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# BROILERS' HEAT AND MOISTURE PRODUCTION UNDER AIR VELOCITY TREATMENTS IN SUMMER CONDITION

**Highlights**

- Updated broilers' heat and moisture production data for 35-61 d age
- Heat-stressed birds' heat and moisture production varies diurnally
- Broilers' heat and moisture production changes due to air temperature
- Sensible heat and moisture production is significantly higher under High air velocity treatment

***Abstract.*** *Modern poultry producers raise bigger broilers (2.3-4.5 kg) in about 63 days to satisfy the growing demand. Hot and humid summer conditions, especially in Southeastern states of United States (US), cause heat stress to these heavier birds, ultimately compromising their welfare and performance. Moreover, existing facilities' ventilation systems need to be more efficient to mitigate such heat stress. Heat production (HP) and moisture production (MP) rates are the fundamental design parameters for the ventilation system of a broiler house. However, the current HP and MP standards are 20 to 50 years old. This study investigated broilers' HP and MP values under summer conditions. The experiments were conducted in the poultry engineering chamber complex of North Carolina State University as a part of a comprehensive study on the effectiveness of wind chill applications to mitigate heat stress on heavy broilers. A total of five flocks of broilers were raised in the chamber complex under hot summer conditions. Two different dynamic air velocity (AV) treatments (High and Low) were applied from 35-61d in the six chambers, with three chambers per treatment and 44 birds per chamber. Energy and mass balance approach was used to calculate the HP and MP rates from the insulated chambers. The variations in HP and MP were evaluated under different air temperatures (T), bird's age, time of the day, and AV treatments. From its 35~61 d age, the current broilers produce 5~20 W/kg sensible heat and 4~37 g/hr-kg moisture on an average under summer conditions. Heat-stressed broilers HP and MP varied diurnally, and High AV treatments helped birds release more heat and moisture into the surrounding environment. These new HP and MP values will enhance the design and ventilation of heavy broiler housing for improved performance and welfare of the birds.*

***Keywords.*** *Heavy broiler, heat-stress, heat production, moisture production, air velocity.*

## INTRODUCTION

Broiler integrator companies are meeting the market demand for separated cuts, such as breasts and thighs, by increasingly raising larger chickens (Maharjan et al., 2021). As a result, over 70% of broilers grown in 2020 were "heavier" with a body weight (BW) greater than 2.73 kg within 5-7 weeks post-hatch age (Maharjan et al., 2021), with over 50% of these birds reaching a final market size BW of 3.4 kg or more in about 60 days. This increase in size is due to genetic selection, improved diet, and management practices (Havenstein et al., 2003; Zuidhof et al., 2014; Rajcic et al., 2021). As the BW increases, their metabolic heat production increases (S. T. Nascimento et al., 2017), but the heat released to the environment decreases (Chepete et al., 2004). This imbalance between heat generation and release causes heat stress and negatively impact their performance and welfare, especially in hot summer months, leading to significant financial losses (St-Pierre et al., 2003; Lara et al., 2013). To address this issue, it is essential to properly design the ventilation system in broiler houses to maintain the targetted performance and welfare of the birds.

The appropriate ventilation systems of broiler houses depend on the rates of heat production (HP) and moisture production (MP) by the birds, which must be monitored throughout the production cycle to ensure a comfortable environment (Reece and Lott, 1982; Chepete et al., 2004; Watts et al., 2011). The current standards for ventilation system design are based on studies conducted between 1961 and 1982, but these studies were carried out on broilers with lower BW than the current market-sized birds (A. D. Longhouse et al., 1968, Reece and Lott, 1982). Several approaches were taken to update broilers' standards of HP and MP under different treatment and environmental conditions. Reece and Lott (1982) updated the heat and moisture production data from A. D. Longhouse et al. (1968) and found a constant SHP value of about 2.97 W/kg at 26.7 $^{o}$C and 63% RH for birds weighing 0.5 to 1.8 kg. But Feddes et al. (1984) estimated a bird of about 1.71 kg could produce 6.36 W/kg of SHP under commercial conditions. Xin et al. (1994) found that 6-week-old 2.88 kg birds produce lower MP (6.3 g/kg-hr) and higher sensible heat production (SHP) (4.2 W/kg) than that of

Reece and Lott (1982). Later, Simmons et al. (1997) assessed that five to six-week-old broilers' (1.6~2.1 kg BW) could generate 1.3 to 1.9 W/kg SHP under high Ta (29~35 $^{o}$C). Genc et al. (2005) calculated SHP 2.1$\pm$0.4 W/kg for BW 2 to 2.3 kg broilers. Liang et al. (2012) estimated birds with a bodyweight 1-3 kg loses a total of 7.6 W/kg heat under summer condition. Thus the existing literature has SHP and MP for broilers of age up to six weeks and BW up to 2.88 kg. Therefore, there is a need to update the HP and MP rates for current, larger broilers to optimize ventilation rates and ensure their well-being.

Increased air velocity (AV) is suggested by many researchers to give comfort birds under heat stress conditions (Mitchell, 1985; Hillman, 1993). For example, Simmons et al. (1997) estimated a 50% increase in SHP from five to six-week-old broilers at 29 to 35 $^{o}$C T due to a 200% increase in AV. However, it is also important to identify the effect of increased AV on bigger broilers' HP and MP. But the existing reports listing AV effect on HP and MP are lacking the information for birds older than six weeks of age.

Therefore, the HP and MP for broilers of age six weeks ore more and BW greater than 2.88 kg under summer environmental conditions are unavailable. Hence, the objective of this research was to determine the HP and the MP from 35 to 61 d old broiler chickens subjected to two AV treatments under summer conditions.

## MATERIALS AND METHODS

The experimental use of birds was approved by the Animal Care and Use Committee and conducted in compliance with the Guidelines for Care and Use of Laboratory Animals at North Carolina State University (NCSU) (IACUC#16-279-A).

### EXPERIMENTAL UNIT

The study took place in the NCSU Poultry Engineering Laboratory (PEL) for three consecutive summers. The PEL has six identical poultry chambers. A total of five flocks of birds were run (two flocks in 2017 and 2018, and one flock in 2019) for this objective. Each chambers were insulated and comprised of a core chamber of dimensions 2.4m x 2.4m x 2.4m to house the birds, while a belt-driven blower with variable frequency drive controlled the AV in the range of 0.9-4.6 m/s at the birds' height. More detailed information about the laboratory and operations can be found in previous studies by Wang-Li (2013), and Akter et al. (2022).

### ANIMALS

At NCSU poultry unit, 400 male broilers (ROSS 708 in first four flocks and COBB500 for fifth flock) were hatched and raised in floor pens under comparable conditions. Later, 264 birds that did not have leg defects were randomly chosen and placed in chambers with 44 birds per chamber at there age 28 d. After 7 days of  acclimation period, AV treatments were started to apply on 35 d. Birds stayed in the chambers until they reached 61 d, with a final stocking density of $40 \leq \text{kg/m}^2$ to comply with animal welfare regulations.

### CORE CHAMBER ENVIRONMENTAL DATA MONITORING

Calibrated Thermocouples (TC) (range: −5 °C to 50 °C, and accuracy: ±0.002 °C) was installed at the air inlet and outlet to measure dry bulb T. A HOBO Pro v2 External T/RH Data Logger, Model U23-002 (Onset, Computer Corporation, MA, USA) was installed at each chamber’s inlet to measure temperature (T) and relative humidity (RH) (Figure 1a). The TC  recorded each chamber’s data at 1-minute intervals while the HOBO sensors recorded T and RH at 10-minute intervals. During the 5th flock, Fiber Optic (FO) cables with a diameter 0.9 mm (AFLTelecommNSX001509U601-BIF, Graybar, NY, USA) was installed to measure T at all the wall surfaces of the chamber (Figure 1b). Duct tape secured the FO cables inside the chambers to avoid the chicken accidentally breaking or deforming. While the TC and HOBO recorded point measurements of T at inlet and outlet, the FO measured the T from a line and hence improved the temporal and spatial resolution of measurements.

(a) (b)

**Figure 1. Locations of sensors, feeders, and drinker lines inside of the core chamber**

### AIR VELOCITY TREATMENTS

Depending on the inlet T, the thermal condition inside the chamber was divided into six classes: Below optimum, About optimum, Moderate, Severe, Life-threatening, and Warning. Two AV treatments were designed according to the bird's age and thermal condition classes (Table 1). The treatments were dynamic, i.e., treatments were applied depending on the real-time T and bird age. Each of the AV treatments was applied in three replicated chambers.

Air velocity treatments started to apply on the birds from 35 d of age, one week after the birds' placement into the chambers. Table 1 explains how different the AV was between "High" and "Low." The High and Low AV treatments did not differ while the environment was "Below optimum" at any age and "Optimum" up until the 52 d age of birds. The difference between the two treatments reached its maximum of 0.93 m/s while the thermal condition became "Life-threatening" (Table 1). More details about the AV treatments are given in Akter et al. (2022).

**Table 1. High and Low AV treatment design**

| Treatment | Age (days) | Below optimum T | | About optimum T | | Above optimum T (**Moderate**) | | Above optimum T (**Severe**) | | Above optimum T (**Life-threatening**) | | Above optimum T (**Warning**) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | T ºC | AV (m/s) | T ºC | AV (m/s) | T ºC | AV (m/s) | T ºC | AV (m/s) | T ºC | AV (m/s) | T ºC | AV (m/s) |
| High | 28-34* | <26.0 | 0.9 | 26.0-27.8 | 1.23 | 27.8-28.9 | 1.33 | 28.9-32.2 | 1.48 | 32.2-33.9 | 1.64 | >33.9 | 1.75 |
| Low | | | 0.9 | | 1.23 | | 1.33 | | 1.48 | | 1.64 | | 1.75 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High | 35-40 | <21.7 | 0.9 | 21.7-26.0 | 1.23 | 26.0-30.0 | 2.02 | 30.0-33.0 | 2.77 | 33.3-37.8 | 3.45 | >37.8 | 3.95 |
| Low | | | 0.9 | | 1.23 | | 1.48 | | 2.02 | | 2.77 | | 3.45 |
| High | 41-42 | <21.1 | 1.48 | 21.1-26.0 | 1.48 | 26.0-30.0 | 2.02 | 30.0-33.0 | 2.77 | 33.3-37.8 | 3.45 | >37.8 | 3.95 |
| Low | | | 1.48 | | 1.48 | | 1.48 | | 2.02 | | 2.77 | | 3.45 |
| High | 43-52 | <20.6 | 1.48 | 20.6-26.0 | 1.75 | 26.0-30.0 | 2.02 | 30.0-33.0 | 2.77 | 33.3-37.2 | 3.95 | >37.8 | 4.33 |
| Low | | | 1.48 | | 1.75 | | 1.75 | | 2.43 | | 3.02 | | 3.65 |
| High | 53-54 | <19.4 | 1.48 | 19.4-25.0 | 1.75 | 25.0-29.5 | 2.43 | 29.4-32.7 | 3.02 | 32.7-36.1 | 3.95 | >36.1 | 4.33 |
| Low | | | 1.48 | | 1.48 | | 1.75 | | 2.43 | | 3.02 | | 3.65 |
| High | 55-56 | <19.4 | 1.48 | 19.4-25.0 | 1.75 | 25.0-29.5 | 2.43 | 29.4-32.7 | 3.02 | 32.7-35.6 | 3.95 | >35.6 | 4.33 |
| Low | | | 1.48 | | 1.48 | | 1.75 | | 2.43 | | 3.02 | | 3.65 |
| High | 57-58 | <18.9 | 1.48 | 18.9-25.0 | 1.75 | 25.0-29.5 | 2.43 | 29.9-32.2 | 3.02 | 32.2-35.6 | 3.95 | >35.6 | 4.33 |
| Low | | | 1.48 | | 1.48 | | 1.75 | | 2.43 | | 3.02 | | 3.65 |
| High | 59-60 | <18.9 | 1.48 | 18.9-24.4 | 2.43 | 24.4-28.9 | 3.02 | 28.9-31.7 | 3.45 | 31.7-35.0 | 4.33 | >35.0 | 4.43 |
| Low | | | 1.48 | | 1.75 | | 2.43 | | 2.77 | | 3.65 | | 3.8 |
| High | 61 | <18.3 | 1.48 | 18.3-23.9 | 2.43 | 23.9-28.9 | 3.02 | 28.9-31.7 | 3.45 | 31.1-33.9 | 4.33 | >33.9 | 4.6 |
| Low | | | 1.48 | | 1.75 | | 2.43 | | 2.77 | | 3.65 | | 3.95 |

*non-treatment period (in the first week) allowed broilers to acclimate to their new environment

### DATA PROCESSING

The collected data from all sensors were cleaned first for any instrumental malfunction and errors. Data collected during open door time, for example, screen cleaning, were also excluded. The TC, HOBO, and FO data were first averaged for every hour. Then the average hourly data from different sensors were averaged for further analysis. For the 5th flock, the heat loss through building surfaces was determined as FO was installed at both sides of each wall. The first four flocks did not have sensors placed on wall surfaces to calculate the heat transfer through them. Therefore, the 5th flock's data developed a regression equation between T (TC and HOBO sensor) measurement at the inlet and T at wall surfaces (FO sensor) for each chamber. This equation was then used to calculate heat loss through building surfaces for the previous four flocks.

### CALCULATION OF HEAT AND MOISTURE PRODUCTION

During the experiments, no supplemental heat was needed. The equipment heat source (such as lights) inside the chamber was neglected due to insignificant contribution. The hourly average sensible heat production (SHP) and MP from each chamber was calculated using the following steady-state equations (Xin et al., 2001):

$$\text{SHP} = \frac{Q}{V_a} \times C_p \times (t_o - t_i) + \frac{A}{R_T} \times (t_i - t_o) \qquad (1)$$

Where:

SHP = sensible heat production, W
Q = ventilation rate $m^3/s$ (calculated from fan curve)
$V_a$ = specific volume of exhaust air, $m^3/kg$
$C_p$= Specific heat of air J/kg-°C
$t_o$= air temperature at the outlet, °C
$t_i$= air temperature at inlet, °C
A = area of building surface component, $m^2$
$R_T$ = total resistance to heat flow of the component, $\frac{m^2 - K}{W}$
and:

$$MP = \frac{60\,Q}{V_a} \times (W_o - W_i) \tag{2}$$

Where:

MP = moisture production rate, kg/hr
Q = ventilation rate, $m^3/s$
$W_o$ = humidity ratio of air at the outlet, $kg_{\text{water vapor}}/kg_{\text{dry air}}$
$W_i$= humidity ratio of air at inlet, $kg_{\text{water vapor}}/kg_{\text{dry air}}$

Later, SHP and MP values were expressed per-kilogram basis by dividing the mass of the birds in the chambers.

### STATISTICAL ANALYSIS

Both High and Low AV were applied in three replicated chambers. The differences in treatments considering multiple factors were calculated with a two-way ANOVA test using Rstudio (version 1.0.143) (Rstudio, Boston, MA, USA). For example, while checking the AV treatments' effect under any age of the birds, then age and treatments were considered as two independent factors for ANOVA testing. The main effects and the interactions were considered significant at $p<0.05$. Tukey HSD test was performed to check the differences in the level of factors and if any main effects were detected. Replicated chambers were treated as a blocking factor in the analysis.

## RESULTS AND DISCUSSION

### THERMAL CONDITIONS AT INLET

All the experiments were conducted under summer conditions. Table 2 describes the average thermal conditions: T and RH, from 35-61 d at the chamber's inlet under each treatment. The average

T describes the 1st, 3rd, and 4th flocks were hotter than the 2nd and 5th flocks. The 4th flock was more humid than the others. These inlet conditions were not significantly different under the two treatments at a significance level of $p<0.05$.

**Table 2. Average environmental conditions in chamber's inlet during the broiler experiments**

| Flock | Treatment | T °(C) | RH (%) |
|---|---|---|---|
| 1 | High | 28.36±3.80 | 68.76±13.01 |
|  | Low | 27.87±3.60 | 69.05±12.62 |
| 2 | High | 25.50±4.02 | 70.05±12.90 |
|  | Low | 25.11±3.92 | 70.34±12.65 |
| 3 | High | 27.22±3.95 | 69.46±14.06 |
|  | Low | 27.19±3.78 | 69.90±13.58 |
| 4 | High | 26.32±2.54 | 78.14±11.11 |
|  | Low | 26.26±2.48 | 78.75±10.84 |
| 5 | High | 25.89±4.00 | 69.68±13.90 |
|  | Low | 25.67±3.93 | 70.32±13.82 |

*no significant difference ($p<0.05$) was observed at the inlet thermal condition under two AV treatments

The AV treatments were applied based on the inlet T and the birds' age. Birds were under heat-stressed conditions when the environment exceeded the "About optimum" level defined by the Table 1. Table 3 shows that flocks 1, 2, 3, 4, and 5 exceeded the optimal grow-out conditions by 72, 54, 57, 53, and 38% of the total experiment time, respectively. So, flock 1 and 3 were more stressful than the other three flocks. Flock 5 was the least stressful for the birds.

**Table 3. Time distribution of occurrences of AV treatments in all chambers during experiments**

|  | Percentage of occurrences from total observation |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| Flock | Below optimum | About optimum | Moderate | Severe | Life-threatening | Warning | Exceeded optimum condition |
| 1 | 0.08 | 28.03 | 36.77 | 19.88 | 14.77 | 0.46 | 71.89 |
| 2 | 1.18 | 45.34 | 35.45 | 13.03 | 5.00 | 0.00 | 53.48 |
| 3 | 1.70 | 41.30 | 35.47 | 13.48 | 7.93 | 0.11 | 57.00 |
| 4 | 0.00 | 46.63 | 40.02 | 13.34 | 0.00 | 0.00 | 53.37 |
| 5 | 9.96 | 52.15 | 29.30 | 6.66 | 1.92 | 0.00 | 37.89 |

### AVERAGE SENSIBLE HEAT AND MOISTURE FROM HEAVY BROILERS

The pooled average SHP and MP by the broilers from their age 35-61 d are given in Table 4. The average SHP were signifiacntly different among flocks due to the different thermal conditions inside chamber (Table 4). The 3rd flock produced the highest average SHP among the five flocks, while the 2nd had the lowest SHP. The birds in 4th flock produced more SHP than the 1st, 2nd, and 5th flocks but less than the 3rd flock. The AV treatments significantly affected the SHP for all flocks except for the 5th one. Birds produced higher SHP under High AV treatments. During the 5th flock, birds mostly experienced optimum thermal condition (72% time of the experiment) (Table 3) which caused almost intangible difference between High and Low AV. Hence the treatment effect was not significant during this flock.

**Table 4. Average sensible heat and moisture production by broiler from 35 to 61 d**

| Flock | Treatment | SHP (W/kg) | | MP (g/hr-kg) | |
|---|---|---|---|---|---|
| | | By Flock | By AV | By Flock | By AV |
| 1 | High | $11.1 \pm 8.7^{C}$ | $13.7 \pm 10.0^{a}$ | $21.8 \pm 26.8^{C}$ | $28.4 \pm 30.9^{a}$ |
| | Low | | $7.8 \pm 5.2^{b}$ | | $19.1 \pm 24.5^{b}$ |
| 2 | High | $9.1 \pm 5.6^{D}$ | $10.6 \pm 5.9^{a}$ | $7.9 \pm 4.5^{D}$ | $5.3 \pm 5.4^{b}$ |
| | Low | | $7.5 \pm 1.7^{b}$ | | $8.1 \pm 4.3^{a}$ |
| 3 | High | $20.0 \pm 16.9^{A}$ | $26.2 \pm 17.2^{a}$ | $46.2 \pm 33.0^{A}$ | $71.2 \pm 34.0^{a}$ |
| | Low | | $10.2 \pm 6.9^{b}$ | | $36.4 \pm 26.6^{b}$ |
| 4 | High | $13.9 \pm 11.5^{B}$ | $20.9 \pm 12.3^{a}$ | $26.6 \pm 26.2b^{C}$ | $33.1 \pm 31.3^{a}$ |
| | Low | | $7.3 \pm 3.6^{b}$ | | $19.9 \pm 17.4^{b}$ |
| 5 | High | $10.6 \pm 5.7^{C}$ | $10.5 \pm 5.7^{a}$ | $31.8 \pm 33.7^{B}$ | $36.4 \pm 37.4^{a}$ |
| | Low | | $10.7 \pm 5.7^{a}$ | | $25.1 \pm 23.7^{b}$ |

$^{a\text{-}b}$ Means in weeks within flocks with different superscripts are different at $p<0.05$

$^{A\text{-}D}$ Means among flocks with different superscripts are different at $p<0.05$

In this study, SHP was found to be higher than that reported by Reece and Lott, (1982); Feddes et al. (1984); Xin et al. (1996); Simmons et al. (1997); and Liang et al. (2012). Birds' age and corresponding BW in this study was higher than that reported in the literatures hence they produced more metabolic heat. The High AV helped them dissipate more heat to the surrounding air thus produced higher SHP. The magnitude of High AV exceeded 3 m/s at stressful conditions which caused a shift from latent to sensible heat.

Like the SHP, average MP among all the flocks were significantly different for different flocks (Table 4). Except for the 2nd flock, birds MP were signifiacntly higher under High AV treatments. However, the 2nd flock produced the lowest MP, like it had the lowest SHP. The 3rd flock exceeded the optimal grow-out condition more than any other flocks, which let the birds experience more stress due to increased T and age. The majority of the previous studies that investigated latent heat production (LHP), did not publish the amount of MP by birds explicitly; instead they mentioned the LHP amount by birds ( Reece and Lott, 1982; Simmons et al., 1997; Genç and Portier, 2005).

However, Watts et al. (2011) estimated that the ROSS broiler can produce 4.46~5.53 g/hr-kg water in simulated transport chamber at 20 $^{o}$C exposure T which is smaller than the amount calculated in this study. The birds in this study were at least double by BW than that reported by Watts et al. (2011), and the treatment AV helped them release more moisture. So, this study updated the SHP and MP values for future use.

### EFFECT OF BIRDS' AGE ON SENSIBLE HEAT AND MOISTURE PRODUCTION

ANOVA test implies that the birds' SHP was impacted significantly by their age (Table 5). In addition, the AV treatments also significantly (*p*<0.05) affected the amount of SHP during summer conditions for the first four flocks. Although the 5th flock did not observe the AV treatment's effect directly, its interaction with the bird's age influenced the SHP.

**Table 5. Statistical test report for the effect of bird's age and treatment AV on sensible heat production**

| ANOVA table for age effect on SHP | | | | | | |
|---|---|---|---|---|---|---|
| Flock | Factor | Df | SSE | MSE | F | p(<F) |
| F1 | AV | 1 | 20677 | 20677 | 350.17 | <2e-16 *** |
| | Age | 4 | 14953 | 3738 | 63.3 | <2e-16 *** |
| | AV x Age | 4 | 5280 | 1320 | 22.35 | <2e-16 *** |
| F2 | AV | 1 | 4260 | 4260 | 160.03 | <2e-16 *** |
| | Age | 4 | 3212 | 803 | 30.16 | <2e-16 *** |
| | AV x Age | 4 | 548 | 137 | 5.15 | 0.000402 *** |
| F3 | AV | 1 | 124140 | 124140 | 591.46 | <2e-16 *** |
| | Age | 4 | 6326 | 1582 | 7.53 | 5.12e-06 *** |
| | AV x Age | 4 | 1476 | 369 | 1.76 | 0.135 |
| F4 | AV | 1 | 155702 | 155702 | 1961.74 | <2e-16 *** |
| | Age | 4 | 5259 | 1315 | 16.56 | 1.93e-13 *** |
| | AV x Age | 4 | 4576 | 1144 | 14.41 | 1.15e-11 *** |
| F5 | AV | 1 | 25 | 24.5 | 0.784 | 0.3759 |
| | Age | 4 | 2434 | 608.4 | 19.459 | 8.14e-16 *** |
| | Treatment x Age | 4 | 248 | 61.9 | 1.98 | 0.0949 . |

Significance level: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

**Table 6. Average weekly SHP of broiler (35-61 d) under summer condition**

| Flock | Treatment | SHP (mean±sd) (W/kg) | | | | |
|---|---|---|---|---|---|---|
| | | Week 5 | Week 6 | Week 7 | Week 8 | Week 9 |
| 1 | High | 9.09±8.43 | 10.8±7.82$^{a}$ | 10.18±5.46$^{a}$ | 18.15±12.45$^{a}$ | 18.47±10.15$^{a}$ |
| | Low | 4.94±2.48 | 6.7±5.18$^{b}$ | 7.49±4.52$^{b}$ | 8.6±5.7$^{b}$ | 9.42±5.47$^{b}$ |
| 2 | High | 8.12 ±4.64$^{a}$ | 10.8±6.38a | 9.66±4.54$^{a}$ | 11.76±6.1$^{a}$ | 7.54±4.87 |
| | Low | 4.6±3.23b$^{b}$ | 6.5±4.57$^{b}$ | 6.17±3.34$^{b}$ | 9.65±4.78$^{b}$ | 7.61±5.04 |
| 3 | High | 23.77±11.57$^{a}$ | 28.05±18.38$^{a}$ | 26.96±17.77$^{a}$ | 30.08±20.65$^{a}$ | 22.5±15.06$^{a}$ |
| | Low | 9.97±6.88$^{b}$ | 10.56±6.8$^{b}$ | 9.79±6.84$^{b}$ | 11.12±7.4$^{b}$ | 8.69±6$^{b}$ |
| 4 | High | 30.12±16.76$^{a}$ | 19.3±13.08$^{a}$ | 23.14±13.58$^{a}$ | 18.92±10.82$^{a}$ | 24.53±10.74$^{a}$ |
| | Low | 8.36±4.62$^{b}$ | 7.55±3.34$^{b}$ | 7.55±3.45$^{b}$ | 6.9±3.81$^{b}$ | 7.09±3.66$^{b}$ |
| 5 | High | 14.63±3.55 | 11.35±6.03 | 9.86±5.67 | 10.2±5.65 | 10.17±4.77 |
| | Low | 16.36±4.87 | 11.89 ± 5.83 | 10.57±6.22 | 9.95±5.04 | 9.27±4.41 |

From 1st to 4th flock, SHP was always significantly higher under High AV except for the week 5 in 1st flock, and week 9 in 2nd flock (Table 6). At younger age, the thermal condition was optimum hence there was no difference in AV between the treatment. During the week 9 of 2nd flock, the T was below optimum category which caused no difference between the treatments. There was no apparent trend in the change of SHP over the weeks. Birds' average BW between week 5 and 9 varied from 2 ~ 5 kg during all flocks. Birds' SHP decreases with age in the case of smaller birds (BW<1.5 kg) ( Reece and Lott, 1982; Hayes et al., 2013), but when they grow bigger, their SHP depends on their activity level and the surrounding environment, which varies over age, daytime, and environment (Akter et al., 2022). Nevertheless, High AV significantly helped the birds transfer their body heat at any time compared to Low AV.

Like SHP, the ANOVA test (Table 7) implies that the AV treatment significantly affected the MP during all the flocks. Age also affected the amount of MP during the experiment. The MP of the birds was not affected by treatment AV or age during flock 2 but the interaction between them significantly changed the amount of MP.

**Table 7. Statistical test report for the effect of bird's age and AV treatment on heavy broilers' MP in summer**

ANOVA table for age and AV treatment effect on MP

| Flock | Factor | df | SSE | MSE | F | p(<F) |
|---|---|---|---|---|---|---|
| F1 | AV | 1 | 8062 | 8062 | 13.39 | 0.000283 *** |
| | Age | 4 | 24925 | 6231 | 10.35 | 5.64e-08 *** |
| | AV x Age | 4 | 25096 | 6274 | 10.42 | 4.45e-08 *** |
| F2 | AV | 1 | 71 | 71.2 | 3.852 | 0.0524. |
| | Age | 4 | 92.8 | 30.95 | 1.678 | 0.1762 |
| | AV x Age | 4 | 88.3 | 88.3 | 4.789 | 0.0309 * |
| F3 | AV | 1 | 459826 | 459826 | 579.409 | <2e-16 *** |
| | Age | 4 | 92857 | 23214 | 29.251 | <2e-16 *** |
| | AV x Age | 4 | 10533 | 2633 | 3.318 | 0.0102 * |
| F4 | AV | 1 | 12765 | 12765 | 20.709 | 7.9e-06 *** |
| | Age | 4 | 8581 | 2145 | 3.48 | 0.00853 ** |
| | AV x Age | 4 | 3543 | 1181 | 1.916 | 0.127 |
| F5 | AV | 1 | 29740 | 29740 | 29.72 | 6.52e-08 *** |
| | Age | 4 | 94085 | 31362 | 31.34 | <2e-16 *** |
| | AV x Age | 4 | 2293 | 764 | 0.764 | 0.515 |

Significance. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

**Table 8. Average weekly MP by heavy broilers under summer condition**

| Flock | Treatment | MP (g/hr-kg) |
|---|---|---|

| | | Week 5 | Week 6 | Week 7 | Week 8 | Week 9 |
|---|---|---|---|---|---|---|
| 1 | High | $26.01 \pm 10.4^{a}$ | $16.8 \pm 13.6^{a}$ | $45.4 \pm 44.9^{a}$ | $9.2 \pm 6.3^{a}$ | $25.9 \pm 20.1^{a}$ |
| | Low | $32.91 \pm 16.7^{a}$ | $9.66 \pm 8.1^{b}$ | $13.6 \pm 16.1^{b}$ | $28.5 \pm 33.9^{a}$ | $13.2 \pm 18.9^{a}$ |
| 2 | High | NA | $8.3 \pm 5.1^{a}$ | NA | $0.9 \pm 0.9^{b}$ | NA |
| | Low | $6.6 \pm 4.6$ | $8.2 \pm 4.3^{a}$ | $9.3 \pm 3.5$ | $7.4 \pm 4.9^{a}$ | NA |
| 3 | High | $48.2 \pm 24.9^{a}$ | 72.9±34.9a | $72.6 \pm 31.3$ | $82.4 \pm 34.7^{a}$ | $57.8 \pm 29.8^{a}$ |
| | Low | $23.1 \pm 15.6^{b}$ | $33.5 \pm 23.9^{b}$ | $33.7 \pm 23.5$ | $45.9 \pm 30.7^{b}$ | $32.1 \pm 26.3^{b}$ |
| 4 | High | $60.5 \pm 46.9^{a}$ | $6.7 \pm 4.5$ | 32.3±28.3a | $33.1 \pm 38.6^{a}$ | $35.8 \pm 21.9^{a}$ |
| | Low | $20.3 \pm 17.9^{b}$ | $32.3 \pm 28.6$ | $22.2 \pm 17.6^{b}$ | $15.9 \pm 9.9^{b}$ | $18.6 \pm 23.9^{b}$ |
| 5 | High | NA | $25.3 \pm 26.4^{a}$ | $31.3 \pm 41.9^{a}$ | $33.6 \pm 25.7^{a}$ | $54.1 \pm 50.1^{a}$ |
| | Low | NA | $18.7 \pm 15.1^{b}$ | 13.6±11.9b | $22.3 \pm 16.5^{b}$ | $43.7 \pm 31.8^{a}$ |

a-b Means in weeks within flocks separated by AV treatment with different superscripts are different at $p<0.05$
A-D Means among flocks with different superscripts are different at $p<0.05$

The amount of MP under both treatment AV varied with age (Table 8). As the birds increased in size, their skin's exposed surface area decreased due to feathers allowing birds to transfer body heat through latent heat loss over sensible heat loss. Except for some instances, the birds released more moisture under High AV treatments (Table 8). At higher T, birds were not effectively releasing SHP, but they were panting to cool themselves down.

### EFFECT OF TIME OF DAY ON SENSIBLE HEAT AND MOISTURE PRODUCTION BY BROILERS

Time of the day significantly impacted the SHP of the broilers during all the flocks (Table 9). Except for the fifth flock, the AV treatment also significantly changed SHP at any time of the day.

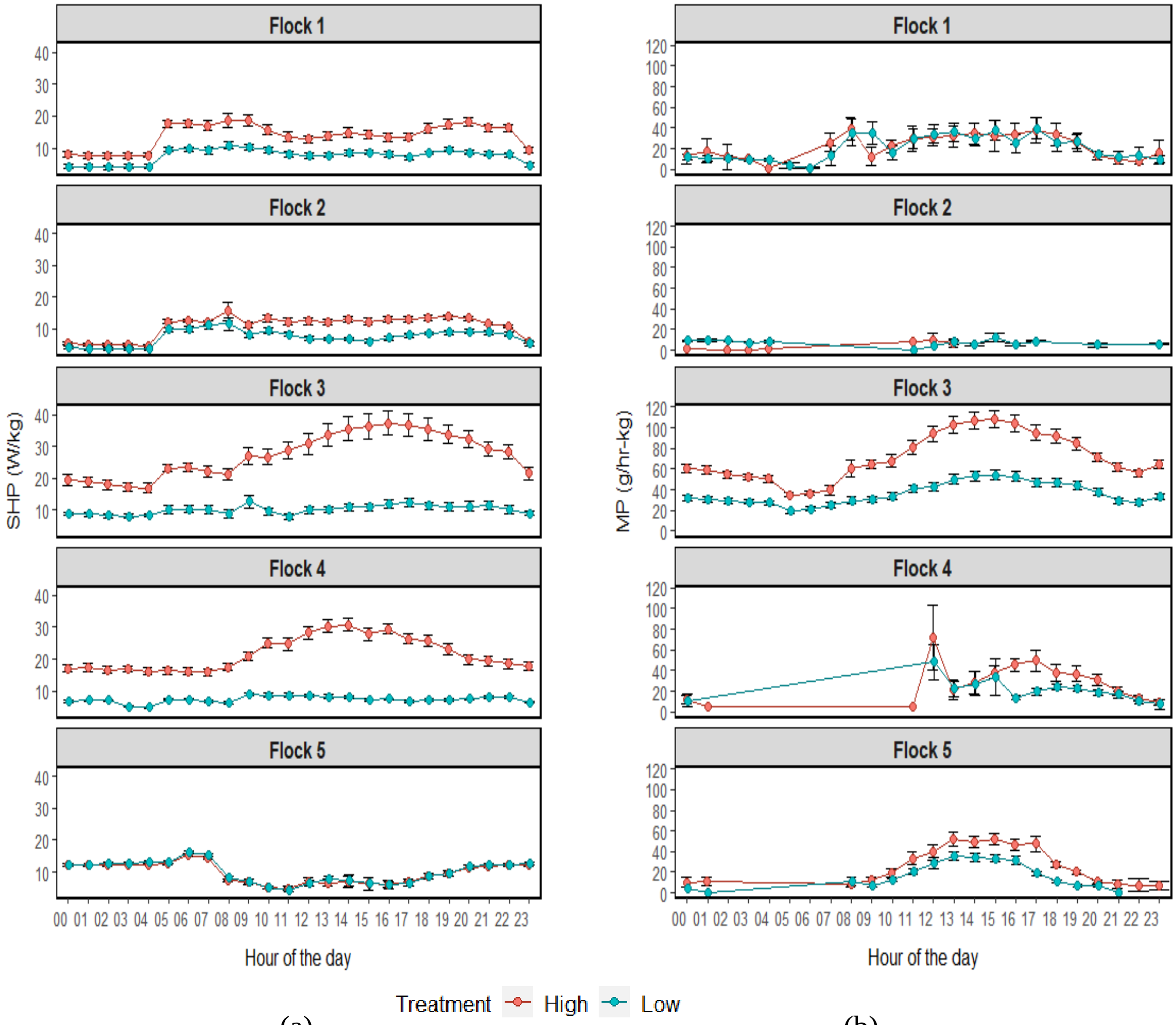
**Table 9. Statistical report to test the effect of hours of the day and treatment AV on SHP by broilers in summer**

| ANOVA table for daytime effect on SHP | | | | | | |
|---|---|---|---|---|---|---|
| Flock | Factor | Df | SSE | MSE | F | $p$(>F) |
| 1 | AV | 1 | 20677 | 20677 | 351.037 | <2e-16 *** |
| | Hour | 23 | 20934 | 910 | 15.452 | <2e-16 *** |
| | AV x Hour | 23 | 1880 | 82 | 1.388 | 0.103 |
| 2 | AV | 1 | 4260 | 4260 | 206.727 | <2e-16 *** |
| | Hour | 23 | 13660 | 594 | 28.818 | <2e-16 *** |
| | AV x Hour | 23 | 1526 | 66 | 3.219 | 4.23e-07 *** |
| 3 | AV | 1 | 124140 | 124140 | 649.991 | <2e-16 *** |
| | Hour | 23 | 34638 | 1506 | 7.885 | <2e-16 *** |
| | AV x Hour | 23 | 13591 | 591 | 3.094 | 1.15e-06 *** |
| 4 | AV | 1 | 155702 | 155702 | 2192.68 | <2e-16 *** |
| | Hour | 23 | 21727 | 945 | 13.3 | <2e-16 *** |
| | AV x Hour | 23 | 17171 | 747 | 10.51 | <2e-16 *** |
| 5 | AV | 1 | 25 | 24.5 | 1.064 | 0.302 |
| | Hour | 23 | 27329 | 1188.2 | 51.566 | <2e-16 *** |
| | AV x Hour | 23 | 100 | 4.3 | 0.188 | 1 |

significance. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Birds tranfered more heat to environment under High AV treatments at any time of the day from 1st to the 4th flock (Figure 2a) compared to than that of Low AV treatments. The lighting period started at 5 AM and ended at 9 PM. After a long resting period, birds started their activity right when the lights were turned on. This phenomenon helped them release some body heat by the jump in SHP at 5 or 6 AM (Figure 2a). Birds produced more heat during the lighting period compared to the darker period due to their increased activities like walking, feeding, standing, etc. (Akter et al., 2022). The effect of High AV is more evident in flocks 1, 3, and 4 as those flocks had a more stressful thermal condition, and hence the difference in High and Low AV treatments were more prominant. Figure 2a shows how the difference between two treatments increased in the daytime which responded to the increased air T. Flock 3 and 4 describes the higher SHP occurred from noon to afternoon time under High AV treatment. Flock five exhibits no difference between treatments due to the least application of AV treatments.

Moisture produced by chicken depicts a diurnal pattern (Figure 2b) except for the 2nd flock. According to the ANOVA test (Table 10), the amount of moisture was significantly affected by AV treatments for all the flocks except for the second one. From the Figure 2b, it is evident that the birds produced more moisture under High AV compared to than that of Low AV during day time.



(a) (b)

**Figure 2. Diurnal variations of broilers' (a) sensible heat and (b) moisture production under air velocity treatments in summer conditions**

**Table 10. Analysis of variance test report to check AV treatment and hour of the day's effect on broiler's MP in summer**

ANOVA table for daytime effect on MP

| Flock | Factor | Df | SSE | MSE | F | *p*(>F) |
|---|---|---|---|---|---|---|
| 1 | AV | 1 | 537 | 537.1 | 10.789 | 0.00111 ** |
|  | Hour | 23 | 3369 | 146.5 | 2.942 | 9.14e-06 *** |
|  | AV x Hour | 23 | 198 | 9.4 | 0.189 | 0.99998 |
| 2 | AV | 1 | 6.47 | 6.466 | 3.541 | 0.0631 . |
|  | Hour | 13 | 21.36 | 1.643 | 0.9 | 0.5565 |
|  | AV x Hour | 6 | 17.97 | 2.994 | 1.64 | 0.1455 |
| 3 | AV | 1 | 134222 | 134222 | 865.464 | < 2e-16 *** |
|  | Hour | 23 | 22471 | 977 | 6.3 | < 2e-16 *** |
|  | AV x Hour | 23 | 10065 | 438 | 2.822 | 9.43e-06 *** |
| 4 | AV | 1 | 471 | 470.9 | 11.332 | 0.00087 *** |
|  | Hour | 14 | 4325 | 308.9 | 7.433 | 4.08e-13 *** |
|  | AV x Hour | 12 | 1274 | 106.2 | 2.554 | 0.003254 ** |

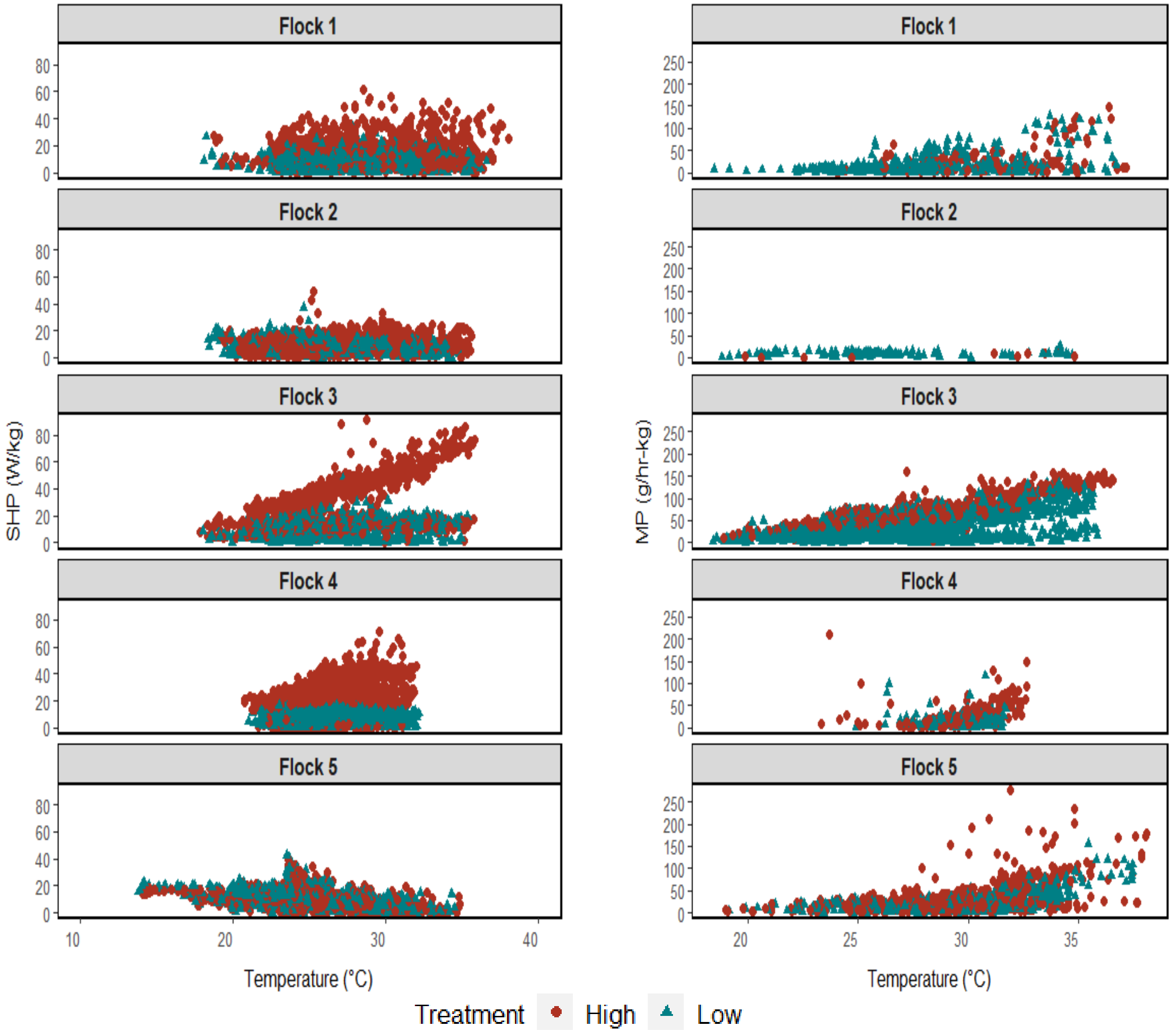
|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | AV | 1 | 169 | 169.1 | 13.706 | 0.000228 *** |
| 5 | Hour | 17 | 9399 | 552.9 | 44.817 | < 2e-16 *** |
|  | AV x Hour | 15 | 132 | 8.8 | 0.712 | 0.774396 |

Significance. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

### EFFECT OF ENVIRONMENTAL TEMPERATURE ON BROILER'S HEAT AND MOISTURE PRODUCTION

Birds transfer body heat to the surrounding air through convection or radiation. Although the Figure 3a does not show a direct relationship between increased SHP and increased T for all flocks, but in most cases, it is evident that the birds released more heat under High AV treatments. However, the difference between High and Low AV incrdeased with increased air T. When the air T increased, the High AV helped the birds release more heat from their body surface to the surrounding air and the birds under Low AV released lower SHP. Under Low AV, birds had significantly higher surface temperature (Akter et. Al., 2022) indicating chickens' body trapped the excessive heat instead releasing. This could be lethal if not taken necessay steps right away. The treatment effect was not noticeable during the 5th flock because of the lower magnitude of AV.

Simmons et al. (1997) found birds decreased SHP with increased ambient T (29~35 $^{o}$C), but an increase in AV (from 1.02 m/s to 3.05 m/s) increased 80-90% SHP for five to six-week-old birds. They also inferred the increased T caused a shift from sensible to latent heat loss. Liang et al. (2012) also discovered broilers' SHP decreases with increased T, but their LHP increases in the presence of sprinklers. In our experiment, we also found bird's MP increased with increased T (Figure 3b) during 3rd, 4th and 5th flock, indicating bird's attempt to produce LHP in higher T.



(a) (b)

**Figure 3. Environmental temperature's effect on sensible heat and moisture production by broilers under AV treatments**

## CONCLUSIONS

Sensible heat and moisture production rates of current market-sized broilers of BW from 2 to 5 kg in hot and humid summer conditions were assessed using indirect calorimetry under two AV treatments. The average SHP and MP for birds aged 35 to 61 d are 5 to 23 w/kg and 4 to 37 g/hr-kg, respectively, higher than SHP production values in the literature, indicating a necessity for ventilation updates in the existing structures. Bigger birds release higher sensbile heat and moisture with the help of high AV under stressful thermal conditions at an older age. So, the current buildings should ensure optimized uniform AV all over the house to provide a comfortable environment for the birds, especially during heat stress episodes. Heavy broilers' SHP and MP vary diurnally; hence birds should be served with a dynamic thermal environment concerning their necessity to give their best performance. Environmental T and RH affect a birds' heat and moisture production. The SHP and MP values from this study will help guide the design and efficient ventilation systems for future facilities for improved performance and welfare of meat-producing birds.

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