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ASSESSMENT ON SPATIAL VARIABILITY OF TEMPERATURE AND RELATIVE HUMIDITY IN A TUNNEL VENTILATED BROILER HOUSE

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ABSTRACT

Providing an optimal thermal environment is essential for efficient broiler production, particularly in tunnel-ventilated broiler houses where temperature and humidity distributions can vary significantly. However, despite the complexity of tunnel ventilation systems, the homogeneity of temperature distribution within the broiler house cannot be guaranteed. In particular, poorly planned tunnel ventilation systems can cause significant differences in the house temperature distribution, leading to excessive heat in some areas and cold places in others, negatively affecting the comfort and welfare of birds, and decreasing production efficiency. This study investigates the spatial variability of temperature and relative humidity in a tunnel-ventilated broiler house equipped with an evaporative cooling system during the summer. Measurements were taken at nine different points over a 42-day period, and analyses were conducted to assess the uniformity of the indoor climate. The results revealed significant differences in temperature and relative humidity between measurement points when the evaporative cooling system was in operation ($p < 0.01$). The mean relative deviation analysis indicated that thermal uniformity for temperature was 0.0240 during the daytime and 0.0169 at night, showing better thermal uniformity during nighttime conditions. Furthermore, Pearson correlation analysis revealed a strong relationship between cooling efficiency and spatial temperature variation ($r = 0.656$, $p < 0.01$), showing that increased airflow is related to these variations. Similarly, relative humidity variation was significantly correlated with cooling efficiency ($r = 0.478$, $p < 0.01$). These findings highlight that it is important to properly determine the air velocity and the location of air deflectors during the design phase to ensure a uniform environment in the house.

Keywords: Broiler houses, Broilers, Tunnel ventilation, Thermal uniformity, Thermal environment

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INTRODUCTION

Providing a suitable indoor thermal environment (temperature, humidity, etc.) in broiler production is of utmost importance for the efficient and healthy development of the poultry industry. Understanding bioenergy (heat and humidity production) and the interaction between animals and their environment is essential for designing efficient modern production systems. In this process, it is also important to select ventilation, heating, and cooling requirements with the characteristics and capacity to meet the needs of the birds (Albright, 1990; DeShazer *et al*., 2009; Mutaf, 2012; Costantino *et al*., 2018).

Thermal comfort conditions for broilers should be between 26–34°C during the incubation phase and 19–25°C during the growing phase (Oliveira *et al*., 2020). Temperatures outside of comfort conditions can cause some diseases in birds or losses in productivity. Unsuitable relative humidity conditions in poultry houses also have a negative effect on production. It has been reported that maximum body weight in broiler chickens can be achieved in a relative humidity environment of 70–75% (Yahav *et al*., 1995; Yahav *et al*., 1996).

Tunnel ventilation systems are widely used in poultry houses and are an important tool in providing suitable environmental conditions in the summer months. These systems work on the principle of exhausting the air out with exhaust fans placed at one end of the poultry house and taking in fresh air through the air inlets (Simmons *et al*., 2003; Menegali *et al*., 2012). On hot days, humid and cool air is given to the interior by wetting the cooling radiators in front of the air inlet openings. These systems can be controlled manually or automatically when needed (Lott *et al*., 1998). The amount of ventilation needed in the house depends on factors such as the growth and development of the chickens and the outside temperature. Increasing the amount of ventilation means more fan operation and increased air speed in the broiler house (Linhoss *et al*., 2020; Al-Zaidi, 2022). Researchers have reported that optimal production performance is achieved when tunnel

ventilation speed is between 1.5 and 2.5 m s^{-1} (Yahav *et al*., 2001; Costantino *et al*., 2018; Çaylı *et al*., 2021). Higher air speeds have adverse effects on bird health (Webster and Czarick, 2000; Mutaf, 2012).

Sudden changes in air velocity can cause spatial differences in indoor temperature and relative humidity, which are usually due to the house design. This means that some regions are defined as more suitable and some as unsuitable in terms of environmental conditions, which may negatively affect the growth and development of birds (Mirzaee-Ghaleh *et al*., 2015; Coulombe *et al*., 2020). When temperatures are not uniform, birds tend to find comfort in cooler areas. This can prevent birds congregating in comfortable areas from getting enough food, leading to increased crushing and mortality rates (Yahav *et al*., 2001; Saltuk *et al*., 2020). Furthermore, temperature differences and thermal gradients within the house (Sohsuebngarm *et al*., 2019) can reduce the uniformity of flock performance and negatively affect the overall health and productivity of birds. Therefore, careful management of temperature distribution within the house is critical for both animal welfare and productivity (Webster and Czarick, 2000).

Tunnel ventilation and evaporative cooling systems, which are commonly used to cool broiler houses during periods of high temperatures, can create spatial differences in the thermal environment, potentially hindering the desired production performance. This study focuses on the thermal variability within the indoor environment of a tunnel-ventilated broiler house. Temperature and relative humidity data, measured at various points in a broiler house equipped with tunnel ventilation and evaporative cooling systems during the summer months, were analyzed to investigate thermal environmental differences and the factors contributing to them.

MATERIALS AND METHODS

The study was conducted for 42 days during the summer period, covering the months of July and August in a commercial broiler production facility located in Kahramanmaraş Province. Temperature and relative humidity were measured at 9 different points. All data loggers in the interior environment were positioned 0.3 m above the ground, taking into account the body height of the animals, to best represent the actual environmental conditions they experience (Ferreira *et al*., 2024). The measurement setup layout is given in Figure 1.

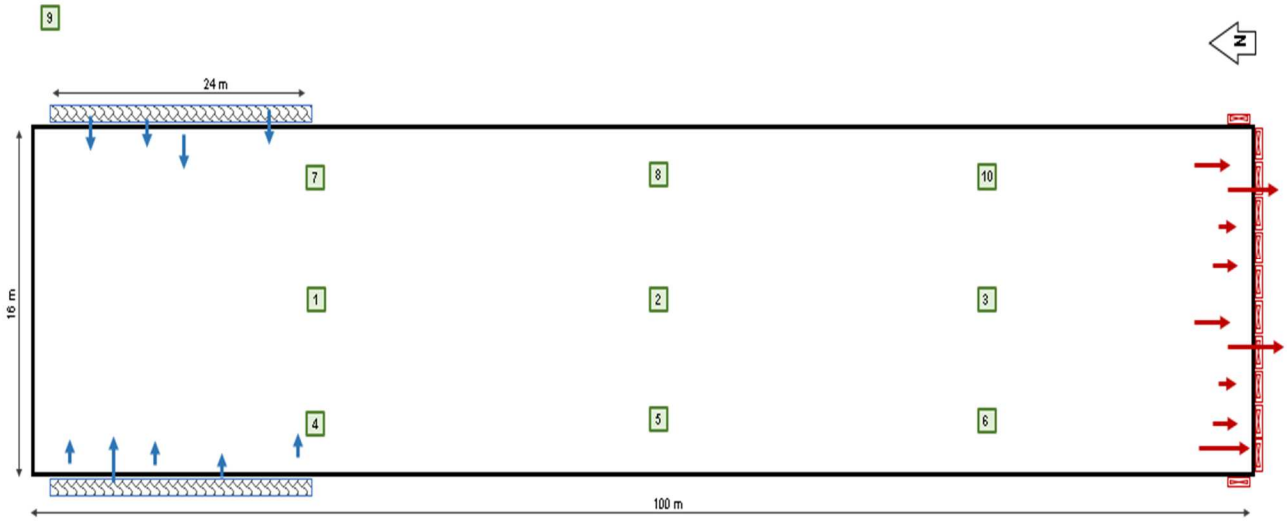

Figure 1. Location of data loggers in the poultry house

Considering the air movement within the house, it was assumed that there were three distinct thermal zones: entrance, middle, and exit. To accurately detect the temperature and humidity differences between these zones, the data loggers were placed systematically at equal distances. Three data loggers were positioned at 4.0 m intervals, starting from the center of the long side of the house. The sensors in the entrance and exit areas were placed 24.0 m away from those in the middle zone.

Measurements were made with HOBO U12 (Onset Computer Corp., MA, USA) model data loggers. The data loggers measure temperatures from -20°C to +70°C with an accuracy of ±0.35°C. The relative humidity measurement range is between 5% and 95%, with a precision of 2.5%. Measurements were made every 15 minutes.

The deep litter system was chosen as the poultry farming method in the house. Rice husk was used as the bedding material. During the study period, Ross 308

broiler chicks were used. The house, which has a total capacity of 25,000, was built with precast concrete structural elements. The side walls were created by mounting 0.05 m thick (expanded polystyrene) EPS-filled facade panels onto the precast structural elements. Similarly, EPS-filled facade panels were used in the roof cladding.

The house is 16.0 m wide, 100.0 m long, and has a floor area of 1600 m². The height of the side walls is 3.0 m, while the height of the roof ridge is 4.45 m. The tunnel air inlet openings on each sidewall of the house, 0.7 m above the ground, measure 1.0 × 24.0 m and have a total area of 48.0 m². The air inlet openings are equipped with 10.0 cm thick cooling pads made of cellulose-based material, which are wetted with water from the water tank by the pump when the evaporative cooling system is activated. There are also 40 sidewall inlets on each sidewall, for a total of 80. Each inlet measures 0.22 × 0.55 m and is sensitive to static pressures ranging from 0 to 30 Pa. The air outlets are located on the short side wall of the house using exhaust fans. There are 12 exhaust fans in the broiler house, each with a ventilation capacity of 40,500 m³ h⁻¹. The total ventilation capacity is 486,000 m³ h⁻¹.

According to long-term meteorological data, the region is dominated by hot Mediterranean climate conditions. The annual average temperature is 16.9°C, the annual highest average temperature is 22.9°C and the annual lowest average temperature is 11.4°C. The highest temperature was measured as 47.2°C in August, and the lowest temperature was -9.6°C in February (MGM, 2024).

The collected data were classified and analyzed for two different conditions: daytime and nighttime. Considering the seasonal variations in day length, measurements taken between 06:00 and 19:15 were categorized as daytime data, while those taken between 19:30 and 06:15 were classified as nighttime data.

The mean relative deviation (MRD) method serves as an effective statistical measure for assessing the distribution and variability of data. MRD quantifies the deviation of data points from the mean value within a given set of measurements, facilitating comparisons of variability across multiple points (Johnson and Wichern, 2002; Ryan, 2011). In this study, we evaluated the spatial variability of temperature and relative humidity based on sensor measurements using the MRD method. Additionally, we examined the maximum difference between the average sensor values and the standard deviation of these averages. While the maximum difference and the average standard deviation indicate the degree of variability in the measurements, MRD reflects uniformity, with lower MRD values indicating better uniformity. We calculated MRD with the formula given below (Wang and Franz, 2015; Ferentinos *et al*., 2017).

$$MRD = \sum \left(|V_i - V_m| \,/\, (N \cdot V_m) \right), i = 1N$$

Here, N represents the number of measurements for a specific variable, V_i denotes the i'th measurement, and V_m is the average value of all N measurements. In addition, MRD values were correlated with cooling efficiency to determine how the evaporative cooling system affected temperature and relative humidity uniformity in the house. The evaporative cooling efficiency for this poultry house is calculated with the following equation (ASHRAE, 2011; Von Zabeltitz, 2011; Çaylı *et al*., 2021).

$$\eta = 100 \times \frac{t_{o,db} - t_{in,db}}{t_{o,db} - t_{o,wb}}$$

Where, η = cooling efficiency (%), $t_{o,db}$ = outdoor dry bulb temperature (ºC), $t_{in,db}$ = dry bulb temperature of the air coming out of the pad (ºC), $t_{o,wb}$ = outdoor wet bulb temperature (ºC). The outdoor wet bulb temperature was calculated using the following equation (Stull, 2011).

$$T_{wb} = T tan^{-1}\left[0.151977\,(RH + 8.313659)^{\frac{1}{2}}\right] + tan^{-1}(T + RH) - tan^{-1}(RH - 1.676331) + 0.00391838(RH)^{\frac{3}{2}}\, tan^{-1}(0.023101RH) - 4.686035$$

Where, T_{wb}= wet bulb temperature (ºC), T dry bulb temperature (ºC), RH = relative humidity (%).

The data collected in the study was analyzed using IBM SPSS Statistics (version 22) software. The normal distribution of the data was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. In particular, the conformity of the data to normality distribution was tested, and appropriate non-parametric tests were applied for data that did not show normal distribution. Analysis of variance (ANOVA) and independent sample t-tests were utilized to assess the regional variability of temperature and relative humidity values.

RESULTS AND DISCUSSION

The average indoor temperature values measured at nine different points were ranged from 30 to 35°C during the first week and subsequently dropped to 25 and 30°C. As the production period ended on the 40th day, it is notable that the indoor and outdoor temperatures were almost equal during the last two days. The temperature differences between the inside and outside were significant ($p < 0.05$), suggesting that the cooling system induced a measurable and consistent change in the environment. In broiler chicken production, it is recommended that temperatures be maintained at 30°C during the brooding period, which is the first week. Furthermore, elevated temperatures exert stress on the thermoregulatory systems of broilers, leading to

decreased feed intake and growth rates (Wasti *et al*., 2020). Research indicates that rising temperatures lead to a decline in feed conversion ratio and a reduction in meat yield (Yahav and McMurtry, 2001; He *et al*., 2018). Excessive heat stress and departures from the optimal growth temperature range might induce behavioral alterations and elevate death rates (May *et al*., 2000; Chaiyabutr, 2004; Nawab *et al*., 2018; Kim *et al*., 2021). In this context, it is evident that the thermal conditions during this period meet the environmental needs of the chicks. According to the literature, varying temperature values in the period following the first week, depending on the growth development of the chickens, contribute to better production performance (Lindley and Whitaker, 1996). The recommended temperature for the first week is 30°C, followed by 24°C in the second week, and 20°C from the fourth week onwards (Mutaf, 2012; Çaylı, 2024b). As illustrated in the graph, the temperatures within the house remain between 25-30°C starting from the second week. Notably, the recommended temperature of 20°C has not been achieved, particularly in the final weeks, and fluctuations of 4-5°C between day and night temperatures have been observed. These fluctuations can be attributed to several factors including, ineffective operation of the ventilation system, system deactivation at night, inadequate wetting of the cooling pads, and occasional manual control.

Figure 2 displays the indoor and outdoor relative humidity measurements taken during the production period. The indoor relative humidity values in the graph represent the average readings from nine distinct measurement points.

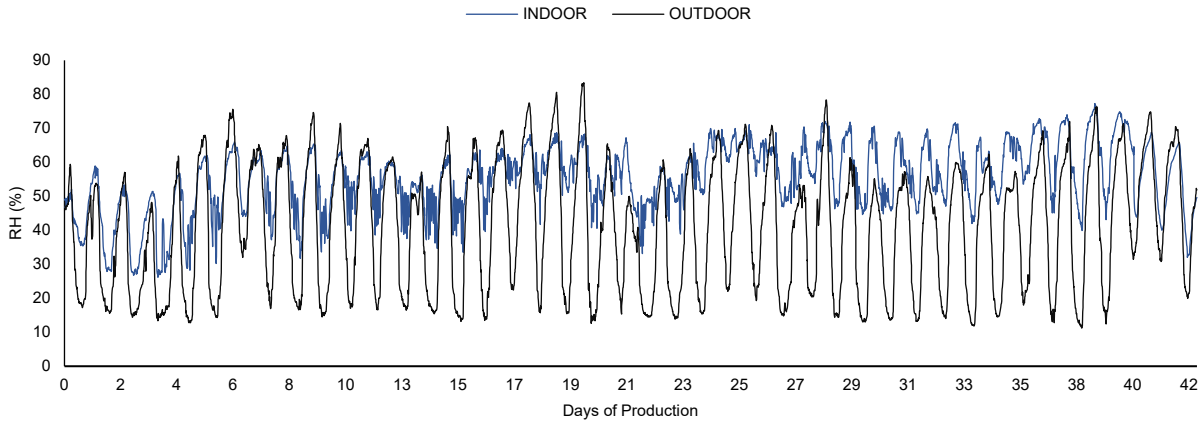

Figure 2. Indoor and outdoor relative humidity during the production period

Figure 2 shows that the outdoor relative humidity remained low during the day and high at night, ranging from 11% to 84% throughout the production period. The difference in relative humidity between indoor and outdoor conditions was significant ($p < 0.05$). This result indicates that the evaporative cooling system has a visible effect on indoor humidity levels. The indoor relative humidity, especially during the daytime, differed significantly from outdoor. Nevertheless, indoor relative humidity ranged from 26% to 72%, while the optimal range for production is 50-75% (Mutaf, 2012; Oloyo, 2018). Low relative humidity in poultry houses may dry out chicken airways, increasing mucus production and susceptibility to respiratory infections. This increases the risk of respiratory diseases and infections. In addition, low humidity negatively affects feed efficiency by increasing water consumption in chickens, which can lead to suboptimal growth and productivity (Anonymous, 2019). Figure 3 illustrates the cooling efficiencies calculated throughout the production process.

The cooling system was not used during the first week, as chicks required a temperature of 30°C (Figure 3). Instead, only minimum ventilation was used. After the first week, the system operated during the day, generally achieving a cooling efficiency of over 50%. The efficiency of the cooling system largely depends on external climate conditions, particularly relative humidity (Çaylı *et al*., 2021). In the research area, the outdoor daytime relative humidity generally ranged between 15% and 25%. These data suggest that they positively contributed to the cooling efficiency of the evaporative system that operated during the day.

Table 1 provides the daytime and nighttime average temperature and relative humidity values recorded by each sensor, along with the maximum mean difference and corresponding standard deviation. Additionally, the table includes the standard deviation of the means and the MRD (Mean Relative Deviation) of the means.

The data reveal that the maximum temperature difference between sensors occurs during the day

(1.35°C), and the minimum difference is found at night (0.79°C). The disparity in relative humidity during the day is 10.16%, while at night it is 8.38%. An assessment of the data using the uniformity criterion MRD indicates that both temperature and relative humidity distributions demonstrate more uniformity during the night. The MRD for temperature is 0.0169 at night and 0.0240 during the day, whereas the MRD for relative humidity shows a comparable pattern, with reduced values at night. This is probably due to reduced cooling requirements at night, as fewer fans function, resulting in lower air circulation and improved uniformity in temperature and humidity. As the external temperature gets closer the evaporative cooling threshold at night, the quantity of active fans in the tunnel ventilation system diminishes. Thus, the reduced indoor air velocity may have allowed enhanced uniformity in temperature and relative humidity.

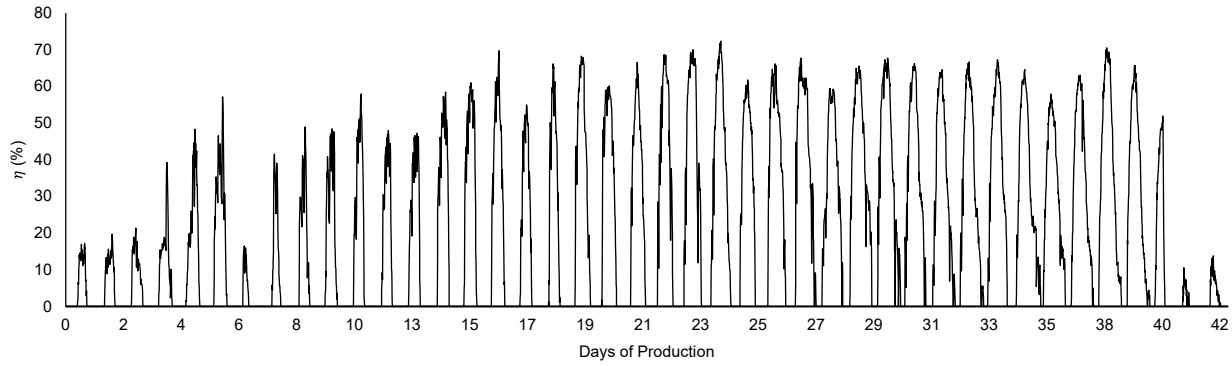

Figure 3. Evaporative cooling efficiency (η) during the production period

Table 1. The spatial uniformity statistics derived from temperature and relative humidity measurements.

Sensor Number	Temperature (°C)				Relative Humidity (%)			
	Day (06.00-19.00)		Night (19.00-06.00)		Day (06.00-19.00)		Night (19.00-06.00)	
	Avg.	Std.	Avg.	Std.	Avg.	Std.	Avg.	Std.
1	29.9	2.5	27.9	2.3	47.3	9.9	57.4	8.4
2	30.1	2.5	28.3	2.2	49.3	9.6	58.1	8.3
3	30.5	2.1	28.6	2.0	47.6	9.4	56.2	8.1
4	29.2	2.7	27.9	2.1	53.7	10.3	60.3	8.4
5	30.1	2.4	28.5	2.1	49.9	9.9	57.9	8.5
6	30.5	2.2	28.7	1.9	53.1	9.5	61.2	7.9
7	29.2	2.7	27.9	2.2	57.5	10.8	64.6	8.8
8	30.2	2.3	28.4	2.1	54.0	9.8	62.6	8.7
9	30.5	2.0	28.6	1.9	50.4	9.5	58.7	8.0
Max diff.	1.35		0.79		10.16		8.38	
Avg std.	0.51		0.32		3.36		2.72	
Avg MRD	0.0240		0.0169		0.0979		0.0672	

This section examines the effect of evaporative cooling, a factor affecting indoor thermal integrity. Evaporative cooling works on the principle of converting sensible heat into latent heat by increasing the humidity of the incoming air. Fans placed at one end of the house exhaust indoor air, reduce the indoor pressure and draw in outdoor air through wet pads. This process increases the humidity of the incoming air inside the house. Due to technical limitations, we were unable to measure indoor air velocity in this study. Therefore, we assumed that there is a direct relationship between evaporative cooling efficiency and air velocity. Based on this assumption, we sought a correlation between MRD and cooling efficiency. We investigated the impact of cooling efficiency on indoor thermal integrity.

The relationship between the MRD of temperature and cooling efficiency was analyzed for daytime, nighttime, and daily. The results indicate a significant correlation, demonstrating a directly proportional relationship. To assess this relationship, a Pearson correlation analysis was conducted. The correlation coefficients for daytime, nighttime, and daily

MRD of temperature in relation to cooling efficiency were 0.083 ($p < 0.01$), 0.085 ($p < 0.01$), and 0.656 ($p < 0.01$), respectively. These statistically significant correlations, based on temperature values measured at various points within the house, suggest that cooling efficiency influences temperature uniformity. Increased air velocity inside the house, resulting from the operation of the cooling system, may lead to temperature variations at different measurement points. Additionally, the lower MRD observed at night may be attributable to the cooling system operating for shorter durations during this period. Similarly, the relationship between the MRD of relative humidity and cooling efficiency was examined for daytime, nighttime, and daily periods. A significant correlation was found between the MRD of relative humidity measurements and cooling efficiency. The correlation coefficients for daytime, nighttime, and daily MRD of relative humidity in relation to cooling efficiency were 0.544, 0.321, and 0.478, respectively, all statistically significant ($p < 0.01$). This indicates that as cooling efficiency increases, the MRD value of relative humidity measurements within the house also rises. A high MRD value signifies low uniformity, suggesting that the operation of the cooling system reduces the uniformity of relative humidity inside the house.

Evaporative cooling is a common practice in broiler chicken houses to improve the environmental conditions for birds. However, its effectiveness in providing a uniform temperature and humidity distribution in the indoor environment is controversial, especially in hot climate conditions (Çaylı, 2024a). Other studies have reported that ventilation or evaporative cooling systems can negatively affect thermal uniformity in indoor conditions (Sohsuebngarm *et al*., 2019; Park *et al*., 2021; Ma *et al*., 2022). In particular, as noted in the study by Blanes-Vidal *et al*. (2007), traditional ventilation systems employed in hot and humid climates fail to deliver high and uniform air velocities at the bird level, resulting in negative impacts on bird comfort. However, producing broiler chickens without cooling systems in hot climates makes it difficult to protect the birds from temperature and humidity stress and negatively affects their productivity (Yalcin *et al*., 1997; Muhieldeen *et al*., 2019; Saltuk *et al*., 2020). In this context, despite the limitations of cooling systems in achieving indoor uniformity, it is essential to design these systems appropriately to ensure the health and productivity of broilers in hot climate conditions. Optimizing the design of cooling systems and ventilation strategies in production processes to meet the needs of birds can provide a more balanced and healthier environment in terms of both temperature and humidity.

Conclusion: The notable temperature fluctuations in a tunnel-ventilated broiler house, especially during the operation of the evaporative cooling system were noted. Elevated air velocity resulted in spatial variations, but nocturnal conditions exhibited enhanced thermal homogeneity. Effective ventilation and cooling are crucial for sustaining a stable interior environment in elevated temperatures. Enhancing climate management measures based on these findings can improve broiler productivity and welfare.

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Conflict of interest: The author declares no conflict of interest.

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