 76–cm adjustable curtain sidewalls were used to provide natural ventilation when the chicken age and outside conditions were appropriate. Each house had a total supplemental heating capacity of 404 kW (1,380,000 BTU/hr) that was provided by 12 brooders of 8.79 kW (30,000 BTU/hr) each and six space furnaces of 49.8 kW (170,000 BTU/hr) each. Each space furnace was equipped with a variable–speed mixing fan (0.6–m diameter; 0.37 kW or 0.5 HP) located 6 m from the furnace and 2 m above the floor. The six mixing fans were arranged to circulate air in a racetrack pattern to reduce room temperature stratification and thus improve energy efficiency. The mixing fans ran during operation of the space furnaces or exhaust fans and continued to run about three minutes after the space furnaces or the exhaust fans were turned off. Ten exhaust and cooling fans (1.2 m diameter; 0.74 kW or 1 HP each) were located at the east end of each house.

Each house was equipped, along the length of the house, with 2 rows of commercial broiler pan feeders (160 feeders per row, each 25.4–cm diameter), 4 rows of nipple drinkers (600 drinkers for each of the 2 outside rows and 480 drinkers for each of the 2 inside rows), and 2 rows of incandescent light bulbs (40, 40–W bulbs per row), which produced a bird–level illumination of 10 lx. In addition, each feed line in the brooding half–house had 80 down–drop tubes for use with feed trays during the initial 5 to 10 d of brooding.

Production Management

Half of the house was used for brooding of the younger birds up to two weeks of age to conserve energy, a typical industry practice. Chicks and feed were furnished by the integrator as part of the growing contract for the flocks. Specifically, 18,800 Cobb × Cobb breed males were placed in each house. Starter ration of 3,146 kcal ME/kg and 21.6% CP was fed during the first 3 wk; finisher ration of 3,234 kcal ME/kg and 19.5% CP was fed during the following 3 wk, and withdrawal ration of 3,278 kcal ME/kg and 18~18.5% CP was fed during the final 2 wk of 8–wk growout periods. During the first 2 wk when birds were brooded in the half house, they had *ad libitum* access to feed. Upon release to full house finishing on the 14th d, mealtime feeding was initiated and continued through the rest of the growth. The mealtime feeding program consisted of six 2–h meals/d every 4 h. This feeding program was an effort to improve the efficiency of feed utilization. The birds had access to water all times.

Continuous lighting was used during the 1st wk of the growouts, followed by natural daytime light with dark nights during the 2nd wk. The dark night in the 2nd wk was used to limit early feed intake, thereby reducing early growth of the birds in an effort to reduce later mortalities/morbidities due to leg problems, heart attack, and ascites, all of which could be induced by fast growth. From the 3rd wk to the end of the growout periods, natural daylight plus intermittent nocturnal lighting was used. The nocturnal lighting (2–h on and 2–h off) coincided with the nighttime meal–feeding times.

Commercial bedding materials consisted of a mixture of saw dust, wood shavings, and rice hulls. The litter (mixture of bedding materials and chicken feces) was removed from the houses once a year. Fresh bedding material (a layer ~1–1.5 cm thick) was added between batches on top of the existing litter for the first 8 flocks. After that chicks were placed directly on the re–used litter except when litter was removed from the houses and new bedding added. The broilers were raised at a year–round stocking density of 790 cm^2/bird (0.85 ft^2/bird). This density was higher, particularly in the summer, than used by most other growers (836 cm^2/bird), but was selected to test the effectiveness of alternative summer cooling schemes. Dead birds were collected twice daily—morning and afternoon.

Ventilation rates were initially based on recommendations by Midwest Plan Service (1990) for broilers and manually adjusted according to aerial ammonia (NH_3) concentration, relative humidity (RH), and dust levels in the houses. Efforts were made to control NH_3 level below 25 ppm and RH between 50% to 65%. Internal air temperature was controlled as recommended by the industry, i.e., initially at 29.4 to 30.5°C and decreased about 2.8°C/wk until the birds reached 4 wk of age (air temperature to 21.1°C). Summer cooling for heavy birds (6 to 8 wk) was initiated at the internal air temperature of 27.2°C.

Measurement of Environmental and Production Variables

The following variables were measured for each house, which enabled calorimetric calculations of HP and MP. Unless otherwise noted, the measurements were taken at 2–min intervals and recorded as 10–min averages throughout the growout periods. For detailed description of the instrumentation system, refer to Xin et al. (1994).

1. Inside air temperatures, measured with thermocouples (TC, 0.1°C accuracy) at 28 locations in 4 longitudinal arrays of 7 measurement points each (i.e., 3 points at the bird level across the house, 3 points at 1.5 m height across the house, and 1 point at 3 m height in the center, near the ceiling).
2. Wet–bulb and corresponding dry–bulb temperatures, measured every 10 min at the 4 measurement arrays (1.5 m height, center point). The psychrometers were specially designed for operation in dusty environments (Costello et al., 1991).
3. Exhaust air temperatures, measured with TC placed inside the houses about 1 m from the cold weather exhaust fans.
4. Common outside air temperature, measured with a shielded, precision thermistor at a weather station (Campbell Scientific, Inc, Logan, Utah) about 45 m west of the most southerly broiler house.
5. Common outside RH, measured with a thin–film capacitance sensor (model XN–217, CSI) at the weather station.
6. Solar radiation, measured with a pyranometer (model LI–200SZ, LiCor Instruments, Lincoln, Neb.) at the weather station.
7. Duty cycles (i.e., on time) of exhaust fans, brooders, and furnaces recorded at 10–min intervals.
8. Liquefied petroleum gas (LPG) fuel consumption, measured with calibrated temperature–compensated gas meter with pulse generator over 10–min intervals.
9. Electric power usage for lights, environmental equipment, and the entire house, measured with respective electric meters with pulse generators.

Sixteen flocks were grown in each house during the period of 1991 to 1993. However, not all the data, i.e., the summer flocks, were suitable for determination of the HP and MP values, as discussed later.

Calculation of HP and MP

HP and MP in each broiler house were calculated at 10–min intervals by solution of the following steady–state equations:

$$SHP = \rho \, V \, C_p \, (T_e - T_o) + U \, (T_i - T_o) - Q_{sup} - Q_{equip} \quad (1)$$

where

- SHP = sensible heat production rate, W
- ρ = density of inlet air, kg/m^3
- V = ventilation rate, m^3/s
- C_p = specific heat of inlet air, J/(kg·°C)
- T_e, T_o, T_i = exhaust, outside, and inside air temperature, respectively, °C
- U = building heat transfer coefficient, W/°C
- Q_{sup}, Q_{equip} = heat from heaters and other internal equipment, respectively, W

and

$$MP = \rho \, V \, (W_e - W_o) \quad (2)$$

where

- MP = moisture production rate, kg/s
- W_e, W_o = humidity ratio of exhaust and outside air, respectively, kg/kg.

Calculation of the building heat loss $U(T_i - T_o)$ was performed using the spreadsheet model developed and validated by Berry and Miller (1989). Heat transfers through the roof and walls were calculated separately using the respective inside air temperatures near those surfaces. Sol–air temperature was calculated for each exterior surface, based on the measured wind speed and solar radiation. Sol–air temperature, as defined by ASHRAE (2001), is the temperature of the outdoor air that in the absence of all radiation changes gives the same rate of heat entry into the surface as would the combination of incident solar radiation, radiant energy exchange with the sky and other outdoor surroundings, and convective heat exchange with the outdoor air.

Solar heat collection through unshaded portions of the semi–transparent curtain walls was also estimated. Heat transfer through the floor perimeter was estimated by methods described by Midwest Plan Service (1983), but modified to estimate the effect of increasing depths of litter on the floor between successive flocks. Specifically, thermal resistance of the building perimeter (m·°C/W) was estimated as 0.22 + 0.17 × litter depth (cm). The litter depth was measured after each flock. Vertical heat transfer through the floor was considered negligible.

Transfers of heat and moisture by ventilation were based on the published volumetric airflow rates for the ACME Engineering exhaust fans and attached shutters. The measured duty cycles of the fans over 10–minute periods were used to estimate ventilation rates. Ventilation rates of the exhaust fans were further checked by velocity traverse method and the results agreed well (>95%) with the manufacturer–specified values. The fans and attached shutters were carefully cleaned after each flock to maintain their efficiency. Infiltration rates (during periods when curtains were closed) were considered negligible because of the new condition of the houses and no sign of air leaks.

Q_{sup}, heat from space furnaces and brooders, was estimated from the measurements of LPG use, assuming that both the unvented furnaces and unvented brooders had a combustion efficiency of 95% (personal communication with local vendors). The combustion moisture from the heaters was estimated as 0.03362 g/kJ heat output (Berry and Miller, 1989) and subtracted from the psychrometric calculations of building MP, so that the final estimates of latent heat production (LHP) would be for only the chickens and their litter. Note that MP (kg/s) and LHP (W) are related by LHP = MP × 1000 g/kg × 2450 J/g.

Q_{equip} included heat from lighting, internal stirring fans, and feeder motors. Lighting heat was estimated based on the measured duty cycles of the lights and lighting power demand. Similar procedure was used for internal stirring fans, except that the manufacturer's power ratings of the fan motors were used. Heat from feeder motors was estimated by subtracting the lighting and ventilation power measurements from the total building power measurements.

Data Processing and Statistical Procedures

Because the broiler houses were operated as commercial production facilities instead of direct calorimeters, extensive editing and filtration of the raw data were necessary to meet the assumptions for calculation of HP and MP, thus obtaining reasonable estimates of the building HP and MP. The raw data at 10–min intervals were accumulated in spreadsheets for each house–flock. The first step of filtration consisted of marking obvious spurious data resulting from occasional sensor or instrument failure with an error code that was carried on to subsequent calculations. During this process, TC readings in the houses were averaged into separate records for the bird–level, wall, and ceiling values. To facilitate later recognition of the spurious data, calculations of building HP and MP by solution of equations 1 and 2 were conducted with the 10–minute data. Psychrometric properties of the air were determined by equations from ASAE (2000), except that Teten's equation (Weiss, 1977) was used for calculation of saturation vapor pressure. Building HP and MP values were converted to specific (per unit body mass of chicken) values by adapting the body mass (M) equations from Xin et al. (1994b). M values from the equations were modified by proportionately adjusting its daily values to yield the same M at the harvest of the flock. Similarly, equations for cumulative bird mortality from the same source were modified to calculate the number of birds and total M in the house at a given age.

Additional filtration was done after the SHP and LHP had been calculated. First, data during the first 3 wk of growth from both houses were highly variable. This presumably resulted from the low magnitude of chicken HP in comparison to heat or moisture exchanges of ventilation, furnaces, and building surfaces. Thus these data were omitted. Second, data during warm climates (i.e., summer flocks) that involved either open curtains or operation of the evaporative cooling pads were questionable due to the uncertainty in building ventilation rates when curtains were opened and the uncertainty in the amount of water usage by the cooling pads when used in conjunction with mechanical ventilation. Third, large increases in the calculated LHP, and to a lesser degree in SHP, occurred when inside temperature rose high enough to cause the winter fans to start running continuously after extended part–time operation on 5–min timers. The large increases in the calculated HP were due to the delay in the response of the house and litter conditions after the sudden increase in ventilation rates. For this reason, unusually high values of the calculated SHP and LHP occurring for two hours after such events were excluded from the final data set.

As a result of the above data filtration, SHP and LHP were determined from the two tunnel–ventilated houses during moderate and cold weather, when winter ventilation fans were used. This amounted to approximately 20 house–flocks (2 houses ×10 flocks/house). After the filtration, the 10–min values were converted to hourly averages, with only those containing six 10–min values being retained. A total 10,780 hourly sets of observations were retained for further analyses.

Specific total heat production (THP, W/kg) from the chickens, including litter HP, was fitted to the following regression equation. Selection of the equation form was based on the surface law of metabolic rate and conventions in delineating impacts of physical factors on bioenergetics, as described later.

$$THP = M^{b_1} \cdot e^{(b_0 + b_2 \times LT + b_3 \times T_{db} + b_4 \times T_{db}^2)} \quad (3)$$

Taking natural logarithm on both sides of equation 3 to linearize it for standard regression yields:

$$\ln(THP) = b_0 + b_1 \times \ln(M) + b_2 \times LT + b_3 \times T_{db} + b_4 \times T_{db}^2 \quad (4)$$

where

- M = body mass of the chicken, kg
- T_{db} = dry bulb temperature at the bird level, °C
- b_0,...b_4 = coefficients determined by least squares
- LT = light code, 0 for 100%–time light, 1 for 100%–time darkness, and between 0 and 1 for partial light/darkness during the hour, determined by:
- LT = (LOT/100) × MIN(1,MAX(0.0,(6.02 – I_r)/ 6.02))

where

- LOT = light off time for the hour, %
- I_r = intensity of outside solar radiation, W/m^2.

The M term in the function was selected because of Brody's (1945) concept that metabolic heat production from an animal is nearly proportional to $M^{2/3} \sim M^{3/4}$ (W/animal); hence, specific body heat should about equal to $M^{-1/3} \sim M^{-1/4}$ (i.e., $M^{2/3} \cdot M^{-1}$ or $M^{3/4} \cdot M^{-1}$) (W/kg). The variable LT (0 to 1) was calculated before regressions were performed. The threshold value of 6.02 used in the definition of LT was determined by repeated regressions to maximize the multiple correlation coefficient of equation 3. The rationale for assigning LT = 0 when adequate amount of light existed for the entire hour was that THP of equation 3 would not be reduced because $e^0 = 1$. In contrast, LT = 1 when darkness existed for the entire hour would result in a reduction of THP as determined by the negative coefficient of b_2.

LHP was described in regression form as percentage of THP by the following equation:

$$LHP\% = b_0 + b_1 \times T_{db} + b_2 \times T_{db}^2 + b_3 \times RH \quad (5)$$

where

- LHP% = % of THP in latent form
- RH = relative humidity, %

with other terms described with equation 3 or 4.

Results and Discussion

The potential house effects on HP and MP were first examined by analysis of variance. The results revealed highly non–significant differences (P > 0.33) between the two houses. Thus pooled data from both houses were used in subsequent analyses and presented here.

Regression of M vs. THP

The relationship between THP and M, without consideration of other variables, is shown in figure 1. For all data, the means of THP and ln(THP) were 9.220 and 2.151, respectively. The plots of hourly average data indicate a large degree of variation in THP. The regression of ln(THP) vs. ln(M) accounted for only 28.2% of the total variation about the mean, but was highly significant ($P < 0.01$; table 1). The coefficient of ln(BM), –0.460, implies that the coefficient in Brody's equation is only (1.0 – 0.460), or 0.540. The relationship between THP and M, as adjusted for light on (LT = 0) and the mean bird–level T_{db} of 23.3°C by equation 3 as a statistical model, is shown in figure 2. The inclusion of LT and T_{db} in the regression slightly changed the ln(M) coefficient to –0.4638 (table 2). The inclusion of the LT, T_{db}, and T_{db}^2 terms in the regression increased R^2 from 0.282 to 0.456, indicating that the selected model explained 45.6% of the total variation around the mean. None of the other variables (i.e., interactive terms among M, LT, and T_{db}) that were tested in the model further increased R^2 by more than 0.02. It should be noted that the relatively low R^2 for the model was not surprising considering the dynamic nature of the hourly data that included the effects of bird activity. Unfortunately the effects of bird activity on THP magnitude could not be quantified from these data. Although R^2 could be readily improved if the hourly THP data were pooled into daily THP averages, doing so would inevitably mask the inherent dynamic profile of the biological system and thus would not be desirable.

Effects of Lighting Condition on THP

With LT =1.0 for total darkness, $e^{(-0.1969 \times 1.0)} = 0.82$,

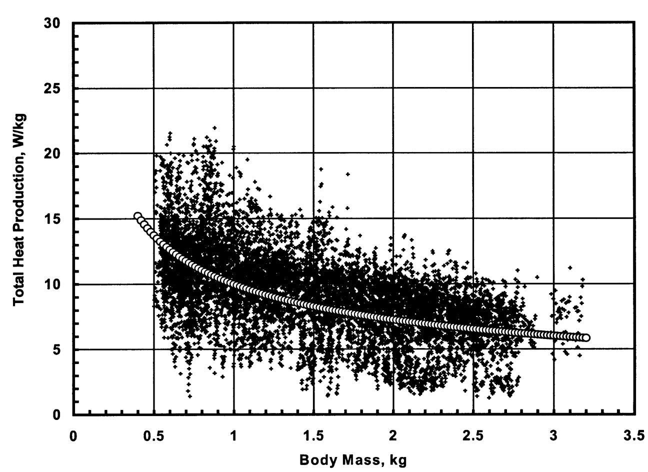

Figure 1. Specific total heat production vs. body mass (M) for broilers, unadjusted for other variables; THP, W/kg = 9.974M$^{-0.46}$.

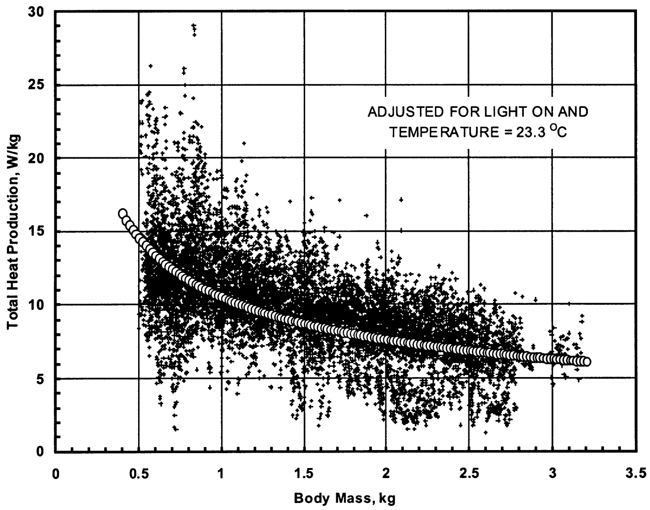

Figure 2. Specific total heat production vs. body mass (M) for broilers, adjusted for light and temperature. THP, W/kg =

$$M^{-0.466} \cdot e^{(-1.727 - 0.1969LT + 0.4066T_{db} - 0.00983T_{db}^2)}$$

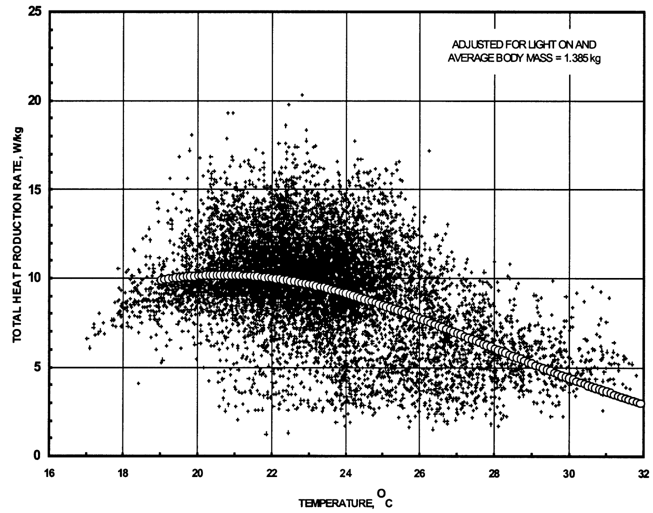

Figure 3. Total heat production of broilers vs. air temperature, adjusted for body mass of 1.385 kg and light on.

Table 1. Linear regression of ln(THP) = $b_0 + b_1 \times \ln(M)$; (R^2 = 0.282, SE = 0.340).

Variable	Mean	Coefficient	Standard error	Significance level
Intercept		b_0 = 2.300	0.004001	<0.0001
ln(M)	0.3256	b_1 = –0.460	0.007077	<0.0001

Table 2. Regression based on equation 4 as the statistical model, ln(THP) = $b_0 + b_1 \times \ln(M) + b_2 \times LT + b_3 \times T_{db} + b_4 \times T_{db}^2$; ($R^2$ = 0.456, SE = 0.295).

Variable	Mean	Coefficient	Standard error	Significance level
Intercept		b_0 = –1.7270	0.2121	<0.0001
ln(M)	0.3256	b_1 = –0.4660	0.0062	<0.0001
LT	0.3044	b_2 = –0.1969	0.0071	<0.0001
T_{db}	23.3	b_3 = 0.4066	0.0176	<0.0001
T_{db}^2	546.9	b_4 = –0.00983	0.00036	<0.0001

indicating that THP would be reduced to 82% of the level under the light conditions. This magnitude of reduction in THP (18%) was less than the value of 25 to 26% measured by Xin et al. (1996) for broilers raised on litter in totally controlled (including light) calorimeter chambers. With the current criterion for defining lighting, nominal darkness occurred for about 3,000 hours of the 10,780 hours retained in the study. In reality, the birds were not in complete darkness but were exposed to certain levels of light from the moon, stars, and a yard light about 30 m from the nearest broiler house. The buffering effects of litter HP might also have contributed to the less THP reduction in the darkness.

Effects of Temperature on THP

The effects of temperature on THP are indicated in table 2 (equation expression in the caption of figure 2). The inclusion of the T_{db}^2 term increased R^2 from 0.4195 to 0.4564. The temperature regression coefficients indicate that a maximum THP occurred at 0.4066/(2 × 0.00983) or 20.7°C. However, relatively few data below 20°C admit the possibility that THP actually remains constant or increases at lower temperatures. Thus, the quadratic term in the model may indicate a plateau in the temperature response, rather than a true maximum. The plateau, over the range of about 20–24°C would correspond to the thermoneutral zone for larger (≥4 weeks) broiler chickens.

Effects of Temperature on LHP

LHP was quantified as the percent of THP in the data analyses. For all data, the average LHP was 50.6% THP. Table 3 shows the results of regression analyses using equation 5 as a model. The R^2 statistic increased progressively from 0.5314 to 0.5677 and 0.6270 as T_{db}^2 and RH terms, respectively, were added to T_{db} in the original regression model. Figure 4 shows that LHP, as a percent of THP, increased sharply at the higher temperatures. Of course, above 25°C, the LHP% increase resulted partially from a decrease in THP, rather than just an increase in the rate of water evaporation.

Effects of RH on LHP

As shown in figure 5, LHP decreased about 15% as RH increased from about 40% to 80%. Use of RH proved to be more responsive than partial vapor pressure in this simple regression.

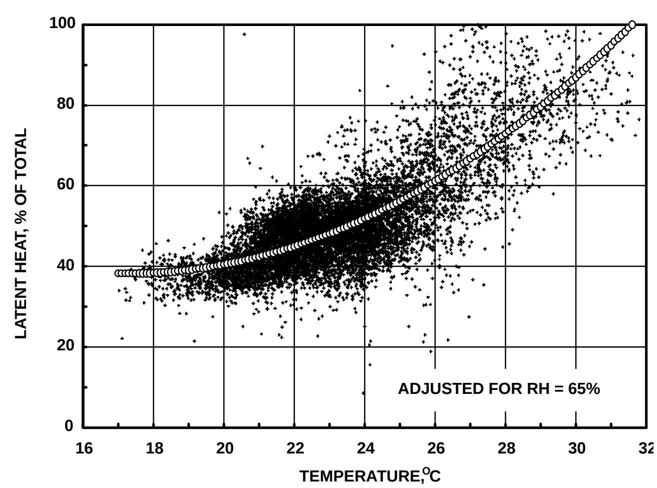

Figure 4. Latent heat production (LHP) as % of total heat production (THP) of broilers vs. air temperature, adjusted for relative humidity (RH); LHP, %THP = 149.7 – 10.36 × T_{db} + 0.3002 × T^2_{db} – 0.3409 × RH.

Table 3. Regression based equation 5 as the statistical model, $LHP\% = b_0 + b_1 \times T_{db} + b_2 \times T_{db}^2 + b_3 \times RH$; ($R^2 = 0.627$, SE = 7.887).

Variable	Mean	Coefficient	Standard error	Significance level
Intercept		$b_0 = 149.7$	5.586	<0.0001
T_{db}	23.3	$b_1 = -10.36$	0.4645	<0.0001
T_{db}^2	546.9	$b_2 = 0.3002$	0.009629	<0.0001
RH	65.0	$b_3 = -0.3409$	0.008237	<0.0001

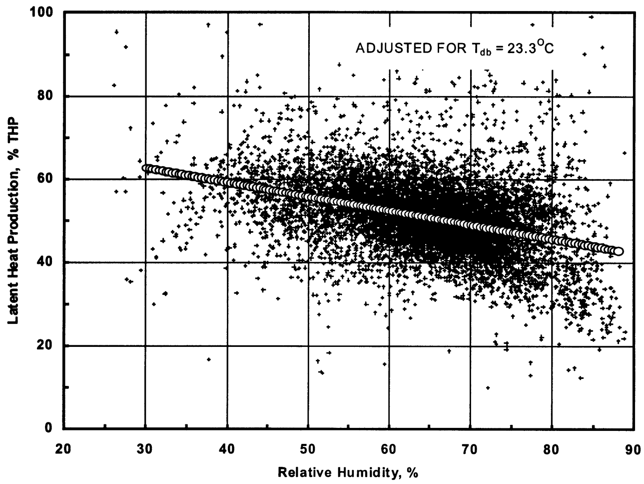

Figure 5. Latent heat production as % of total heat production (THP) of broilers vs. relative humidity, adjusted for air temperature (T_{db}) of 23.3°C.

Comparisons with Literature Data

Prediction equations from Reece and Lott (1982) for SHP and LHP from broilers were compared with regression equation 3. The older data were obtained from chickens grown separately at 15.6, 21.1, and 26.7°C above three weeks of age. The temperatures of 21.1, and 26.7°C were substituted in equation 3 for this comparison because 15.6°C never occurred in the current study. Also, light was set to be on continuously, as was the case in the older study. The results are shown in figure 6. THP of the current study was slightly greater at 21.1°C. At 26.7°C, THP of the current study was somewhat greater at lighter M (<0.6 kg), but decreased more rapidly at heavier M. The relationship of reduced THP at higher air temperature for *ad libitum* fed birds was shown consistently in the current study, whereas the two THP lines for 21.1°C and 26.7°C crossed in the older study. The authors of the older study did not explain or stipulate why the two lines crossed.

In the older study, LHP from the chickens and litter was considerably greater than SHP for all M at both 21.1 and 26.7°C. In contrast, LHP averaged 50.6% THP for all data from the current study, and, by the prediction equation, exceeded 50% only after temperature rose above about 23°C. This difference was likely due to the reduced water loss from the modern nipple drinkers, as compared to the open–surface (trough) drinkers used in the older study. The result of reduced LHP% was consistent with the recent reports by Gates et al (1996) and Xin et al. (1996) for broiler chickens housing systems.

Equation 3 of the current study was further compared with the equation of $THP = 10.0M^{0.75}$ of CIGR (1999) for broiler chickens at thermoneutrality, as shown in figure 7. Note that a variable thermoneutral T_{db} of 23.9 to 21.1°C (decrease

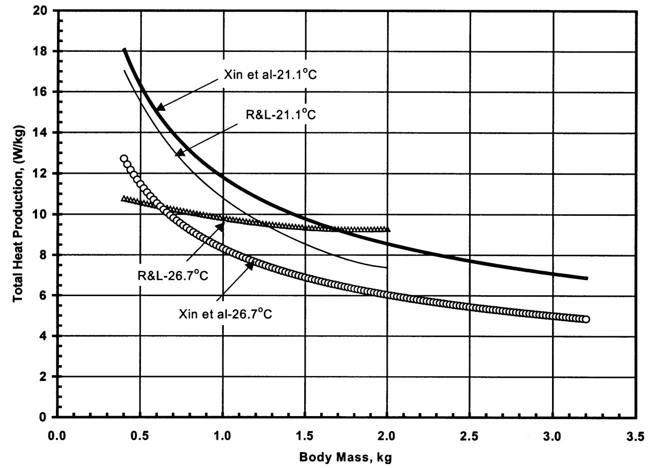

Figure 6. Comparison of total heat production (THP) of broilers between the current study and the study by Reece and Lott (1982).

linearly with M) corresponding to the M range of 0.4 to 0.9 kg was used in equation 3 when calculating the THP. For M ≥ 0.9 kg, constant T_{db} of 21.1°C was used. It can be seen that THP of the current study was quite higher, up to 31% at 0.4 kg, than that predicted by the CIGR equation for younger birds, and the differences diminished as M approached 2.3 kg. Hence, the new data confirmed that modern broilers exhibit higher metabolic rate, presumably resulting from faster growth rate and improved nutrition.

Conclusions

Heat and moisture production rates (HP, MP) of modern broilers in commercial production housing conditions were quantified from 20 house–flocks of data. Extensive instrumentation of the houses and farm site for monitoring and recording of the environmental and production variables enabled such quantification. The following conclusions were drawn from this field study.

- Regression equations were established to predict HP and MP in modern broiler houses over common ranges of body mass (0.4 to 3.2 kg), air temperature (20 to 32°C), relative humidity (30% to 80%), and lighting condition (light or dark).

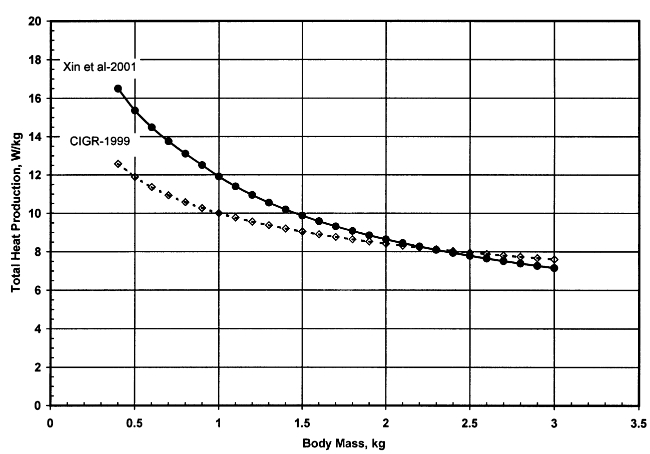

Figure 7. Comparison of total heat production of broiler chickens between the current study (Xin et al., 2001) and the CIGR (1999) equation at thermoneutrality (23.9 to 21.1°C).

- Specific total HP in modern commercial broiler houses at thermoneutrality was considerably higher (up to 31%), particularly for younger birds, than that stated in the literature, presumably arising from faster growth rate and improved diet/nutrition of the modern birds. The differences diminish as birds approach 2.3 kg in body mass.
- Latent HP in modern broiler housing is reduced as compared with that in the literature, presumably resulting from use of nipple drinkers as opposed to open–surface (trough) drinkers.
- Results of the study confirmed the need to systematically update the literature HP and MP data for efficient design and operation of poultry housing ventilation.

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