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# Thermal performance of aviary located in the semiarid region of Pernambuco based on computer simulation[1]

## Desempenho térmico de aviário localizado no semiárido pernambucano a partir de simulação computacional

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*HIGHLIGHTS:*

*The EnergyPlus software package can assist in designing facilities with better comfort environmental conditions.*
*The relative humidity values of the air simulated in the aviary were the same for all types of tiles.*
*To promote thermal comfort at the most critical times, it is necessary to make secondary changes in the aviary environment.*

**ABSTRACT:** For studies of thermal performance, computational modeling has been presented as an important decision-making tool to solve complex and everyday problems in poultry production and research. Thus, the present study aimed to validate computational models developed using the EnergyPlus software package and, based on these, evaluate the thermal performance of a poultry house with different types of tiles (thermoacoustic, ceramic, fiber-cement, and metal). The research consisted of two stages: an experimental phase and another phase in which the climatic conditions in four aviary models are numerically simulated, considering different types of tiles. The experimental phase was conducted in two climate seasons, winter (2019) and summer (2020), where air temperature and relative air humidity data were measured and recorded using six HOBO model H12 data loggers distributed inside an aviary located in the semiarid region of Pernambuco state, Brazil. For the computer simulation, a virtual model of the house was developed using the OpenStudio graphical user interface in Sketchup, and the thermal performance was calculated using the EnergyPlus software package. The models were validated, showing a strong correlation between the experimental and simulated data, with Pearson's correlation coefficient (r) values greater than 0.95. The simulations demonstrated the influence of the roof tiles on the thermal performance of the evaluated building. For the climatic conditions of the semiarid region of the Pernambuco state, thermoacoustic roof tiles presented the best thermal performance, followed by ceramic, fiber-cement, and metal roof tiles.

**Key words:** thermal comfort, rural facilities, energy simulation software

**RESUMO:** Para estudos de desempenho térmico, a modelagem computacional tem sido apresentada como uma importante ferramenta na tomada de decisões para solucionar problemas complexos e cotidianos na produção e pesquisa em avicultura. Desta forma, o presente estudo teve como objetivo validar modelos computacionais desenvolvidos por meio do programa EnergyPlus e a partir destes avaliar o desempenho térmico de um aviário com diferentes tipos de telhas (termoacústicas, cerâmicas, fibrocimento e metálicas). A pesquisa consistiu em duas etapas: uma fase experimental e outra fase para a simulação computacional das condições climáticas em quatro modelos de aviário, considerando diferentes tipos de telhas. A fase experimental foi conduzida em duas estações climáticas, inverno (2019) e verão (2020), onde foram aferidos e registrados os dados de temperatura e umidade relativa do ar através de seis data loggers HOBO modelo H12, distribuídos no interior de um aviário localizado no semiárido pernambucano. Para a simulação computacional, foi desenvolvido um modelo virtual do galpão com auxílio da interface gráfica de usuário OpenStudio no Sketchup, e posteriormente o cálculo do desempenho térmico foi realizado por meio do software EnergyPlus. A validação dos modelos mostrou uma forte correlação entre os dados obtidos de maneira experimental e os simulados, apresentando valores do coeficiente de correlação de Pearsons (r) maiores que 0.95. As simulações demonstraram a influência das telhas no desempenho térmico da edificação avaliada, onde para as condições climáticas do semiárido pernambucano, o melhor desempenho térmico foi apresentado pelas telhas termoacústicas, seguido das telhas cerâmicas, de fibrocimento e metálicas.

**Palavras-chave:** conforto térmico, instalações rurais, software de simulação energética

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## Introduction

Poultry farming is an activity that stands out for its well-structured production chain, where in recent years, Brazilian chicken meat production has grown by 112% (Schmidt & Silva, 2018). Despite the growth in poultry farming, housing birds in facilities that provide thermal comfort throughout the production period poses a major challenge (Brettas et al., 2017; Liu et al., 2017).

Within the facilities, the greatest thermal gain among the structural elements occurs through the roof. The study of coverings, regarding their different materials and modifications, has been the focus of research in the pursuit of improved thermal comfort conditions and installation models more suitable for confinement (Carneiro et al., 2015; Fachinello Krebs & Johansson, 2021). According to Oliveira Júnior et al. (2021), understanding the factors that hinder the natural process of animal production, such as microclimate variations inside the facility, is essential for optimizing this activity.

One way to evaluate the thermal performance of a building is through computer simulations, and these properly validated tools allow the prediction of thermal comfort indices in a representative manner (Silva et al., 2016). According to Resende et al. (2019), EnergyPlus stands out among thermal performance simulation programs, and it is one of the tools recommended by the NBR 15575 standard (ABNT, 2013).

In this context, this research aimed to validate computational models developed using the EnergyPlus program and, based on these, evaluate the thermal performance of an aviary with different types of roof tiles, leveraging thermal analyses of the air temperature, relative air humidity, and temperature and humidity index (THI).

## Material and Methods

In this study, procedures were adopted to evaluate the thermal performance of an aviary from the data of air temperature, relative air humidity, and the THI inside the facility by means of computer simulation. Before starting the simulation stage, it was necessary to conduct an experiment to measure the microclimate data inside the aviary, such that the real data could subsequently be correlated with the simulated data to validate the results. To simulate the thermal performance of a building, the software used the climatic characteristics of the region and the physical and thermal properties of the construction materials of the structure under study.

The experiment was conducted in a facility for rearing broilers located in the Instituto Federal de Educação, Ciência e Tecnologia do Sertão Pernambucano (IF Sertão), campus Petrolina Zona Rural, located on PE 647, km 22, Senador Nilo Coelho N4 Project, PE, Brazil. It is important to note that during the entire research period, the aviary was not being used for the confinement of animals.

The city of Petrolina, PE, Brazil, is 721 km from the capital, located at 09° 09' S and 40° 22' W, with an average altitude of 365 m. It has a semiarid tropical climate, type BshW, dry and hot, according to the Köppen-Geiger climate classification. Data were recorded during two climate seasons: winter (2019) and summer (2020). Each experimental period had a collection duration of 30 days, owing to the availability of the equipment.

The aviary where the experiment was conducted has the following construction features: width of 8.0 m; length of 14.0 m, total area of 112 m², ceiling height of 2.5 m, 1.0 m wide overhang, 0.5 m eaves on the northern and southern facades, and 1.0 m eave on the eastern facade. The facility is east-west oriented with a concrete floor, wood-frame roof, and ceramic tiles with a 25% slope. On the north and south facades, the aviary has 0.65 m walls and windows of width 3.25 m and height 1.60 m. This facility is illustrated in Figure 1.

The environmental elements measured were the air temperature and relative air humidity. Data were recorded using five HOBO dataloggers distributed inside the facility, as shown in Figure 2.

The sensors were installed at a height of 1.50 m, where they remained in operation throughout the experimental period and were programmed to take readings every 15 min and averages every hour.

From the measured data, the THI was determined using the equation proposed by Thom (1959):

$$THI = Ta + 0.36Tpo + 41.5 \quad (1)$$

where:

THI - temperature and humidity index;
Ta - air temperature (°C); and,
Tpo - dew point temperature (°C).

The computer simulations were performed using the EnergyPlus software package, version 8.7, and the models developed to evaluate of the thermal performance referenced

A. B.

A. - North facade; B. - Aviary interior

**Figure 1.** General view of the installation (A) and roof structure inside the aviary (B)

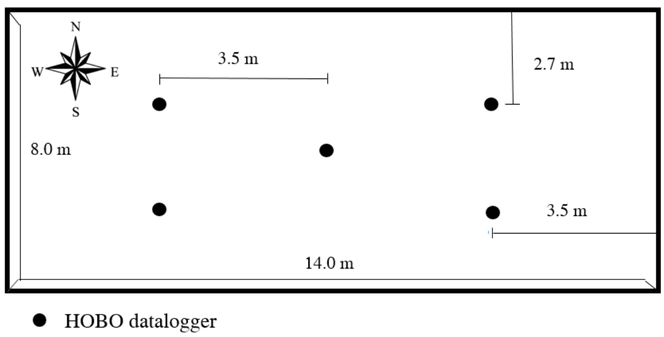



**Figure 2.** Sensor distribution scheme in the experimental area

the climatic characteristics of Petrolina, PE, Brazil, and the structural characteristics of the studied aviary, with modified tile types.

The aviary was modeled in the OpenStudio® SketchUp plug-in, an extension of Trimble's SketchUp 3D modeling tool, which allows users to quickly create the geometry required for EnergyPlus.

The entire interior of the facility, which had no subdivisions, was considered a thermal zone, and OpenStudio® was used to define all the building materials considering the external and internal surfaces, floor, and openings. At this stage, it was necessary to have knowledge of the thermal and physical properties of the building materials, such as the thermal conductivity (W $m^{-1}$ $K^{-1}$), specific heat (kJ $kg^{-1}$ $K^{-1}$), bulk density (kg $m^{-3}$), and thickness (m).

Initially, the simulation consisted of modeling the installation with its real structural characteristics (Figure 3), and then other models were created by modifying the type of tile and considering the recommended inclination for each of them.

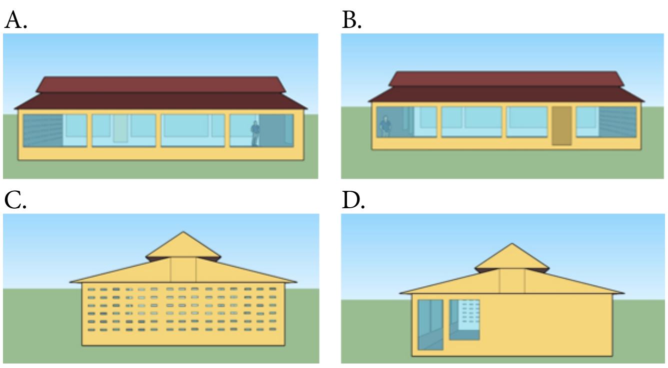
After modeling, the properties of the materials used in the developed model were inserted into the OpenStudio® SketchUp plug-in program. The physical and thermal properties of the construction elements employed in the simulations are listed in Table 1.

These characteristics were inserted into the EnergyPlus platform, in the IDF Text Editor section. In this section, all the characteristics of the study environment, output variables, and climate files for the city of Petrolina, PE, Brazil, were inserted. These climate files are available on the EnergyPlus website and include georeferenced data, soil temperature, and typical summer and winter days.

The environmental climate conditions of the following aviary models were simulated to evaluate the thermal performance of aviaries with different types of tiles:

Model 1: aviary with ceramic tiles
Model 2: aviary with fiber-cement roof tiles
Model 3: aviary with metal tiles
Model 4: aviary with thermoacoustic tiles.

Simulations of air temperature, relative air humidity, and THI were set up for two climatic seasons: winter and summer. During the simulations, the shed was considered under empty conditions, that is, without electrical appliances and occupants. This consideration was adopted to estimate the thermal performance of the facility for each tile type.




A. North facade; B. South facade; C. East facade; D. West facade

**Figure 3.** Model of the aviary with its real characteristics

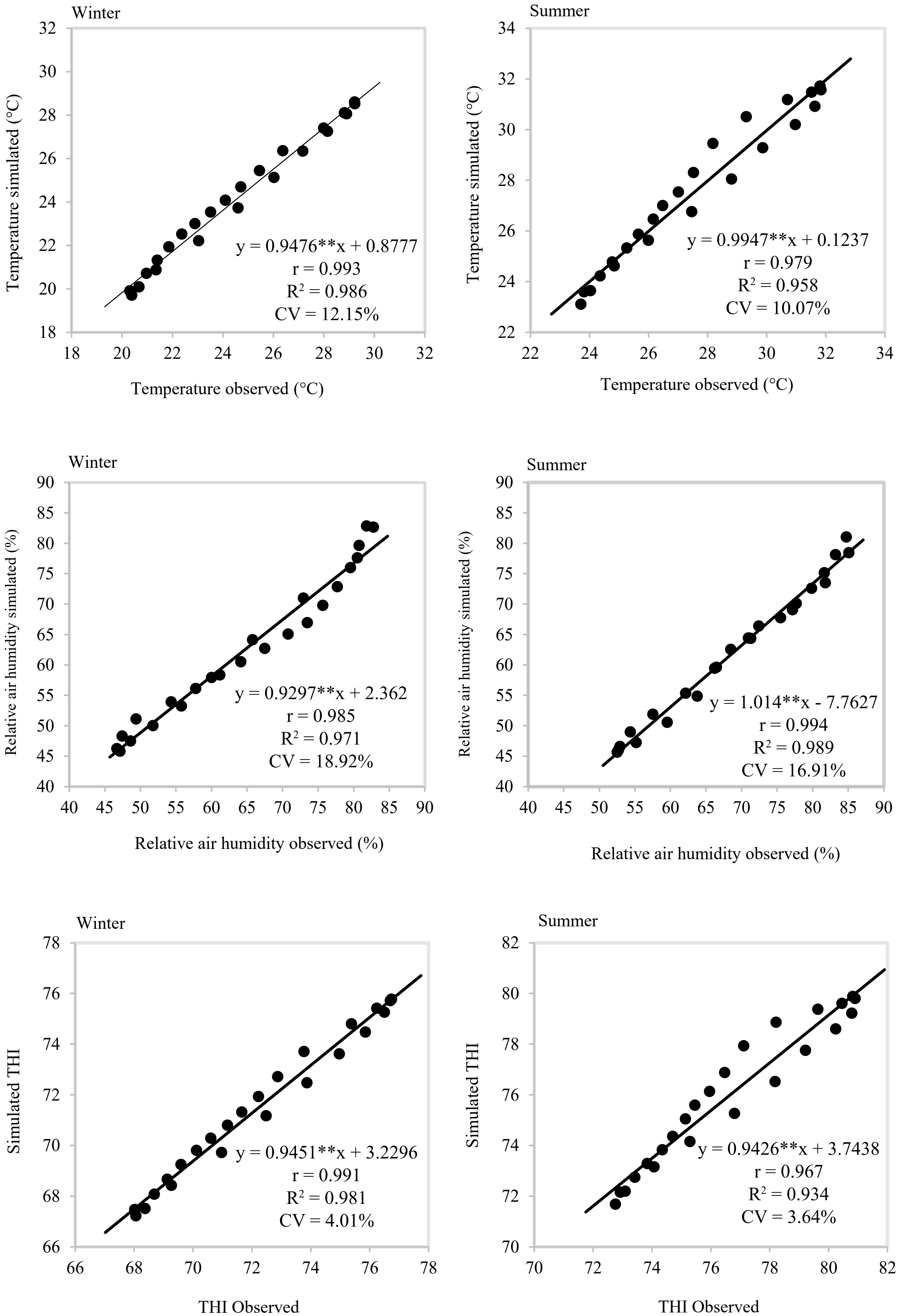
**Table 1.** Physical and thermal properties of building materials in the aviary

| Material | Material caracteristics |
|---|---|
| Ceramic brick | Composition: Ceramic material<br>Thickness: 9.0 cm<br>Thermal conductivity: 1.05 W $m^{-1}$ $K^{-1}$<br>Specific mass: 2000 kg $m^{-3}$<br>Specific heat: 0.92 kJ $kg^{-1}$ $K^{-1}$<br>Source: ABNT (2008) |
| Mortar | Composition: Cement, sand and water<br>Thickness: 2.5 cm<br>Thermal conductivity: 1.15 W $m^{-1}$ $K^{-1}$<br>Specific mass: 2000 kg $m^{-3}$<br>Specific heat: 1.00 kJ $kg^{-1}$ $K^{-1}$<br>Source: ABNT (2008) |
| Aluminum Screen | Composition: Aluminum<br>Thickness: 0.05 cm<br>Thermal conductivity: 230 W $m^{-1}$ $K^{-1}$<br>Specific mass: 2700 kg $m^{-3}$<br>Specific heat: 0.88 kJ $kg^{-1}$ $K^{-1}$<br>Source: ABNT (2008) |
| Ceramic tile | Composition: Ceramic material<br>Thickness: 2.0 cm<br>Thermal conductivity: 1.05 W $m^{-1}$ $K^{-1}$<br>Specific mass: 2000 kg $m^{-3}$<br>Specific Heat: 0.92 kJ $kg^{-1}$ $K^{-1}$<br>Slope: 25%<br>Source: ABNT (2008) |
| Fiber-cement tile | Composition: Cement reinforced with synthetic thread<br>Thickness: 2.0 cm<br>Thermal conductivity: 0.95 W $m^{-1}$ $K^{-1}$<br>Specific mass: 1900 kg $m^{-3}$<br>Specific Heat: 0.84 kJ $kg^{-1}$ $K^{-1}$<br>Inclination: 15%<br>Source: LabEEE (2020) |
| Metal tile | Composition: Cement reinforced with synthetic thread<br>Thickness: 2.0 cm<br>Thermal conductivity: 0.95 W $m^{-1}$ $K^{-1}$<br>Specific mass: 1900 kg $m^{-3}$<br>Specific Heat: 0.84 kJ $kg^{-1}$ $K^{-1}$<br>Inclination: 15%<br>Source: ABNT (2008); Dias (2011) |
| Thermoacoustic tile | Composition: Galvanized steel + polyurethane + galvanized steel<br>Thickness: 2.0 cm<br>Polyurethane data: Thermal conductivity: 0.03 W $m^{-1}$ $K^{-1}$<br>Specific mass: 20 kg $m^{-3}$<br>Specific Heat: 0.16 kJ $kg^{-1}$ $K^{-1}$<br>Inclination: 10%<br>Source: Dias (2011) |

To validate the computational modeling results, the experimental values of air temperature, relative air humidity, and THI were correlated with and those observed through simulation, under the same conditions. The correlation used simple linear regressions with a 95% confidence interval and evaluation of the degree of elevation of Pearson's correlation coefficient (r).

## Results and Discussion

The relationship between the microclimatic variables (air temperature, relative air humidity, and THI) observed and simulated by the EnergyPlus computer program, for a poultry house located in the city of Petrolina, PE, Brazil in the winter and summer seasons is presented in Figure 4, with a confidence interval of 95%.




** - Significant at $p \leq 0.01$ by t test

**Figure 4.** Correlation between observed and simulated microclimatic variables (air temperature and relative air humidity) and thermal comfort index (THI) in winter and summer seasons

Analyzing the scatter diagram (Figure 4), a strong correlation was found between the experimental values and those simulated by EnergyPlus for air temperature, relative air humidity, and THI, with a Pearson's correlation coefficient (r) greater than 0.966. These results demonstrate that the computer models generated using this tool provide reliable predictions regarding the microclimate characteristics simulated inside the aviary under study.

The results presented in Figure 4 corroborate those reported by Pereira et al. (2020), who also studied the thermal comfort conditions of a building through computer simulations in EnergyPlus and verified that there was a strong correlation between the measured and simulated air temperature data, with a Pearson's linear correlation coefficient of 0.95.

According to Coakley et al. (2014), validating the computer simulation results is essential to ensure the reliability of the program output data, in order that they may be used safely.

It can be seen that the environmental information generated from the computational models developed in EnergyPlus is reliable and should be used to create thermal comfort strategies in broiler breeding facilities in the region, so as to improve the microclimatic conditions of the facilities for the confinement of these animals, as well as to help rural producers in the design and execution phase of such installations.

Figures 5, 6 and 7 present the simulation results of air temperature, THI, and relative air humidity in the aviary models, respectively, generated using EnergyPlus with respect to different types of roof tiles (ceramic, fiber-cement, metal, and thermoacoustic).

From the results shown in Figures 5 and 6, it can be seen that the roof tile that presented the best thermal performance was the thermoacoustic tile, with ranges of air temperature and THI in winter and summer, respectively, varying from 19.5 to 26. 4 °C and 67 to 73, and 22.2 to 28.8 °C and 70 to 76; followed by the ceramic tile (19.5 to 28.1 °C and 67 to 75; 23.1 to 31.3 °C and 72 to 79), fiber-cement (21.9 to 29.7 °C and 70 to 77; 25.8 to 33.3 °C and 75 to 82), and metal (22.9 to 30.7 °C and 71 to 79; 26.7 to 34.7 °C and 76 to 84).

Similar results were observed by Tokusumi & Foiato (2019), who analyzed the thermoacoustic performance of roof tiles and noted that their performance exceeded that of ceramic tiles and fiber-cement tiles, with respect to both greater sound attenuation and lower heat transfer into the built environment.

Studies developed by Oliveira et al. (2015) also confirmed the results described in this research, where they found that poultry houses covered with thermoacoustic tiles showed more favorable thermal index values than sheds with metal tile roofing.

Silva et al. (2015), in evaluating the thermal performance of types of coverings inside reduced models of poultry houses,

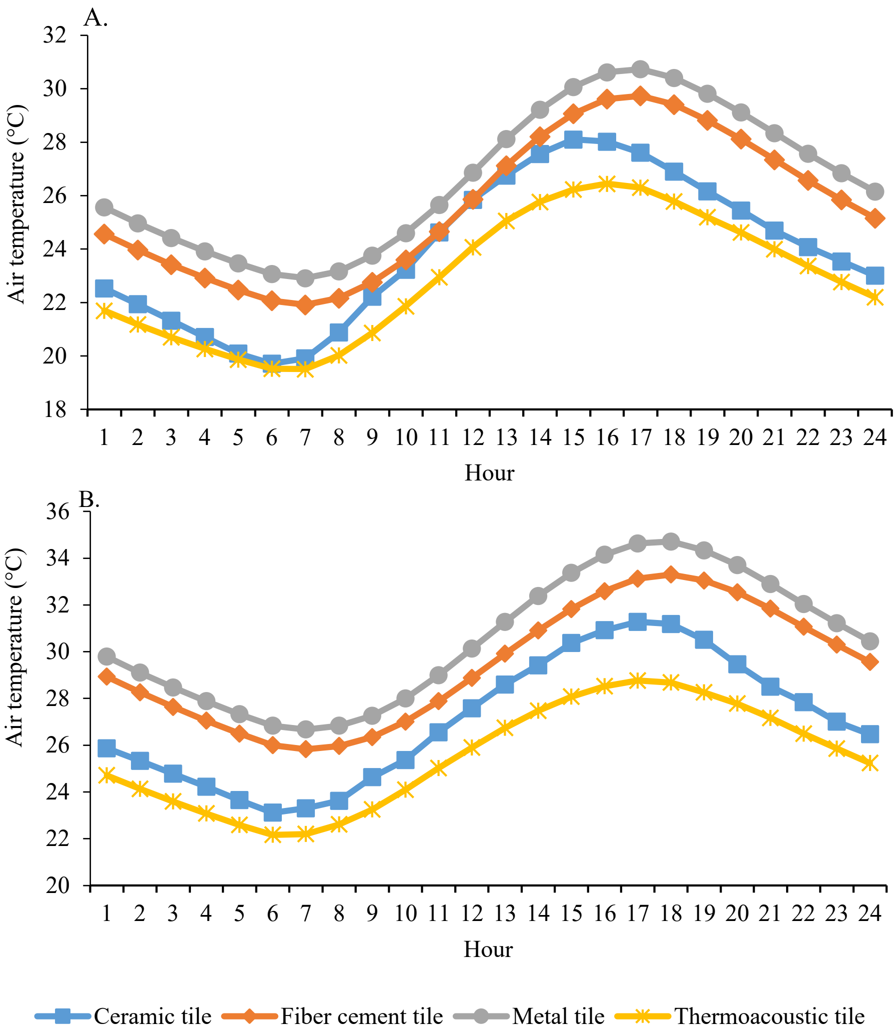



**Figure 5.** Mean simulated air temperature at different times throughout the winter (A) and summer (B) seasons for different types of roof tiles

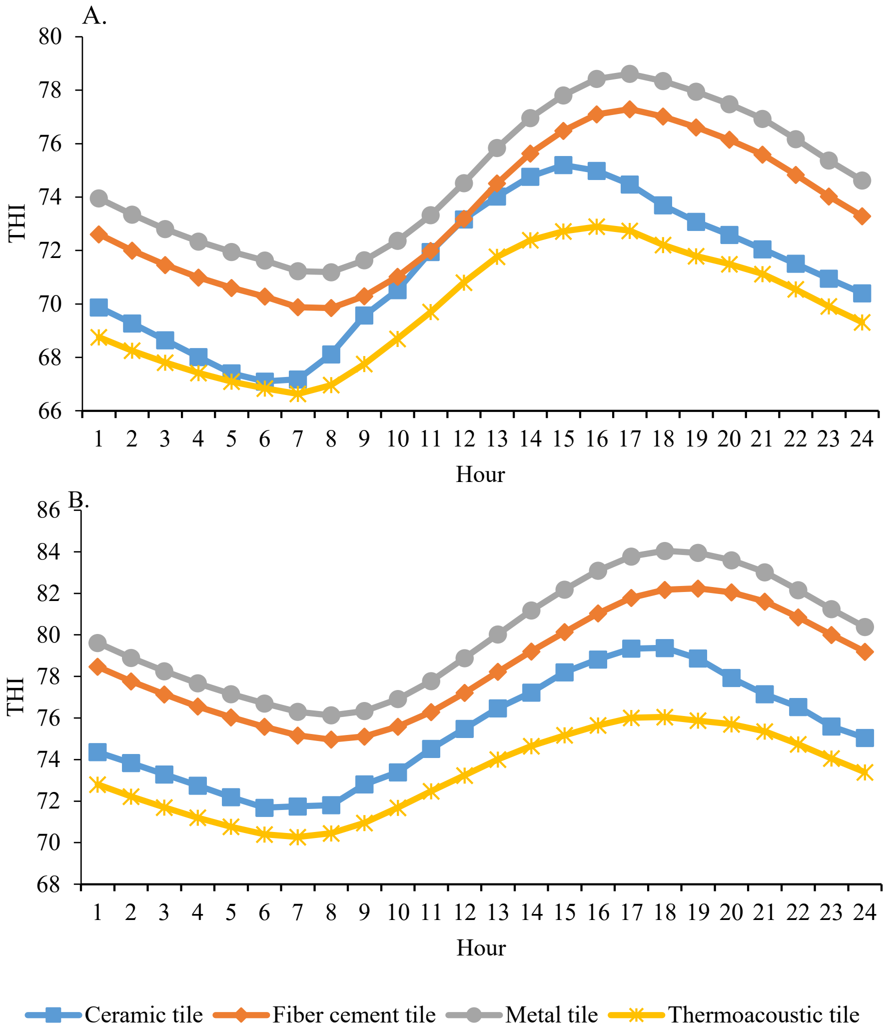



**Figure 6.** Average simulated temperature and humidity index (THI) at different times throughout the winter (A) and summer (B) seasons for different types of roof tiles

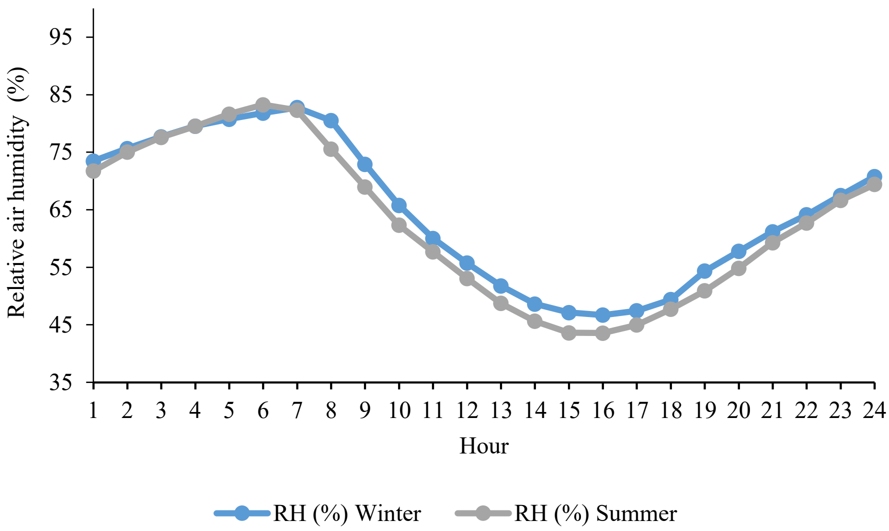



**Figure 7.** Mean simulated relative air humidity at different times throughout the winter and summer seasons

also inferred that the use of ceramic tiles, when compared to the other tiles tested (fiber-cement and metal), provides better thermal comfort conditions. Despite not having verified the thermal performance of thermoacoustic roof tiles, these results corroborate those presented in this study.

Baêta & Souza (2010) indicated that the air temperature should be between 18 and 26 °C in a production environment with thermal comfort conditions for broilers. Abreu & Abreu (2011) considered the ideal relative air humidity for broiler confinement to be in the range of 60-70% and recommended that the THI should vary between 60 and 72.

Considering the results of the air temperature (Figure 5) and THI (Figure 6) and the recommendations of the authors cited in the previous paragraph, it can be inferred that during the winter, the model aviary with thermoacoustic tiles provided thermal comfort conditions for broilers at all times, which was not observed in the summer. For the models with ceramic and fiber-cement roof tiles, the thermal environment indicated scenarios of comfort and discomfort during both seasons, unlike the model developed with metal tiles, which for the summer season showed adverse conditions for broiler chickens on 21 days at all times.

This result is due to the physical and thermal properties of the materials that make up the tiles. The thermoacoustic tile showed the best performance because it is formed by two metal plates, whose interior is composed of a layer of insulating material that promotes thermal insulation and improves the quality of the building's internal environment.

Owing to the lower thermal conductivity coefficient of the thermoacoustic tile (0.04 W $m^{-1}$ $K^{-1}$) compared to the fiber-cement tile (0.95 W $m^{-1}$ $K^{-1}$), ceramic tile (1.05 W $m^{-1}$ $K^{-1}$), and metal tile (55 W $m^{-1}$ $K^{-1}$), its heat conduction to the interior of the building is lower. Consequently, the thermoacoustic tile causes a decrease in the thermal load inside the house and thus provides better thermal comfort conditions for the animals and probably lower implementation and maintenance costs of a refrigeration system.

The results presented above also show that the thermal environments of the aviaries using ceramic tiles and fiber-cement roof tiles, between 9 a.m. and 1 p.m., during winter, are practically the same. According to NBR 15220-2 (ABNT, 2008), the thermal conductivity and specific heat of ceramic tiles are 1.05 W $m^{-1}$ $K^{-1}$ and 0.92 kJ $kg^{-1}$ $K^{-1}$, respectively, while those of fiber-cement tiles are 0.95 W $m^{-1}$ $K^{-1}$ and 0.84 kJ $kg^{-1}$ $K^{-1}$.

Although new fiber-cement tiles present a thermal performance close to that of ceramic tiles at certain times, as shown in this study, as these tiles age, their physical and thermal characteristics will change, as verified by Coelho et al. (2017). When evaluating the thermal performance and solar absorptance of fiber-cement roof tiles subjected to different natural aging processes, they concluded that after 36 months, these tiles showed an increase in absorptance and surface temperatures, indicating that the aging process of this material can increase the solar heat gains of buildings.

Oliveira et al. (2016) demonstrated that, although the implementation cost of a roof with fiber-cement tiles is lower than that of other systems, its thermal performance is worse than that of ceramic tiles.

As for the results for the relative air humidity (Figure 7), the simulated values were the same for all types of roof tiles; that is, according to the program, the thermal properties of the roofing materials do not interfere with the relative humidity of the air inside the facility. For this variable, the program determined variation ranges of 82-46% in winter and 85-52% in summer.

According to the recommendation of Abreu & Abreu (2011), the models presented situations of comfort and discomfort during the two periods analyzed. However, one should mainly pay attention to the high values of relative air humidity associated with high air temperature conditions, an especially prevalent situation with the model with metal tiles, which can be extremely detrimental to the confinement of animals, because relative air humidity is inversely proportional to heat dissipation by evaporation, which is the most efficient way for birds to lose heat.

It is important to point out that relative air humidity levels below the comfort zone combined with high air temperature values are not ideal for broiler chickens, as these conditions lead to dryness of the respiratory tract and possibly dehydration of the birds (Cordeiro et al., 2016).

## Conclusions

1. Validation of the models generated by EnergyPlus has shown it to be a useful and reliable tool for project design.

2. Thermoacoustic tiles provided the best thermal performance, followed by ceramic, fiber-cement, and metal tiles.

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