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Spatial variability of enthalpy and illuminance in free-range broiler sheds¹

Variabilidade espacial da entalpia e da iluminância em galpões de frangos caipiras

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HIGHLIGHTS:

*The wood shed with a coconut straw roof provided a better thermal environment than the masonry shed with a clay tile roof.
The lack of edges and adequate curtain management contributed to low-quality illuminance in the masonry shed.
No facility provided an ideal environment for free-range broilers in the afternoon.*

ABSTRACT: Free-range broiler producers are concerned with the thermal environment and lighting of their facilities and seek to improve these factors for the increased welfare of their broilers. The objective of this study was to evaluate the spatialization of illuminance and enthalpy in two free-range broiler sheds, one of masonry with a clay tile roof and the other built of wood with a straw roof. The data on air temperature, relative air humidity, and illuminance were recorded between September and October 2018 for five non-consecutive weeks in two periods during the day: morning (9 hours) and afternoon (15 hours). The data were collected at 42 points per shed, spaced 0.40 × 0.75 m. The experimental design was completely randomized in a 2 × 2 factorial scheme, considering two periods and two sheds. Spatial dependence was evaluated using geostatistics and interpolation maps by kriging. The facilities presented strong or moderate spatial dependence for all observed variables and periods. The small edges and lack of management of curtains resulted in the masonry shed having higher illuminance values during both periods. Although it did not present ideal values for a comfortable environment, the wood shed was more thermally efficient.

Key words: environment, avian, thermal comfort, rural buildings, geostatistics

RESUMO: Os produtores de frango caipira se preocupam com o ambiente térmico e iluminação das instalações, buscando proporcionar bem-estar às suas aves. Objetivou-se com esta pesquisa, avaliar a espacialização das variáveis iluminância e entalpia, em dois galpões de frangos caipira de corte: um de alvenaria com telha de barro, e o outro de madeira com cobertura de palha. Os dados de temperatura do ar, umidade relativa do ar e iluminância foram registrados entre setembro e outubro de 2018, por cinco semanas não consecutivas, em dois períodos do dia: manhã (9 horas) and tarde (15 horas). Os dados foram coletados em 42 pontos por galpão, espaçados por 0,40 x 0,75 m. O delineamento experimental foi inteiramente casualizado no esquema fatorial 2 x 2, considerando dois períodos e dois galpões. A dependência espacial foi avaliada por geoestatística e mapas de interpolação por krigagem. Os galpões apresentaram dependência espacial forte ou moderada em todas as variáveis e períodos observados. Devido aos pequenos beirais e manejo inadequado das cortinas no galpão de alvenaria, este apresentou maiores valores de iluminância nos dois períodos. Embora não ter apresentado valores ideais para um ambiente confortável, o galpão de madeira foi mais eficiente termicamente.

Palavras-chave: ambiência, aviário, conforto térmico, construções rurais, geoestatística



INTRODUCTION

Poultry farming is no longer a subsistence activity but is currently highly profitable, presenting a socioeconomic function and generating a source of income and protein. However, there are few bioclimatological studies on facilities suitable for free-range broilers.

In Brazil, poultry facilities are mostly built without thermal insulation planning, especially those intended for free-range broilers. Open facilities are more susceptible to climate change, exposing broilers to large thermal amplitudes and high light intensities (Paulino et al., 2019).

The intensity, distribution, color, and duration of light stimulate the broilers to search for food and water (Archer & Mench, 2014). Excess luminosity increases temperature, generating agglomeration of broilers in areas of the shed with milder temperatures, increasing density, and rendering areas with higher illumination ineffective (Queiroz et al., 2017).

Consequently, understanding the environmental variables inside the sheds allows adequate visualization of critical points controlled, which is vital for the broilers to reach their full productive potential (Schiassi et al., 2015; Lopes et al., 2020). The representation of geostatistics by kriging maps allows identifying and accurately interpreting possible critical points causing thermal stress in broiler housing (Queiroz et al., 2017).

Thus, the goals of this study were to evaluate the spatial variability of lighting and enthalpy in two different facilities for broiler chickens during two periods, via geostatistics through the analysis of semivariograms and the construction of interpolation maps by kriging.

MATERIAL AND METHODS

The experiment was conducted between June and September 2018 at the Universidade Federal do Vale do São Francisco, located in the municipality of Juazeiro, BA, Brazil, in the São Francisco Submedium region. The research was approved by the UNIVASF Ethics Committee on the Use of Animals, registered under number 0005/260218.

According to the Köppen climate classification, the region's climate is BSwH, characterized as a semi-arid climate with an average annual precipitation of approximately 542 mm and maximum air temperature ranging from 29.6 °C to 33.9 °C. The average relative humidity of the air varies from 62% to 67%.

In this experiment, two sheds were evaluated, one of ceramic masonry and clay tile, and the other with wood walls and straw roofing, with dimensions of 3 × 6 × 2.80 m (width, length, and ceiling height), side walls (0.50 m), gable roof, and an outdoor area of 200 m² with Tifton 35 grass.

Each shed had 100 broilers of the heavy red French hillbilly lineage, with a housing density of 5.6 poultry m⁻². According to the ABNT (2016) standard, the maximum stocking density was 7 poultry m⁻². During the finishing phase (68 to 90 d), they were reared in an extensive system with access to the outside area during the day. Both sheds were oriented east to west.

The masonry shed (MS) has a clay tile roof with 0.50 m edges, a concrete floor with 0.10 m of wood shavings for bedding, and sides protected by galvanized wire screens and blue polyethylene curtains.

The wood shed (WS) had a coconut straw roof with 1.50 m edges, hard ground with 0.10 m of wood shavings for bedding, sides of eucalyptus piles with galvanized wire screens, and blue polyethylene curtains. The sheds did not have a mechanical ventilation system.

The environmental variables air temperature (°C) and relative air humidity (%) were evaluated using a hot-wire thermo-anemometer, model Tafr 190 (Instrutherm) with measurement precision of 0 to 50 °C with a resolution of ± 1 °C for temperature and an operating humidity less than 80%.

The illuminance values were collected using a digital luxmeter for Led (Instrutherm), model LD-550, with ± 3% accuracy. The readings were taken by positioning the photocell base in a horizontal plane at a height of 1.20 m, recording the value in lx. The sheds had a single 40 W fluorescent lamp, from 5 p.m. to 6 a.m.

During the reading of temperature, humidity, and illuminance data, the sides of both sheds were 50% closed by the curtains during both periods throughout the experimental phase.

The data were collected over 5 day at 42 points along the entire length of the shed, during the morning (9 hours) and afternoon (15 hours) shifts. From these data, the enthalpy was calculated using the equation proposed by Rodrigues et al. (2011).

In the statistical analysis of the data, a completely randomized design (CRD) was used in the 2 × 2 factorial scheme, considering two evaluation periods (morning and afternoon) and two sheds (MS and WS). Means were compared using the Tukey test with a 5% probability. All analyses were performed using R software.

For analysis of data variability, the classification criteria of Warrick & Nielsen (1980) were considered, with low variability for the coefficient of variation (CV) being < 12%, moderate 12% < CV < 62%, and high CV > 62%.

The semivariograms were estimated by the GS+7.0 software (2007) using Matheron's classic semivariogram, given by Eq. 1.

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (1)$$

where N(h) is the number of pairs of values sampled Z(x_i) and Z(x_i + h), is separated by a vector of h. The graph of γ*(h) as a function of the corresponding values of h, called a semivariogram, was a function of the vector h and depended exclusively on the distance h.

After calculating the semi-variances, the following semivariograms were adjusted: spherical, exponential, and Gaussian (Mello et al., 2013).

Spatial dependence analysis was performed according to the classification proposed by Zimback (2001), with the spatial dependence index (SDI) equal to the ratio C₁ / (C₀ + C₁) and the intervals considered included: weak (SDI < 25%), moderate (25% ≤ SDI < 75%), and strong (SDI ≥ 75%).

The models were evaluated using the highest coefficient of determination (R²), the lowest sum of the square of the residues (SSR), and the range that determines the spatial dependence limit. After analyzing the spatial dependence, interpolation was performed using the kriging method, and maps were created using the Surfer 14.0 program (2014).

RESULTS AND DISCUSSION

Table 1 shows the statistical analysis of the mean values of the illuminance and enthalpy variables. There was a significant interaction between the shed and period factors.

A high value of illuminance was observed for the MS, compared to that of the WS (Table 1) in both periods. This occurred because of the characteristics of the small edges of this shed, allowing a higher incidence of natural light inside.

The average illuminance was higher in the morning in the MS. Although the curtains were partially open, the solar radiation fell inside the facilities. High illuminance values (up to 1878 lx) were observed by Lopes et al. (2020) in Pesqueira, PE, Brazil, in open broiler houses. Nonetheless, these values were lower than those found in this experiment during the morning.

The illuminance CV was high (above 30.68%). This variability could be explained by the higher incidence of solar radiation inside the MS than the WS. Lopes et al. (2020) reported that the variability of luminosity in aviaries surveyed occurred because of the longitudinal orientation in the Northwest-Southeast quadrant. Although the aviaries in this study were oriented in an east-west direction, there was an influence of solar radiation during both periods.

Significant differences in enthalpy were observed during the morning and afternoon periods. The afternoon period obtained higher values (72.01 kJ.kg⁻¹ dry air) in the WS, which differed from that of the MS.

According to Barbosa Filho (2004), the enthalpy limits considered ideal for broilers for the sixth week of life are 37.4 to 52.1 kJ.kg⁻¹ of dry air, considering a moderate environment from 52.2 to 63.01 kJ.kg⁻¹ of dry air, severe from 63.1 to 72.61 kJ.kg⁻¹ of dry air and lethal from 72.7 to 106.01 kJ.kg⁻¹ of dry air.

In this research, both sheds during the two periods had an environment in the severe state or lethal zone. Queiroz et al. (2017) affirmed that when environmental variables are in the critical zone, this strongly indicates that urgent measures

for controlling the internal environment of the shed should be adopted.

The adjusted semivariogram model, nugget effect, threshold, range, and degree of spatial dependence are shown in Table 2.

According to Zimback's classification (2001), the semivariograms adjusted in the morning and afternoon periods in the MS and WS had the strongest SDI, whereas the others were moderate. Strong spatial dependence was observed between collection points during morning hours and in the lighting and enthalpy variables in the MS.

During the afternoon, the variable that showed strong spatial dependence was illuminance in both sheds and enthalpy in the WS. The higher the spatial dependence, the lower the contribution of the nugget effect to the variability of the data, and consequently, the better the estimates by kriging.

Thus, the distributions of microclimatic characteristics and thermal comfort indices in space are not random because all presented moderate or strong values for the degree of spatial dependence (Curi et al., 2014).

The lowest and highest range values (A) observed were 1.39 to 12.6. The illuminance achieved the best range in the morning and the worst in the afternoon. During the morning, the range provided better homogeneity of data for this variable.

Based on the collected data and by kriging, maps were generated for illuminance distribution and the enthalpy of the sheds during the morning (Figure 1).

The illuminance varied from 4800 to 700 lx (Figure 1) in the sheds. During the morning, the greatest illumination occurred in the northern facades of both sheds because of the incidence of solar radiation.

Table 1. Means of light and enthalpy in two sheds and periods

	Sheds	Period		CV (%)
		Morning	Afternoon	
Illuminance (lx)	Masonry shed	2963.87 aA	2060.13 aB	30.68
	Wood shed	805.71 bA	1004.67 bA	
Enthalpy (kJ.kg ⁻¹)	Masonry shed	70.41 aB	71.85 aA	0.64
	Wood shed	69.24 bB	72.01 aA	

CV - Coefficient of variation; lowercase letters compare the column, and uppercase letters compare the rows, with distinct letters indicating a significant difference according to Tukey's test at $p \leq 0.05$

Table 2. Estimated models and parameters of experimental semivariograms for illuminance and enthalpy in the different sheds (MS and WS) during the morning and afternoon periods

Periods	Variables	Sheds	Model	C ₀	(C ₀ + C ₁)	A	SDI (%)	R ²	SSR
Morning	Illuminance (lx)	MS	GAU	1.00E+03	6.43E+05	1.6	9.90E+01	0.97	1.30E+10
		WS	EXP	7.33E+03	1.47E+04	12.6	5.00E+01	0.83	1.00E+06
	Enthalpy (kJ.kg ⁻¹)	MS	GAU	0.06	1.1	6.5	9.50E+01	0.98	2.30E-03
		WS	SPH	0.06	0.22	0.98	7.10E+01	0.58	2.50E-03
Afternoon	Illuminance (lx)	MS	GAU	1.00E+03	3.20E+05	1.39	9.90E+01	0.90	7.10E+09
		WS	SPH	3.44E+04	1.60E+06	2.33	7.80E+01	0.95	3.90E+08
	Enthalpy (kJ.kg ⁻¹)	MS	GAU	0.05	0.12	3.0	5.80E+01	0.85	5.40E-04
		WS	SPH	0.02	0.17	1.6	9.00E+01	0.61	5.80E-03

MS: masonry shed; WS: wood shed; C₀: nugget effect; (C₀ + C₁): Sill; A: Range; SDI: Spatial dependence index; R²: Coefficient of determination; SSR: Sum of squares of residues; GAU: Gaussian; EXP: exponential; SPH: spherical

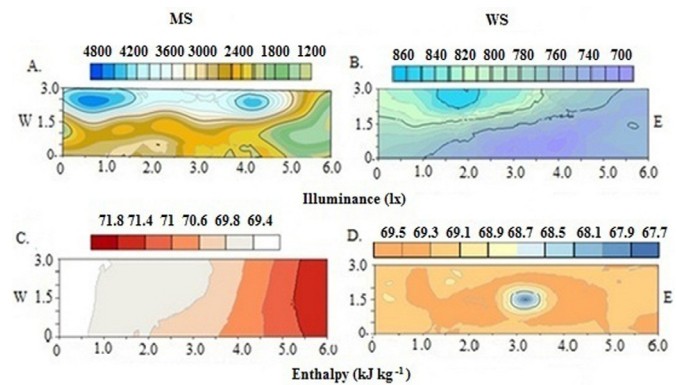


Figure 1. Illuminance (A, B) and enthalpy (C, D) spatial distribution in the masonry shed (MS) and wood shed (WS), at 9:00 a.m.

Queiroz et al. (2017), in a study in open facilities during October in the state of Ceará, Brazil, presented the morning period illuminance variability (3100-1300 lx), which was close to that found in this study for the MS.

The MS suffered interference from direct solar radiation on the east wall, contributing to the heating of the environment and increasing enthalpy value (Figure 1). This could be mitigated by the presence of edges on these sides, which should reduce the temperature inside the facility.

The WS was favored because of the material and construction, which allowed air passage, resulting in a more uniform distribution of environmental parameters.

During the morning, high enthalpy values were observed in the Eastern region, followed by lower values for the Western facade (Figure 1). In the WS, enthalpy values were more homogeneous, with lower values in the central region.

During the experiment, the enthalpy varied from 67.7 to 71.8 kJ kg^{-1} , which is above the recommended value of Barbosa Filho (2004). Queiroz et al. (2017), to evaluate the internal environment of broiler houses, found values higher than 63.1 kJ kg^{-1} during the morning and afternoon periods. They classified this environment in the critical range, requiring greater control of environmental variables, as in this study.

In Figure 2, the kriging maps of the sheds show differences between them in the afternoon because of their construction.

Figure 2 shows that for the MS, the greatest illuminance occurred in the center and Northern facade because of the penetration of solar radiation directly into the installation. The WS received more significant solar radiation on the Southeast facade but had no direct sun radiation problems because it had a larger edge.

During the afternoon, the average illuminance value was 1004.67 lx for the WS, and the MS had an average value of 2060.13 lx. The illuminance level should be as low as possible, allowing only viewing and moving to the feeders and drinking. Thus the recommendation is for 5 lx for chickens past the first 7 day of life.

According to Pan (2015), chickens will move more with a high level of illuminance, providing maximum muscle development and a higher energy requirement. On the other hand, Pan (2015) reported that low light levels decrease aggressive behavior and improve food conversion.

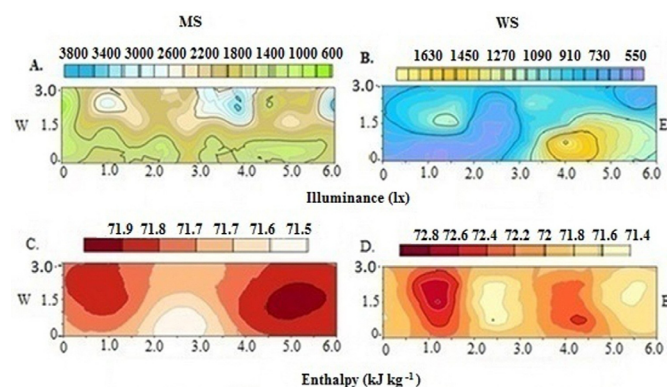


Figure 2. Illuminance (A, B) and enthalpy (C, D) spatial distribution in masonry shed (MS) and wood shed (WS) at 3:00 p.m.

Considering the study and recommendations, the WS provided an environment with less illuminance than that of MS, but with values much higher than indicated as adequate and could influence the productivity of broilers.

In the MS (Figure 2C), the enthalpy variation showed heat islands with high values on the North and South sides. In these warmer locations, the broilers stayed longer under the trough, where they could cool down by wetting the bedding.

In the afternoon, there was heterogeneity in the enthalpy in the WS, with the highest values observed in the Western region, where direct solar radiation was concentrated during this time. In both sheds, the values were higher than the limits recommended by Barbosa Filho et al. (2007).

Thus, it can be concluded that the internal environment of the sheds was out of the comfort conditions for broilers during the entire trial period, demonstrating the importance of the study of thermal comfort in the facilities, as well as the application of different techniques to improve animal welfare (Ferraz et al., 2016; Ribeiro et al., 2016; Sampaio et al., 2018; Coelho et al., 2019; Lourençoni et al., 2019).

CONCLUSIONS

1. There was strong spatial dependence during the morning and afternoon periods of illuminance in both sheds.
2. The enthalpy showed strong spatial dependence during the morning period in the MS and the afternoon period in the WS.
3. Owing to the small edges and the lack of management of the curtains, the MS had higher illuminance values during both periods.
4. The WS was more thermally efficient, although it did not present ideal values for a comfortable environment.

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