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Thermal behavior of alternative materials used as roof and efficiency of the reflective painting on the external face

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Comportamiento térmico de materiales alternativos utilizados como techos y eficiencia de la pintura reflectante sobre la faz externa

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ABSTRACT: This study was developed in order to compare the thermal behavior of different types of roofs by measuring the External Surface Temperature (EST) and the Internal Surface Temperature (IST) over the days. The experimental design was completely randomized, with five treatments: AC - Asbestos cement tiles, BA -Bamboo tiles, BAP - Bamboo tiles painted in white, FB -Vegetable fiber tiles and bitumen, FBP -Vegetable fiber tiles and bitumen painted in white, with 15 repetitions, being adopted as repetitions the days of measurement. The temperature of the internal and external roofing surfaces was collected at 8:00 am, 10:00 am, 12:00 pm, 2:00 pm, 4:00 pm and 6:00 pm. Data were analyzed by SISVAR 5.1® program through the analysis of variance and Skott Knott test for comparison of means, significance level at 1%. The FB coverage showed the worst thermal performance compared to other types of coverage, with the best results observed in BAP coverage.

RESUMEN: El estudio se realizó con el fin de comparar el comportamiento térmico de los diferentes tipos de tejas mediante la medición de la temperatura de la superficie externa (EST) y la temperatura de la superficie interna (IST) durante el día. El diseño experimental fue completamente al azar, compuesto por 5 tratamientos: AC– Asbesto Cemento; BA–Bambú; BAP– Bambú Pintado de Blanco; FB– fibra vegetal y betún; FBP– fibra vegetal y betún pintado de Blanco, con 15 repeticiones, siendo considerados como repeticiones los días de medición. Fueron registradas las temperaturas de la superficie interior y de la superficie exterior de las tejas, a las 8:00 am, 10:00 am, 12:00 pm, 2:00 pm, 4:00 pm y 6:00 pm. Los datos fueron analizados por el programa SISVAR 5.1®, mediante el análisis de varianza y la prueba de Scott Knott para la comparación de medias, el nivel de significación del 1%. FB tuvo el peor desempeño térmico cuando se compara con las otras tejas, con mejor resultado para BAP.

1. Introduction

In a building, the thermal environment is directly affected by the roof, due to the transmission of energy of the solar radiation absorbed by it to the interior, which increases the thermal gains and, consequently, the internal temperature. This is due to the large area of radiation interception [1] because the roof is a larger relative surface in a building.

According to [2], in not shaded areas, the temperature variation tends to follow the local climate, while inside the buildings, the coverage mitigates variations preventing the occurrence of abrupt thermal fluctuations. Among the characteristics of the roof that influence the thermal behavior of a cover, the most important are the constituent material, surface nature, existence and effectiveness of thermal insulation and liners [3, 4]. The ideal material for covering must meet the recommendations where the top surface has high solar reflectivity and high thermal emissivity, and the internal surface, low solar reflectivity and low thermal emissivity [5].

According to [4], many of the buildings use corrugated tiles, such as asbestos cement, for presenting lower cost than ceramic tiles. Furthermore, the construction is faster, easier to clean, which explains the preference of such cover [6]. In industrialized countries, asbestos has been banned from civil construction because it is harmful to health, favoring the use of natural fibers in materials that

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previously used asbestos as a raw material [7]. Despite the ban on the production of tiles and other asbestos-containing materials, in some regions of Brazil, it is possible to find asbestos cement, being common to find recent research involving the use of this material [8-10]. In Brazil, the State of Goiás is the main extractor of asbestos fiber, extracted at the mine located in the Municipality of Minaçu [11-13]. *Eternit*® is the main supplier of asbestos products in the national market, which is supported by Federal Law 9055/95, which governs the extraction, industrialization, use, marketing and transport of chrysotile asbestos and products containing it throughout the national territory [14].

The use of alternative materials in construction has been widely studied with the aim of combining low cost with thermal effectiveness [15-20]. Among the roofing studied, we found that those made from vegetable fibers [4] and bamboo have excellent resistance and high durability [21], besides being raw material found in large quantities and with low cost. Other methods can be combined to improve the thermal efficiency of coverage, such as reflective paint on the external surface. According to [22], the white color in the external surface is a simple and efficient artifice in the reduction of internal surface temperature of roofing, reducing until 9 °C the temperature in the hottest schedules.

Considering the importance of roofing material in thermal environment of buildings and the emergence of new materials, we conducted a study to evaluate the thermal behavior of different types of roofing by evaluating the temperature of the inner surface and external surface of the different types of roofing in different schedules.

2. Material and methods

The experiment was conducted at the State University of Goiás, Anápolis, state of Goiás (GO), Brazil. Meteorological data from the period of the experiment were obtained from a meteorological station located approximately 20 meters from the experimental area. During the experimental period, it was observed the following values in the region: mean wind speed: 5.5 m.s -1; mean relative humidity: 68%; mean air temperature: 21.2 ºC.

The experimental design was a completely randomized (CRD), which used five reduced models, where each model randomly received a different type of roof, where Internal Temperature Surface (ITS) and External Temperature Surface (ETS) were collected at 8:00 am, 10:00 am, 12:00 pm, 2:00 pm, 4:00 pm and 6:00 pm, for 15 non-consecutive days, considering the collection day as repetition. Only the days of full sun were considered, without the presence of clouds in the sky. When cloud formation occurred the collection day was canceled.

The reduced models were constructed in masonry, distorted in scale with dimensions of 1.5 m x 1.0 m x 1.0 m (L x W x H), and only the east and west sides were closed, maintaining a spacing of 4 m between the models. For the construction of roofs, it was adopted a tilt of tiles of 25º, a value considered ideal according to [23], who recommends a roof inclination between 20º and 30º.

In order to compose the treatments, the following types of coverage were used: AC - asbestos cement tiles; BA -bamboo tile; BAP -bamboo tiles painted in white, FB - vegetable fiber tiles and bitumen; FBP - vegetable fiber tiles and bitumen painted in white. It was used asbestos cement tiles with a thickness of 5 mm, which were installed in one of the shelters, in order to compare their performance with alternative covers (Figure 1).

Figure 1 Reduced models with the respective roofing installed

To make the bamboo tiles, the giant bamboo was used (*Dendrocalamus giganteus* sp.). Bamboos were treated by immersion in solution of chromated copper borate at 3%, and they remained submerged for 24 hours. After treatment, bamboos were cut in half so that, for each piece of bamboo, two grooves were formed. The grooves received holes for screw fixation of parts, thereby forming the tiles.

The vegetable fiber tiles and bitumen were purchased in a construction material store, and they were composed of vegetable fibers obtained by paper and cardboard recycling, and a paste was made with this product and the bitumen was added. The tiles were cut according to the size of the cover and were installed with the aid of staples, and, for the treatments composed by tiles with painting on the outer surface, it was used latex paint in ice white.

For the collection of surface temperatures of roofs, we use an infrared thermometer (precision +/-(2%+2 °C) from 0 °C to 180 °C, being the temperatures collected at three points of the inner surfaces and outer surfaces of the roofs, and then, the average temperature was calculated in each schedule. Samples were collected respecting the distance between the tile and the infrared thermometer established on the instrument technical manual.

Data were analyzed by analysis of variance and Skott-Knott test for comparison of means, at 1% of significance level, and were processed using the software SISVAR 5.1® [24].

3. Results and discussion

There were significant differences ($P<0,01$) for EST and IST between the different treatments (Table 1). For EST

Table 1 Mean values of External Surface Temperature (EST) and Internal Surface Temperature (IST) in °C, with their coefficients of variation and statistical probabilities

Variable	Treatments					Mean	C.V (%)	Prob. F
	AC	BA	BAP	FB	FBP			
EST	29.2 b	31.4 c	25.6 a	36.5 d	25.3 a	29.6	9.53	0.001
IST	28.1 b	28.3 b	26.2 a	33.3 c	26.3 a	28.5	8.27	0.001

AC - Asbestos cement tiles, BA - Bamboo tiles, BAP - Bamboo tiles painted in white, FB - Vegetable fiber tiles and bitumen, FBP -Vegetable fiber tiles and bitumen painted in white. *Different lower case letters, at the rows, differ statistically by Scott Knott test, at 1% probability.

the highest value was found at FB (36.5°C), followed for CA (29.2°C) and BA (31.4°C). The treatments that showed lower values for EST were FBP (25.3°C) and BAP (25.6°C). It is verified a decrease of 30.7% in the EST between treatments FB (dark surface) and FBP (light color surface) showing the efficiency of the reflective paint on the cover in the increased of reflectance and decreased of absorptance thereof. This result is according to findings of [25], who observed a heat gain 30% lower when using light-colored roof regarding the dark-colored roof. In the case of bamboo roof (BA and BAP), the difference between the roof with and without the reflective paint was lower (18.5%), due to the fact the bamboo tile naturally presents a lighter color in relation to the vegetable fiber tile and bitumen, in which case the smallest variation in temperature between this type of roof with and without use of reflective paint was already expected.

It is also observed that the use of reflective painting over the tiles, (BAP and BPF) had mean values of EST and IST lower than observed for asbestos cement (AC), demonstrating that there is a possibility of replacing this type of coverage for a roofing obtained from alternative materials, without loss regarding thermal behavior. Additionally, [26] verified the efficacy of reflective paint over the roofing in the reduction of thermal discomfort and energy consumption with refrigeration systems, where the solar reflectance of inks affected the thermal performance of the painted surfaces, considering that the higher is the solar reflectance of the ink (or the absorptance is lower) the lower is the surface temperature of the roofing

For IST, the highest value was found for FB (33.3 °C), and the lowest values in BAP (26.2 °C) and FBP (26.3 °C), with the other treatments presenting intermediate values. The EST behavior reflected in the IST behavior, and in this study, the treatment that presented the worst thermal performance, with lower capacity reduction of EST and IST was the FB treatment, while the BAP and FBP treatments showed the best performance, reinforcing the reflective paint efficiency in reducing heat absorption by the roof. Moreover, [27] found smaller values of EST in light-colored roofing in relation to the dark-colored roofing, verifying that the behavior of EST also influenced the IST behavior, similar to that observed in this study, where roofing with higher EST values had higher IST values and roofing with lower EST values had lower IST values. Likewise, [22] also found a higher thermal efficiency on roofs using reflective paint on the outer face, observing significantly lower values of EST on the tiles with the use of this artifice. For [28], the thermal behavior is intrinsic of tiles, in view that the greater the energy absorption by the roof, the greater the amount of energy transmitted into the installation, thereby increasing both the temperature of the outer and inner surfaces of the tiles as well as the internal environment.

There were significant differences ($P<0.01$) between the schedules for EST and IST (Table 2). For EST, it was verified that the values were different in all analyzed schedules, the highest value was observed at 12:00 pm (39.7 °C), and the lowest value observed at 6:00 pm (17.7 °C). For IST, the schedule that showed the highest values were 2:00 pm (35.9 °C) and 12:00 pm (35.7 °C), with the lowest value of IST observed in the first collection schedule, i.e. at 8:00 am (19.3 °C).

It is possible to observe that the EST value remains above the IST average to about 2:00 pm, starting this schedule, EST and IST are similar, and that from 4:00 pm EST started to present lower values than IST. The heat absorbed by the external surface of the tiles is gradually driven by the roofing material until warming the inner face of same. Between 12:00 pm and 2:00 pm, it was found that the variation in the IST values was minimal, as it in this period the heat absorption by the external face begins to undergo a gradual decrease after reaching its moment of maximum absorption (around 12:00 pm). After 4:00 pm, the surfaces of tiles begin to lose heat to the environment (gradient

Table 2 Mean values of External Surface Temperature(EST) and Internal Surface Temperature (IST) in the different schedules

Variable	Schedules					
	8:00 am	10:00 am	12:00 pm	2:00 pm	4:00 pm	6:00 pm
EST	22.0 b	31.8 d	39.7 f	36.7 e	29.6 c	17.7 a
IST	19.3 a	28.1 c	35.7 e	35.9 e	30.6 d	21.1 b

*Different lower case letters, at the rows, differ statistically by Scott Knott test, at 1% probability.

Table 3 Means of External Surface Temperature EST (°C) in the different treatments and schedules

Treatments	Schedules					
	8:00 am	10:00 am	12:00 pm	2:00 pm	4:00 pm	6:00 pm
AC	22.1 bB	31.2 dB	38.0 fB	35.3 eB	29.7 cB	19.0 aB
BA	23.1 bB	33.8 dC	41.8 fC	40.1 eC	31.3 cC	18.3 aB
BAP	18.1 aA	26.5 bA	33.5 dA	31.6 cA	26.5 bA	17.2 aA
FB	28.4 bC	41.3 dD	52.6 fD	45.7 eD	33.5 cD	17.3 aA
FBP	18.2 bA	26.4 cA	32.7 eA	31.0 dA	27.1 cA	16.7 aA

AC - Asbestos cement tiles, BA - Bamboo tiles, BAP - Bamboo tiles painted in white, FB - Vegetable fiber tiles and bitumen, FBP -Vegetable fiber tiles and bitumen painted in white, External - Environment outside the shelters. *Different lower case letters, at the rows, differ statistically by Scott Knott test, at 1% probability. **Different upper case letters, at the columns, differ statistically by Scott Knott test, at 1% probability.

difference), being that the external face tends to lose heat faster due to increased contact of the same with the atmospheric air and the movement of air masses, which leads to greater heat loss by convection, while the inner face convection loss is slower compared to the external face, explaining the fact that the IST values are higher than the EST values after 4:00 pm.

There was a significant difference (P <0.01) between the schedules for all treatments (Table 3) observing higher EST values at 12:00 pm. There was also a significant difference between treatments at the different schedules, being smaller EST values observed in BAP treatment and FBP, confirming that the reflective paint is efficient in reducing the absorbed heat by the roof. At 12:00 pm, time when the EST value is maximum, the treatment that had the worst performance was FB (45.7 °C), presenting EST significantly higher than the other treatments at the same schedule. At all schedules analyzed with the exception 6:00 pm, FB treatment showed the highest EST values, showing that this type of coverage tends to absorb a greater amount of power compared to other types of coverage studied.

It is noted that the FBP and BAP treatments have a very similar behavior, with these two most effective treatments in reducing EST, demonstrating that the use of white paint on the toppings was highly efficient, so the FB treatment showed the worst performance (52.5 ºC at 12:00 pm), while the same coverage associated with reflective paint (FBP) showed the best performance (32.7 ºC at 12:00 pm) between the tiles studied. The same happened with the BA treatment where the use of reflective paint on the roofing (BAP) was able to significantly reduce EST (reduction of 24.8% in the EST in BAP compared to BA).

There was a significant difference (P <0.01) among the schedules to IST in all treatments (Table 4). In the FB treatment, the highest value of IST was obtained at 12:00 pm (45.4 °C), while in BA the highest value was obtained at 14:00pm (35.7 °C) while the other treatments the highest IST values were found between 12:00 pm and 2:00 pm. Furthermore, it was observed a significant difference (P <0.01) for IST between treatments at different schedules, where FB presented the highest values of IST for all collection schedules, except for 6:00 pm.

It was found that at 12:00 pm, the use of reflective paint on the vegetal fiber tile and bitumen was able to provide a reduction of 13.3 °C (29.3%) in the IST of roofing. A similar result was found by [22], who observed an IST reduction of 9.0 °C in the asbestos cement roofs when used in the reflective paint. Moreover, [29] also observed a smaller surface temperature values in light-colored surface tiles in relation to the of dark-colored surfaces, being observed a difference of more than 12 °C between them. The behavior observed for IST was similar to that observed for EST,

Table 4 Mean of Internal Surface Temperature IST (°C) in the different treatments and schedules

Treatments	Schedules					
	8:00 am	10:00 am	12:00 pm	2:00 pm	4:00 pm	6:00 pm
AC	18.9 aB	27.7 cB	35.1 eB	35.4 eB	30.3 dB	21.2 bB
BA	18.9 aB	27.1 cB	34.6 eB	35.7 fB	30.7 dB	23.2 bC
BAP	17.6 aA	25.0 cA	31.4 eA	32.2 eA	29.1 dA	22.0 bB
FB	22.8 bC	34.6 cC	45.4 eC	43.7 dC	33.6 cC	19.4 aA
FBP	18.3 aB	26.0 cA	32.1 eA	32.6 eA	29.2 dA	19.9 bA

AC - Asbestos cement tiles, BA - Bamboo tiles, BAP - Bamboo tiles painted in white, FB - Vegetable fiber tiles and bitumen, FBP - Vegetable fiber tiles and bitumen painted in white, External - Environment outside the shelters. *Different lower case letters, at the rows, differ statistically by Scott Knott test, at 1% probability. **Different upper case letters, at the columns, differ statistically by Scott Knott test, at 1% probability.

where FB had the lowest efficiency among treatments, with significantly higher IST value to other treatments throughout the day, except for 6:00 pm. Similarly, [30] found that materials capable of reflecting greater amount of radiation back to the atmosphere, provide a lower temperature of the roofing surface and, consequently, a more pleasant indoor environment. Being that according to [25], the decrease in absorption of solar energy by the roofing is extremely important in reducing spending with the cooling in the indoor of building, this result is similar to that observed in this study, where the reflective paint on the outside of the coverage promoted smaller IST values and EST the same, being observed the positive effect of reflective paint on the lower absorption of solar energy.

Another important factor to note is the thermal inertia of the covers. For EST, the asbestos cement tiles (AC) showed a higher thermal inertia between the roofs studied (13.9 °C / 39.6%), followed by BAP (16.3 °C / 48.7%) FBP (16.0 °C / 48.5%), BA (23.5 °C / 56.2%) with the worst result to FB (35.3 °C / 67.1%). Regarding IST, the best result was observed for BAP (10.2 °C / 31.7%), followed by BA (12.5 °C / 35.0%) FBP (12.7 °C / 38.9%), AC (13.9 °C / 39.6%) with the worst result to FB (26.0 °C / 57.3%). In this context, considering that the IST interferes directly in the thermal environment where coverage is installed, bamboo tiles, with and without reflective paint on the tiles (BAP and BA, respectively) showed satisfactory results with less oscillation in temperature throughout the day, this being highly desirable considering that in physiological terms the body would work harder to adjust the daily temperature fluctuation [31] and in financial terms there would be a greater energy expenditure to drive equipment for air conditioning (greater number of actuation generate more energy expenditure) due to the heterogeneous distribution of temperature throughout the day [32] . Additionally, [33] also observed a greater thermal inertia of roofing with light-colored external surfaces than dark-colored surfaces, and according to the authors, this behavior reflects in a better environmental comfort level and less expenditure of energy in maintaining the ambient temperature in a favorable situation. Finally, [34] emphasize the fact that the thermal inertia is something very important to note when choosing a roof, and greater thermal inertia reflected in a more comfortable environment both in summer and winter, reducing the cost of air conditioning (heating and cooling).

4. Conclusions

The vegetal fiber tile and bitumen (FB) had the worst thermal performance compared to other tiles, observing the highest daily average of EST and IST, as well as the lower thermal inertia. The reflective paint on the roof was able to significantly reduce the temperature of the external and internal surfaces of bamboo tile and vegetal fiber tile with bitumen. The bamboo tile associated with reflective paint on the external face showed the best thermal performance between the tiles studied due to its higher thermal inertia, being a great option to replace the asbestos cement tile. The substitution of asbestos-cement tiles with tiles made from vegetable fibers is possible from the thermal performance point of view and further studies are required regarding the physical and mechanical characteristics of these roofs to determine the feasibility of using them.

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