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Assessment of spatial variability of environmental variables of a typical house of laying hens in Colombia: Antioquia state Case

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Abstract. This paper aimed to analyze the magnitude and spatial variability of environmental variables: Temperature and Relative Humidity Index (THI), Radiant Thermal Load (RTL), Globe Temperature and Relative Humidity Index (BGTH) and Enthalpy (H), inside a house for laying hens, in the state of Antioquia (Colombia) during the month of August. A traditional Colombian poultry house with natural ventilation was used. All variables were manually measured at equally spaced 1.0×1.0 m points, totaling 99 data collection points inside the poultry house. Geostatistical techniques were used through semivariogram analysis, and isochore maps were generated through data interpolation by kriging. The semivariogram was fitted by the restricted maximum likelihood method. The used mathematical model was the spherical one. After adjusting the semivariograms, the data were interpolated by ordinary kriging. The semivariograms and the isochore maps allowed identifying the non-uniformity of the spatial distribution of all evaluated variables throughout the poultry house. The results show that THI, RTL, BGTH and, H presented values above the comfort limits in the most significant part of the poultry house during the observed period. It is possible to concluded that the use of natural ventilation alone was not sufficient to guarantee the homeothermy conditions for the layers. Thus, it is suggested that in addition to natural ventilation, secondary modifications should be used to improve farm productivity.

Key words: animals production, animal welfare, natural ventilation.

INTRODUCTION

The environment in which birds are raised comprises all the physical, chemical, biological, social and climatic elements that influence their development and growth. Among those, environmental conditions, composites of air temperature, relative humidity, airspeed, and radiation, it has generated direct and immediate action on the behavioral, productive and reproductive responses of birds (Baêta & Souza, 2010).

Environmental conditions different from the thermoneutral zone could cause effects on the performance of the laying hens. When the birds are submitted to thermal stress conditions, it can compromise the most important vital functions of those animals, their homeothermy (Vale et al., 2016). Thermal stress may affect the animal welfare, and it also could result in economic losses for the industry, and it can not be ignored (Lee et al., 2015).

Generally, the hens that are exposed to environmental conditions different of their thermal comfort could suffer a reduction in their food consumption, which could be a probable cause of the decline in their productivity. In particular, thermal stress depresses egg production (Silva et al., 2015; Sousa et al., 2018), in addition to the deterioration in the quality of the eggs (Lemos et al., 2014; Lana, et al., 2017). Therefore, according to Freitas et al. (2017) and Lee et al. (2015), the understanding of the environmental conditions in which the birds are submitted is crucial for the laying hens rise with good productivity and adequate animal welfare.

It is expected that in a commercial production system, the environmental variables inside the facility will be homogeneous. The spatial distribution of these thermal variables could be assessed using spatialization and geostatic tools (Massari et al., 2016; Ribeiro et al., 2016). Geostatistics is a tool that allows having more knowledge of these factors that affect the environment where the animals are raised. This tool gives more precision and accuracy in the systems of exploration (Carvalho et al., 2012; Massari et al., 2016).

In tropical countries like Colombia, there are few studies to evaluate the thermal comfort of poultry production facilities, mainly for the egg production. In the most part of the year, these types of facilities have operated with natural ventilation, and they are located at altitudes above 1,800 meters. That means that these houses are located in cold temperatures for most of the year, with average air temperatures around 15 °C and relative humidity of 70%.

Therefore, the objective of this work was to analyze the magnitude and spatial variability of environmental variables: Temperature and Relative Humidity Index (THI), Radiation Thermal Load (RTL), Black Globe Temperature and Humidity (BGTH) and Enthalpy (H), inside a typical house for laying hen using natural ventilation without thermal insulation, located in the state of Antioquia (Colombia).

MATERIALS AND METHODS

The experiment was carried out in an experimental house for laying hens at the National University of Colombia Campus Medellín. The farm is located at the San Pablo Experimental Agrarian Station, in the eastern sector of the department of Antioquia, municipality of Rionegro, during August of 2017. August is known to be the mouth with the highest record of high temperatures of the year. The region is characterized by the most significant egg production in the department. Besides, it presents during the summer seasons, high temperatures and during the winter seasons high precipitation and hight thermal amplitude. These conditions generate a lot of problems for the environmental control of the different climatic variables, and they can cause a reduction in egg production in the state of Antioquia.

The farm is located at an altitude of 2,100 meters with an average annual air temperature between 12 and 23º C. Annual precipitation regime is around 2,280 mm and relative humidity of 75.5% that is considered according to Holdriged classification as a bmh - MB in the tropic (Espinal, 1992).

The outside of the facility used were 34.0 m long, 11.0 m wide. The laying hen house was built of reinforced concrete, and solid bricks, asbestos-cement roofing, concrete floor, the lateral side openings of mesh, having surrounding grass around the installation and surrounding vegetation that work as windbreaks on the south side of the plant. The longer axis facility is located East-West, which makes possible the use of natural ventilation in the summer and reduces the radiation (Fig. 1).

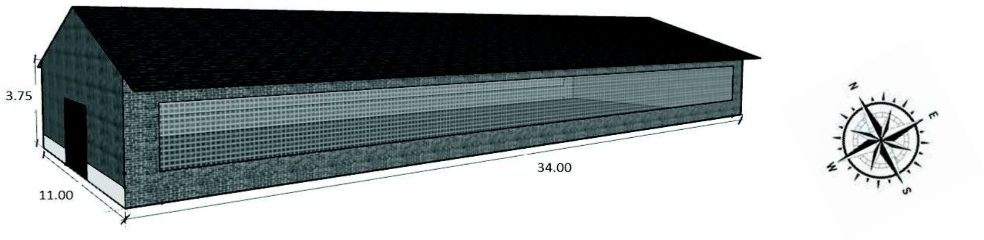

Figure 1. Scheme of the experimental facility.

The facility had three rows of cages arranged in a two-store vertical structure. Each cage has 2.90 meters long, 1.00 meters wide, and 1.90 meters high, with 4 chickens Lohmann Brown® per cages with a total of 1,200 birds. Water and feed for the birds were available *ad libitum* throughout the experimental period. The diets provided to the animals were formulated to meet the nutrient requirements for the age group.

To evaluate the thermal comfort measurement of dry bulb temperature (t_{db}, ºC), black globe temperature (t_{bg}, °C), relative humidity (RH, %), air velocity (V_{air}, m s^{-1}) were made in the geometric center of each cage.

T_{db} and RH were measured using a hygrometer (Extech Instruments®, mod. RHT20, USA, the precision of ± 1%). The V_{air} was measured using one anemometer of hot wire (Extech Instruments®, mod. AN100, USA, precision de ± 3%). T_{gn} was measured using a BGT DELTA OHM HD 32.2 Thermal Stress, Italy, with a precision of ± 0.15 °C.

All variables were measured in 99 different points located at the same distance in one mesh of 1.0×1.0 m, inside of the facility. The data were collected in four moments of the day at 9:00 am, 12:00 pm, 15:00 pm, and 18:00 pm.

According to Behura et al. (2016), based on the collected thermal variables, some thermal indices were calculated. Temperature and Humidity Index (THI) that represents the combination of the effect of the air temperature, and humidity associated with the animal thermal stress level was proposed by Zulovich & Deshazer (1990), according to the Eq. (1):

$$THI = 0.6\, t_{db} + 0.4\, t_{wb} \tag{1}$$

where t_{db} – dry bulb temperature (°C); t_{wb} – wet bulb temperature (°C).

Radiation Thermal Load (RTL) was calculated with the Eq. (2), according to Esmay (1969), in W m^{-2}, and the Stefan-Boltzman ($\sigma = 5.67 \cdot 10^{-8}$ W m^{-2} ·K^{-4}).

$$RTL = \sigma \cdot (\mathrm{RTA})^4 \tag{2}$$

Radiant Temperature Average in K (RTA) was obtained by Eq. 3, the air velocity in m s^{-1} and t_{db} and t_{bg} in K:

$$\mathrm{RTA} = 100 \cdot \left[2.51 \cdot V_{air}{}^{0.5} \cdot \left(t_{bg} - t_{db}\right) + \left(\frac{t_{\mathrm{bg}}}{100}\right)^4 \right]^{\frac{1}{4}} \tag{3}$$

Using the t_{bg}, and the THI, was calculated the Black Globe Temperature and Humidity (BGTH) according to Eq. 4. Values above 75 could generate low thermal comfort in the hens with age above 15 days of life (Rocha et al., 2010):

$$BGTH = t_{bg} + 0.36 t_{dp} + 41.5 \tag{4}$$

where t_{bg} – black globe temperature in °C; t_{dp} – dew point temperature in °C.

The enthalpy H was calculated using Eq. 5, according to Albright (1990), to the characterization of the thermal environment inside of the facilities.

$$H = 1.006 \cdot t_{db} + W \cdot (2.501 + 1.805 t_{db}) \tag{5}$$

where H – is the Enthalpy, in $kJ \cdot kg^{-1}_{\mathrm{dry\ air}}$; W in kJ·kg^{-1}; t_{db} – dry bulb temperature, in °C.

The spatial dependence of the environmental variables (THI, RTL, BGTH, and H) were analyzed using semivariogram adjustments, classic and ordinary Kriging interpolation. The classic semivariogram was estimated by Eq. 6, described by Bachmaier & Backes (2008):

$$\hat{\gamma}(\mathrm{h}) = \frac{1}{2\mathrm{N(h)}} \sum_{\mathrm{i=1}}^{\mathrm{N(h)}} [\mathrm{Z(x_i) - Z(x_i + h}]^2 \tag{6}$$

where N (h) – is the number of experimental pairs of observations Z (X_i); $Z_{(xi+h)}$ separate by a distance h.

The semivariogram is represented by the graph $\hat{\gamma}(\mathrm{h})$versus h. From the adjustment of a mathematical model, the calculated values of $\hat{\gamma}(\mathrm{h})$, are estimated the coefficients of the theoretical model for the semivariogram called pepita effect, C0; contribution, C1; threshold, C0 + C1; and the reach described by Bachmaier & Backes (2008).

The method of ordinary least squares (OLS) or the method of maximum restricted likelihood (REML) was used to make the adjustment of a mathematical model. According to Mello et al. (2005), the ordinary least squares method consists consist to obtain of the values of the parameters of a model to minimize the sum of the difference square between the observed and estimated values.

The principle of REML is to estimate the parameters of the semivariogram by the maximum likelihood applied to the data using a linear transformation in order to maximize the probability of the profile of the semivariogram parameters is based on the transformation of the variables (Diggle & Ribeiro Jr. 2007). According to the same authors, REML is considered the estimator less suitable for variance parameters in small samples.

The spherical mathematical model for semivariograms was chosen for all environmental variables evaluated in this study. This model has widely used in geostatistical work for animal environments (Ferraz et al., 2016; Oliveira et al., 2016; Ribeiro et al., 2016), and its use could be explained due to its relatively easy ability to adjust to any point cloud. The spherical model is given as follows by Eq. 7:

$$\gamma(h) = \begin{cases} 0, & \text{if } h = 0 \\ C_O + C_1\left[\dfrac{3}{2}\left(\dfrac{h}{a}\right) - \dfrac{1}{2}\left(\dfrac{h}{a}\right)^3\right], & \text{if } 0 < h \leq \\ C_O + C_1 & \text{if } h > a \end{cases} \tag{7}$$

After adjusting the semivariograms, the interpolation of the data was done by ordinary kriging to allow visualization of the spatial distribution patterns of the evaluated variables.

The validation method was used to assess the quality of the adjust of theoretical spatial models. This method was also used by Faraco et al. (2008), Johann et al. (2010), and Ferraz et al. (2012).

According to Isaaks & Srivastava (1989), validation is the technique to evaluate the estimation of the errors that allow comparing predicted values with those sampled in the experimental process. The sample value, at a specific location $\hat{Z}\ (s_{(i)})$, is temporarily discarded of the data set, and then a prediction is made by kriging at the location using the remaining samples. In this way, it is possible to remove some values that would be very useful for choosing the method, such as the Mean Error (ME), the Standard Deviation of the Mean Error (DP_{EM}), the Reduced Mean Error (ER) and the Standard Deviation of the Reduced Mean Error (S_{ER}). Thus, the Mean Error by crossing validation (EM) is obtained by the following expression 8:

$$EM = \frac{1}{n}\sum_{i=1}^{1}\left(Z(s_i) - \hat{Z}(s_{(i)})\right) \tag{8}$$

where n – is the number of data; $Z(s_i)$, value observed at point s_i; $\hat{Z}(s_{(i)})$ is the value predicted by ordinary kriging at the point s_i, without considering the observation $Z(s_i)$ (Faraco et al., 2008).

According to Cressie (1993), the reduced mean error (ER), the standard deviation of mean errors (DP_{EM}), and the standard deviation of the reduced mean errors (SER) can be used to evaluate the models. The reduced mean error (ER) is defined by Eq. 9:

$$ER = \frac{1}{n}\sum_{i=1}^{n}\frac{Z(s_i) - \hat{Z}(s_{(i)})}{\sigma\left(\hat{Z}(s_{(i)})\right)} \tag{9}$$

where $\sigma\left(\hat{Z}(s_{(i)})\right)$ – is the kriging standard deviation at the s_i point without considering the $Z(s_i)$ observation.

The standard deviation of the reduced mean errors (S_{ER}) is obtained from Eq. 10:

$$S_{ER} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left\{\frac{Z(s_i) - \hat{Z}(s_{(i)})}{\sigma\left(\hat{Z}(s_{(i)})\right)}\right\}^2} \tag{10}$$

The average difference between the values will be closer to zero when the estimative will better. The selection criteria based on validation must find the EM and ER values closes to zero. The DP_{EM} value must be the lowest possible, and the S_{ER} value must be the closest to one.

Kriging is the method of Geostatistics interpolation, which uses the spatial dependence expressed in the semivariogram between samples closer to estimated values in any position within the field, without trend and with minimum variance. These features become the kriging an optimal interpolator. The condition of no tendency means that, on the average, the difference between the estimated and measured values is null, and the minimum variance condition means that, even though there may be different points between the predicted and the measured values, these differences are minimal (Burgess & Webster, 1980).

According to Vieira (2000), for the application of kriging, it is assumed that is important to know the realizations $z(x_1)$, $z(x_2)$..., $z(x_n)$ of the spatial random variable $Z(x)$, at locations $x_1, x_2,...,x_n$, (sample); and the semivariogram of the variable has already been determined; and that the interest is to estimate a value $\hat{z}$ at position x. The estimator $\hat{Z}(x)$ of $Z(x)$ is given by Eq. 11:

$$\hat{Z}(x) = \sum_{i=1}^{n} \lambda_i Z(x_i) \qquad (11)$$

where *n* –is the number of neighbors; Z(*xi*) – that involved the estimated value; λ_i – are the weights associated with each measured value.

To understand the conditions of optimal interpolator (kriging), Eqs 12 and 13 were used:

$$E\left\{\hat{Z}(x_0) - Z(x)\right\} = 0 \qquad (12)$$

$$Var\left\{\hat{Z}(x) - Z(x)\right\} = E\left\{\left[\hat{Z}(x) - Z(x)\right]^2\right\} = minimum \qquad (13)$$

In order to $\hat{Z}(x)$ be a non-biased estimator of $Z(x)$, the sum of the sample weights must be equal one (Eq. 14).

$$\sum_{i=1}^{N} \lambda_i = 1 \qquad (14)$$

The Lagrange multiplier (μ) was introduced to obtain the minimum variance. The result of the kriging system is deduced by Eq. 11. The solution of this system of simultaneous equations gives the kriging weights λi (Eq. 15).

$$\sum_{i=1}^{N} \lambda_i \gamma\left(x_{i,} x_j\right) + \mu = \gamma\left(x_{i,} x\right);\ \text{i= 1 a N} \qquad (15)$$

To the geostatistical analysis and for making kriging maps, a computational system R Development Core Team (2019) was used, through the geoR library (Ribeiro Junior; Diggle, 2001).

RESULTS AND DISCUSSION

Based on the geostatistical analysis methodology, it was possible to quantify the magnitude and spatial dependence of THI, RTL, BGTH, and H. Through the validation that is shown in Table 1, it is observed that the adjustments of the semivariograms for the variables under study were well performed. Besides, it was observed that the criteria for a better fit were based on validation: the values of Average Error (EM) and Reduced Mean Error (ER) should be the closest to zero. The value of the Deviation Average Error

Standard (DP_{EM}) should be as small as possible, and the Reduced Average Error (S_{ER}) Standard Deviation value should be closer to 1.0.

The pepita effect (C_0) is an important parameter of the semivariogram, and this indicates unexplained variability, considering the sampling distance used. As it is impossible to quantify the individual contribution of these errors, the pepita effect can be expressed as a percentage of the threshold, thus facilitating the comparison of the degree of spatial dependence (GDE) of the variables under study (Trangmar, Yost & Uehara, 1985) (Table 1). According to Cambardella et al. (1994), the studied variables presented moderate GDE; only RTL presented strong GDE.

Table 1. Methods, models and estimated parameters of the experimental semivariograms for the variables: Temperature and Relative Humidity Index (THI), Radiation Thermal Load (RTL), Black Globe Temperature and Relative Humidity Index (BGTH) and Enthalpy (H, kJ $\mathrm{kg}^{-1}_{\mathrm{dry\ air}}$)

	C_0	C_1	$C_0 + C_1$	a	GDE	EM	DP_{EM}	ER	S_{ER}
THI	0.57	0.56	1.12	3.13	50.45	-0.001	1.21	-0.001	1.18
RTL	16.97	300.69	317.66	2.12	5.34	-0.238	-0.01	20.323	1.17
BGTH	3.05	0.62	3.68	3.49	83.04	-0.001	2.12	0.000	1.11
H	17.69	19.18	36.87	2.77	47.98	-0.010	6.87	-0.001	1.16

C_0 – pepita Effect; C_1 – Spatially dependent component; C_0 + C_1 – Sill; A – Range; SDD – Degree of Spatial Dependence; ME – Mean error; SDME – Standard deviation of mean error; RE – Reduced mean error; SDRE – Standard deviation of reduced mean error.

According to Cressie (1993), the range determines the space under which the variable is correlated. The longest range found was 3.49 m for BGTH, and the shortest range found among the variables under study was 2.12 m for RTL.

Once was made the semivariogram adjustments (Table 1) for the variables under study, the values of these variables were estimated using ordinary kriging. Therefore, it was possible to build spatial distribution maps (isolines) for all of them (Fig. 2), which allowed viewing the spatial variability of the temperature and relative humidity index (THI), the Radiation Termal Load (RTL), temperature index of the globe and relative humidity (BGTH) and enthalpy (H).

The distribution of THI (Fig. 2, A) indicates that most of the area is between 27.2 and 28.2 °C, mainly on the south side of the facility. On the north side, it presents values between 28.2 and 30.2 °C, which is the area that receives the most radiation during the day between 9:00 am and 6:00 pm as shown in Fig. 2. Most of the facility area presented values above 28.0° C, which is considered by Gates et al. (1995) as the upper limit allowed in the production of laying hens.

In the most part of the facility, the RTL (Fig. 2, B) has values below 470 W m^{-2}, on the north side, it has values between 450 and 470 W m^{-2}, which shows that direct solar radiation on the north side of the building causes that RTL presents values higher than 450 W m^{-2}, between 12:00 pm and 4:00 pm, which is the threshold recommended by Esmay (1969) and Rocha et al. (2010).

The BGTH (Fig. 2, C) and H (Fig. 2, D), showed similar behaviour to THI and RTL. Where on the north side of the facility, they present the worst indexes, and the highest amount of energy in the air, with BGTH, has values greater than 75, which could cause stress in the birds, according to Rocha et al. (2010). The H is increased in the north side and in places close to the walls. Also, it is where the airspeed is low since the prevailing winds enter from east to west with an inclination of 30° concerning the horizontal plane of the wall located in the East (Fig. 1). This situation does not allow a uniform distribution of air inside the building, generating a greater thermal load between 12:00 pm and 4:00 pm.

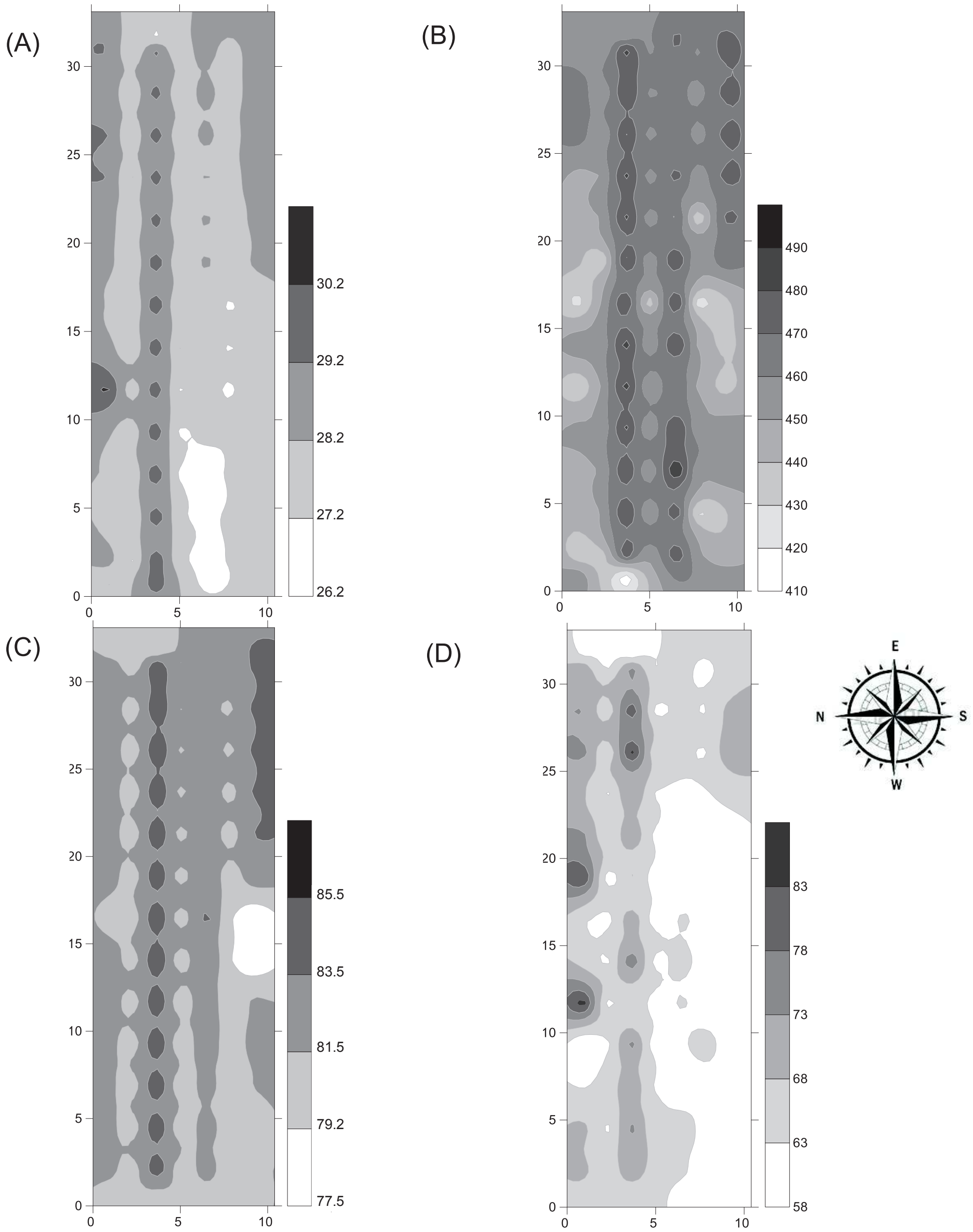

Figure 2. Average Spatial distribution of the four evaluated moments of the day at 9:00 am, 12:00 pm, 15:00 pm, and 18:00 pm of Temperature and Humidity Index (THI, adimensional) (A), Radiation Thermal Load (RTL, $W\ m^{-2}$) (B), Temperature and Humidity Index (BGTH, adimensional) (C), Enthalpy (H, $kJ.kg^{-1}_{\text{dry air}}$) (D).

The facility for laying hens studied in this paper is an ordinary Colombia system to egg production. The RTL, THI, BGTH, and H values were above the comfort limits to the hens. The results showed that the system is not efficient in keeping the animals under the thermal comfort, and it would be necessary to study different models of ventilation systems to be more efficient in the hottest months of the year. Besides the use of natural ventilation, other alternatives to improve the thermal environment, such as forced lateral ventilation or designing new models for Colombian poultry farming, could be adopted to improve the thermal environment. These alternatives can make the system more efficient and more competitive with the global agribusiness in this area of egg production.

CONCLUSIONS

The semivariograms allowed the characterization of the magnitude of spatial variability of thermal indices (RTL, THI, BGTH, and H) inside the studied hen facility.

It was possible to make isoline maps that allowed the observation of spatial variability, from the interpolation by kriging.

It was also possible to identify the heterogeneity of the spatial distribution of these parameters in the hen facility throughout the evaluated period.

The maps also allowed observing the existence of failures in the natural ventilation system in some regions of the hen facility. These failures can result in thermal condition above of the comfort in the most of the day. This condition out of the thermal zone may cause discomfort to the animals and productive and economic losses.

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