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REGULAR ARTICLE

Thermo acoustic tiles performance in small-scale sheds for laying hens

Brayam Moreira da Silva[1], Mario Mollo Neto[1], Diogo de Lucca Sartori[1]

[1]Department of Biosystems Engineering, School of Science and Engineering, São Paulo State University-UNESP, Tupã, SP, Brazil.

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Abstract

Climate change significantly affects the welfare and productivity of laying hens. In this research, the thermal performance of three different roofs for sheds composed of ceramic, fibre cement, and thermoacoustic tiles was analysed with the objective of verifying the performance and the levels of thermal comfort of the different roofs, observing the conditions of thermal comfort inside the environment of the sheds. The internal environment was monitored by dataloggers and sensors, which collected data on air temperature, black globe temperature, and relative humidity from February to March 2020. Data from the internal environment of the facilities were used to calculate comfort indexes for laying hens. With the results, the best observed performance for black globe, temperature, and humidity index (BGTH), and the effective temperature index (ETI) was that of the ceramic tile. The thermoacoustic tile presented a lower performance for the temperature and humidity index (THI), when compared to the others. No significant differences were observed for the thermal radiation load (TRL) between the evaluated tiles, and with these results it was possible to conclude that the ceramic tile presented the best thermal performance compared to the other evaluated kinds.

Keywords

System Dynamics; Poultry; Coverage; Sensors; Comfort; Comfort Index

Introduction

The Brazilian climate has tropical and subtropical characteristics, which leads to observations of high temperatures and high relative humidity, especially in summer. This typical feature generates situations of almost permanent thermal discomfort for birds in production systems, which is one of the main factors that affect productive performance, according to Oliveira et al. (2015). The same authors point out that a few decades ago, the problem of animal thermal comfort was treated as a secondary issue, however, it has gained greater visibility over time.

In tropical countries, the main factors that affect the welfare and productivity of birds are high temperatures and humidity inside the facilities, which cause stress to the animal and, consequently, decrease production (Almeida and Passini, 2013).

The welfare of farm animals is one of the most discussed topics today, with a large growth in campaigns driven by the media and increasing pressure from NGOs, thus generating a sensitivity in public opinion. This mobilization of society has culminated in the re-discussion of norms and laws that regulate animal production in some countries. The economic issue involved should also be considered, as studies show the relationship between thermal and acoustic comfort in relation to poultry production (UBA, 2008).

Birds are animals with homeothermic characteristics, that is, they have the ability to maintain their body temperature at a constant value, regardless of the temperature of the external environment. This characteristic is only changed with considerable shifts in temperature in the external environment, a fact that causes the so-called thermal stress. It is also important to mention that even though laying hens have undergone genetic improvements, they are still subject to thermal stress (Castilho et al., 2015; Riquena, 2017; Silva and Queiroz, 2006).

At high temperatures, laying hens show symptoms such as reduced feed intake, panting, body weight loss, reduced rate of weight gain, increased wing agitation, and decreased egg production. On the other hand, the stress caused by low temperature causes feed consumption to increase, as does agglomeration to reduce heat exchange with the environment (Osorio et al., 2016).

Limitations can be found to obtain high zootechnical indexes in Brazil, due to the hot climate and the precarious environment for housing animals. With this, there is a need for more adequate animal facilities, through adapted buildings or new constructions, considering the physiological needs of

* Corresponding author
E-mail address: mario.mollo@unesp.br (M. M. Neto).

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birds to ensure better thermal comfort, to obtain better development and greater production (Abreu et al., 2011).

In order to identify the level of thermal comfort in the animal production environment, indicators are used, such as the black globe, temperature, and humidity index (BGTH); the thermal radiation load (TRL); the average radiant temperature (ART); the temperature and humidity index (THI), and the effective temperature index (ETI), among others. The indicators are dependent on factors such as temperature, relative air humidity, wind speed, and ambient radiation (Marta Filho, 1993; Fehr et al., 1993; Gomes, 2009; Kawabata et al., 2005; Fernandes and Krüger, 2019; Jácome, 2009; Coutinho et al., 2014; Fante et al., 2017).

In animal production facilities, the roof plays a fundamental role in determining its thermal exchange, especially in hot climate regions (Turnpenny et al., 2000). For birds, the roof is the constructive element that has the greatest significance in a shed in relation to the control of incident solar radiation for thermal comfort (Nääs et al, 2001).

The internal temperature of the environment is greatly influenced by the roof, as it absorbs and repels a large part of the energy from solar radiation and transmits it to the interior of the buildings, increasing the internal temperature through the thermal gain. This occurs due to the large area of interception of radiation that the roof occupies (Almeida et al, 2016). Thus, the use of suitable roofing materials in animal production sheds promotes the reduction of the internal thermal load of the environment when compared to situations of exposure to direct solar radiation, improving the thermal comfort of the occupants (Baêta and Souza, 2010).

The sheds used for poultry production must promote a comfortable, clean, and protected environment, without requiring expenses for energy conversion or bird heat dissipation. This allows the animal to perform its genetic potential to the fullest in a comfortable area, resulting in greater production (Almeida and Passini, 2013; Lopes, 2011).

For egg production to be effective, the thermal comfort zone for laying hens must be between 20 and 30 °C. Below 20 °C and above 30 °C, thermal stress occurs, affecting bird performance, causing a decrease or increased food intake and provoking changes in physical behaviours. In addition to loss of production, such as a decrease in the number of produced eggs, there is also the increase in eggs with poor formation and bird death (Baêta and Souza, 2010; Vitorasso and Pereira, 2009; Costa et al., 2012; Silva et al., 2012).

Therefore, seeking to mitigate the sudden changes that the external environment causes on the internal environment of poultry facilities, it is necessary to develop research for the collection of zootechnical data through electronic equipment.

Researchers such as Nardone et al. (2010), Powers et al. (2013), Chasea et al. (2014), Soutullo et al. (2014), Megersa et al. (2014), Silva et al. (2014), and Mollo et al. (2020) work in this direction. Camerini et al. (2011) also point out that the use of alternative and conventional (2015) dataloggers is expensive and requires software.

The hypothesis of the present work is that thermoacoustic tile present better thermal performance when compared to ceramic tiles and fibre cement sheets.

Therefore, the objective of this work was to evaluate the thermal performance of thermoacoustic tiles in roofs of poultry production sheds in relation to traditional tiles (ceramic and fibre cement), analysing the performance and the thermal comfort indexes of the facilities with the different coverings, verifying which type of tile provides the best thermodynamic response for the installations.

Materials and methods

The research was conducted on the campus of the São Paulo State University (UNESP), latitude 21° 55' 40.9" S and longitude 50° 29' 30.8" W and 530 m altitude. The city has a tropical climate (Cwa in the Köppen classification), with average maximum temperature of 29.3 ºC, minimum of 19.6 ºC, and average annual rainfall of 1365 mm.

The experiment consisted of using three types of tiles that can be applied to cover sheds for laying hens, namely: Portuguese Ceramic Tiles (PCT), Corrugated Fibre Cement Sheets (CFC), and Trapezoidal Thermoacoustic Tiles (TT).

Ceramic tiles initially appeared in China, then spread around the world, and are considered as one of the oldest materials used as roofing. These tiles need a minimum slope of 30 to 45 degrees for rainwater runoff (Lessa 2009; Lengen, 2009). The Portuguese Ceramic Tile used in this research has dimensions of 40 x 25 cm. Per square meter (m²), these tiles weigh around 40 kg, so to support their weight, a strong wooden or metallic structure is needed, also requiring a minimum slope of 30 % (Reis, 2007).

Fibre cement sheets, which appeared after ceramic tiles, were initially manufactured using a mixture of water, cement, limestone, chrysotile asbestos fibre, cellulose, and lime mud. However, with the discovery that asbestos is harmful to the health of those who manipulate the mineral and of those who use the material derived from it, the manufacture of these sheets with asbestos fibre was prohibited. Since then, factories started to manufacture them using synthetic fibres (Lessa, 2009; Petrucci, 1979). Fibre cement sheets are lighter, do not need a structure as robust as that of ceramic tiles, and their minimum slope is also lower than the one required by the latter. They can be found in different thicknesses and models, requiring different slopes for the drainage of rainwater (Lengen, 2009; Logsdon, 2002). In this research, the Corrugated Fibre Cement Sheet used measures 244 cm x 110 cm, with a thickness of 0.60 cm.

Thermoacoustic tiles are normally formed by two zinc tiles or a zinc tile and an aluminium sheet, with a polystyrene (Styrofoam) or polyurethane filling that can measure from 3 to 5 cm, which serves as a thermal and acoustic insulator (METAL FORTE, 2020). For the use of these tiles, a structure as robust as those needed for ceramic tiles is not necessary and, for rainwater to run off, a slope of 5% is enough, although a slope of 20% is recommended. The Trapezoidal Thermoacoustic Tile used in this research is composed of two zinc tiles measuring 0.050 cm, with a 3 cm Styrofoam filling between them, and dimensions of 300 cm x 100 cm.

The tiles were installed in small-scale sheds in the experimental area of the university campus. The existing roof structure consisted of wooden purlins, and, for the installation of the ceramic tiles, the structure was adapted to support them through the additional installation of rafters and slats.

The experimental units constructed were three small-scale sheds, with concrete floor and a 10% slope for the roof, with an East-West orientation. The east and west walls were closed with bricks, while the north and south walls were covered with screens that were kept closed during the experiment.

From February 21, 2020 to March 23, 2020, the thermal variables of the internal environment were collected through dataloggers (so that observers could control the variables) and through hardware built with a plate of Arduino Mega as well as DHT22 and LM35 micro sensors, which were installed inside the sheds on a reduced scale to collect temperature and humidity data (Figures 1 and 2).

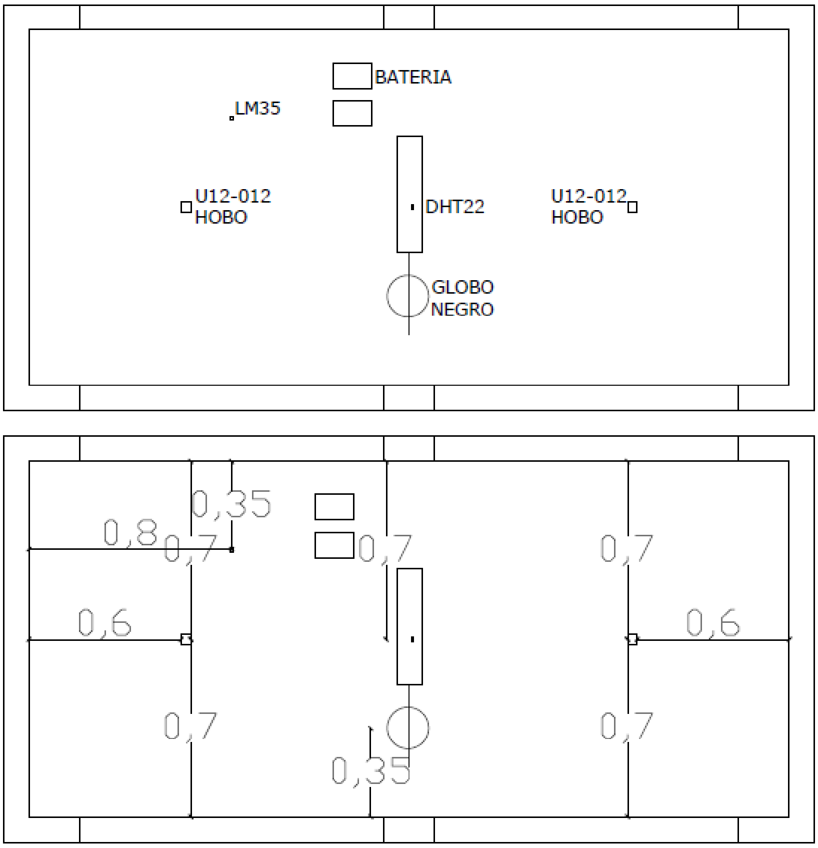

Figure 1. Top view of the distribution of sensors and batteries for powering the hardware.

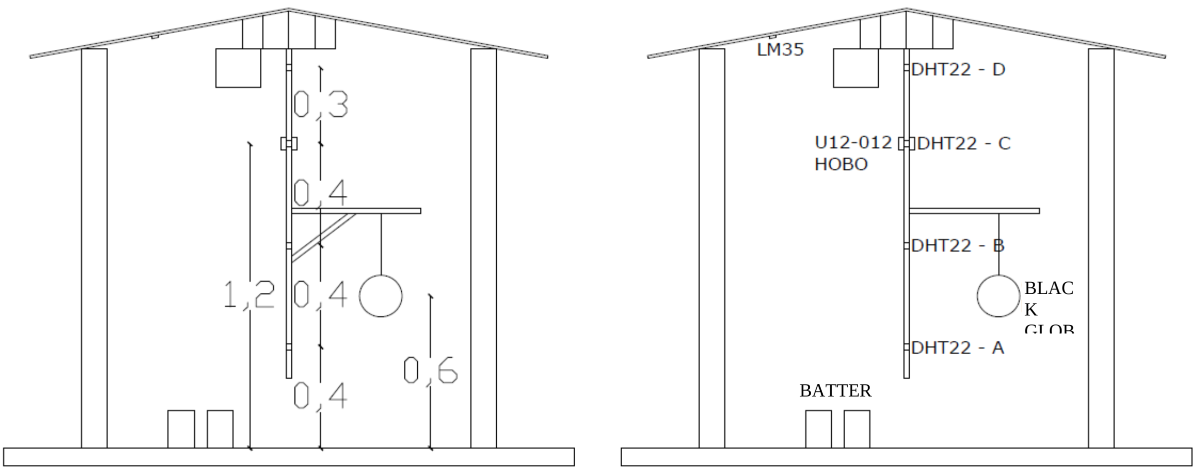

Figure 2. Front view of the distribution of sensors and batteries for powering the hardware.

The values of the average, maximum, and minimum temperatures, as well as the average, maximum, and minimum humidity and black globe temperature were recorded for each shed. Then, the calculation of comfort indexes took place aimed at evaluating the environment in which the birds would be housed (Table 1).

AUTHOR	INDEX	EQUATION
Buffington et al. (1981)	Black globe temperature and humidity index	$ITGU = Tgn+0.36*Tpo+41.5$
Esmay (1969)	Radiation heat load	$CTR = \sigma*(TMR)^4$
Bond and Kelly (1955)	Average radiant temperature	$TRM = 100*[2.51*v^{1/2} * Tgn- Tbs)+(Tgn/100)^4]^{1/4}$
Thom (1959)	Temperature and humidity index	$ITU = 0.8*Tbs+(UR/100)*(Tbs-14.4)+46.4$
Missenard (1937)	Effective temperature	$TE = T - 0.4*[(1 \frac{UR}{100})]*(T - 10)$

The thermal comfort indexes were calculated, as indicated by the authors in Table 1, for each of the reduced models with different coverages on 17 consecutive days, at 08:00, 12:00, and 16:00. For the calculations, the data collected by the micro sensors and stored in the Arduino Mega 2560 R3 modules were used.

A total of 17 days of data collection were considered for the calculation of comfort indexes in the period from March 6 to 22, 2020, at three times (8:00, 12:00, and 16:00).

In order to have a better understanding and to be able to identify the conditions inside the sheds, different colours were used to define whether the environment was under thermal stress or thermoneutrality. Thus, it was defined that:

A. Severe stress caused by cold is represented by the colour blue;
B. Mild stress caused by cold is represented by the colour turquoise;
C. Thermoneutrality is represented by the colour green;
D. Mild heat stress is represented by the colour yellow;
A. Severe heat stress is represented by the colour red.

Results and discussion

Based on the definitions of thermoneutrality and stress presented by Teixeira (1983), Armstrong (1994), Barbosa Filho (2004), Vale (2010), UBA (2008), Alves (2006), Bento (2010), Souza and Nery (2012), and Andrade (2017), the classification ranges of the results of THI, BGTH, and ETI were prepared for the study (Table 3), following the colour scheme described previously on the methodology section.

Table 3. Comfort and thermal stress ranges according to the temperature and humidity index (THI), black globe, temperature, and humidity index (BGTH), and effective temperature index (ETI).

Comfort and thermal discomfort ranges	THI	BGTH	ETI
Severe stress caused by the cold – Danger	< 59	<67	< 21 °C
Mild stress caused by the cold – Alert	59 - 67	68 - 70	21 – 23 °C
thermoneutrality – Comfort	67.01 - 77	70 - 77	24 – 28 °C
Mild stress caused by heat – Alert	77.01 - 89	78 - 88	29 – 31 °C
Severe stress caused by heat – Danger	> 89	> 88	> 31 °C

Source: Adapted from Teixeira (1983), Armstrong (1994), Barbosa Filho (2004), Vale (2010), Uba (2008), Alves (2006), Bento (2010), Souza and Nery (2012), and Andrade (2017).

With the results obtained for the BGTH (Table 4), it is possible to observe that only in the period of early morning (8:00), there is comfort for laying hens in all Sheds (Green). However, one can notice that this does not occur in Shed 01 on the days 15/03 – 22/03, and in Shed 02 on 18/03. In Shed 03, the entire period from 8:00 is comfortable, and the other periods in all Sheds are on alert due to mild heat stress (Yellow).

. **Table 4.** Calculation of the black globe, temperature, and humidity index (BGTH) thermal comfort index

DATE	SHED 01 - FIBRE CEMENT SHEET			SHED 02 - THERMOACUSTIC TILE			SHED 03 - CERAMIC TILE		
	8:00	**12:00**	**16:00**	**8:00**	**12:00**	**16:00**	**8:00**	**12:00**	**16:00**
06/03	69.58	80.89	80.65	70.13	79.32	79.96	70.01	78.24	79.06
07/03	68.71	80.64	80.66	69.25	79.35	79.67	69.09	77.96	78.08
08/03	68.05	80.88	81.89	69.06	78.82	80.63	68.45	77.91	79.05
09/03	69.77	81.85	81.00	70.25	80.43	80.35	70.13	79.23	78.36
10/03	71.85	83.48	85.44	72.33	83.20	84.69	71.73	81.14	81.77
11/03	73.07	82.75	83.88	73.59	83.02	84.13	73.42	80.63	81.65
12/03	74.13	84.54	85.48	74.09	84.45	85.71	73.93	81.71	82.11
13/03	72.93	84.60	85.48	73.34	84.24	85.15	72.68	81.71	82.09
15/03	82.92	85.47	85.72	74.79	83.72	86.73	74.23	82.09	83.67
16/03	85.18	84.67	84.13	76.37	84.01	84.48	75.18	81.38	81.55
17/03	84.20	85.66	85.51	74.58	84.60	86.05	74.45	81.77	83.18
18/03	85.58	85.93	86.21	80.36	81.20	84.70	76.63	80.32	82.93
19/03	84.80	86.00	83.91	75.49	83.24	76.51	75.34	81.68	74.94
20/03	86.11	85.92	85.49	74.31	78.04	80.74	73.78	77.61	79.64
21/03	86.71	86.44	85.73	76.31	82.99	84.61	74.55	79.41	80.14
22/03	80.49	83.81	81.57	75.26	86.51	86.46	71.65	79.11	78.62

Table 5 shows TRL values. Accordingly, Sheds 02 and 03 had higher TRL than Shed 01 in almost the entire period (Table 5). Shed 01 displayed a higher TRL value than Sheds 02 and 03 only on days 06/03, 07/03, 10/03, 12/03, 13/03, 15/03, 16/03, 17/03, 20/03 and 21/03 at 8:00 am, and on 06/03 and 19/03 at 4:00 pm. Nevertheless, the difference is minimal, reaching a maximum of around 10%.

On 21/03 at 12:00 and at 16:00, as well as on 22/03 at 8:00, 12:00, and 16:00, Shed 02 had a TRL value much higher than Sheds 01 and 03 (in pink in Table 5), with a difference of 20 to 30% between the TRL values of the other Sheds.

According to research that addresses the recommended thermoneutrality zone, THI should be up to 78 (Armstrong, 1994), BGTH up to 77 (Teixeira, 1983), and TRL up to 498.3 wm² (ROSA, 1984). Following that, it was observed that, for the three sheds, the values obtained for TRL are, most of the time, within the range recommended as thermoneutral by Rosa (1984) and the difference of approximately 10%, for birds, is imperceptible and thus does not cause physiological damage.

Table 5. Calculation of the thermal radiation load (TRL) thermal comfort index (Wm ²).

DATE	SHED 01 - FIBRE CEMENT SHEET			SHED 02 - THERMOACUSTIC TILE			SHED 03 - CERAMIC TILE		
	8:00	**12:00**	**16:00**	**8:00**	**12:00**	**16:00**	**8:00**	**12:00**	**16:00**
06/03	425.50	439.31	468.44	418.61	447.34	466.13	421.39	488.46	485.69
07/03	416.88	439.12	466.27	412.24	463.13	477.80	412.16	499.65	495.32
08/03	401.91	431.34	470.62	410.54	441.37	473.97	403.12	483.12	492.88
09/03	415.31	437.94	469.27	416.92	462.28	470.21	420.07	498.54	488.79
10/03	423.60	449.28	495.64	425.28	480.35	495.97	412.35	500.18	512.70
11/03	429.18	446.38	467.23	428.18	467.95	478.14	432.87	482.05	502.34
12/03	446.26	460.50	474.65	428.44	488.74	489.65	433.96	490.62	493.91
13/03	439.43	470.26	497.88	436.23	495.79	512.47	426.28	521.21	520.76
15/03	440.98	470.36	472.20	437.24	481.18	498.44	431.99	496.50	516.09
16/03	443.07	453.37	477.07	447.71	491.63	491.32	435.12	486.68	490.50
17/03	443.22	443.54	493.25	439.31	493.99	509.71	443.04	496.45	512.59
18/03	456.13	455.37	474.88	527.13	456.78	491.70	456.34	470.99	501.41
19/03	437.26	473.88	410.85	439.77	482.14	405.30	442.19	494.94	397.17
20/03	435.76	442.46	460.42	429.60	450.54	469.12	433.96	458.06	483.08
21/03	438.86	451.77	463.06	462.09	520.95	566.98	435.95	465.99	482.68
22/03	413.28	433.96	454.22	533.64	658.70	684.77	439.52	491.70	485.79

The values obtained from ART are shown in Table 6. The results obtained from the ART analysis were used to calculate the TRL. In both cases, Sheds 02 and 03 have the highest values of these indexes, since one uses the other.

A greater emphasis can be given to Shed 02 where, on 21/03 at 12:00 and at 16:00, as well as on 22/03 at 8:00, 12:00, and 16:00 had an ART value greater than that of the other Sheds (highlighted in pink in Table 6). The same case occurs for the TRL in Table 6, however the value of the difference between the ART of Shed 02 on the days and hours highlighted in pink is not equal to or equals the difference shown in Table 6 of the TRL which is highlighted in pink as well.

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Table 6. Calculation of the average radiant temperature (ART) thermal comfort index (Wm ²)

DATE	SHED 01 - FIBRE CEMENT SHEET			SHED 02 - THERMOACUSTIC TILE			SHED 03 - CERAMIC TILE		
	8:00	**12:00**	**16:00**	**8:00**	**12:00**	**16:00**	**8:00**	**12:00**	**16:00**
06/03	294.33	296.69	301.49	293.13	298.03	301.11	293.61	304.66	304.22
07/03	292.82	296.65	301.14	292.01	300.63	302.98	291.99	306.39	305.72
08/03	290.16	295.33	301.84	291.71	297.03	302.37	290.38	303.82	305.34
09/03	292.55	296.45	301.62	292.83	300.49	301.77	293.38	306.22	304.71
10/03	294.00	298.35	305.77	294.29	303.38	305.82	292.03	306.47	308.37
11/03	294.96	297.87	301.29	294.79	301.41	303.03	295.59	303.65	306.80
12/03	297.85	300.20	302.48	294.83	304.70	304.84	295.78	304.99	305.50
13/03	296.71	301.78	306.12	296.16	305.79	308.33	294.46	309.64	309.57
15/03	296.97	301.79	302.09	296.34	303.52	306.20	295.44	305.90	308.88
16/03	297.32	299.03	302.86	298.09	305.15	305.10	295.98	304.38	304.97
17/03	297.34	297.40	305.40	296.69	305.52	307.92	297.31	305.89	308.35
18/03	299.49	299.36	302.52	310.52	299.59	305.16	299.52	301.90	306.66
19/03	296.34	302.36	291.76	296.76	303.67	290.77	297.17	305.66	289.30
20/03	296.08	297.22	300.19	295.03	298.56	301.60	295.78	299.80	303.82
21/03	296.61	298.77	300.62	300.46	309.60	316.22	296.12	301.09	303.75
22/03	292.19	295.78	299.17	311.47	328.30	331.51	296.72	305.16	304.24

With the results of the THI (Table 7), a situation very different from that of the BGTH (Table 4) is observed.

Only one day at 8:00 in Shed 01 there is mild stress caused due to heat, otherwise the general state is that of alert.

In Shed 03, only on 18/03 and 19/03 it was obtained values relative to mild stress caused by heat, while all other days should be on alert.

In Shed 02, on 10/03 – 13/03, and on 15/03 – 21/03, there was mild stress caused by heat, and a state of alert for a much longer period than Sheds 01 and 03. In addition to the fact that only on 03/20 at 12:00 pm, and 03/19 and 03/20 at 4:00 pm, the internal environment can be described as mild stress caused by heat, while on the other days, the environment is that of severe stress caused by heat, thus existing danger.

Table 7 shows results that contribute to the objectives of the present research, as it is clear that the thermoacoustic tile is not efficient.

The red highlight shows that the THI values indicate severe stress for Shed 2, extrapolating the THI of up to 78, indicated in the research by Armstrong (1994).

Table 7. Calculation of the temperature and humidity index (THI).

DATE	SHED 01 - FIBRE CEMENT SHEET			SHED 02 - THERMOACUSTIC TILE			SHED 03 - CERAMIC TILE		
	8:00	**12:00**	**16:00**	**8:00**	**12:00**	**16:00**	**8:00**	**12:00**	**16:00**
06/03	69.74	82.09	81.00	74.13	90.11	91.50	70.40	77.87	78.74
07/03	69.03	81.59	80.81	73.38	90.25	92.66	69.64	77.10	77.26
08/03	68.73	82.15	82.05	72.71	89.22	93.08	69.12	77.74	78.38
09/03	70.63	83.16	81.28	74.67	91.54	93.60	70.78	78.55	77.78
10/03	72.80	84.99	84.88	77.03	94.97	97.96	73.10	80.74	80.65
11/03	74.18	83.83	84.06	79.00	95.31	97.77	74.49	80.78	81.00
12/03	74.81	85.51	85.75	79.88	96.06	99.42	75.05	81.93	81.88
13/03	73.59	84.81	84.76	79.44	98.11	100.39	73.84	80.13	80.35
15/03	75.69	84.66	86.20	81.31	95.86	101.02	76.09	82.07	82.78
16/03	76.80	84.67	84.10	82.08	95.36	97.62	76.92	81.88	81.48
17/03	75.18	85.59	85.44	80.11	95.90	99.58	75.68	81.88	82.34
18/03	78.25	82.78	85.39	84.21	90.77	96.61	77.79	81.50	82.95
19/03	76.14	83.70	76.40	81.39	93.78	84.39	77.17	82.07	77.82
20/03	74.78	78.89	82.30	78.81	84.46	89.36	75.29	79.21	80.25
21/03	75.61	82.83	82.41	79.51	89.92	91.12	76.40	80.78	80.85
22/03	71.06	82.42	80.97	75.80	91.24	92.40	71.75	78.98	78.31

The results for the ETI values obtained are presented in Table 8, where the effective temperatures were coloured according to the values of the thermal comfort index ranges represented in Table 3, using the indications by Missenard (1937) and Fante et al., (2017).

Table 8. Calculation of the effective temperature index (ETI).

DATE	SHED 01 - SHED 01 - FIBRE CEMENT SHEET			SHED 02 - THERMOACUSTIC TILE			SHED 03 - CERAMIC TILE		
	8:00	12:00	16:00	8:00	12:00	16:00	8:00	12:00	16:00
06/03	18.76	30.03	30.42	19.43	27.85	28.92	18.86	26.53	27.97
07/03	18.71	31.27	32.35	19.29	28.27	30.44	18.86	27.21	29.01
08/03	18.06	30.14	32.46	18.74	27.33	30.07	17.99	26.02	28.59
09/03	19.20	31.64	32.27	19.63	28.59	30.56	18.97	27.34	29.17
10/03	20.01	32.46	33.78	20.46	29.98	32.17	19.85	27.85	29.91
11/03	20.80	31.46	32.77	21.32	30.35	32.12	20.64	27.97	29.45
12/03	21.23	31.36	33.51	21.80	30.42	32.64	21.11	27.82	29.44
13/03	21.44	34.66	36.08	22.14	32.60	34.35	21.48	30.45	32.04
15/03	21.52	31.06	34.29	22.44	30.50	33.59	21.48	28.34	30.43
16/03	21.37	30.92	32.18	22.35	29.94	31.75	21.19	27.28	29.07
17/03	20.55	31.61	33.38	21.52	30.18	32.86	20.60	27.57	29.79
18/03	22.59	27.24	31.00	23.48	27.04	30.53	22.10	25.56	28.49
19/03	20.80	28.81	21.28	21.86	28.78	23.55	21.05	26.60	21.47
20/03	19.35	22.55	26.89	20.11	23.03	26.17	19.57	22.26	24.58
21/03	19.68	26.63	27.13	20.48	26.22	27.27	19.90	24.45	25.29
22/03	18.77	28.43	29.72	19.79	27.83	29.35	18.86	25.81	27.32

As it can be seen in Table 8, according to the ETI classification, as presented in the research by Missenard (1937) and Fante et al., (2017), in all the Sheds, there were times when a state of danger and alert due to cold were observed, mainly in the period of early morning (8:00).

Considering the periods of 12:00 and 16:00, indications of comfort and alert due to heat, and also of danger due to heat were observed, making it clear that Shed 01 was the one that presented the highest number of days in which there was danger due to both cold and heat, with the fewest days of comfort, requiring greater acclimatization effort for the birds.

On the other hand, Shed 02 was in a balance between all classifications, not depending on any, as the difference was minimal within the classifications pointed out by Missenard (1937) and Fante et al., (2017). Furthermore, in Shed 03, it was possible to observe the highest number of days with comfort, with only 1 day of danger due to heat, which shows the best performance for the ceramic tile.

In general, analysing all the obtained results, we can consider that, according to the BGTH data, the ceramic tile had an average performance of 2.35% lower than the temperatures of the thermoacoustic tile, but both tiles had a better performance than the fibre cement sheet. The ceramic and thermoacoustic tiles provided comfort at 8:00 and mild heat stress at 12:00 and 16:00, whereas the fibre cement sheet provided comfort and mild stress caused by heat at 8:00, with no noticeable difference in the other times.

Nonetheless, according to the data obtained by the THI, the thermoacoustic tile presented the worst performance, displaying periods with severe stress caused by heat representing danger. The fibre cement and ceramic tile were the ones that obtained the best results according to with the THI, and even so, the ceramic tile had a better performance than the fibre cement, having an average result of 2.20% less in the index, which is positive for the evaluation.

The results obtained by the TRL of all the tiles are similar, reaching a maximum of 10% of positive and negative difference, that is, a small difference between them, which would not affect the birds physiologically. Yet, in two days of data collection, it can be seen that there was a significant difference value for the thermoacoustic tiles, which displayed a TRL much higher than the fibre cement and ceramic tiles, reaching this difference up to 40% of the index.

The ETI results show that, among the three roofs, ceramic tile has the best result for the ETI, with an average lower by 6.55%, followed by the thermoacoustic tile with an average lower by 5.70%, and finally, the fibre cement sheet with an average ETI at 7.36% more for the index.

Conclusions

According to the results obtained from all the indexes studied in the field survey, the analysis carried out allowed us to conclude that: the ceramic tile obtained the most adequate performance of the black globe, temperature, and humidity index (BGTH) and the effective temperature index (ETI). The thermoacoustic tile presented lower performance for the temperature and humidity index (THI), when compared to the others. In addition, no significant differences were observed for the thermal radiation load (TRL) between the evaluated tiles. Thus, we can consider that, under the conditions of the proposed study, the ceramic tile is the one that best performs its role to reduce thermal gain and heat exchange. The thermoacoustic tile represents a second option, while the fibre cement sheet presented the least favorable results to attenuate thermal gain and heat exchange in the sheds.

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