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THERMAL EFFICIENCY OF INDIVIDUAL SHELTERS FOR GIROLANDO CALVES IN BRAZILIAN SEMI-ARID REGIONS

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ABSTRACT: The objective of this research was to evaluate the thermal efficiency of roofs used on individual shelters during milk-feeding stage of Girolando calves. The research was conducted at a farm located in a dry region of Pernambuco state, Brazil. The experimental design was completely randomized, with 27 Holstein × Gir dairy crossbred calves housed in shelters with three roofing materials (fibre cement tile, recycled tile, and thatched roofs). The recycled tiles and thatched roofs provided reductions of 18.7 and 14.6% in radiant thermal load, respectively. Regardless the roofing material, all animals increased their respiratory rate to maintain thermal equilibrium.

KEYWORDS: ambience, dairy cattle, roofing materials, thermography.

EFICIÊNCIA TÉRMICA DE ABRIGOS INDIVIDUAIS PARA BEZERRAS DA RAÇA GIROLANDO NO SEMIÁRIDO BRASILEIRO

RESUMO: Objetivou-se, com esta pesquisa, avaliar a eficiência térmica de materiais de cobertura em abrigos individuais, durante a fase de aleitamento de bezerras da raça Girolando. A pesquisa foi conduzida em uma fazenda, localizada na região Agreste do Estado de Pernambuco, Brasil. O delineamento foi o inteiramente casualizado, com 27 bezerras mestiças Holandês × Gir, distribuídas aleatoriamente em abrigos com três tipos de materiais de cobertura (telha de fibrocimento, telha reciclada e cobertura de palha). Os abrigos cobertos com telha reciclada e palha proporcionaram redução de 18,7 e 14,6%, respectivamente, na carga térmica radiante. Independentemente do tipo de cobertura, todos os animais elevaram a frequência respiratória para manter a homeotermia.

PALAVRAS-CHAVE: ambiência, bovinos leiteiros, materiais de cobertura, termografia.

INTRODUCTION

Heat stress is one of the main limiting factors of livestock performance in tropical regions, mainly when associated with high humidity associated and inadequate facilities. Adverse climatic conditions directly influence thermal comfort and may cause decline in production with consequent economic losses. Therefore, animal thermal comfort should be considered when seeking greater efficiency in livestock (ROBERTO & SOUZA et al., 2011).

Thermal stress magnitude in tropical environments is caused by high temperature and relative humidity combined with intense solar incidence and low wind speeds, reducing heat loss efficiency (DIKMEN & HANSEN, 2009) and thus limiting animal development, production and reproduction.

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Therefore, it is of utmost necessity the availability of shade for preventing overheating (FAÇANHA et al., 2011) and reducing solar radiation effects (RODRIGUES et al., 2010).

Roofs can significantly reduce thermal increment inside facilities and promote animal welfare (FAGHIH & BAHADORI, 2009; KAWABATA et al., 2005). A large roof area exposed to solar radiation and proper selection of tile material may assist in maintaining such thermal comfort (SAMPAIO et al., 2011). Thermography is a tool that allows determinations of temperature distribution on investigated surfaces and heat transfer processes occurred in roofing materials; therefore, it can also be used to quantify thermal efficiency of these materials (FIORELLI et al., 2012). Moreover, it is a non-invasive diagnostic technique that measures surface emitted heat (BROWN-BRANDL et al., 2013) and pinpoints physiological thermoregulation events that identify changes in surface temperature and evaluate animal thermal stress, providing decision support for enhancing animal health and welfare (ROBERTO et al., 2014).

In this context, this research intended to evaluate the thermal efficiency of roofing materials in individual shelters for Girolando calves during milk-feeding stage.

MATERIAL AND METHODS

The experiment was carried out at Várzea Alegre farm, a commercial dairy farming located in Pesqueira, Pernambuco state, Brazil. The area is within the Agreste mesoregion and Vale Ipojuca microregion, which lies at 8º 17' 10" south latitude, 36º 53' 03" west longitude and 800 m of altitude. Annual Mean rainfall and temperature are about 730 mm and 24.8 °C, respectively. According to Köppen's classification, local climate is characterized as semiarid – BSh type (ALVARES et. al., 2013).

The studies were conducted from January to March of 2012, lasting 55 days. We assessed twenty-seven female dairy crossbred calves, composed of 7/8 Holstein and 1/8 Gir and with age of 15 days and weight of 40.24 kg. The animals were distributed in individual shelters covered by three types of roofing materials: 4-mm fibre cement tile, 6-mm recycled tile (75% polymer and 25% aluminium) and 50-mm palm-thatched roofs (*Syagrus coronata*). The animals could choose to stay under the shade or full sun the entire day.

The individual shelters had dimensions of 1.80 m long, 1.50 m wide and 1.45 m Mean height, without side locks. The roofs were set longitudinally at a 3-degree slope and east-west orientation.

Animal feeding consisted of 4 L milk in individual buckets twice a day (5 am and 5 pm). Water and pelletized concentrate feed (with 18% crude protein) were provided ad libitum in feeders and drinkers installed inside shelters.

Climate variables such as dry bulb temperature (DBT, °C), relative humidity (RH, %) and black globe temperature (BGT, °C) were recorded every hour inside each shelter and in the external environment using HOBO U12-12 data loggers (Onset Computer Corporation Bourne, MA, USA). These tools were assembled in the middle of shelters at 1.40 m height. Outside, the equipment was installed in a meteorological shelter at 1.50 m height, next to the experimental shelters. Wind speed (WS, m s^{-1}) was measured hourly with a digital anemometer (model TAFR-180) scaled from 0.10 to 20.0 m s^{-1} and resolution of 0.10 m s^{-1}.

Each roofing material thermal efficiency was determined by calculating the radiant thermal load (RTL, W m^{-2}) using the methodology proposed by ESMAY (1982) at 5 am, 8 am, 11 am, 2 pm and 5 pm, Eq. (1).

$$\mathrm{RTL} = \sigma(\mathrm{MRT})^4 \tag{1}$$

$$\mathrm{MRT} = 100\left\{\left[2.51(\mathrm{WS})^{0.5}(\mathrm{BGT} - \mathrm{DBT}) + \left(\frac{\mathrm{DBT}}{100}\right)^4\right]^{0.25}\right\} \tag{1.1}$$

where,

MRT = mean radiant temperature (K)

σ = Stefan-Boltzmann constant (5.67×10^{-8}W K^{-4} m^{-2});

WS = Wind speed (m s^{-1});

BGT = Black globe temperature (K);

DBT = Dry bulb temperature (K).

Thermography images were used to analyse upper- and lower-surface thermal characteristics for the three roofing materials. For that, we used a FLIR i60 camera to record images twice a week at 5 am, 8 am, 11 am, 2 pm and 5 pm; it was placed at 0.50 m from roof surfaces. We used particular mobile structure to access the upper roof surface at the image recording time. From these images, we could draw perimeters and measure the upper and lower surface mean temperatures. The images were corrected and analysed by FLIR QuickReport. This software set emissivity values according to roofing material, being 0.96 for fibre cement, 0.75 for thatched roof and 0.65 for recycled one.

Physiological parameters were assessed by records of respiratory rate (RR, breathes min^{-1}), coat surface temperature (TSC, °C) and rectal temperature (RT, °C) taken at the same hour and on the days of thermal image recording. The measurements of RR were made by counting the number of movements in the animal flank region per minute. After that, thermal images records were taken to determine TSC. The images were taken on the left side of calves in a standard distance of 2.50 m between the camera and the animal, which were subsequently corrected and analysed by the FLIR Quick Report software. The emissivity was adjusted to 0.98 (MONTANHOLI et al., 2009), and thermo-hygrometric variables (air temperature and humidity) according to values obtained at the registration moment. TSC measurements were based on rectangular areas delimited on animal's body on a longitudinal neck-to-femoral and transversal dorsum-to-ventral abdomen shafts. Subsequently, RT measurements were carried with the aid of a digital clinical thermometer ranged from 20 to 50 °C and 0.10 °C accuracy, until temperature stabilization.

Surface thermographic profiles were analyzed on specific day (24 February of 2012) and at specific hour (11:00 am), which were chosen by being of high uncomfortable thermal conditions and higher radiant thermal load, besides being coincident with registration time of thermographic images of both roof surfaces and animal TSC. A pair of thermal images (upper and lower surface) were randomly selected for each type of material, being a pair of thermographic images of sun-exposed surfaces and another shade-exposed. All images had temperature ranges standardized within a range of 30 to 60 °C, to facilitate the understanding of thermal variability.

The experimental design was completely randomized, and animals were distributed into individual shelters with three different types of roofing materials: 1) fibre cement tile, 2) recycled tile and 3) thatched roofs, with nine repetitions for each treatment.

Data underwent ANOVA analysis through the Statistical Analysis System software (SAS, 2007), using the following model:

$$Yij = \mu + Ri + Eij,$$

where,

Yij is the value of each observation,

μ is general mean,

Ri is the roof effect (i = 1, 2, 3) and

Eij is the effect of the error associated with each observation.

When there were differences between treatments, we used the Tukey's test at 95% significance level to multiple comparison of Means. We also applied regression analysis to determine functional relationships between external and internal temperature values, using the following model:

$$Yi = \beta 0 + \beta 1 \cdot Xi + Ei,$$

where,

Yi is the value of temperature inside the shelters,

β0 is the constant of regression,

β1 is the coefficient of regression,

Xi is the temperature external environmental and

Ei is the error associated with the observation.

RESULTS AND DISCUSSION

The temperatures inside shelters covered by fibre cement had an increase of 2.02% when compared to the external temperatures (Fig. 1A). For those covered with recycled tile, this relationship was 1.15% (Fig. 1B). This ratio decreased for thatched roofs, presenting a drop of 0.38% in temperature from inside to outside shelter (Fig. 1C).

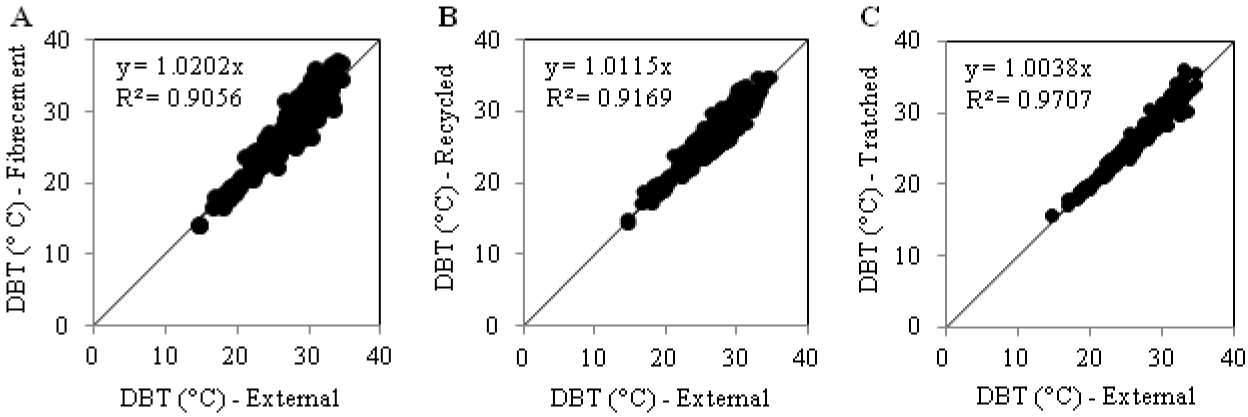

FIGURE 1. Functional relationships between external (environment) and internal temperatures of shelters covered with fibre cement tile (A), recycled tile (B) and thatched roof (C). DBT - dry bulb temperature.

These differences can be explained by absorbance and thermal conductivity of the materials. The fibre cement tile, recycled tile and thatched had absorbance values of 68, 56 and 46%, (LIMA et al., 2007; PERALTA, 2006), and thermal conductivity of 0.76, 0.30 and 0.12 W m^{-1} $°C^{-1}$ (INCROPERA et al., 2008), respectively. According PERALTA (2006), internal temperature reveals the influence of roofing material absorbance on facility thermal performance. Thus, we can infer that thatched and recycled tile roofs were most efficient in thermal conditioning, once they presented lower values of thermal conductivity and absorbance (Fig. 1).

Table 1 shows mean values and standard deviations for radiant thermal load inside and outside all shelters. Results showed statistical difference ($p < 0.05$) between RTL of fibre cement tile and recycled tile at 8 am and 11 am. Recycled tiles got greater efficiency in RTL reduction compared fibre cement tiles that had the worst performance. However, no significant effects were observed ($p > 0.05$) between all roofing materials at 5 am, 2 pm and 5 pm.

Tiles were important for RTL reduction comparing with the external measurements, which showed significant difference ($p < 0.05$) at the hottest hour of the day. In fact, it was the worst situation since the black globe was fully exposed to direct solar radiation (Table 1). Comparing with external temperatures, the RTL values decreased by 8.9, 13.1 and 14.8% at 8:00 am, by 10.1, 14.6 and 18.7% at 11 am and by 11.0, 14.0, and 16.8% at 2 pm, inside shelters covered with fibre cement tile, thatched and recycled tile, respectively (Table 1).

The RTL differences between recycled and fibre cement tiles, at 8 and 11 am, can be explained by the thermal properties of recycled tile constituent materials. Aluminium fragments (25%) contribute for reflection and recycled polymers (75%) for low thermal conductivity. These characteristics may delay heat transmission to inside areas. However, solar radiation incidence during the day increase upper surface energy absorption that is gradually conducted to the lower part; thus, we did not find differences between these materials at 2 pm ($p > 0.05$) (Table 1)

TABLE 1. Means and standard deviations of radiant thermal load (RTL) recorded inside and outside individual shelters during the experimental period.

Environments	RTL (W m^{-2}) at the times assessed				
	5 am	8 am	11 am	2 pm	5 pm
External	406.8±7.0b	525.0±27.6a	592.1±33.9a	584.6±55.5a	467.9±18.0a
Fibre cement tile	414.1±5.5a	478.0±10.7b	532.1±19.4b	520.2±23.5b	464.1±10.7a
Thatched roofs	413.5±4.9a	462.7±7.9bc	514.2±23.4bc	511.8±22.6b	459.6±12.4a
Recycled tile	418.7±8.9a	456.4±22.8c	496.2±20.8c	498.6±19.7b	458.9±20.8a

Means followed by the same letter within the same column do not differ at 5% probability by the Tukey's test.

Fibre cement RTL values were between 414.1 and 532.1 W m^{-2}, being in accordance with the findings of SAMPAIO et al. (2011). In addition, recycled tile RTL varied from 418.7 to 498.6 W m^{-2} between 5 am to 5 pm.

We observed that there was no RTL reductions inside thatched roof shelters; interspaces on this surface allowed direct solar radiation passage, increasing RTL from 414.1 to 532.1 W m^{-2}. KAWABATA et al. (2005) found similar RTL values using cellulose fibre tiles in individual shelters for calf with side locks. These small RTL variations might be related to shelter material type, which showed no further differentiation between tested materials due to the absence of side locks; such protection favours dissipation of energy transmitted by roofing materials.

Fig. 2 shows thermographic images from upper and lower roof surfaces of different materials, by which differences can be identified.

According to UEMOTO et al. (2010), material colour influences reflection, causing reductions of up to 10 °C on surface temperatures aside from improving thermal comfort inside facilities.

Through thermographic images in Fig. 2, we can note some variations in temperatures of both upper and lower surfaces. We can also highlight upper surface mean temperatures of 50.2, 46.5 and 42.8 °C for fibre cement tile (Fig. 2A), recycled tile (Fig. 2C) and thatched roofs (Fig. 2E), , respectively. Such variations were also observed in lower surfaces, with values of 46.8, 42.0 and 38.7 °C for fibre cement tile (Fig. 2B), recycled tile (Fig. 2D) and thatched (Fig. 2F), respectively.

In a day of great discomfort, we could register major differences between upper and lower surface temperatures, coinciding with higher radiant heat load records. Based on that, we identified a downward heat flow direction, i.e. from the upper to the lower surface, for all types of cover material. Upper and lower surface had temperature differences of 3.4, 4.5 and 8.8 °C, being respective to fibre cement tiles, recycled tile and thatched roofs (Fig. 2). However, this order and magnitude may be reversed concerning RTL and material thermal properties (absorptivity, reflectivity and transmissivity) (MICHELS et al., 2008). Conversely, ABREU et al. (2011) reported an upward heat flow during the day on diver tile types, being attributed to condensation on the upper surface of these coverages.

Temperature differential between upper and lower surface of thatched roof (8.8 °C) and recycled tile (4.5 °C) were higher than the fibre cement tile one was (3.4 °C) (Fig. 2), which may be justified by material properties. For example, thatched roofs have considerable water-absorbing capacity. In fact, during night time, surface temperature was lower than air temperature, with differences of up to 5.6 °C; therefore, water condensation occurs on this surface, being absorbed by the thatched material. During the daytime, part of the incident radiation is used in evaporation, and thus surface heating only starts after the end of this process (MICHELS et al., 2008). This way, heat transfer from the upper to the lower surface is slowed, what provides minor temperatures on the lower surfaces. This fact was also observed with recycled tiles; also being explained by its material characteristics. It can be inferred that aluminium within its composition contributes to reflection of part of the incident solar radiation on this covering surface, as well as the recycled polymers for their low thermal conductivity (TINÔCO, 2001) that retards heat transfer from inside to outside surface.

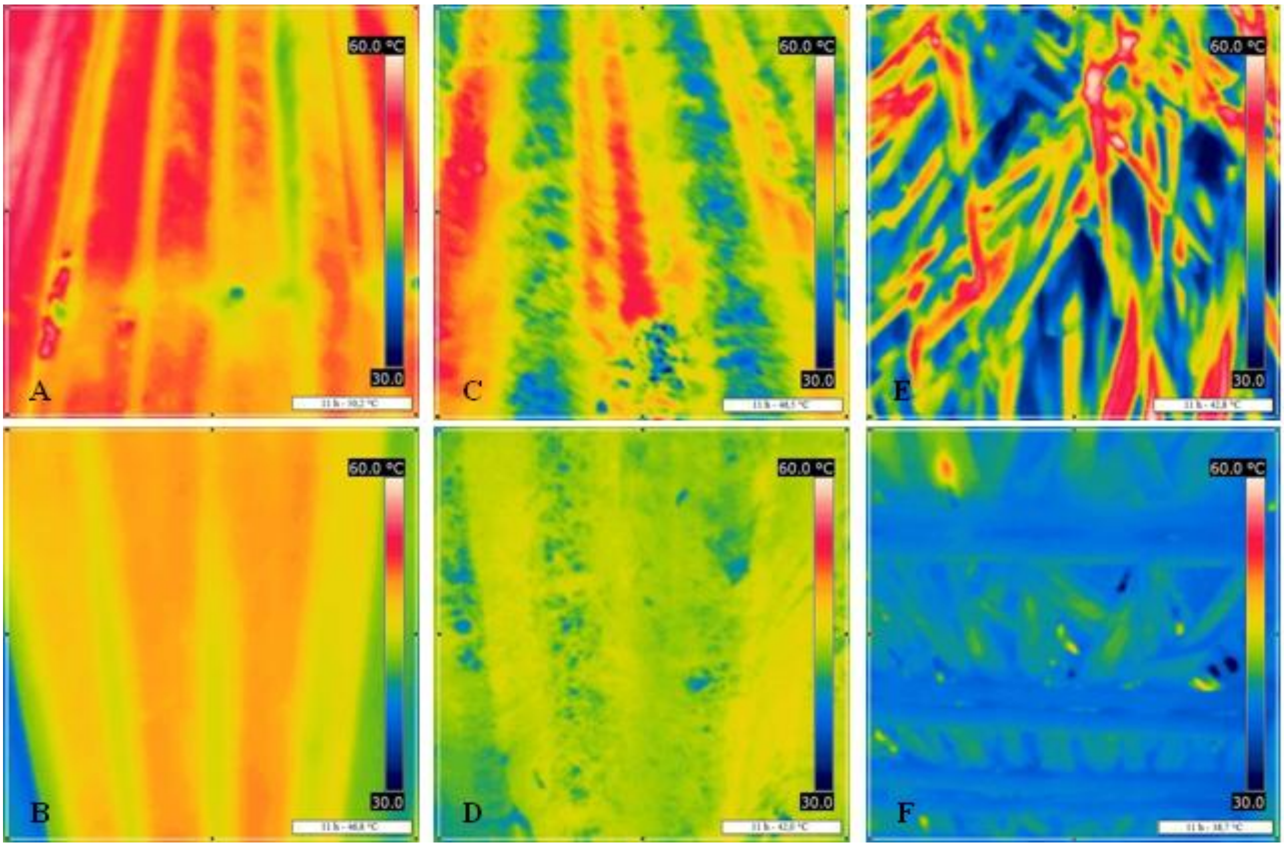

FIGURE 2. Thermographic images from upper and lower surfaces of different roofing materials: fibre cement tile – upper (A) and lower (B); recycled tile - upper (C) and lower (D); thatched roof - upper (E) and lower (F). These images were taken on February 24, 2012, at 11 am, being captured at a distance of 0.50 m.

Significant differences were found between fibre cement and recycled upper surface temperatures at 5 am, 8 am, 2 pm and 5 pm ($p < 0.05$), with reductions of 2.4, 3.5, 7.2, and 4.4 °C, respectively (Table 2). The same was found for internal surfaces, with significant differences for thatched and recycled against fibre cement; we observed reductions of 3.9 and 1.5 °C at 8 am, 13.4 and 11.6 °C at 11 am and 8.4 and 8.8 °C at 2 pm, respectively (Table 2). These results suggest that thatched and recycled tile roofing were more effective at reducing RTL. On this basis, we can state that such materials should be used to provide microclimate improvement inside shelters (Table 2), allowing better thermal conditions for animals, so that they can express enhanced productive potential, contributing positively to the dairy farming success.

The best thermal performance of thatched roofs compared to fibre cement tiles (Table 2) was most likely due to its water-absorbing capacity. This effect might be added by air circulation through vegetal fibres and layers. Recycled tile great performance is derived from physical properties of its constituent materials (aluminium and polymers). As cited by MICHELS et al. (2008), polymers have low heat conductivity that hampers heat transfer and, the low emissivity and high reflectivity of aluminium reduces long-wave radiation inside facility.

At 5 am and 5 pm, upper surface mean temperatures were below those of lower surface (Table 2). This is because the surfaces are absorbing heat from 8 am until 2 pm, when solar radiation is most intense, so increasing temperatures on the upper surface. However, after two hours, this same surface begins to lose heat to the environment; and these values decrease at next hour (5 pm). Subsequently, this energy is transmitted by conduction between material particles or molecules, heating thus the inner face of the roof (ABREU et al., 2011). Based on the above, we can see that lower surface temperatures were numerically higher than the upper ones at 5:00 pm. However, thatched and recycled tile lower surfaces presented lower temperatures (Table 2) when compared with fibre cement tile. According INCROPERA et al. (2008), these results are explained by the thermal conductivity of the fibres that compose thatched roofs (0.12 W m-1 °C-1), recycled polymers in recycled tile (0.30 W m-1 °C-1) and the higher thermal conductivity in fibre cement tiles (0.76 W m-1 °C-1).

TABLE 2. Mean and standard deviation of temperature and relative humidity in the external environment and temperature of the upper and lower covering surfaces of the individual shelters during the experimental period.

Time	External Temperature (°C)	External Humidity (°C)	Roof surface	Temperatures (°C)		
				Fibre cement	Thatched roof	Recycled tile
5 am	18.7±1.3	88.2±3.7	Upper	16.8±1.5a	16.0±1.4ab	14.4±1.6b
			Lower	17.6±1.6b	18.8±1.1b	20.6±0.9a
8 am	23.7±1.2	70.4±7.9	Upper	28.8±1.7a	27.0±2.1ab	25.3± 1.3b
			Lower	28.1±1.5a	24.2±1.4b	26.6±0.7b
11 am	29.0±1.8	49.2±10.2	Upper	44.1±6.2a	36.9±5.9a	37.2±7.1a
			Lower	41.9±4.9a	30.7±1.9b	33.3±4.1b
2 pm	30.7±2.8	41.9±14.6	Upper	41.4±4.1a	38.0±5.9ab	34.2±4.9b
			Lower	40.5±3.6a	32.1±2.2b	31.7±2.8b
5 pm	27.7±2.2	51.1±15.3	Upper	26.3±1.3a	25.2±1.4a	21.9±1.5b
			Lower	27.2±1.7a	26.0±2.9a	24.7±0.9a

Means followed by the same letter within the same line do not differ at 5% probability by the Tukey's test.

Against this background, the heat flow coupled with the high temperatures on the underside of the roof is detrimental to such animal production systems, once thermal energy of the upper surface is transferred to bottom surface, increasing temperatures inside facilities and causing thermal discomfort to the animals. Nevertheless, it is important to note that lower temperatures on tile surfaces do not mean animal thermal comfort; this condition should be reasserted by measuring the RTL, to which animals are subjected (ABREU et al., 2011).

Physiological variables showed no significant differences ($p > 0.05$) among calves reared under the different roofing materials (Table 3).

TABLE 3. Mean and standard deviations of the respiratory rate (RR), coat surface temperature (TSC) and rectal temperature (RT) of the calves during the experimental period.

Time	Physiological variables	Roof materials		
		Fibre cement tile	Thatched roof	Recycled tile
5 am	RT (°C)	38.6 ± 0.3	38.4 ± 0.3	38.5 ± 0.1
	RR (mov min^{-1})	39.7 ± 4.0	36.5 ± 2.4	38.1 ± 3.4
	TSC (°C)	26.4 ± 0.4	26.3 ± 0.4	26.1 ± 0.6
8 am	RT (°C)	38.8 ± 0.3	38.7 ± 0.3	38.7 ± 0.3
	RR (mov min^{-1})	55.8 ± 6.2	50.1 ± 4.2	51.9 ± 6.5
	TSC (°C)	32.6 ± 2.9	33.2 ± 3.1	33.8 ± 2.1
11 am	RT (°C)	39.0 ± 0.3	38.9 ± 0.3	38.9 ± 0.2
	RF (mov min^{-1})	67.8 ± 9.2	60.3 ± 4.6	66.4 ± 7.3
	TSC (°C)	36.9 ± 3.4	37.9 ± 3.1	37.7 ± 2.0
2 pm	RT (°C)	39.1 ± 0.3	39.1 ± 0.2	39.0 ± 0.2
	RR (mov min^{-1})	71.5 ± 9.9	66.0 ± 5.2	67.5 ± 8.3
	TSC (°C)	35.1 ± 1.7	35.8 ± 1.4	35.9 ± 1.8
5 pm	RT (°C)	39.2 ± 0.3	39.1 ± 0.3	39.1 ± 0.3
	RR (mov min^{-1})	51.6 ± 4.9	48.8 ± 4.7	48.0 ± 6.1
	TSC (°C)	30.4 ± 0.5	30.2 ± 0.5	30.5 ± 0.7

Rectal temperature mean values were within normal range (38.0 to 39.3 °C) proposed by DUKES (1996), varying from 38.4 to 39.2 °C from 5 am to 5 pm respectively (Table 3).

Yet respiratory rate mean values ranged from 36.5 to 71.5 breathes min^{-1} (Table 3), being above the normal range indicated by DUKES (1996) (21 to 25 breathes min^{-1}) for young cattle. Before rise rectal temperatures, homeothermic animals increase respiratory rate when subjected to high temperatures. Nonetheless, when the ambient temperature is high and quite close to the body temperature, the sensible heat removal is most difficult, indicating latent losses (SOUZA & BATISTA, 2012).

The results showed that, regardless roofing material, animals intensified latent heat loss to maintain their body temperature; however, not exceeding the RT upper limit (39.3 °C), as shown in Table 3. The RR is the most used thermoregulatory mechanism when animals are subjected to thermal stress, undergoing thus through greater variations. This demonstrates that increased RTL values (Table 1) made animals use peripheral vasodilatation, i.e. blood flow to body surface was increased in an attempt to maintain homeothermy, causing increased temperature on animal surface (RIBEIRO et al., 2008).

TSC mean values were similar to those found by KOTRBA et al. (2007) in Holstein dairy cattle, also by means of thermal images recorded in environments with mean temperature at 29.2 °C. The authors observed small variations throughout the different body parts (neck, dewlap, trunk, body forepart, barrel, body hind part, forelimb and rear limb), being a useful information for animal heat stress studies (BOUZIDA et al., 2009).

Fig. 4 shows that TSC mean values February 24, at 11:00 am, with higher RTL were 42.1 and 36.5 °C, respectively, for sun-exposed (Fig. 4A) and shade-exposed (Fig. 4B) animals. Under these conditions, body surface temperature of animals exposed to the shade was 5.6 °C, being below the TSC of animal exposed to the sun.

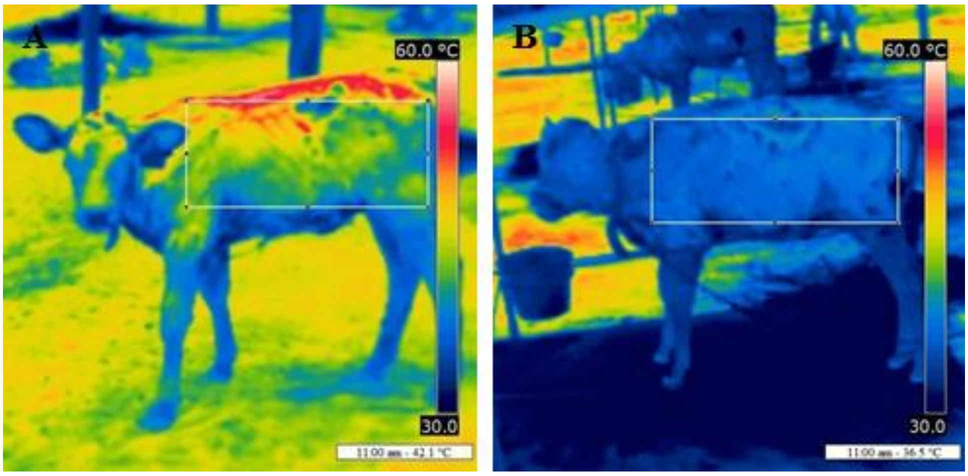

FIGURE 4. Thermographic images of the body surface of calves; sun-exposed animals reared in shelters with thatched roofs (A) and shade-exposed animals reared in shelter with recycled tile (B) on February 24, 2012 at 11 am. These images were recorded at a distance of 2.50 m.

Body-surface temperatures in sun-exposed animals were different from shade-exposed ones because of a higher energy absorption. Through this, we may state that thermography is a valid tool to observe animal skin temperatures under various conditions, as a non-invasive method. According to BUSTOS MAC-LEAN (2012), D'ALTERIO et al. (2011), FERREIRA et al. (2011), MOURA et al. (2011), NÄÄS et al. (2010) and SCOLARI et al. (2009), this technique has advantages over conventional methods. Moreover, ZOTTI (2010) reported that errors can be minimized by the use of such device, beyond of providing high precision and accurate records, as well as convenience for data manipulation and temperature measurements (ROBERTO & SOUZA, 2014).

CONCLUSIONS

Individual shelters covered with recycled tile and thatched roofs showed better thermal efficiency, providing lower values of radiant thermal load and surface temperatures, as well as minor temperatures inside shelters. Regardless roof material, all animals had their respiratory rate increased to maintain homeothermy. Thermography enabled thermal mapping to quantify temperatures on the surfaces and, thus, evaluate the thermal efficiency of the different materials. This process aided in understanding heat transfer processes between the upper and lower surfaces, in addition to the distribution of coat surface temperature for animals exposed to sun and shade.

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