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THERMAL EFFICIENCY OF DIFFERENT COVERAGE MATERIALS IN REDUCED MODELS OF ANIMAL HUSBANDRY FACILITIES: A CASE STUDY

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ABSTRACT: This study aimed to assess different combinations of coverage materials in reduced models of animal husbandry facilities based on thermal comfort indices. It was conducted in an experimental area of the Research Center in Ambience located in São Paulo State, Brazil (22°42′30″ S and 47°38′00″ W). The performance of ceramic and fiber-cement (white painted) tiles was assessed associated with two types of polypropylene commercial linings (lining A and B) installed below the roof, and a thermo-reflective screen (lining C) installed above the fiber-cement roof. Microclimatic assessment of distorted reduced-scale models was performed at 15-minute intervals by registering the air temperature, black globe temperature, relative humidity and air velocity. Subsequently, black globe humidity index, specific enthalpy, and radiant heat load were calculated. The experimental design was randomized block design with 5 treatments and 15 blocks (replications), totaling 75 experimental units. The reduced-scale models with lining B presented a reduction for all thermal comfort indices. Lining C, installed on the coverage, showed no upgrading of environmental thermal conditions. Thus, lining B presented a better thermal performance regardless the tile type.

KEYWORDS: ambience; thermal comfort; tiles; poultry facility; linings.

INTRODUCTION

Thermal efficiency of a facility depends on several factors such as the internal heat produced by animals, heat entering the building by solar incidence, heat transferred by conduction through walls and roofs, and thermal exchanges of heating or cooling caused by the surrounding air (CRAVO et al., 2012; PASSINI et al., 2013; ALMEIDA & PASSINI, 2013; SANTOS et al., 2014).

Coverage is the facility area most exposed to solar radiation, exerting a greater influence on the heat exchanges between external and internal environments. Solar radiation that reaches the roof is reflected, absorbed or transmitted in quantities that vary according to material physical properties (MICHELS et al., 2008; TONOLI et al., 2011). Therefore, there were no convection or irradiation losses of the energy falling on tiles, so that being absorbed and heating them and, consequently, being transmitted to the attic (region between the tile and the lining). In the attic, energy is conducted by convection and radiation to the lining surface, which absorbs some of that energy that will be transmitted into the building (MICHELS et al., 2008).

Due to the low thermal conductivity of the air present in the attic region, radiation transfer to the inside facility is reduced (MICHELS et al., 2008; TANGJUANK & KUMFU, 2011). Thus, the use of thermal insulation, such as under-roof lining, reduces thermal transmission and increases thermal inertia, which provides a better comfort to animals, thus becoming one of the most used types of insulation in poultry farming.

Some authors have studied the combination effects of different tiles and linings of animal husbandry facilities on thermal comfort and productive performance of animals. ABREU et al. (2007) observed that aviaries with polyethylene lining presented the best results of thermal comfort

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and productive indices when compared to unlined aviaries. Similarly, CRAVO et al. (2014) reported that an environment with lining (peanut shell and green coconut fiber) presented lower radiation values at all the assessed times, thus demonstrating a reduction in the amount of radiation transmitted into the aviaries.

In this sense, FIORELLI et al. (2010) and SILVA et al. (2015) concluded that the use of long life packaging-based recycled tiles presented thermal comfort indices similar to those found with ceramic tiles and could be indicated as a coverage option for animal husbandry facilities.

Reflective surfaces have also been used as a thermal insulation due to their low emissivity and absorptivity characteristics, in addition to their high reflectivity in the infrared spectrum (MICHELS et al., 2008). When assessing the combination of reflective painting (white latex paint on asbestos cement tiles) and artificial ventilation, PASSINI et al. (2013) observed a reduction in the values of radiant heat load (RHL), black globe humidity index (BGHI), and temperature- humidity index (THI) in broiler chicken rearing.

In order to improve the thermal comfort of broiler chickens, LAVOR et al. (2008) assessed the effect of thermal insulators (carnauba straw, recycled cardboard, white synthetic raffia, and blue synthetic raffia) and their effects on broiler chicken performance. These authors concluded that blue raffia presented the best zootechnical performance, being the worst performance observed in white raffia. In this sense, the use of materials that exhibit a low absorption coefficient, low thermal conductivity and diffusivity, and higher thermal inertia is essential to reduce heat transfer inside a building (TONOLI et al., 2011).

A great number of materials used as thermal insulation in rural buildings can be found in the market. However, the thermal efficiency and performance of these different materials need to be assessed when associated with different types of tiles in order to provide comfort to animals. Thus, this study aimed to assess the use of different combinations of coverage and lining materials in reduced models of animal husbandry facilities based on thermal comfort indices.

MATERIAL AND METHODS

This study was conducted for 55 days during the winter season at the experimental area of the Center for Research in Ambience (NUPEA) of the Luiz de Queiroz College of Agriculture (ESALQ/USP), located in Piracicaba - SP, Brazil. This season was chosen based on specific enthalpy parameters. According to ÇENGEL & BOLES (2001), the higher the specific enthalpy value is, the higher the amount of thermal energy in the dry air. Due to climate change (atypical conditions with warm days and a great thermal amplitude), the experiment was carried out during a winter with high temperatures, providing a rearing environment out of the thermal comfort ranges for farm animals.

The region where the research was conducted is located at the geographical coordinates 22°42′30″ S and 47°38′00″ W and at an altitude of 546 m, with an average atmospheric pressure of 753 mmHg. Regional climate is classified as Cwa (tropical humid) according to Köppen classification, with three months drier (June, July, and August), rains in the spring and summer, and droughts in the winter.

Five models constructed in a distorted reduced-scale according to the similitude theory were used (JENTZSCH et al., 2013). Models were constructed in the east-west direction on the 1:10 scale in the horizontal dimensions and 1:2 in the vertical dimensions, with measures of 4.02 m in length, 1.20 m in width, and 1.50 m of ceiling height. Model structure was formed by masonry of bricks without sidewalls, with concrete floor, and two-story roof. Facility surroundings were composed of an area covered with Bahia grass.

The experiment was composed of five treatments with two different tile types (ceramic and white painted fiber-cement) associated with three different lining types (A, B, and C), as follows: CA – ceramic tile + lining A, CB – ceramic tile + lining B, FA – fiber-cement tile + lining A, FB – fiber-cement tile + lining B, and FC – fiber-cement tile + lining C. Commercial linings named A, B, and C (Figure 1) were found in most poultry facilities of the region (Table 1) and used in this study.

TABLE 1. Characteristics of lining materials used.

Material	Composition
Lining A	99% polypropylene and 1% pigments and anti-UV (Figure 1A)
Lining B	92.1% polypropylene and 3% pigments and anti-UV (Figure 1B)
Lining C	Thermo-reflective screen formed by a braided mesh composed of high-density polyethylene and aluminum, with 50 to 55% shading (Figure 1C)

A. B. C.

FIGURE 1. Different linings used in the experiment (A, B, and C).

Linings A and B are blue and were installed inside the model and below the roof, separating the attic space from the rest of the building (Figures 2A and 2B). Lining C was installed above the roof of the reduced-scale model, at 0.10 m from the roof ridge, transposing 0.50 m from the eaves, forming a shading on the roof (Figure 2C).

Inside the models, 10 lamps of 100 W (Figure 2B) were placed to simulate the heat released by 2.1-kg chickens housed at a density of 12 birds per m^{-2}, considering that each animal emits 20 W of energy, according to the recommendations of HELLICKSON & WALKER (1983).

A. B. C.

FIGURE 2. Internal view of the model with lining (A), side view of the model with lining under the fiber-cement roof (B), and frontal view of the model with lining above the fiber-cement roof (C).

Air temperature (T, °C), black globe temperature (Tbg, °C), and relative humidity (RH, %) were registered daily at 15-minute intervals during the period from 8:00 to 17:00 h. For this, a meteorological shelter was installed in the external area and at the geometric center of each reduced-scale model. Each meteorological shelter was constructed of white painted plastic material and equipped with a thermistor sensor and a data logger Hobo®, with two external channels, one of them connected to the external temperature and black globe temperature sensors (thermistor). Air velocity (Av, m s^{-2}) was recorded at 8:00, 11:00, 14:00, and 17:00 h by means of a direct reading digital anemometer ICEL® model AN–10.

The environmental indices used were the black globe humidity index (BGHI), radiant heat load (RHL), and specific enthalpy (h). These indices were calculated by means of the equations proposed by BUFFINGTON et al. (1981), ESMAY (1979), and RODRIGUES et al. (2011) and using the previously registered meteorological variables.

Due to the high cost to obtain the experimental units, the assessed days were considered as blocks, providing to the experiment sufficient replications for the analysis conditions. Thus, the experimental design was randomized block design with 5 treatments and 15 blocks (days with the greatest enthalpy), totaling 75 experimental units, as suggested by BAILEY (2008), who considers the day as a local control factor for high-cost experimental units.

Different times (8:00, 11:00, 14:00, and 17:00 h) were used for the analyses by means of the F-test of the analysis of variance and the Tukey's test at 5% significance. All statistical analyses were performed using the statistical software SAS 9.2 (SAS INSTITUTE, 2010).

RESULTS AND DISCUSSION

The 15 days with the highest specific enthalpy registered were considered for assessing the thermal environment inside the distorted reduced-scale models, i.e. the days with the greatest thermal discomfort over the experimental period (55 days). Specific enthalpy values ranged from 49.26 to 55.43 kJ kg^{-1} dry air.

Comfort range and the upper and lower critical limits of specific enthalpy were established considering the atmospheric pressure of 759.81 mmHg in Piracicaba, a temperature range from 21 to 24 °C, and a relative humidity of 60%, as proposed by MACARI & FURLAN (2001) and NASCIMENTO et al. (2012, 2013) for sixth-week broiler chickens. Based on this standard information, the enthalpy range of comfort considered was between 45.89 and 53.92 kJ kg^{-1} dry air.

According to the results obtained from the experimental period characterization, the assessed period should be considered in the winter season, with the lowest temperature values in relation to the warmer periods in the region. This fact allows predicting that the results found in this study will have maximized effects in the summer.

Table 2 shows a statistical difference between treatments for air specific enthalpy at all times. LAVOR et al. (2008) also observed a statistical difference between different types of thermal insulation (carnauba straw, recycled cardboard, white synthetic raffia, and blue synthetic raffia).

TABLE 2. Average values of specific enthalpy (kJ kg^{-1} dry air) registered for all treatments at different measurement times.

Treatment	8:00 h	11:00 h	14:00 h	17:00 h
CA	46.25 a	51.90 ab	52.20 ab	49.44 ab
CB	44.89 b	51.10 b	51.31 bc	49.36 ab
FC	44.80 b	52.67 a	52.84 a	50.40 a
FA	45.30 b	51.66 ab	51.69 abc	49.54 ab
FB	45.37 ab	50.83 b	50.70 c	48.52 b

CA – ceramic tile + lining A (99% polypropylene and 1% pigments and anti-UV); CB – ceramic tile + lining B (92.1% polypropylene and 3% pigments and anti-UV); FA – fiber-cement tile + lining A; FB – fiber-cement tile + lining B; and FC – fiber-cement tile + lining C (thermo-reflective screen formed by a braided mesh composed of high-density polyethylene and aluminum, with 50 to 55% shading). Means followed by different letters on the columns indicate statistical differences ($P<0.05$) for each time by the Tukey's test.

Treatments with fiber-cement and ceramic tiles, associated with lining B (FB and CB, respectively) at all times, except at 8:00 h, registered the lowest specific enthalpy values, with no statistical differences regarding the other treatments. The fiber-cement tile with lining C presented the worst specific enthalpy values at all times, except at 8:00 h, and differed statistically from the treatments FB and CB at the warmest times (11:00 and 14:00 h).

The difference between the highest and lowest average specific enthalpy at all times was lower than 2.15 kJ kg^{-1} dry air, being 14:00 h the time that showed the greatest difference. Based on the specific enthalpy values, the use of thermo-reflective screen (lining C) above the roof caused no reduction of the internal heat of prototypes as expected since it differed statistically from the other treatments, presenting higher enthalpy values.

GOMES FILHO (2010), using reduced-scale models, found that a 50% shading screen positioned at 0.05 m above an asbestos-free fiber-cement roof and without white painting in the external surface reduced the values of BGHI (80.31) and enthalpy (78.84 kJ kg^{-1} dry air). However, these values were out of the thermal comfort range for broiler chickens.

When directing the assessments to the days of higher and lower enthalpy, in this study the days of lesser and greater comfort, respectively, a variation was observed in the values found between the studied environments and the external environment, as in Figures 3A and 3B.

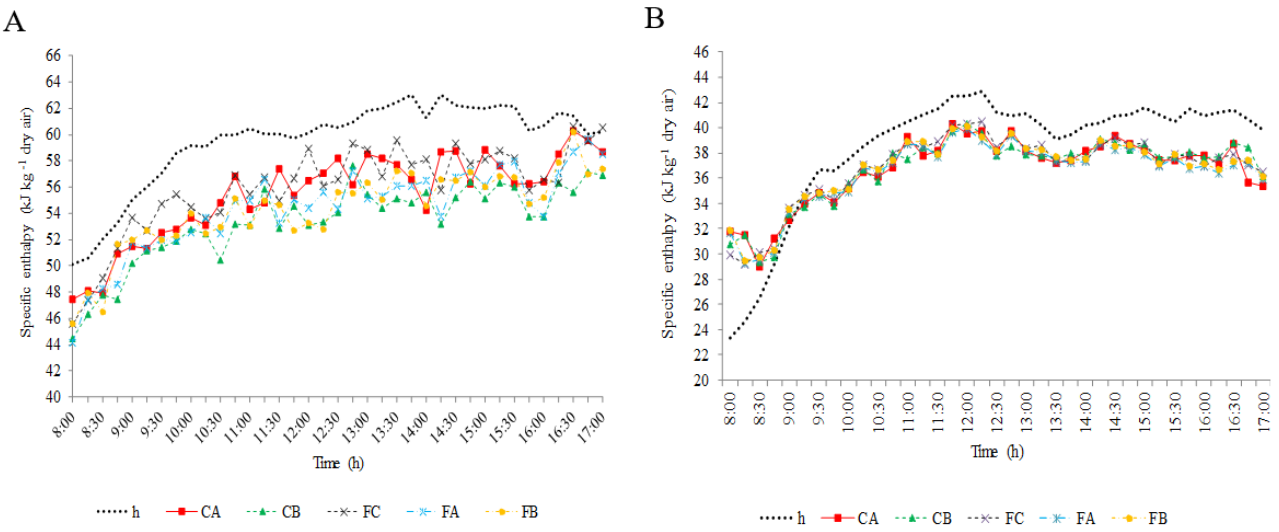

FIGURE 3. Average specific enthalpy variation of the external air (h) and inside the models (CA, CB, FC, FA, and FB) over the experimental period (8:00 to 17:00 h.) on the day of higher (A) and lower (B) specific enthalpy.

Reduced-scale models presented the same cyclic behavior of the enthalpy curves in the external environment. On both days, the specific enthalpy inside the models was lower in the external environment, except in the initial period of the day with the lowest specific enthalpy, evidencing the importance of using the materials as insulating elements of radiant heat load (Figure 3B).

At times with low temperature associated with a high relative humidity, an internal heat conservation occurs in the facilities, which resulted in a higher air enthalpy in the different treatments. In addition, a lower variation can be observed between the average values of treatments on the day of lower enthalpy, showing to be more homogeneous.

When assessing three different coverage types formed by palm straw, recycled polymer tile, and fiber-cement tile, BARNABÉ et al. (2015) observed that on the days of higher and lower enthalpy (62.75 and 52.84 kJ kg^{-1} dry air, respectively), animals were under thermal discomfort conditions for most of the day. Furthermore, treatments with recycled tiles presented the lowest values of specific enthalpy and radiant heat load (kJ kg^{-1} dry air and 444.8 W m^{-2}, respectively).

From the data analysis, an effect of treatment was observed for the dry-bulb temperature at all times ($p<0.05$). The treatment with fiber-cement tiles and lining B showed the lowest average at all times but presented a statistical difference in relation to the other treatments only at 11:00 h (Table 3). In addition, at 14:00 h, temperature variation between the lowest (FB) and highest (CA) average was 0.59 °C, which was a small but significant difference ($p<0.05$). These results differ from those found by FIORELLI et al. (2010), who observed the highest average values of air temperature and radiant heat load at different times in poultry prototypes with fiber-cement roofing but without using lining in the prototypes.

TABLE 3. Average values of air temperature (°C) registered for all treatments at different measurement times.

Treatment	8:00 h	11:00 h	14:00 h	17:00 h
CA	18.31 b	25.38 a	28.59 a	26.85 a
CB	18.89 a	25.17 a	28.03 b	26.77 a
FC	17.77 c	25.33 a	28.32 ab	26.88 a
FA	18.03 bc	25.15 a	28.16 b	26.80 a
FB	17.75 c	24.75 b	28.00 b	26.54 a

CA – ceramic tile + lining A (99% polypropylene and 1% pigments and anti-UV); CB – ceramic tile + lining B (92.1% polypropylene and 3% pigments and anti-UV); FA – fiber-cement tile + lining A; FB – fiber-cement tile + lining B; and FC – fiber-cement tile + lining C (thermo-reflective screen formed by a braided mesh composed of high-density polyethylene and aluminum, with 50 to 55% shading). Means followed by different letters on the columns indicate statistical differences ($P<0.05$) for each time by the Tukey's test.

Considering as an optimum range the values between 21 and 24 °C and a critical range the values between 15 and 35 °C (MACARI & FURLAN, 2001; NASCIMENTO et al., 2012, 2013), the average dry-bulb temperature was outside the optimum range of thermal comfort (Figure 4A). PASSINI et al. (2013) found similar results. Environmental variables may cause positive and/or negative effects on poultry production. Therefore, high temperatures may reduce food intake, increase water consumption, influence thermal changes, and lead to metabolic diseases (ABDELQADER & AL-FATAFTAH, 2014; SILVA et al., 2015). Therefore, the microclimate inside the facilities needs to be improved to avoid possible economic losses.

High-temperature values are classified as one of the most important stress-causing agents in poultry production, especially the thermal stress resulting from interactions between air temperature, relative humidity, radiation, and air circulation (LIN et al., 2005; ABDELQADER & AL-FATAFTAH, 2014).

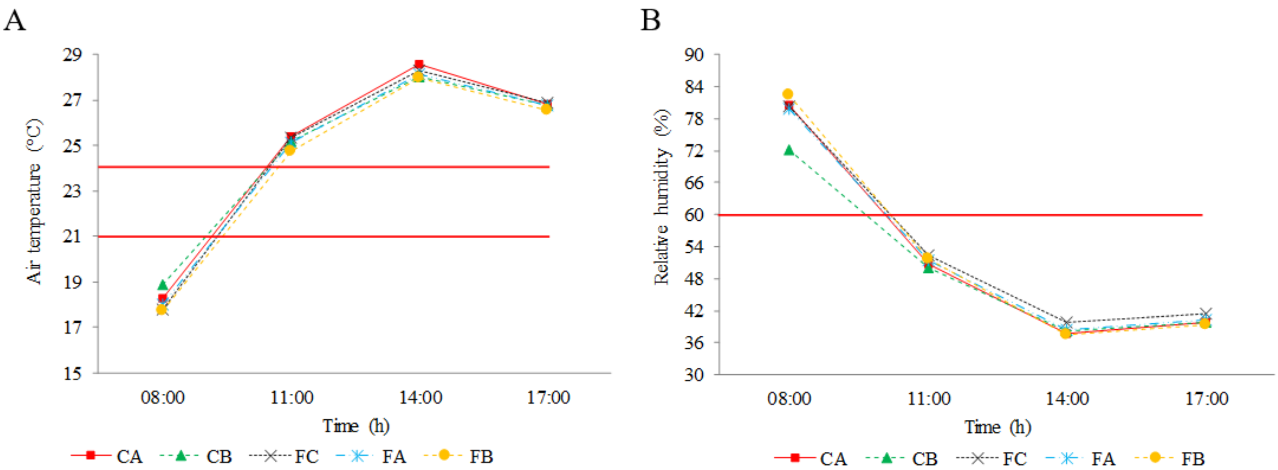

FIGURE 4. Average values of dry-bulb temperature (A) and relative humidity (B) for treatments, assessment times, and thermal comfort range (horizontal red lines).

The ideal relative humidity for sixth-week broiler chickens is 60% and the critical range varies between 40 and 80% (MACARI & FURLAN, 2001; NASCIMENTO et al., 2012, 2013). In this sense, no treatment presented a relative humidity close to the comfort value (Figure 4B). At 14:00 h (the highest temperature), all treatments presented an average relative humidity below the lower critical range. This happened because the relative humidity tends to decrease considerably when the air temperature reaches its highest levels over the day (LIN et al., 2005). However, the treatments FB, CA, and FC (82.35, 80.49, and 80.27%, respectively) exceeded the upper limit range at 8:00 h (the lowest temperature).

Relative humidity acts on evaporative heat loss (increases with temperature and decreases with increasing relative humidity) and its effect on bird thermoregulation will depend on air temperature and bird age (LIN et al., 2005; ABDELQADER & AL-FATAFTAH, 2014). Relative humidity values above 60% reduce heat transmission from the inner part of the body to the periphery, which hinders the thermal changes with the environment (LIN et al., 2005; ABDELQADER & AL-FATAFTAH, 2014).

FONSECA et al. (2012) concluded that individual shelters with different coverage types had no influence on dairy calf performance. However, these authors observed a significant difference in the animal respiratory rate, with the lowest value observed in treatments with zinc tiles (56.9 mov min^{-1}) and the highest value was observed in the treatment with fiber-cement tiles without white paint (70.25 mov min^{-1}). Thus, the authors concluded that the different environments interfered with the thermoregulatory physiology of animals.

BGHI ranged from 67 and 69 and were within the comfort range for broiler chickens in the last week of rearing for most of the treatments and times, except for CA at 14:00 h and FC and FB at 8:00 h, considering 65 and 77 respectively as the lower and upper limits for BGHI values (MEDEIROS et al., 2005). Different average BGHI values were found by CARDOSO et al. (2011), who found that most of the time facilities were uncomfortable for broiler chickens.

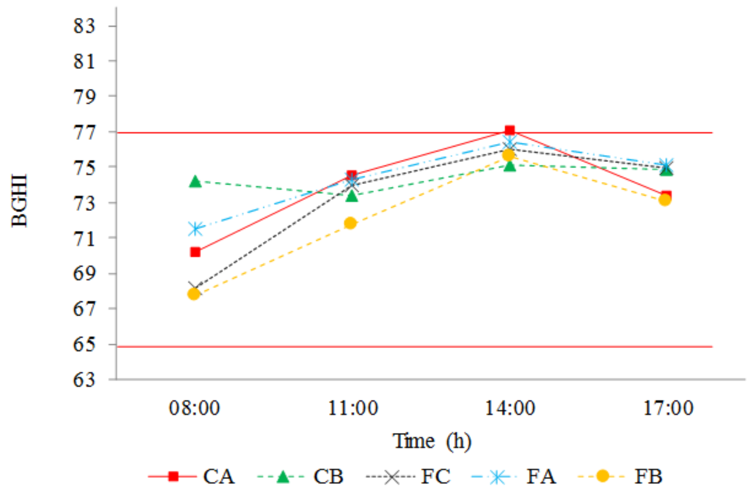

FIGURE 5. Lower and upper (horizontal red lines) critical limit of the black globe humidity index (BGHI) for all treatments at different measurement times.

No statistical difference (P<0.05) was observed for BGHI values between treatments. In this sense, CA and FA reached the highest average BGHI values at 11:00 h (74.51 and 74.33, respectively) and at 14:00 h (77.11 and 76.44, respectively); for FB, the lowest BGHI values were reached for all assessed times.

A progressive increase in BGHI values was observed from the first assessment time, with maximum values obtained at 14:00 h. This was due to the increasing temperature that surrounded the black globe, caused mainly by facility heating. In addition, at real conditions, this situation is aggravated due to the increased heat generated by the birds, leading to a discomfort.

PASSINI et al. (2013) also found that the average BGHI values were high at 14:00 h (81,24) and concluded that even with the combined use of reflective painting and natural ventilation, the average BGHI values were unfavorable for rearing birds in all treatments (77.7). However, the authors observed higher values of BGHI (78) and RHL (473 W m^{-2}) when comparing the results with the data from treatments with the absence of reflective painting, with or without air circulation.

Also working with reduced-scale models, MORAES et al. (1999) observed that the treatment with water sprinkled on the coverage reduced BGHI values, followed by the treatment with polyethylene lining. In addition, the authors concluded that the most efficient treatment for RHL was that with polyethylene lining, followed by sprinkling. According to them, at the time between 10:00 and 16:00 h, all treatments registered average BGHI values above 76, remaining out of the comfort range.

Researchers have questioned to what extent thermal comfort indices (in this case, BGHI) can be efficient to verify animal thermal comfort. This questioning is supported even by the contradiction found in several studies, as this index disregard air velocity, as occurs, for instance, in RHL. In BGHI, air velocity is considered indirectly by means of the black globe temperature, resulting from the combined effects of radiant energy, air temperature, and air velocity, which occur during heat exchanges between the black globe and the environment where it is inserted.

In contrast to this index, radiant heat load (RHL, W m^{-2}) values were used, differing statistically between treatments within each time (Table 4). The variation in RHL values observed in this study was also verified by several authors (FIORELLI et al., 2012; SILVA et al., 2015), who agreed with the use of this radiant load as the most effective to measure animal comfort level inside structures.

TABLE 4. Average values of radiant heat load (RHL, W m^{-2}) registered for all treatments at different measurement times.

Treatment	8:00 h	11:00 h	14:00 h	17:00 h
CA	488.92 bc	542.52 a	573.36 a	503.22 ab
CB	552.32 a	519.71 ab	528.26 cd	516.09 ab
FC	461.52 c	526.36 a	544.05 cb	520.04 a
FA	511.73 ab	540.87 a	565.45 ab	525.33 a
FB	469.61 bc	493.32 b	515.36 d	493.56 b

CA – ceramic tile + lining A (99% polypropylene and 1% pigments and anti-UV); CB – ceramic tile + lining B (92.1% polypropylene and 3% pigments and anti-UV); FA – fiber-cement tile + lining A; FB – fiber-cement tile + lining B; and FC – fiber-cement tile + lining C (thermo-reflective screen formed by a braided mesh composed of high-density polyethylene and aluminum, with 50 to 55% shading). Means followed by different letters on the columns indicate statistical differences ($P<0.05$) for each time by the Tukey's test.

The treatments CB and FB registered the lowest RHL values at 11:00 and 14:00 h, respectively, with no statistical differences ($P<0.05$) from the others. At these times, treatments with lining A, for both ceramic and fiber-cement tiles, presented the highest radiant heat load.

When assessing thermal comfort in reduced models, SILVA et al. (2015) found no statistically significant differences between RHL values in treatments with Tetra Pak® packaging-based recycled tiles (486.64 W m^{-2}) and ceramic tiles (492.24 W m^{-2}) but found the lowest average values in treatments with recycled tiles. These authors also concluded that Tetra Pak® packaging lining contributed to a reduction in the average values of THI, BGHI, and RHL.

However, FONSECA et al. (2011) found a statistical difference between treatments when assessing facilities with tiles of zinc, asbestos cement, and asbestos cement white painted on the upper face. These authors observed that the lowest values of RHL and BGHI (489.28 W m^{-2} and 76.8, respectively) were found in facilities covered with asbestos cement tiles white painted on the upper face whereas the highest values were found in facilities with zinc tiles (523.55 W m^{-2} and 81.6, respectively).

Thus, a great variation in treatments was observed within each time and the thermal behavior of ceramic and fiber-cement tiles (when were analyzed separately) was similar, making it difficult to distinguish the best treatment. The results found in this study are in accordance with those found by SAMPAIO et al. (2011), who observed a better thermal performance in environments with tiles white painted on the upper face, being similar to the results found when using ceramic tiles.

CONCLUSIONS

Ceramic and fiber-cement (white painted on the external surface) tiles showed similar thermal performance, regardless the lining used.

Treatments with lining B (composed of polypropylene) under the coverage presented the highest reductions in radiant heat load and black globe humidity index, regardless the tile used.

The use of roof shading (lining C, a thermo-reflective screen) in distorted reduced-scale models showed no improvement in thermal conditions of the assessed environment when compared to the effect of using linings.

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