INVESTIGATION OF THERMAL ENVIRONMENT UNIFORMITY IN A TUNNEL-VENTILATED BROILER HOUSE IN THE SUMMER

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Abstract. In broiler farming, providing a suitable environment for the birds in the summer months when temperatures rise is very important for bird health and high productivity. In the summer months, broiler houses are generally cooled using evaporative cooling techniques. This can lead to an increase in relative humidity (RH) while lowering the temperature in the indoor environment, which can negatively affect thermal uniformity. This study aims to evaluate the thermal environment by spatially examining environmental factors, including temperature, RH, and temperature-humidity index (THI), in a tunnel-ventilated broiler house. For this purpose, evaluations related to problematic areas and heat stress formations were conducted using temperature and RH data collected from multiple indoor locations throughout the summer season in a commercial broiler facility. The findings revealed a significant temperature difference in the broiler house, with the exhaust fan area exhibiting higher temperatures than the air inlet area. Moderate levels of heat stress were recorded during the daytime hours, indicating that additional cooling measures may be necessary. Moreover, there was a more homogeneous heat distribution at night compared to the daytime.
Keywords: *animal welfare, environmental conditions, temperature-humidity index, THI, cooling*

Introduction

Broiler houses widely use ventilation and cooling systems to provide suitable environmental conditions. Mechanical ventilation, the main element of cooling systems, has basic functions such as removing generated heat and excess moisture, minimizing odor and dust, limiting the accumulation of harmful gases, and providing the oxygen necessary for respiration (Barnwell and Rossi, 2003). Temperature, in particular, is the main environmental factor affecting the health, behavior, and production of poultry (Mutaf, 1988, 2012; Wang et al., 2019). The required temperature range for broiler houses varies between 20°C and 32°C depending on the growth stage. During the brooding period, higher temperatures are necessary, but toward the end of the production period, lower temperatures were preferred. According to Yalcin et al. (1997), broilers exposed to high temperatures experienced a 23% reduction in body weight and a 15% reduction in food consumption compared to their counterparts reared at optimum temperatures between 18°C and 20°C, which achieved optimum growth conditions for adult broilers.

Similar to high temperatures, high humidity negatively affects feed conversion, weight gain, and feather formation in birds. Milligan and Winn (1964) reported that high humidity has a significant effect on productivity at temperatures above 35 °C. In poultry production, especially in commercial broiler production with high growth potential, inadequate environmental conditions create stress in chickens, reduce feed intake and productivity, and increase mortality rates (Arjona et al., 1988; Warriss et al., 2005; Garriga et al., 2006; Kocaman et al., 2006; Mutaf, 2012; Jahromi et al., 2016; Boyacı, 2018). Therefore, poultry houses widely use evaporative cooling methods such as fan pads, water spraying, fogging, and misting techniques to provide a comfortable

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environment for birds, particularly in high-temperature regions where heat stress poses a significant problem.

Although achieving the desired temperature reduction in broiler houses cooled with these systems is an important, however challenging criterion (Miragliotta et al., 2006) due to the structure of the system. This is because, depending on the speed, the cold air entering the house heats up toward the exit, potentially causing significant differences in spatial thermal conditions. Increasing the air speed (i.e., increasing the amount of air exchange per unit time) may be a solution to prevent spatial thermal variability (Webster and Czarick, 2000). However, prolonged exposure to high air speed has negative effects on the health of the birds (Furlan et al., 2000). According to Yahav et al. (2001), the recommended air speed range to maintain comfort and high production is 1.5 to 2.5 m/s. When the temperature is not uniform, birds tend to congregate in cooler areas of the house where they feel comfortable, leading to inadequate feeding, thereby increasing the risk of crushing and mortality.

The lengthways temperature gradient in tunnel-ventilated broiler houses may occur due to factors such as the physical structure of the house, the ventilation system, and the inadequacy of mechanisms to distribute heat evenly. This gradient causes heat accumulation, especially at one end of the house, and lower temperatures at the other end. The temperature gradient significantly influences the house's thermal homogeneity (Xin et al., 1994), which can adversely impact the welfare and productivity of broilers. This is because chickens may congregate in one area of the house for thermal comfort, potentially leading to excessive densification. This can lead to increased stress levels, increased disease risk, and decreased growth performance. In addition, the thermal gradient reduces the homogeneity of flock performance in the house (Webster and Czarick, 2000). Providing optimal environmental conditions in poultry farming has a critical impact on bird welfare, health, and production efficiency. Kahramanmaraş province, where the study was conducted, is under the influence of the Mediterranean climate and is characterized by high temperatures and low humidity in the summer months. While temperatures generally exceed 35°C in the summer months, relative humidity can drop below 20% during daylight hours. These climatic conditions increase the risk of heat stress in broiler farming and can negatively affect animal welfare. High temperatures can cause reduced feed consumption, reduced growth rates, and increased mortality rates. In particular, the performance of tunnel ventilation systems in balancing temperature and relative humidity is crucial, as is the extent to which these systems contribute to animal welfare. We planned the study to address the need for effective ventilation systems to reduce the thermal stress broilers face in hot climate conditions. The main purpose of this study is to analyze how environmental parameters such as temperature, RH, and temperature-humidity index (THI) change spatially in a tunnel-ventilated broiler house. The study seeks to ascertain the size of the temperature gradient within the house, assess the homogeneous distribution of environmental factors, and assess their potential impact on the birds' welfare. The study solely focuses on measurements conducted within a house environment and tunnel ventilation system. This study does not cover climate conditions in different geographical regions, the use of different ventilation and cooling systems, or seasonal changes. Furthermore, this study only examines summer conditions, so it does not present findings related to the winter period.

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Materials and methods

The study was conducted in a commercial broiler chicken house (37.355576, 37.301673, WGS84) located in Kahramanmaraş Province, southern Turkey. This broiler house examined in the study has similar design and operating characteristics to commercial poultry houses commonly used in Kahramanmaraş province and its surroundings. The house is equipped with a tunnel ventilation system and is supported by evaporative cooling pads and mechanical fans. In addition, the physical structure of the house, ventilation capacity, and operating conditions largely overlap with other commercial production facilities in the region. Therefore, it is evaluated that the findings obtained are representative of broiler production facilities in the study region and can be generalized. Oriented north-south, the house could accommodate a total of 20,000 chickens. It was 100 m long, 16 m wide, 2.85 m high on the side walls, and 4.45 m high on the roof ridge. The air inlet openings on both side walls of the house, measuring 1.0 m in height and 24.0 m in width, were equipped with 10 cm thick evaporative cooling pads. A total of 11 exhaust fans, each with a diameter of 1.2 m, ventilated the house, with 9 located on the south wall and one at each end of the side wall. The maximum ventilation capacity of these fans was 35,000 m^3 h^{-1}, and the power was 1.55 kW. During the cooling periods, ventilation was controlled manually in the first weeks and then mostly by the climate control system.

Fig. 1 illustrates the theoretical division of the broiler house into three equal sections: Section 1 (S1), Section 2 (S2), and Section 3 (S3). Each piece was thereafter partitioned into three segments along the width, with data loggers positioned at their midpoints. The data loggers recorded temperature and relative humidity at an elevation of 30 cm above the ground at 15-minute intervals. Hourly averages were calculated from these measurement data. Furthermore, temperature and relative humidity were recorded using a data logger positioned at a suitable location outside the house. HOBO U-12 data loggers (Onset Corp., MA, USA) were utilized for these measurements. These instruments can gauge temperatures ranging from -20°C to 70°C with an accuracy of ± 0.35°C and relative humidity from 5% to 95% with an accuracy of ± 2.5%. The measurement accuracies of the devices were verified against reference devices before their placement in the house. The assessments in this study were conducted using data collected during the summer, from July 1, 2020, to August 12, 2020. The graphs presented provide an overall evaluation of the thermal environment. Indoor and outdoor climate variables were statistically analyzed with each other.

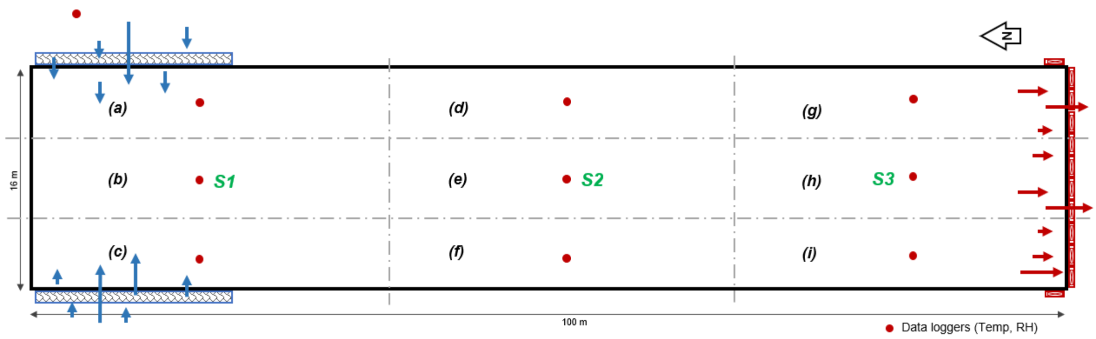

Figure 1. *The schematic layout of cooling and ventilation equipment along with data loggers in the broiler house*

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The coefficient of variation (CV) of the measurement values in the theoretical sections was calculated by the following *Equation 1* and used to compare the spatial variability of the sections in the house.

$$CV = \left(\sigma/_{\mu}\right)100\% \tag{Eq.1}$$

Here σ represents the standard deviation and μ represents the mean. CV is dimensionless, and values from one parameter to another can be compared regardless of what units are used for measurements. Warrick and Nielsen (1980), categorized the variability for houses as low if CV <12%, medium if CV <12%–24%, and high if CV > 24%. In this study, an evaluation was made on the variability of the sections according to CV values.

In this study, a spatial analysis was also performed based on the Temperature-Humidity Index (THI). THI is an important tool that helps to better understand thermal conditions by considering the combined effects of temperature and humidity (Gates et al., 1995; Purswell et al., 2012) and is widely used to quantitatively assess heat stress levels for animals (Ha et al., 2018). As the researchers emphasize, THI values were calculated using the equation recommended by LPHSI (1990) and adapted as given below. The calculated THI values were compared with certain limit values to evaluate the suitability of each section in terms of thermal comfort. The THI limit values are as follows: Normal <27.8, Moderate 27.8-28.8, Severe 28.9-29.9, and Very Severe (Emergency) ≥ 30.0 (Marai et al., 2001).

THI was calculated by the following *Equation 2*:

$$THI = T_{db} - [(0.31 - 0.31RH)(T_{db} - 14.4)] \tag{Eq.2}$$

Here THI is the temperature-humidity index, T_{db} is the dry bulb temperature (°C), and RH is the relative humidity (RH/100%).

In addition, to better understand and visualize the spatial variability within each house, spatial variability maps were created for temperature, RH, and THI variables during the day, day, and night periods. To create these maps accurately and precisely, a large number of point measurements were required, but in practice this was difficult and not possible. Therefore, the widely used Kriging spatial correlation modeling method was used (Krige, 1951; Matheron, 1971). This method mathematically estimated higher-resolution data for the entire house using the data measured at various points. SPSS and Minitab programs were used for statistical analysis. Surfer v9 was used to visualize spatial variability, Spyder 5.4.3 for processing and analysis of some data, some Python 3.11 libraries (numpy, matplotlib, pandas, scipy), and sci-kit (Pedregosa et al., 2011) were used. ANOVA was used to compare the data, and a Friedman non-parametric test was used for data that did not show a normal distribution. A Tukey post hoc test was performed to determine between which sections there were significant differences.

Results and discussion

Thermal environment analysis based on measurements in the broiler house, spatial variability between sections, contour maps, and visual analysis of the broiler house environment were used to identify problem areas. The daily average indoor and outdoor air temperature during the production period is shown in *Fig. 2*.

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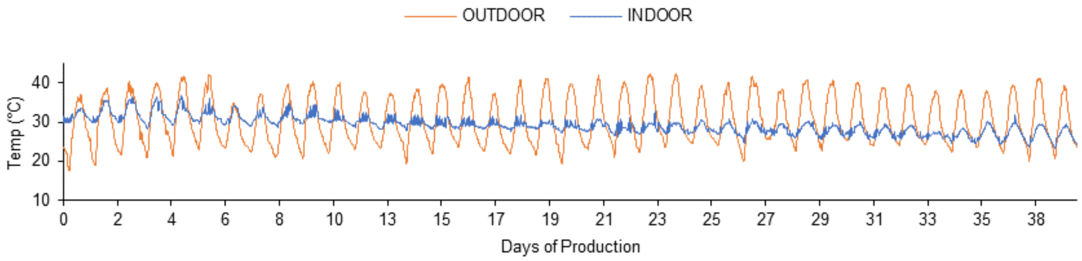

Figure 2. *Average daily temperatures in indoor and outdoor environments*

When *Fig. 2* is examined, it is observed that the outdoor temperatures show a cyclical pattern, reflecting daily fluctuations, whereas the indoor temperature fluctuations are more limited. Indoor temperatures ranged from 23.1°C to 36.7°C, with an average temperature of 29.2°C. Outdoor temperatures ranged from 17.6°C to 42.5°C, with an average of 30.4°C. The difference between indoor and outdoor temperatures was found to be statistically significant ($p < 0.001$). Daily average indoor and outdoor RH values during the production period are presented in *Fig. 3*.

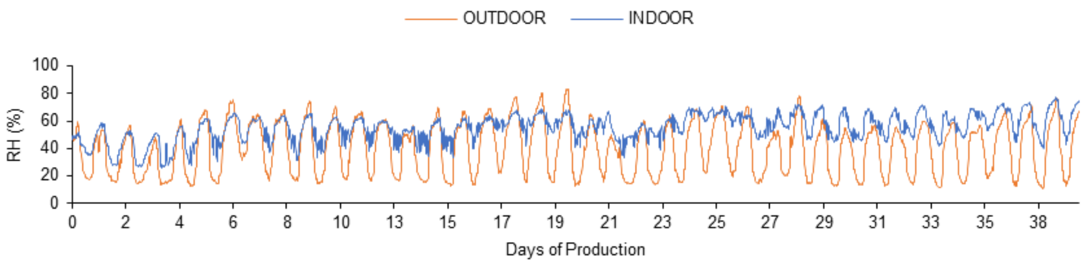

Figure 3. *Average daily RH in indoor and outdoor environments*

Examining *Fig. 3* reveals significant fluctuations in the outdoor relative humidity based on the day-night cycle. Since the summer season is generally dry in the region, the relative humidity rate drops below 20% during the day. The fluctuations were more limited indoors. While the indoor relative humidity varied between 25.0% and 77.3%, the average value was determined as 55.4%. The outdoor relative humidity varied between 11.2% and 83.4%, and the average was measured as 40.7%. The difference between indoor and outdoor relative humidity was found to be statistically significant ($p < 0.001$).

There were fluctuations in all parameters during the production period. Outdoor temperatures showed a slight increasing trend over time. Indoor temperature remained more constant, but there was a steady decrease toward the end of the production period. RH showed significant fluctuations for both indoor and outdoor air and was higher toward the end of the production period than in the first weeks. These observations suggest that the indoor environment was managed to some extent, probably through climate control systems, as less variability was observed compared to the outdoor environment. *Fig. 4* provides average daily THI values for both indoor and outdoor environments as a measure of heat stress.

Examining *Fig. 4* reveals that the indoor THI values range from 25.1 to 29.3. The outdoor THI changed between 25.1 and 28.6, and its average value was calculated as 27.1. The difference between indoor and outdoor areas was not found to be statistically

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significant ($p > 0.05$). Significant fluctuations were observed between day and night in outdoor THI values. However, the indoor area showed a more balanced course after the first 12 days. Higher temperature requirements during the first twelve days of the chick period caused the THI value to be above 27.8. According to the THI values calculated with average daily data, it was determined that heat stress conditions did not occur in the broiler house.

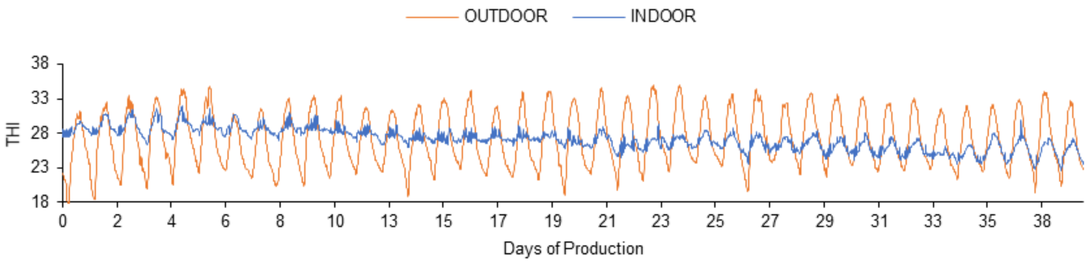

Figure 4. *Average daily THI in indoor and outdoor environments*

Lengthways spatial variability of temperature, humidity, and THI in the broiler house

In this section, the changes in the temperature and relative humidity measured in the broiler house were examined by analyzing the data classified as daily, night, and day. *Table 1* presents the descriptive statistics for daily average temperature, relative humidity, and THI on a section basis, along with the CV value.

Table 1. *Descriptive statistics and CV values for daily climate variables*

Section	Variable	Mean	Median	Std. E.	Std. D.	Min	Max	CV (%)
S1	Temp	28.7	28.4	0.175	1.967	25.7	33.2	6.8
	RH	56.6	56.2	0.688	7.720	38.8	72.0	13.6
	THI	26.7	26.6	0.129	1.444	24.5	29.9	5.4
S2	Temp	29.3	28.9	0.164	1.836	26.4	33.0	6.3
	RH	55.1	55.8	0.633	7.109	36.7	68.8	12.9
	THI	27.2	27.0	0.120	1.352	28.4	29.7	5.0
S3	Temp	29.6	29.4	0.132	1.485	27.2	32.4	5.0
	RH	54.3	55.5	0.599	6.722	34.6	66.9	12.4
	THI	27.4	27.4	0.097	1.088	25.4	29.4	4.0

ANOVA results show that there is a significant difference in temperature between sections ($p < 0.001$). Pairwise comparisons revealed that there were significant differences between all sections. Accordingly, S1 was significantly colder than S2 (diff = -0.6°C, p < 0.0001) and S3 (diff = -0.9°C, $p < 0.0001$). S2 was significantly colder than S3 (diff = -0.3°C, $p < 0.0001$). RH analysis results also show that there was a significant difference in RH between sections (p < 0.001). Pairwise comparisons revealed that there were significant differences between all sections. S1 had significantly higher RH than S2 (diff = 1.5%, $p < 0.0001$) and S3 (diff = 2.3%, $p < 0.0001$), while S2 had significantly higher RH than S3 (diff = 0.8%, p = 0.0120). The analysis results for THI also showed that the difference between sections was significant, as was the case for

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temperature and RH ($p < 0.001$). Pairwise comparisons revealed significant differences between all sections ($p < 0.0001$). *Table 2* presents the CV value along with descriptive statistics for daytime mean temperature, RH, and THI.

Table 2. *Descriptive statistics and CV values for daytime climate variables*

Section	Variable	Mean	Median	Std. E.	Std. D.	Min	Max	CV (%)
S1	Temp	29.3	28.9	0.066	2.632	23.8	36.7	9.0
	RH	53.1	53.8	0.274	10.912	23.8	78.7	20.6
	THI	27.1	26.9	0.047	1.865	22.7	32.0	6.9
S2	Temp	30.1	29.7	0.060	2.400	23.9	36.7	8.0
	RH	51.3	51.5	0.247	9.810	24.0	73.8	19.1
	THI	27.7	27.5	0.043	1.707	22.9	32.3	6.2
S3	Temp	30.4	30.3	0.053	2.111	24.1	36.4	6.9
	RH	50.6	50.7	0.242	9.611	23.6	72.6	19.0
	THI	27.9	27.9	0.037	1.478	23.1	31.7	5.3

Examining the *Table 2* reveals that S1 (CV = 9.0%) exhibits the highest temperature variability during the day, while S3 (CV = 6.9%) displays the lowest variability. A similar situation is valid for relative humidity, but the values are quite close to each other. ANOVA results show that there is a significant difference in temperature between the zones ($p < 0.001$). Pairwise comparisons also reveal that there are significant differences between all zones. Accordingly, S1 is significantly colder than S2 (diff = -0.8°C, $p < 0.0001$) and S3 (diff = -1.1°C, $p < 0.0001$). S2 is significantly colder than S3 (diff = -0.3°C, $p < 0.0001$). The ANOVA results for RH showed that there was also a significant difference in RH between sections ($p < 0.001$). In pairwise comparisons, significant differences were found between all sections. S1 had significantly higher RH than S2 (diff = 1.8%, $p < 0.0001$) and S3 (diff = 2.5%, $p < 0.0001$), while the difference between S2 and S3 was not found to be significant (diff = 0.7%, p = 0.139). The analysis results for THI showed that the difference between sections was significant ($p < 0.001$). In daytime, pairwise comparisons for THI also showed significant differences between all sections ($p < 0.0001$). *Table 3* shows descriptive statistics and CV values for nighttime average temperature, relative humidity, and THI calculated from temperature and relative humidity values measured on a section basis.

Table 3. *Descriptive statistics and CV values for nighttime climate variables*

Section	Variable	Mean	Median	Std. E.	Std. D.	Min	Max	CV (%)
S1	Temp	28.0	27.8	0.059	2.231	22.8	33.6	8.0
	RH	60.5	61.2	0.242	9.185	27.2	82.8	15.2
	THI	26.3	26.2	0.045	1.707	22.1	30.3	6.5
S2	Temp	28.5	28.7	0.566	2.147	23.2	33.5	7.5
	RH	59.3	60.2	0.234	8.878	34.5	80.1	15.0
	THI	26.7	26.9	0.043	1.636	22.4	30.1	6.1
S3	Temp	28.7	29.1	0.051	1.952	23.0	33.5	6.8
	RH	58.4	59.7	0.221	8.385	30.1	76.9	14.3
	THI	26.8	27.1	0.040	1.508	22.0	30.1	5.6

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Examining the *Table 3* reveals that S1 (CV = 8.0%) has the highest nighttime temperature difference and S3 (CV = 6.8%) has the lowest. A similar situation applies to RH. It is understood that the average temperature and THI values in all compartments increase, but there is a decrease in CV values, and on the contrary, the CV values increase in RH.

The statistical analysis results showed that there was a significant difference in temperature between the zones ($p < 0.001$). Pairwise comparisons also revealed significant differences between all zones. S1 was significantly colder than S2 (diff = -0.5°C, $p < 0.0001$) and S3 (diff = -0.7°C, $p < 0.0001$). S2 was significantly colder than S3 (diff = -0.3°C, $p = 0.004$). The difference in RH between zones was also significant ($p < 0.001$). Pairwise comparisons of RH revealed significant differences across all zones. Accordingly, S1 had significantly higher RH than S2 (diff = 1.2%, $p < 0.0001$), and S1 had significantly higher RH than S3 (diff = 2.0%, $p < 0.0001$). The difference between S2 and S3 was not significant (diff = 0.8%, p = 0.029). ANOVA results for nighttime THI also revealed that the difference between compartments was significant, as was the case for temperature and RH ($p < 0.001$). In pairwise comparisons, there were significant differences between all compartments ($p < 0.0001$).

According to the CV classification categorized by Warrick and Nielsen (1980), the temperature and THI variability in the house under study were low, with a CV of less than 12%. However, the relative humidity variability was moderate. Anonymous (2019) reports that for bird comfort and health, there should be no temperature difference over 2.8°C throughout the house. The difference between the temperatures of compartments S1 and S3 was found to be 1.2°C in daily data, 1.1°C during the day, and 0.7°C at night. These findings demonstrated that the temperature variability throughout the house remained within acceptable limits, posing no threat to the comfort and health of the birds.

There was also a clear gradient in temperature from S1 (coldest) to S3 (warmest), and all differences were statistically significant. A reverse gradient was observed in RH, with S1 being the highest and S3 being the lowest. The difference between S2 and S3 was smaller than the others and was not significant. THI followed the same pattern as temperature, with S1 having the lowest THI and S3 having the highest THI. All differences were statistically significant. The increase in THI from S1 to S3 indicates that S3 was the least comfortable for the birds. However, it is important to note that although these differences are statistically significant, the absolute differences in means are relatively small (about 1°C for temperature, about 2% for RH, and less than 1 unit for THI). The practical significance of these differences will depend on the specific context and the sensitivity of the birds to these environmental conditions. However, these results suggest that the three zones have different microclimates. S1 is the coldest and most humid zone, S2 is intermediate in terms of both temperature and humidity, and S3 is the hottest and least humid zone.

Temperature, RH, and THI gradients throughout the house

The spatial temperature variability inside the house was investigated, and the temperature data obtained for this purpose were converted into heat maps in line with the methodology explained in detail in the materials and methods section of the study. *Fig. 5* is shown as a contour map presenting the temperature variability derived from the mean temperature data on a daily basis (a), separately for daytime hours (07:00–18:00) and nighttime hours (19:00–06:00).

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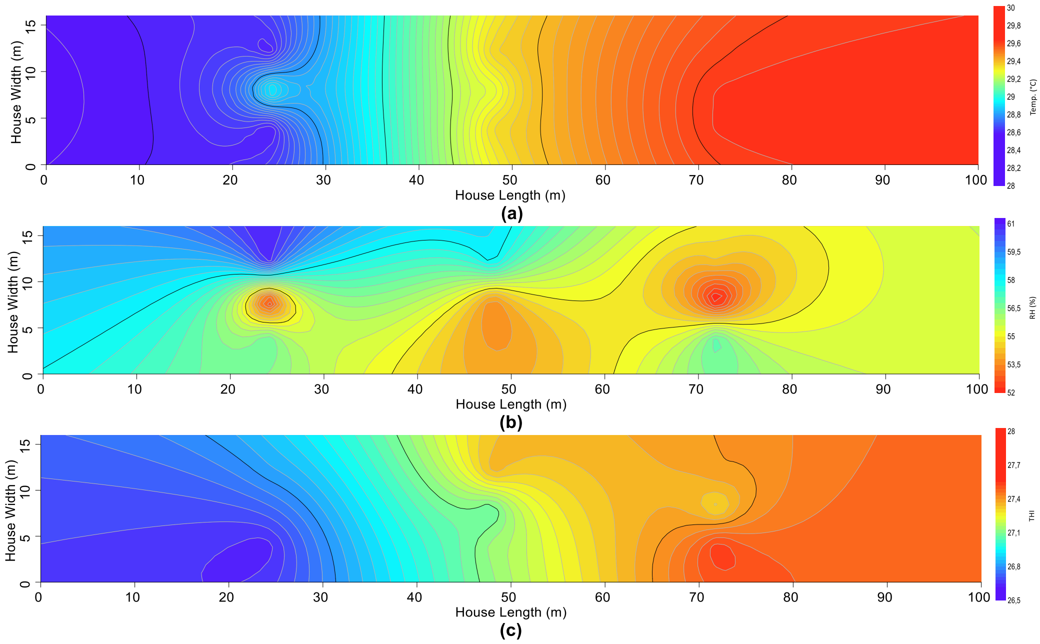

***Figure 5.** Temperature distribution estimation contour map. (a) daily, (b) daytime (c) nighttime*

The contour map in *Fig. 5* reveals that a temperature gradient is formed from the evaporative cooling pads to the exhaust fans. The temperature difference in this gradient reaches an average of 2°C in the daily data (*Fig. 5a*) and is 1.4°C during the daytime (07:00–18:00) and 0.9°C during the night (19:00–06:00). These findings are in general agreement with the data reported in the literature, but some important differences are also observed. In particular, the fact that the temperature difference is more pronounced in the daily data and a more balanced temperature distribution is observed during the nighttime suggests that the tunnel ventilation evaporative cooling system operates for a longer time due to higher temperatures during the daytime, while the system operates for a shorter time at night due to the outdoor environmental conditions being close to the comfort range. This may have resulted in a lower temperature difference during the nighttime.

Compared with the studies in the literature, the magnitude of this temperature gradient is below the maximum temperature difference limit of 2.8°C suggested by Anonymous (2019). This situation shows that the results of the current study are within acceptable limits and the temperature distribution in the house is kept at an optimal level. On the other hand, in a study conducted by Xin et al. (1994), it was reported that the temperature differences in the tunnel-ventilated house varied between 3.5°C in the winter and 0°C-1.8°C in the summer. The summer findings of Xin et al. (1994) coincide with the low daytime and nighttime temperature differences observed in our study, which supports the effective operation of tunnel ventilation and evaporative cooling systems in the summer months.

Wheeler et al. (2003) reported in a study that the temperature difference between the air inlet and outlet points was between 2.6 and 2.8°C and stated that such a temperature distribution remained within acceptable limits. In our present study, the average temperature difference was measured as 2°C, which is slightly lower than the findings of Wheeler et al. (2003). This difference may be due to various factors, from the specific environmental conditions in which the study was conducted to the effectiveness of the cooling pads used or the ventilation system parameters. However, since this difference

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still remains within the acceptable limits stated in the literature, it shows that the temperature distribution in the house is generally balanced and meets the desired conditions. *Fig. 6* presents a contour map showing the RH variability derived from the mean data on a daily, daytime, and nighttime basis.

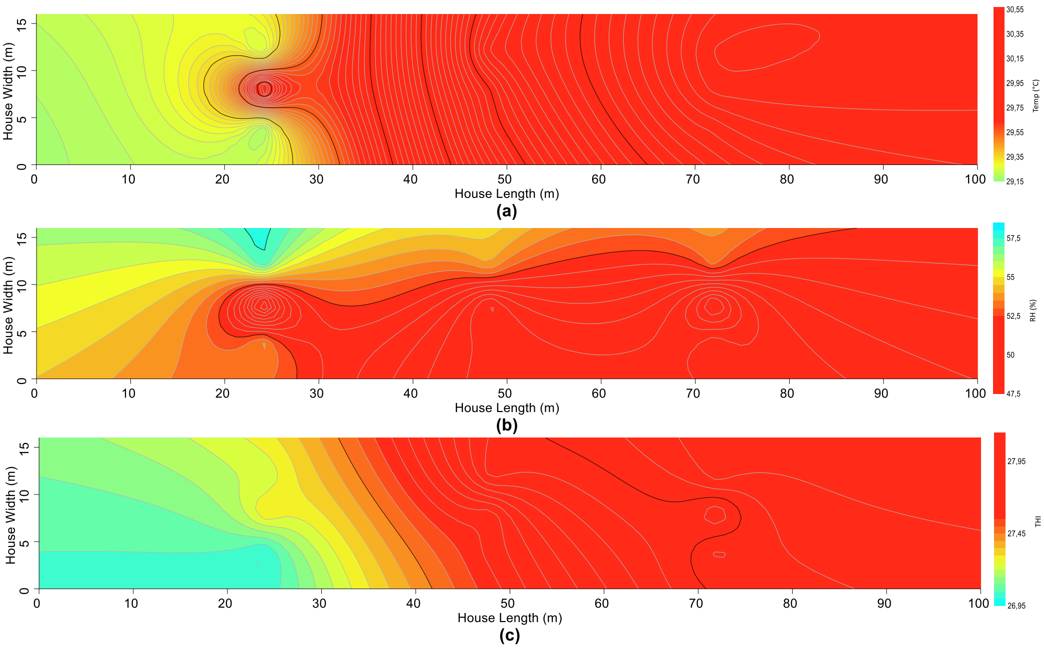

Figure 6. *RH distribution estimation contour map. (a) daily, (b) daytime (c) nighttime*

This increase in RH during the daytime occurs as a result of outdoor conditions and the intensity of the use of evaporative cooling systems. Increasing temperatures during the daytime lead to longer operation of the cooling system. According to the working principle of evaporative cooling systems, the evaporation of water increases the humidity of the environment and creates a gradient in the direction of air flow (Çayli et al., 2021). The fact that this gradient becomes more pronounced from the pads to the exhaust fans can be considered an indication that the system is working effectively. These findings reveal that the RH gradient is within acceptable limits and is largely consistent with other studies in the literature. *Fig. 7* presents a contour map showing the THI variability derived from the mean data on a daily, daytime, and nighttime basis.

The findings obtained in the study are of great importance in terms of evaluating the thermal conditions in the poultry houses and the heat stress to which the animals are exposed. The contour map presented in *Fig. 7* shows that a THI gradient is formed from the air inlet openings to the exhaust fans. This gradient exhibits an increase of 1.5 in daily data, 1.0 for daytime, and 0.75 units for nighttime. In addition, the lowest and highest THI values vary between 26.5°C–28.0°C daily, 26.95°C–27.95°C during daytime, and 26.1°C–26.85°C during nighttime, respectively.

The comparison of these findings with the THI limit values in the literature reveals that the thermal conditions in the poultry houses are generally within acceptable limits. The fact that the THI levels to which the animals are exposed are within this range indicates that a suitable environment is provided for the prevention of heat stress and for the healthy growth and development of the animals.

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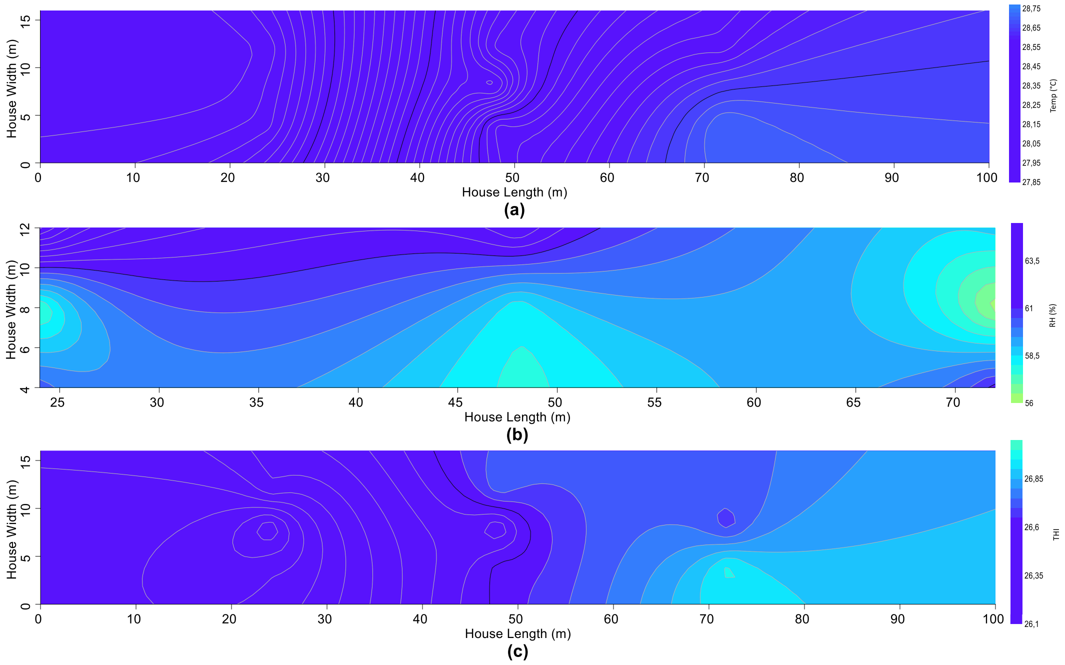

Figure 7. *THI distribution estimation map. (a) daily, (b) daytime (c) nighttime*

According to the THI limits determined by Marai et al. (2001), THI values below 27.8 are classified as normal 27.8–28.8 as moderate, 28.9–29.9 as severe, and ≥30.0 as very severe or heat stress requiring urgent intervention. The daily THI data yields the lowest value of 26.5 and the highest value of 28.0, suggesting that THI typically hovers between normal and moderate levels. In particular, the highest THI value of 28.0 reveals that it slightly exceeds the 27.8 limit and enters the moderate heat stress region but does not reach a severe stress level. THI values during the daytime indicate moderate heat stress in the house. This finding indicates that tunnel ventilation and evaporative cooling systems are working effectively, considering that temperature increases are more pronounced during the daytime. Purswell et al. (2012) stated that tunnel ventilation systems are effective in controlling heat stress, and the findings of this research also support this view. These systems provide sufficient thermal comfort by keeping the animals' exposure to heat stress at low levels during the daytime. THI values at night show that heat stress does not occur in the broiler house, and they remain completely within normal limits. According to Gates et al. (1995), heat stress on animals decreases during periods when THI is low, which provides better protection for animal welfare during the night. Lower THI values at night support that the tunnel ventilation system works more effectively and that the environment provides more constant thermal comfort. These findings are generally consistent with the limit values presented in the literature, indicating that heat management in the poultry houses is effective and that there is no excessive heat stress that would endanger animal welfare. However, the approach of THI values to limit values during the daytime may indicate the need for additional measures in extremely hot weather. Especially in the summer months when temperature increases are more intense, improving the performance of tunnel ventilation systems and evaporative cooling pads may be important to protect animal welfare.

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Conclusion

This study conducted a spatial analysis of the thermal environment in a tunnel-ventilated broiler house, examining factors such as temperature, RH, and THI. The results showed that there were spatial differences in the temperature and humidity distribution inside the house. The coldest and most humid area of the house was determined as S1, while the hottest and least humid area was determined as S3. The results showed that the temperature and humidity changes inside the house were within acceptable limits for the comfort and well-being of the birds. It was also understood that the temperature and humidity range during the production period was manageable, and the tunnel ventilation system provided a more uniform distribution of temperature and RH, especially at night. THI data showed that there was no serious heat stress in the broiler house; only moderate heat stress was experienced during the day. In order to provide equally suitable environmental conditions in the indoor sections, especially on extremely hot days, it is vital to determine the system capacity correctly and to take the necessary measures for more efficient operation. Although the internal conditions of the broiler house are ideal for production, the airflow pattern of the tunnel ventilation system should be optimized to minimize temperature differences in certain areas of the house, and the efficiency of evaporative cooling pads should be increased. Additionally, the use of automatic climate control systems can stabilize temperature changes. Such optimizations will encourage broilers to grow in a more comfortable environment, increasing productivity.

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