ISSN 2359-6562 (ONLINE) 2359-6562 (CD-ROM)

EFICIÊNCIA TÉRMICA DE TELHAS DE DIFERENTES MATERIAIS EM INSTALAÇÕES ANIMAIS DE PRODUÇÃO

EDUARDO TORRES M. DA SILVA[1], SILVIA REGINA LUCAS DE SOUZA[2], LEDA GOBBO DE FREITAS BUENO[3], CLEBER ALEXANDRE DE AMORIM[4], DAVI RODRIGO DE MIRANDA[5].

[1] Departamento de Engenharia Rural e Socioeconomia, FCA – UNESP Campus Botucatu, Rodovia Alcides Soares, Km 3 - Fazenda Experimental Lageado -Botucatu/SP -CEP 18610-034. Email: eduardo.torres@unesp.br
[2] Departamento de Engenharia Rural e Socioeconomia, FCA – UNESP Campus Botucatu, Rodovia Alcides Soares, Km 3 - Fazenda Experimental Lageado -Botucatu/SP -CEP 18610-034. Email: silvia.souza@unesp.br
[3] Departamento de Engenharia Rural e Socioeconomia, FCA – UNESP Campus Botucatu, Rodovia Alcides Soares, Km 3 - Fazenda Experimental Lageado -Botucatu/SP -CEP 18610-034. Email: leda.bueno@unesp.br
[4] Departamento de Engenharia Rural e Socioeconomia, FCA – UNESP Campus Botucatu, Rodovia Alcides Soares, Km 3 - Fazenda Experimental Lageado -Botucatu/SP -CEP 18610-034. Email: cleber.amorim@unesp.br
[5] Departamento de Engenharia Rural e Socioeconomia, FCA – UNESP Campus Botucatu, Rodovia Alcides Soares, Km 3 - Fazenda Experimental Lageado -Botucatu/SP -CEP 18610-034. Email: davi.miranda@unesp.br

RESUMO: A eficiência térmica das telhas em instalações para produção animal impacta diretamente a temperatura interna dos alojamentos e, por consequência, o bem-estar dos animais. Este estudo compara a temperatura superficial interna das telhas de diferentes materiais nos períodos matutino e vespertino para avaliar o conforto térmico. Imagens termográficas da câmera TESTO 875 – 2i foram registradas na parte interna dos telhados de duas instalações animais da FMVZ - Unesp Campus Botucatu, uma composta por telhas de cerâmica e outra por telhas de fibrocimento. Após a seleção de pontos aleatórios nas imagens, utilizou-se a análise exploratória dos dados para cada material de telha e período do dia, aplicando o teste T (95% de significância). Verificou-se que a telha de cerâmica é mais indicada para instalações animais, devido à maior eficiência térmica e capacidade de dissipação de calor em comparação ao fibrocimento. Entretanto, no período vespertino, a aspersão das telhas de fibrocimento favoreceu a diminuição da temperatura interna. Conclui-se que as telhas de cerâmica proporcionam maior conforto térmico para os animais, enquanto a aspersão da telha de fibrocimento contribui para a redução da carga térmica no telhado durante a maior incidência solar.

Palavras-chaves: conforto térmico e ambiência, bem-estar animal, temperatura superficial, construções rurais.

THERMAL EFFICIENCY OF ROOFS MADE OF DIFFERENT MATERIALS IN ANIMAL PRODUCTION FACILITIES

ABSTRACT: The thermal efficiency of roofing materials in animal production facilities directly impacts the internal temperature of buildings and, consequently, animal well-being. This study compared the internal surface temperatures of different roofing materials in the morning and afternoon to assess their thermal comfort. Thermographic images were taken via a TESTO 875–2i camera from the interior of the roofs in two animal facilities at FMVZ - Unesp Campus Botucatu, one with ceramic tiles and the other with fiber cement tiles. After random points in the images were selected, exploratory data analysis was conducted for each roof material and time of day, and a t test (95% significance) was applied. Compared with fiber cement tiles, ceramic tiles are more suitable for use in animal facilities because of their higher thermal efficiency and heat dissipation capacity. However, in the afternoon, sprinkling the fiber cement tiles helped reduce the internal temperature. It is concluded that ceramic tiles provide greater thermal comfort for animals, whereas sprinkling with fiber cement tiles contributes to reducing the thermal load on the roof during periods of high solar incidence.

Keywords: thermal comfort and ambiance, animal welfare, surface temperature, rural constructions.

Recebido em 2011/2023 e aprovado para publicação em 08/02/2024
DOI: http://dx.doi.org/10.17224/EnergAgric.2024v39p6-14

1 INTRODUCTION

Brazil is a major producer and exporter of animal protein, playing a significant role in the Brazilian economy, contributing to job creation, increasing food production and boosting the agro-industrial sector.

Since Brazil is a country located in the tropics, most of the regions destined for agricultural production occur in places with hot climates, which require adequate facilities to provide thermal comfort, animal welfare and consequently greater productivity and sustainability (Pandorfi; Almeida; Guiselini, 2012).

The importance of climate suitability in facilities for raising livestock is considered a crucial factor in the success or failure of an enterprise. To this end, facilities must provide thermal comfort and ambiance through projects that integrate the use of appropriate materials to minimize direct and indirect solar radiation inside facilities (Tinôco, 1998; Kawabata, 2003).

The material of the tiles used is the place where solar radiation has greater intensity, which is extremely important for the value of the effective temperature, since the heat flow that passes through the tile, during the hottest times of the day, can be five times greater than that of the internal environment (Gomes Filho, 2010).

The most commonly used roof tiles in animal production facilities are aluminum, ceramic and fiber cement (Tinôco, 2001). Fiber cement roof tiles absorb considerable amounts of radiation, which increases the temperature inside the facility. Moura (2001) stated that there are several ways to minimize the effects of solar radiation on roofs at low cost, such as reflective paint and constant fogging on the outside.

Fiorelli *et al.* (2010) carried out a comparative evaluation between different materials, both recycled and conventional, intended for the construction of roofs for animal production facilities. The results indicated that the recycled tiles demonstrated levels of thermal comfort similar to those observed in ceramic tiles. The prototype covered with fiber cement tiles presented the highest levels of thermal comfort, whereas the prototype with white ceramic tiles registered the lowest levels (Fiorelli *et al.*, 2010).

Studies have demonstrated the effectiveness of thermography as a technique for assessing various materials, including the surface temperature of animals, in a noninvasive manner. This tool has proven useful in detecting problems related to thermal inertia in rural buildings and is used to analyze the distribution of temperature on the surface of animals, identify physiological events, diagnose diseases and assess meat quality (Knížková *et al.*, 2007; Montanholi *et al.*, 2008; Bouzida; Bendada; Maldague, 2009; Nascimento *et al.*, 2014).

Thus, this study aims to evaluate and compare the thermal efficiency of two materials used in the construction of roofs for housing for animal production.

2 MATERIALS AND METHODS

Data collection was carried out at the Lageado experimental farm of the Faculty of Veterinary Medicine and Animal Science (FMVZ), Unesp, Botucatu/SP campus (22.51°S; 48.25°W). The city of Botucatu has a climate classification according to Köppen, as Cfa has a warm temperate (mesothermal) humid climate, and the average temperature of the hottest month is above 22°C.

Two sheds were used for raising animals, one specifically for pigs, intended for the maternity phase, and the other for rabbit farming.

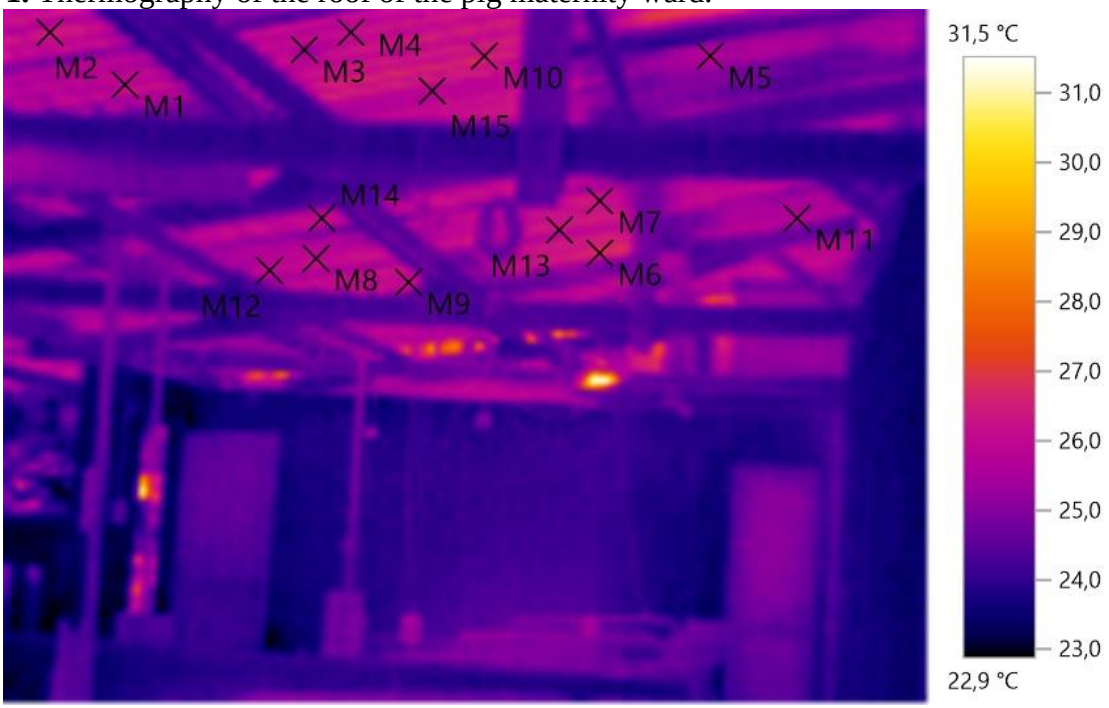
With respect to the pig maternity room, heating was not used for the piglets since the females were pregnant and adapting to the cage during data collection. Therefore, the maternity room is equipped with fans, curtains and sprinklers on the roof to control the internal temperature of the facility. Finally, the material that makes up the maternity roof is fiber cement.

The rabbit farming facility, in turn, has fans and curtains to control the internal temperature. The roof tiles used in the shed are ceramic.

The images were collected via a TESTO 875–2i thermal imaging camera between January 25 and 27, 2016, at two different times for the pig maternity unit: between 8 and 9 a.m. (minimum) and between 2 and 3 p.m. (maximum). Meanwhile, for the rabbit farm installation, images were recorded on January 22 and between January 26 and 29, 2016, at the same time and time intervals in relation to the pig shed.

In the IRSoft software (version 5.0) , points corresponding to the roofs of the facilities were selected, and only the temperatures of the fiber cement tiles for the pig housing were recorded (Figure 1).

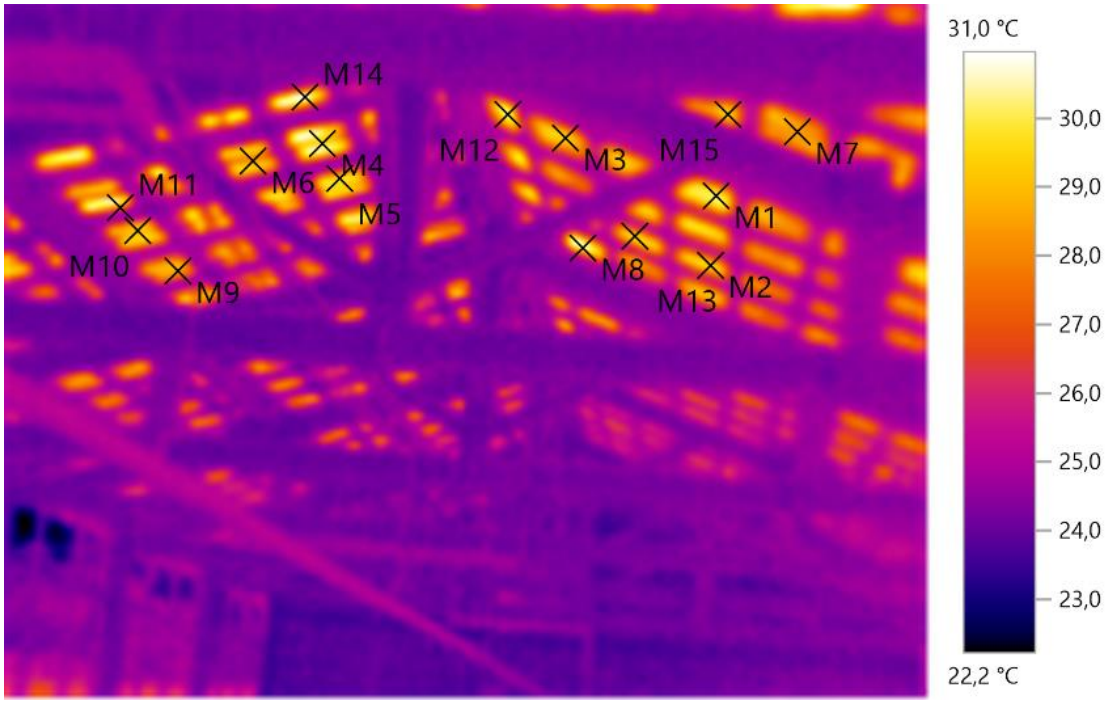
Figure 1. Thermography of the roof of the pig maternity ward.



Source: Personal archive (2022).

The same was done for the rabbit farming sector accommodation; that is, points corresponding to the roof were selected, and only the temperatures of the tiles were recorded (Figure 2).

Figure 2. Thermography of the rabbit farm roof.

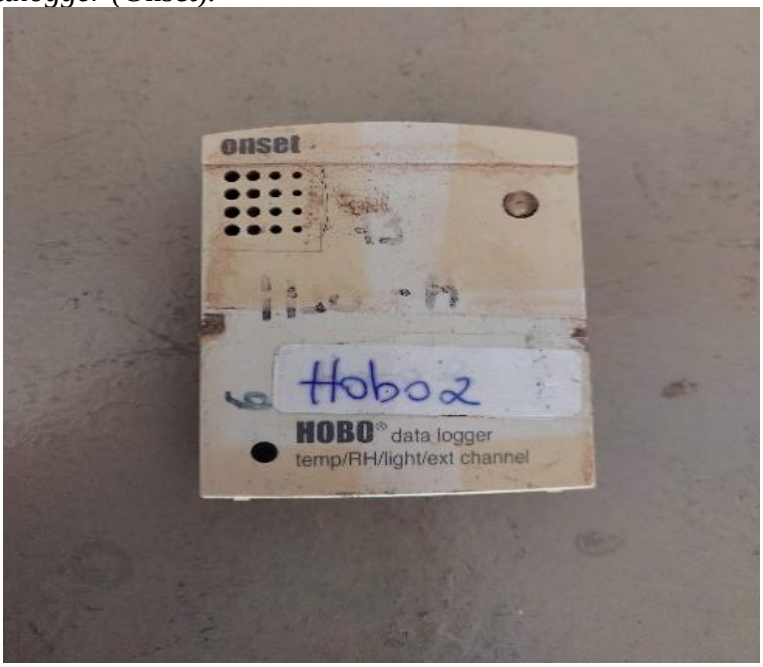


Source: Personal archive (2022).

The camera was positioned toward the inside of the facilities, and care was taken to select 15 random points closest to those captured by the thermal imager. A total of 13 images were analyzed, 5 from the morning period and 3 from the afternoon period for the rabbit farming sector and 3 from the morning period and 2 from the afternoon period for the pig farming sector.

The emissivity of both materials was 0.93. The air temperature and relative humidity were measured at the time of collection via a HOBO datalogger (Onset) (Figure 3).

Figure 3. HOBO *datalogger (*Onset).



Source: Personal archive (2022).

2.1 Statistical analysis

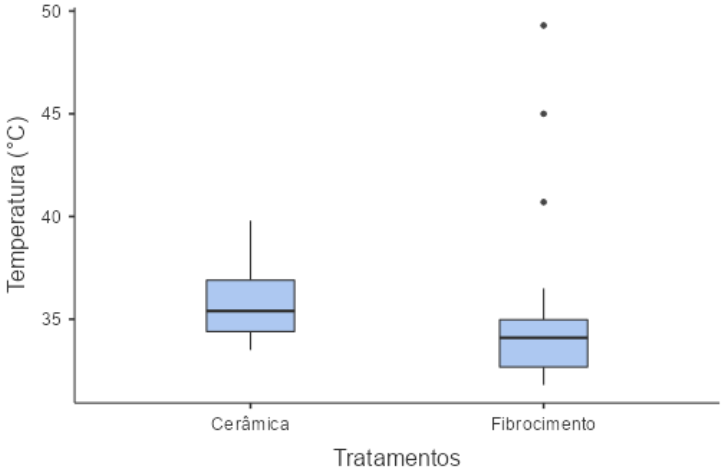
Exploratory data analysis was performed, with graphs developed for each tile material and separating the morning and afternoon periods. Student's t test was applied with a significance interval (95%). Thus, it was possible to determine the thermal efficiency of each material via the JAMOVI® statistical program (version 2.3.28).

3. RESULTS AND DISCUSSION

3.1 Afternoon period

Figure 4 shows the exploratory analysis of the tile materials in the afternoon.

Figure 4. Exploratory analysis for the afternoon period.



Source: Personal archive (2022).

According to Silva (2021), ceramic tiles have better performance in reducing thermal gain and heat exchange than fiber cement tiles do. Similarities (p value: 0.149) were found between the ceramic and fiber cement tiles (Table 1). However, it is important to highlight that during the critical period of the day (afternoon), sprinkling is applied to the fiber cement roof, reducing solar incidence on the roof.

Table 1. Independent samples t test was performed in the afternoon.

	Treatments	Average	Standard error	P value
Temperature (°C)	Ceramics	35.9a	0.278	0.149
	Fiber cement	34.9a	0.694	

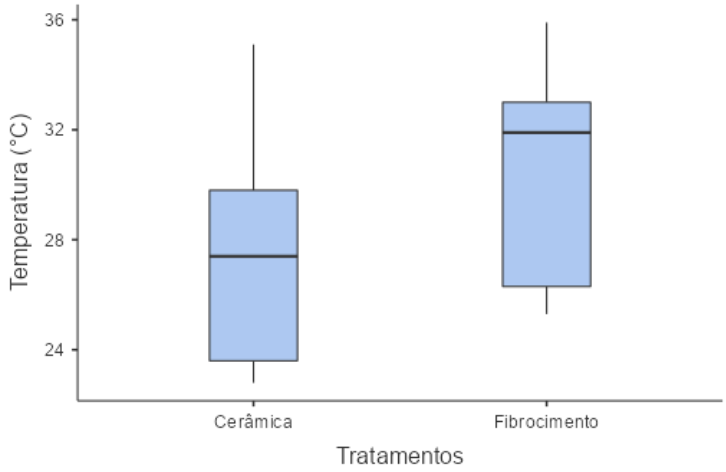
Different letters between lines indicate differences between means according to the t test for independent samples (0.05).
Source: Personal archive (2022).

Thus, although ceramic tiles are more suitable for facilities for producing animals, the sprinkling of fiber cement tiles contributed to reducing the thermal load on the roof.

3.2 Morning period (morning)

For the results in the morning period, Figure 5 presents the exploratory analysis of the tile materials.

Figure 5. Exploratory analysis for the morning period.



Source: Personal archive (2022).

During this period, it was possible to observe a p value <0.001, indicating a substantial and significant difference between the treatments (Table 2). This may be due to time (morning); when both the solar incidence on the tiles and the external temperature are lower, the sprinklers remain off, using only the fans and curtains to control the internal temperature of the maternity ward. On the basis of this information, the significant differences between the two materials are due to the better performance of the ceramic tiles in reducing thermal gain and heat transfer, as previously reported by Silva (2021).

Table 2. Independent samples t test was performed during the morning period.

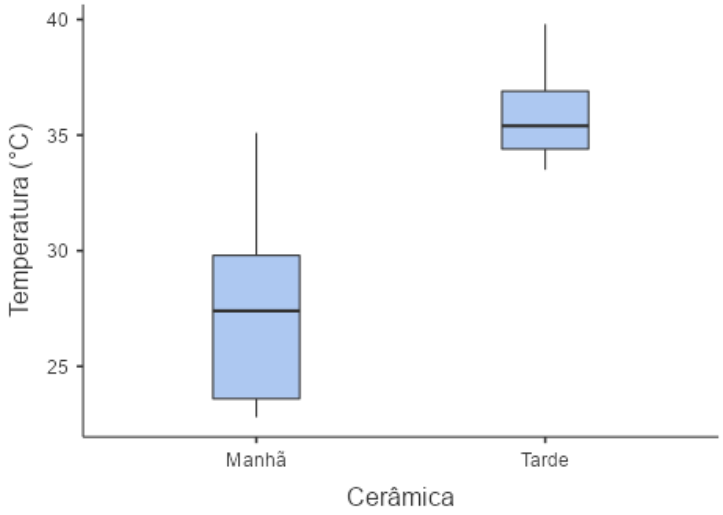
	Treatments	**Average**	**Standard error**	**P value**
Temperature (°C)	Ceramics	27.2a	0.391	<0.001
	Fiber cement	30.4b	0.485	

Different letters between lines indicate differences between means according to the t test for independent samples (0.05).
Source: Personal archive (2022).

3.3 Thermal amplitude related to the ceramic tiles

As in the comparison analysis between materials, Figure 6 illustrates the exploratory analysis, however, between the morning and afternoon periods for ceramic tiles.

Figure 6. Exploratory analysis between the morning and afternoon periods of the ceramic tile.



Source: Personal archive (2022).

The thermal amplitude refers to the difference between the maximum and minimum temperatures recorded in a given time interval, usually over the course of a day. It can be influenced by a variety of factors, including latitude, altitude, cloud cover, air humidity, and vegetation. For example, in regions characterized by low humidity and sparse cloud cover, the thermal amplitude tends to be more pronounced, resulting in higher temperatures during the day and lower temperatures at night. In view of this, understanding temperature variations throughout the day and how these variations can impact the thermal comfort and performance of animals of zootechnical interest is of paramount importance (Ramos; Vianna; Marin, 2018; Allen, 1995; Santana; Cavali; Modesto, 2014).

In the exploratory analysis of the data related to the morning and afternoon periods of the internal surface temperature of the ceramic tile, a discrepancy between the times is noted. This fact can be seen (Table 3) when the T test (95%) is applied, where a p value <0.001 is observed and the average internal surface temperature value of the tiles is 24% higher than that in the morning period.

Table 3. Independent samples t test was performed during the morning period.

	Ceramics	Average	Standard error	P value
Temperature (°C)	Morning	27.2a	0.391	<0.001
	Afternoon	35.9b	0.278	

Different letters between lines indicate differences between means according to the t test for independent samples (0.05).
Source: Personal archive (2022).

Therefore, it is possible to observe a greater thermal load on the ceramic tiles in the afternoon.

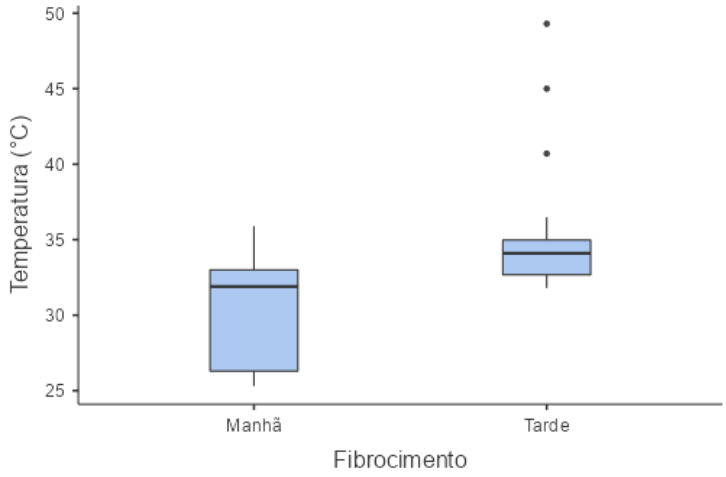
3.4 Thermal amplitude related to the fiber cement tiles

Similarly, from the images collected, through the recorded temperature points measured by the thermographic image analysis tool, statistical analysis was performed between the morning and afternoon periods for the fiber cement tile.

Therefore, Figure 7 illustrates the exploratory analysis for the morning and

afternoon periods for the fiber cement tile.

Figure 7. Exploratory analysis between the morning and afternoon periods of the Fiber Cement tile.



Source: Personal archive (2022).

Using the same statistical analysis tools used previously, a significant difference was observed between the morning and afternoon periods for the same material, with an op value < 0.001 (Table 4).

Table 4. Independent samples t test was performed during the morning period.

	Fiber cement	Average	Standard error	P value
Temperature (°C)	Morning	30.4a	0.485	<0.001
	Afternoon	34.9b	0.694	

Different letters between lines indicate differences between means according to the t test for independent samples (0.05).
Source: Personal archive (2022).

In other words, during the afternoon, there was a greater thermal load on the fiber cement tiles. Importantly, only in the afternoon was the air conditioning used by spraying the tiles, and there was even a 12.89% increase in the internal surface temperature of the tiles.

4. CONCLUSION

From the data collected, it is possible to conclude that the characteristics presented by the ceramic tile material make them more suitable for use in animal facilities, with the aim of ensuring the internal thermal comfort of the facilities. Despite this, for fiber cement tiles, which have a low performance in reducing the internal thermal load of the accommodation, spraying the roof contributes significantly to reducing the temperature of the tiles.

5. REFERENCES

ALLEN, RG **Evaluation of procedures for estimating mean monthly solar radiation from air temperature** . Rome : FAO, 1995.

BOUZIDA, N.; BENDADA, A.; MALDAGUE, XP Visualization of body thermoregulation by infrared imaging . **Journal of Thermal Biology ,** Oxford, vol. 34, no. 3, p. 120-126, 2009.

FIORELLI, J.; FONSECA, R.; MORCELI, JAB; DIAS, AA Influence of different roofing materials on thermal comfort of broiler facilities in western São Paulo. **Agricultural Engineering** , Jaboticabal , v. 30, n. 5, p. 986-992, 2010.

GOMES FILHO, JS **Shading screen and**

painting on roofs of reduced models of poultry sheds . 2010. Thesis (Doctorate in Animal Science) – Faculty of Agricultural and Veterinary Sciences, São Paulo State University, Jaboticabal, 2010.

KAWABATA, CY **Thermal performance of different types of roofs in individual calf pens** . 2003. Dissertation (Master in Animal Science) – Faculty of Animal Science and Food Engineering, University of São Paulo, Pirassununga, 2003.

KNÍŽKOVÁ, I.; KUNC, P.; GÜRDÍL, GAK; PINAR, Y.; SELVÍ, K. Ç. Applications of infrared thermography in animal production . **Anadolu Tarim Bilimleri Dergisi** , Aydın , vol. 22, no. 3, p. 329-336, 2007.

MONTANHOLI, Y. R; ODONGO, NE; SWANSON, K.C.; SCHENKEL, FS; MCBRIDE, BW; MILLER, SP Application of infrared thermography as an indicator of heat and methane production and its use in the study of skin temperature in response to physiological events in dairy cattle (*Bos taurus)*. **Journal of Thermal Biology** , Ontario, vol. 33, no. 8, p. 468-475, 2008.

MOURA, DJ Ambience in poultry farming. *In* : SILVA, IJO (ed.). **Ambience in poultry production in a tropical climate** . Piracicaba: FUNEP, 2001. p. 75-149.

PANDORFI, H.; ALMEIDA, GLP; GUISELINI, C. Precision animal production : Basic principles and news in the swine production . **Brazilian Journal of Animal Health and Production** , Salvador , v. 13, n. 2, p. 558-568, 2012.

RAMOS, JPA; VIANNA, MS; MARIN, FR Estimation of global solar radiation based on thermal amplitude for Brazil. **Agrometeoros** , Piracicaba , v. 26, n. 1, p. 37-51 , 2018.

SANTANA, MCA; CAVALI, J.; MODESTO, VC Influence of climate on animals of zootechnical interest. **Científic @-Multidisciplinary Journal** , Goianésia , v. 1, n. 1, p. 86-98, 2014.

SILVA, BM **Performance of thermoacoustic tiles in reduced-scale sheds for laying hens** . 2021. Dissertation (Master in Agribusiness and Development) – Faculty of Science and Engineering, Universidade Estadual Paulista, Tupã, 2021.

TINÔCO, IFF Ambience and facilities for industrial poultry farming. *In* : BRAZILIAN CONGRESS OF AGRICULTURAL ENGINEERING, 27th; NATIONAL MEETING OF RURAL CONSTRUCTION TECHNICIANS, RESEARCHERS AND EDUCATORS, 3rd, 1998, Poços de Caldas. **Proceedings** [...]. Lavras: UFLA: SBEA, 1998. p. 1-86.

TINÔCO, IFF Industrial poultry farming: new concepts of materials, designs and construction techniques available for Brazilian poultry sheds. **Brazilian Journal of Poultry Science** , Campinas, v. 3, n. 1, p. 1-26, 2001.

BIRTH, GR; NÄÄS, IA; PEREIRA, DF; BARACHO, MS Infrared thermography in the estimation of thermal comfort of broilers. **Brazilian Journal of Agricultural and Environmental Engineering** , Campina Grande , v. 18, n. 6 , p. 658-663, 2014.