SCAP
SOCIEDADE DE CIÊNCIAS AGRÁRIAS DE PORTUGAL

Use of thermography on roofing performance for rural constructions

Uso da termografia no desempenho de coberturas para construções rurais

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A B S T R A C T

Roof coverings are responsible for promoting a suitable environment for animal production, in addition to be one of the main factors interfering with heat transfer. In this context, this study aimed to assess different roof covers over reduced-scale shed prototypes through thermography. The experimental design was completely randomized with five treatments (TT, thermal; RT, recycled (Tetra Pak); ACT, asbestos-cement; BT, bamboo; and AT, aluminum tile) and 14 repetitions, one for each assessment day. For roofing thermal analysis, thermographic images were taken by a thermographic camera (FLIR® TR420), which measured surface temperature changes (external and internal) at 8:00, 10:00, 12:00, 14:00 and 16:00 h, over 14 days. Environmental temperature was measured inside each prototype. BT roofing showed to be efficient, with values of intermediate surface temperatures, enabling its use in replacing RT, AcT and AT roofing tiles. These other tiles had no difference from each other and showed the worst performances.

Keywords: alternative roof coverings, construction components, infrared thermography.

R E S U M O

As coberturas são responsáveis por promover um ambiente mais adequado à produção animal, sendo os materiais de cobertura uns dos principais fatores que interferem nessa transferência térmica. Nesse contexto, objetivou-se avaliar através da termografia, o desempenho de diferentes coberturas em modelos reduzidos de galpões. O delineamento adotado foi inteiramente casualizado com cinco tratamentos, sendo diferentes tipos de coberturas: TER – Térmica; REC – Reciclada (Tetra-Pak); CIA – Cimento-amianto; BAM – Bambu e ALU – Alumínio, com 14 repetições, referentes aos dias de coleta. Para a análise térmica dos materiais de cobertura foram utilizadas imagens termográficas utilizando-se uma câmera termográfica TR420, da FLIR, que mensurou a variação das temperaturas superficiais (externa e interna) registradas nos horários das 8, 10, 12, 14 e 16 h, no período de 14 dias experimentais. Foi coletada a temperatura ambiente no interior de cada modelo reduzido. A cobertura de bambu mostrou-se eficiente, apresentando valores de temperaturas superficiais intermediários, o que possibilita seu uso em substituição às telhas reciclada, cimento amianto e alumínio, as quais não diferiram entre si e apresentaram os piores desempenhos.

Palavras-chave: componentes construtivos, coberturas alternativas, termografia infravermelha.

INTRODUCTION

Climatic suitability in facilities play an important role in animal husbandry since provides thermal comfort, ensuring animal welfare combined with productivity and economic viability. Therefore, it is relevant to improve shelters and management to overcome harmful effects of critical environmental factors, such as high temperatures and relative humidity (Nascimento *et al*., 2014).

Incident radiation is mostly significant being somewhat related to ambience and thermal comfort in tropical regions, where often there is a high incidence of solar radiation. Such high intensity of solar rays may damage environment quality inside farming facilities, because of thermal inertia of construction materials and thermal loads released by animals.

Absorbed solar energy increases roof temperature to levels above those in the environment (Abreu *et al*., 2011). This fact is due to large areas of interception of solar radiation; therefore, in tropical regions, roof tiles should be carefully chosen once they becomes the main factor for thermal comfort (Sampaio *et al*., 2011).

According to Wray and Akbari (2008), solar-radiation reflective materials reduce transfers of thermal energy from roof surface to the facility interior. Several types of covering materials may promote reductions of up to 30% radiant heat load (Baêta and Souza, 2010). In addition, an ideal material must have low absorption coefficient, low thermal diffusivity and high thermal retardation (Tonoli *et al*., 2011). Therefore, it is of utmost importance to assess thermal performance of roof materials and construction components, concerning heat transfer, enabling thermal control inside rural facilities.

To quantify temperature variations in building materials of zootechnical facilities, some precision tools are indispensable. One of the possibilities for determining thermal properties of materials is infrared thermography, which is used to measure surface temperatures of objects (Altoé and Oliveira Filho, 2012).

Reduced-scale physical prototypes can be used, based on similitude theory, to assess different covering materials. It has become quite important in choosing best materials for intensive rearing of farm animals (Cardoso *et al*., 2011; Sampaio *et al*., 2011; Almeida and Passini, 2013). These prototypes show a few advantages, such as low cost of materials and reduced labor, in addition to allow testing different constructive configurations (Jentzsch *et al*., 2013).

Latest technologies, such as infrared thermography, emerged as alternatives to clarify impacts of environmental factors on animal husbandry, backing decisions as well as improving animal health and welfare. In this context, this study aimed to assess the thermal performance of different roof coverings through thermography, using reduced-scale prototypes.

MATERIAL AND METHODS

The experiment was conducted at the State University of Goiás, Campus of Exact Sciences and Technology (CCET), Anápolis – GO, Brazil; during the months of May and June, 2015. The city is located at the geographical coordinates of 16°22′56.76″ S and 48°56′45.46″ W and altitude of 1.017 m. According to Köppen's classification, regional climate is Aw (humid tropical) with two distinctive seasons: one is dry and characterized by a cooler period extending from May to September, and the other rainy with a warmer period from October to April.

Reduced-scale prototypes were built in masonry, in distorted scale with dimensions of 1.5 × 1.0 × 1.0 m (L × W × H). They remained spaced in four meters between each other. Tile slope was set at 25° for roof construction.

The experiment was developed in a completely randomized design with five treatments (TT, thermal tile; RT, recycled tile (Tetra Pak); AcT, asbestos-cement tile; BT, bamboo tile; and AT, aluminum roof tile) and 14 repetitions, one on each assessment day. Figure 1 shows the roof covers used in this experiment.

The images taken by a thermographic camera (FLIR® TR420) were used for roofing thermographic analysis. Through this, we could determine variations between external (T_{SE}) and internal (T_{SI}) surface temperatures at 8:00, 10:00, 12:00, 14:00 and 16:00 h, over 14 non-consecutive days. The camera was set at a distance of 1.0 m from the analyzed surfaces.

Image analysis was made by FLIR QuickReport software, fitting emissivity, reflected temperature, environment temperature and relative humidity to 0.95, 25 °C, 20 °C and 65%, respectively. For TT, RT and AT, temperature measurements were taken at

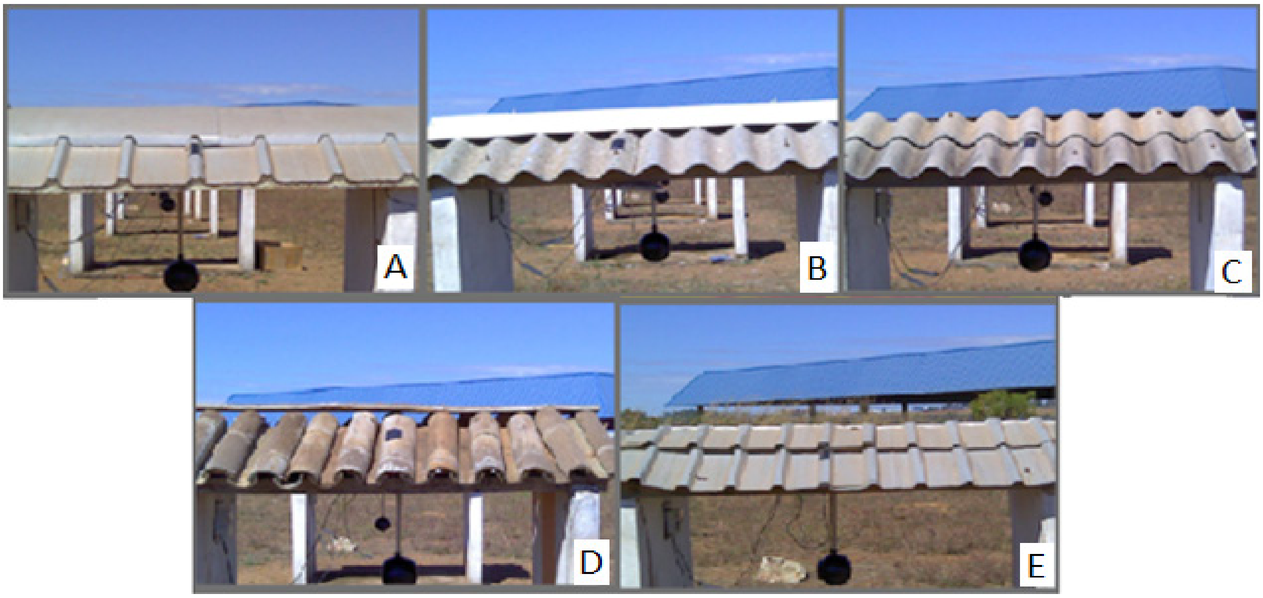

Figure 1 - Reduced-scale prototypes covered by thermal tile (A), recycled tile (Tetra Pak) (B), asbestos-cement tile (C), bamboo tile (D) and aluminum tile (E).

pre-set points, at which PVC insulating tapes were fixed. These insulating tapes were used to enable a correct reading of temperatures, as the assessed materials have high reflectance. Data loggers measured environmental temperatures inside each prototype.

Statistical analyses were performed by SisVar software version 5.3 (Ferreira, 2011). Data underwent analysis of variance, in which we verified normality and homogeneity of variances. If means were significant, they were compared by the Scott Knott's test at 1% significance level.

RESULTS AND DISCUSSION

Table 1 shows the temperature averages of internal and external surfaces of coverings at many times of the day. There was no significant difference for T_{SE}. However, it was observed significant differences (P<0.01) for T_{SI} between treatments at the different times analyzed.

Table 1 - Average values of the internal (T_{SI}) and external (T_{SE}) surface temperature for thermal tiles (TT), recycled tiles (RT), asbestos-cement tiles (AcT), bamboo tiles (BT) and aluminum tiles (AT), at different times of the day

Tratamentos	8h	10h	12h	14h	16h
			T_{SI} (ºC)		
TT	16,95 Ac	23,52 Bb	29,75 Ca	30,15 Ca	29,14 Ba
RT	17,30 Ad	28,36 Ac	33,73 Aa	35,68 Aa	32,00 Ab
AcT	17,60 Ad	28,55 Ac	38,14 Aa	36,77 Aa	32,54 Ab
BT	16,76 Ad	24,97 Bc	32,86 Ba	33,45 Ba	30,12 Bb
AT	18,42 Ad	27,96 Ac	37,96 Aa	37,72 Aa	33,57 Ab
			T_{SE} (ºC)		
TT	19,44 Ac	32,52 Ab	39,68 Aa	40,33 Aa	33,34 Ab
RT	17,16 Ac	29,56 Ab	36,63 Aa	36,61 Aa	30,92 Ab
AcT	18,05 Ac	28,24 Ab	35,76 Aa	35,73 Aa	31,49 Ab
BT	18,62 Ac	28,91 Ab	38,47 Aa	38,02 Aa	31,56 Ab
AT	20,01 Ac	31,68 Ab	39,19 Aa	38,36 Aa	32,01 Ab

*Different lowercase letters in the rows differ statistically by the Scott Knott test at 1% probability. **Different uppercase letters in the columns differ statistically by the Scott Knott test at 1% probability.

At 10:00 h, TT and BT presented lower T_{SI} compared to the others. However, at 12:00 and 14:00 h, only TT presented the lower T_{SI}, BT showed intermediate values and the other materials had higher values (P<0.01). A great variation of T_{SE} was observed for both coverings, which may be due to occurrence of days with higher and milder temperatures. Such distinctive values in temperatures are because of the material constitution of each tile, besides their varied absorptance property.

Among all treatments, the higher T_{SI} averages were registered at 12:00 and at 14:00 h, with the lowest value for TT; therefore, this material showed to have a better performance compared to the others. By contrast, RT, AcT and AT showed the worse performance and without differing from each other, averaging 35.68, 36.77 and 37.72 °C, respectively, at 14:00 h.

Given that TT and AT have reflective capacity, they showed similar results for T_{SE}. Notwithstanding, TT was able to reduce in 9.93 °C T_{SI}; whereas AT was less efficient, reducing only 1.23 °C in T_{SI} at 12:00 h.

The improved thermal responses by TT at 12:00 and at 14:00 h may be justified by its physical properties (aluminum and polystyrene polymer). Polymers owns a good thermal resistance, hindering heat flow. Besides that, aluminum is commonly applied as heat reflective thermal insulator for having low emissivity and high reflectivity; therefore, it reduces long-wave radiation emission into the facility (Michels *et al.*, 2008). In conclusion, summer thermal gain and winter heat loss are both reduced. Therefore, the best thermal solution for the installations.

BT was effective to reduce T_{SI} (4.57 °C), reaching 33.45 °C at 14:00 h, which denotes greater thermal inertia if compared to the other materials, except for TT, which achieved 30.15 °C and 10.18 °C reduction, at the same time. Bamboo makes a good alternative as raw material for roof manufacturing, given its low cost and high endurance after treatment. Almeida and Passini (2013), when studying different coverings in reduced-scale prototypes, observed similar or even superior performance of bamboo coverings in detriment to asbestos-cement coverings.

A higher T_{SI} thermal amplitude was observed for AcT, reaching 20.54 °C from 8:00 to 12:00 h. Excessive variations in temperature either during the day or between the day and night, or throughout the year, affect poultry and swine development, arising the use of equipment that increase production costs.

TT and BT reached thermal amplitudes of 13.20 and 16.69 °C at 8:00 and 14:00 h, respectively, showing the greater thermal lag and thermal inertia of their constituents.

At the last assessed time (16:00 h), RT, AcT and AT presented lower averages for external temperatures, being similar to the findings of Barnabé *et al*. (2014), who studied straw, recycled tiles and fiber cement roofs. Nevertheless, differing from the results reported by Sampaio *et al*. (2011), who assessed ceramic, metal and fiber cement materials under Southern Brazil conditions and found higher temperatures on the upper surface for all assessed times.

Difference in temperature between media is essential for heat transfers, what is termed as temperature gradient. This gradient indicates heat flow direction, regularly flowing from the highest to the lowest value. If both mean temperatures are equal, there will be no heat transfer, so being in equilibrium from each other (Abreu *et al*., 2011).

In this line, Figure 2 demonstrates that heat flow had positive direction, i.e. from the upper to the lower tile surface, which occurred throughout the entire period and for all types of roofs. Nonetheless, it was different for AcT from 10:00 to 16:00 h, and for RT at 8:00 and at 16:00 h. Both AcT and RT tiles overheated their lower surfaces instead of the upper one, i.e. showing a negative heat-flow direction. The height of the prototypes was 1m, so they operate in a different way from the sheds in real situations where the roof is further away from the ground and possibly there are air currents inside the buildings, and can modify the temperature of the area.

Figure 2 displays peak differences between the curves. TT reached a higher peak, which might have occurred because of its low heat conduction, increasing gradient between surfaces. This phenomenon derives from the use of insulating

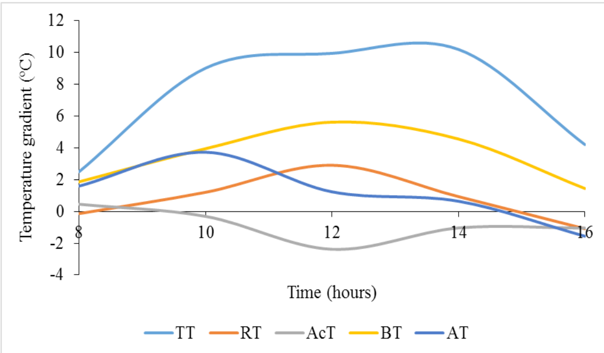

Figura 2 - Temperature gradient between external and internal roof surfaces ($Gt = T_{SE} - T_{SI}$). Gt: temperature gradient, T_{SE}: external surface temperature, and T_{SI}: internal surface temperature.

materials (expanded polystyrene) in its composition. Conversely, we observed lower gradients for AT at the hottest times of the day, being related to the high efficiency of heat conduction by its constituent materials.

Figure 3 shows internal surface images of all studied roof materials at 12:00 h. It is possible to observe the temperature variation range at each thermographic image. Corroborating Table 1, where we can observe higher temperatures for RT, AcT and AT, averaging 40.0, 43.2 and 40.8 °C, respectively, at the hottest points.

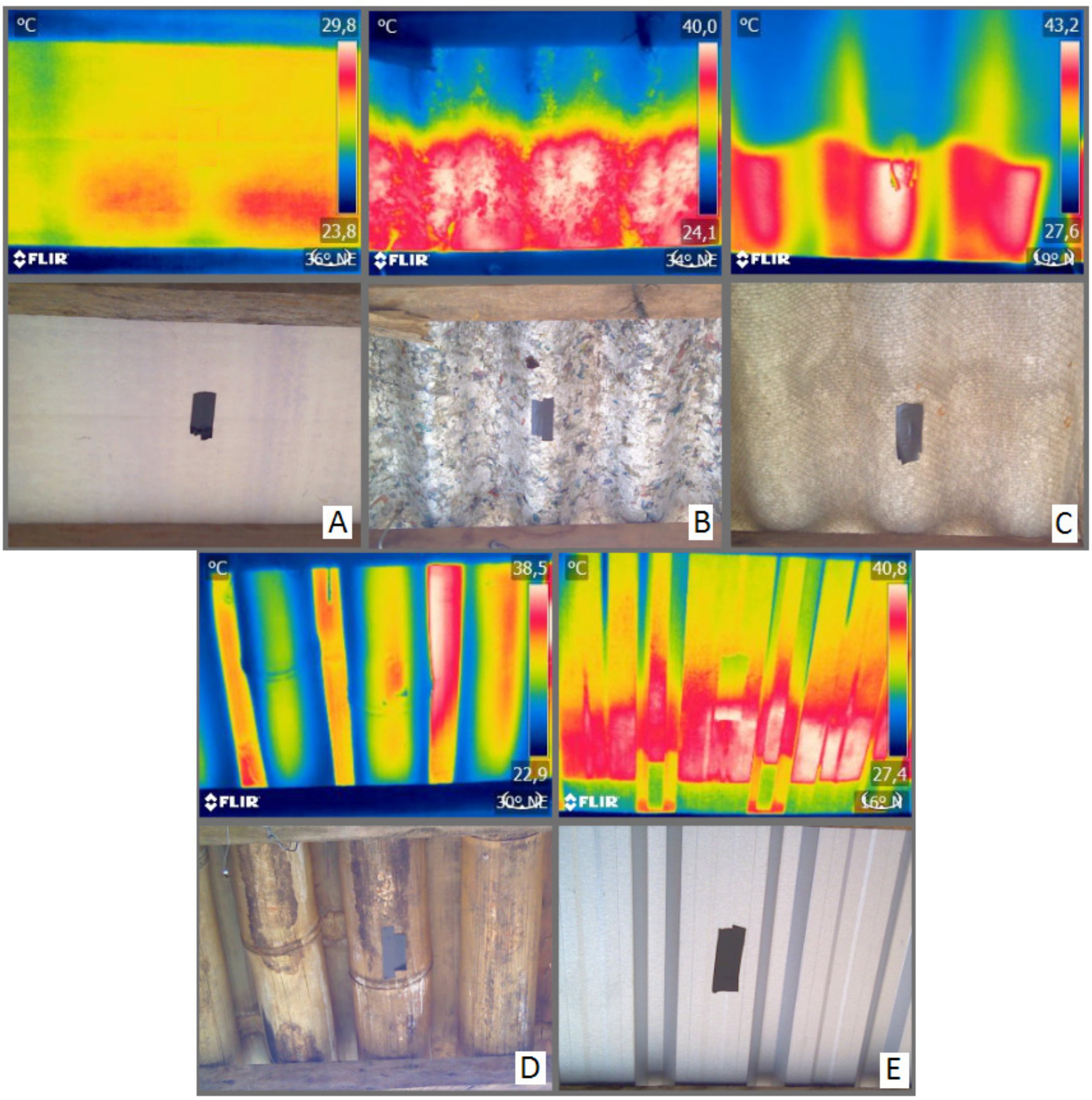

Figura 3 - Real and thermographic images of internal surfaces of the following roof materials: thermal (A), recycled (B), asbestos-cement (C), bamboo (D) and aluminum (E).

Figure 4 exhibits the averages of internal surface temperature of the roof coverings for each assessed time and environment temperature (T_{amb}). Based on it, we may see a simultaneous decrease of T_{SI} with T_{amb} from 14:00 h. At all studied times, T_{SI} of all tiles were higher than T_{amb}, confirming the results found by Sampaio *et al*. (2011) with ceramic, metal and fiber cement materials in Southern Brazil. These authors observed internal surface temperatures higher than T_{amb} for all assessed times and studied coverages. However, it differs from the studies conducted by Barnabé *et al*. (2014), who found average internal surface temperatures lower than T_{amb} for RT, due to the low emissivity of aluminum in its composition, explains the author.

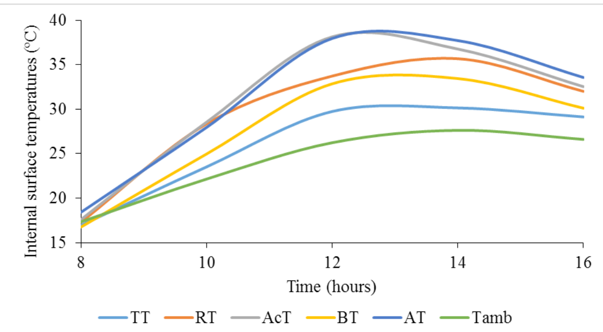

Figura 4 - Average internal surface temperatures of roof coverings at the assessed times and ambient temperature.

Environmental temperature had no significant differences. It can be explained by a fast heat exchange between internal and external environments, leading to an equilibrium state inside sheds. In real situations there is a different dynamic in which this heat exchange influences the exchange of heat between the animals and the environment and also the use of ventilators, exhaust fans and other equipment.

Another factor directly influencing the thermal equilibrium of facilities is ventilation, which is responsible for a large part of heat mass exchange with the external environment. In case of completely open buildings, this exchange is maximized, speeding up thermal equilibrium with the surroundings (Almeida and Passini, 2013).

CONCLUSIONS

Thermal tile had better performance whether compared to the other materials, reaching the lowest internal surface temperatures in the hottest hours of the day. Also bamboo showed to be efficient, being able to replace recycled, asbestos-cement and aluminum roof tiles, thus encouraging the use of new alternative materials. However, it is necessary to carry out a cost and lifespan of the bamboo cover so that it is not only a sustainable alternative, but also, economically feasible.

Thermographic images seem to be an innovative technique but still little known in Brazil. Conversely, it has a high potential for thermal analysis of constructive elements. Thermal technology can be extremely useful to improve animal comfort and reduce energy consumption, inasmuch as contributes to choose the best roof materials.

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