DETERMINATION OF THERMAL AND ACOUSTIC PROPERTIES OF THE FIBROUS SHEATH FROM THE PALM TREE LIVISTONA CHINENSIS AS POTENTIAL INSULATING MATERIAL FOR PANEL APPLICATION

Jobim, Silvie Janis M.[1] Dilly, Jaqueline[1] Lauren C. Duarte[2]

[1] Student at the Postgraduate Program in Design, Laboratory of Design and Material Selection, Federal University of Rio Grande do Sul, UFRGS, Av. Osvaldo Aranha, 99 - sala 604 – Centro Histórico, Porto Alegre, Brazil,

silvie.jobim@gmail.com

jaquedilly@hotmail.com

[2] Postgraduate Program in Design, Materials Engeneering Department, Laboratory of Design and Material Selection, Federal University of Rio Grande do Sul, UFRGS, Av. Osvaldo Aranha, 99 – sala 604 - Centro Histórico, Porto Alegre, Brazil.

lauren.duarte@ufrgs.br

ABSTRACT

The search for thermal and acoustic comfort in residences, associating the energy efficiency with materials from renewable sources, makes vegetal fibers a viable alternative, since they are easy to obtain and found in abundance in nature. There are thousands types of fibers with still unknown characteristics and, in this context, the present work aims with the thermal and acoustic characterization of the fibrous sheath of the Livistona chinensis palm, and thus collaborate with information that may indicate possible applications for the development of new insulation products. The fibrous sheath of the Livistona chinensis palm was characterized by tests of Sound Absorption, Thermal Conductivity and Infrared Thermography. Results obtained from the thermal and acoustic experiments demonstrated comparable properties to those of commercialized materials. Based on these results, associated to its formal aspect that allows its use in natura, the fiber might be used for the application in panels, in order to improve indoor environmental quality, with respect to thermal and acoustic comfort aspects.

KEYWORDS: *Palm tree Livistona chinensis, acoustic absorption, thermal conductivity, infrared thermography.*

I. INTRODUCTION

Environmental comfort involves, in addition to temperature, acoustics, lighting and the visual of the environment. Search for materials from renewable sources that meet this demand, being able to satisfy different needs at the same time, such as low cost, capacity of renovation, low density, among others, turn vegetal fibers into a promising alternative.

Energy efficiency associated with materials from renewable sources, which allow the creation of thermally comfortable environments and seek to satisfy the needs of comfort, is an alternative that helps to optimize sustainability. One way to analyze the efficiency related to the thermal comfort of materials is to investigate their thermal conductivity index.

Thermal conductivity of a material is the physical property that describes its ability to conduct heat, and the coefficient of thermal conductivity (λ) is defined as the physical property of a homogeneous and isotropic material in which a constant heat flux, with a density of 1 W/m^2 when subjected to a uniform temperature gradient of 1 Kelvin/meter [1]. According to the National Brazilian standard norm NBR 15220–2, the thermal conductivity coefficient of materials used in order to provide thermal comfort varies between 0.045 λ (rock wool) and 0.030 λ (polyurethane foam).

Another way in order to analyze the efficiency of materials with regard to thermal comfort is based on infrared thermography, which is a technique that consists of capturing heat images, so called thermograms, not visible to the human eye, emitted by the surface of the material without the need of contact. According to Mendonça [2], all objects emit infrared radiation, and the intensity of radiation depends on two factors: the temperature of the object and its emissivity (the object's ability to emit electromagnetic radiation). The hotter the object is, the higher its radiation.

Infrared thermography is classified into active and passive thermography. In passive thermography no artificial stimulation is used; only a natural temperature difference between the object and the medium into which it is inserted, whereas in active thermography, an external stimulus is required to generate relevant temperature differences [3].

Acoustics is the science of sound, including its generation, transmission and effects. Sound is the sensation produced in the auditory system, whereas noise is defined as any unwanted sound that someone does not need or want to hear, and in some situations may harm health and well-being of individuals or entire populations [4].

According to Bistafa [4], when a sound falls on a surface, part of the sound energy is reflected, while the other part, which disappears behind the surface, is composed of two parts: the dissipated sound energy and the sound energy transmitted by the wall. The ability of a surface to absorb sound is expressed by the sound absorption coefficient (α).

A study carried out by Bastos [5], which developed and characterized several panels made from vegetable fibers (coconut, palm, sisal and acai), analyzed the acoustic absorption of these panels, indicating its good performance of artisanal panels. For frequencies between 1000 and 6000 Hz the acoustic absorption values ranged from 0.40 to 0.9 α. Already, for industrial materials such as Espumex and Sonex, using frequencies between 1000 and 4000 Hz, acoustic absorption values ranged from 0.44 to 0.43 α [4].

The palm tree *Livistona chinensis* belongs to the Arecaceae family, native in Southern Japan and China, and introduced in Brazil as an ornamental plant. The plant is present in tropical, subtropical and temperate regions of the whole planet. It develops well in both full sun and half shade, and adapts well to different types of soils. The plant was ~~a~~ pioneer in potting, being widely used in landscape design and a frequent plant in parks and gardens both as an isolated plant, in groups or in ranks [6, 7].

According to Kobori et al. [8] its reproduction occurs through seeds and seedlings presenting a high percentage of germination (96 to 99%), regardless of temperature and light regime.

The *Livistona chinensis* palm grows up to 20 m high [9], this palm has a petiole that measures about 2 m in length, with its base, where it joins the trunk being wider and flatter than the distal part where the leaf, joined with thorns in the margins and brown fibrous sheath at the base, which goes around the trunk forming a sheath [10].

With the growth of the plant, the older leaves fall down, remaining only the bases of the aged petioles and the fibrous sheath, and if they are not removed they accumulate, forming a clump that normally propitiates the appearance of insects and in this way can harm the development of the plant. The removal of the petioles, which can be done manually, allows the extraction of the fibrous sheath, object of the present study, which besides benefiting the development of the palm tree, can also be used for the design of new products.

The most appropriate materials for the use for absorption of heat and sound should be fibrous or porous. The primary function of a thermal insulation is reducing the transfer rate and heat between the system and the medium so that the energy can be conserved [4, 11,12].

Due to its peculiar characteristics of shape, structure and geometric configuration, fibrous sheath might be used as a perfect *in natura* material, and based on its thermo-acoustic properties, might be defined possibilities of commercial applications for this material. In this context acoustic absorption tests, thermal conductivity index and infrared thermography were performed in the present study.

For a better understanding of the study, in addition to the introduction, the structure of the article is given as follows. Section II is the experimental portion which describes the materials and method. Section III, results and discussion, and finally the conclusion and future work.

II. EXPERIMENTAL

Materials and Methods

Samples of the fibrous sheath of the palm tree Livistona chinensis (Figure 1) used in this study were obtained from southern Brazil, at latitude and longitude coordinates being -27° 49' 26" and -54° 39' 46", respectively. The analysis were performed with the in natura material, previously washed in order to remove surface impurities and then dried at room temperature.

The fibrous sheath is composed by three layers of fibers, with the fiber direction of the inner layer being perpendicular to that of the fibers of the outer layers, and from these fibers leave branches that merge with others, forming a flat, porous and flexible structure.

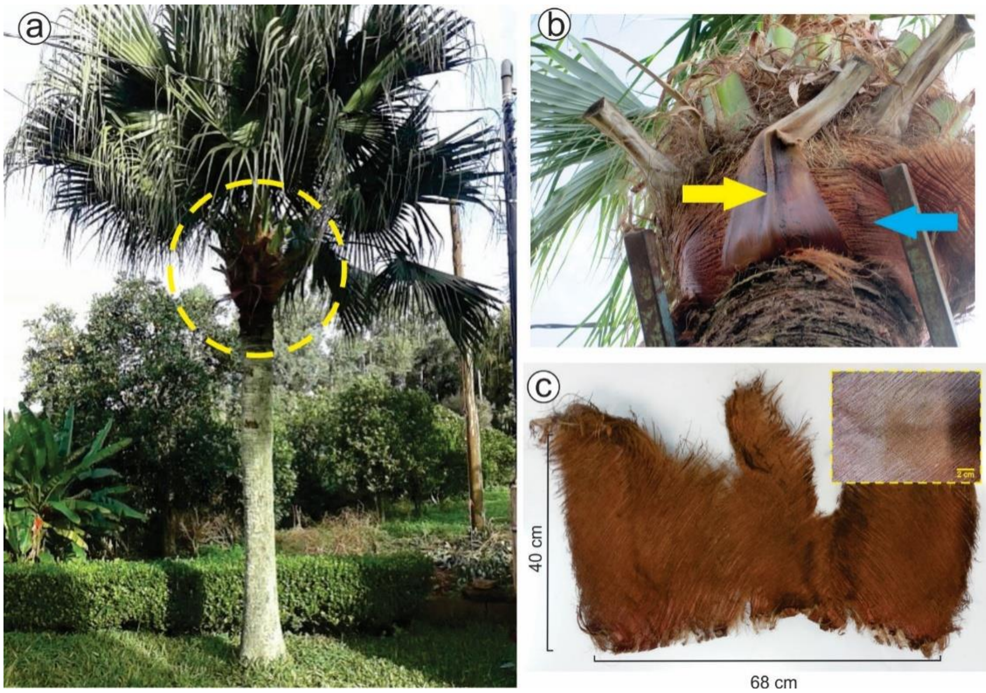

Figure 1. *Livistona chinensis* palm: a) Palm tree *Livistona chinensis* (yellow circle indicates old petioles); b) old petiole (yellow arrow) fibrous sheath (blue arrow); c) sample of fibrous sheath measuring 68 x 40 cm and d) detail.

Sound Absorption

The measurement of the sound absorption coefficient was made by using the impedance tube method in a frequency range between 200 and 6000 Hz. Four samples were taken from the fibrous sheath, and each of them was divided into three circumferences denominated as A, B and C.

Initially the experiment was performed by using only one layer of the fibrous sheath, and subsequently two and three were overlapped, perpendicularly to the direction of the fibers (Figure 2).

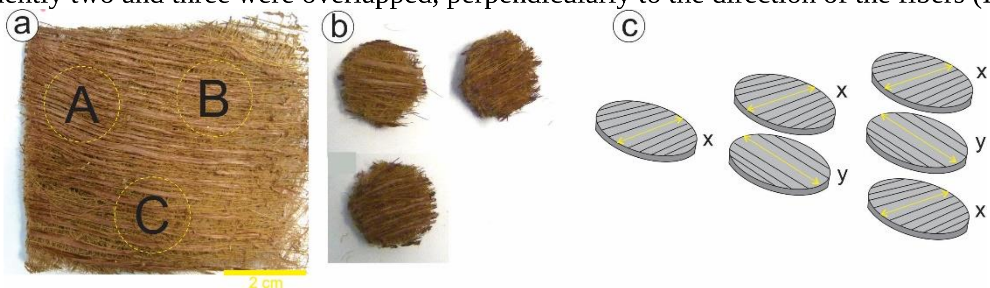

Figure 2. Samples used in the acoustic absorption test: (a) a sample used for the acoustic absorption test; b) the three circumferences A, B and C taken from the sample; c) scheme showing the way the circumferences were overlapped and the direction of the fiber arrangement (x, y).

Thermal Conductivity

The thermal conductivity index of the fibrous sheath was evaluated in a C-Therm TCI Conductivity Meter equipment. Two samples of the in natura material were taken from the same sheath. Analysis were performed on both sides (front and back), with 10 repetitions on each side.

Infrared Thermography

The infrared thermography method was used to verify possible conduction heat transfer differences in the in natura material. According to Silva Junior [13] the existence of a thermal gradient depends on a heat source which flows from warmer to the cooler areas, where the heat transfer occurs by the thermal energy generated by molecular collisions in the material.

The thermography measurements were performed by using a 350 C Portable Thermograph Imaging Camera Testo 890-2, two red ceramic blocks with dimensions of 14 cm height, 19 cm width and 9 cm depth (Figure 4c), and a Skil model 8005 blower with a programmed blowing temperature of 320 °C. In order to concentrate the heat provided from the electric blower, a medium density fiberboard (MDF) chamber was built (dimensions of 28.6 cm height, 20.2 cm width and 40.3 cm depth). Figure 3 represents a scheme of the sample heating process.

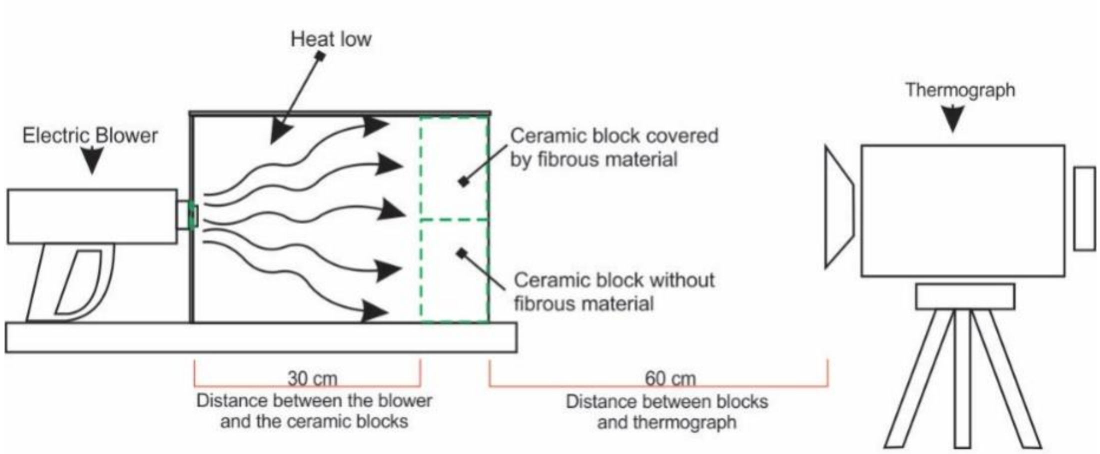

Figure 3. Schematic representation of the thermographic experiment, indicating the position of the blower and the distance between the thermograph and the ceramic blocks.

Initially, one of the ceramic blocks was covered with the fibrous sheath sample (top block), fixed with double-sided adhesive tape, then the second ceramic block was placed on the top of the other, thus closing the front of the chamber. The blower was connected to the back of the chamber, in order to spread the heat in the blocks at a distance of 30 cm from the back of the samples, and these remained at a distance of 60 cm from the thermography equipment. The ambient temperature during measurements was 24 °C. The thermographic images were captured from the front face of the blocks at 10, 30 and 45 minutes heating and analyzed by means of the Testo IRSoft software. The assay was performed using one, two and three layers of the fibrous sheath samples. Figure 4 shows the materials used during the infrared thermography measurements.

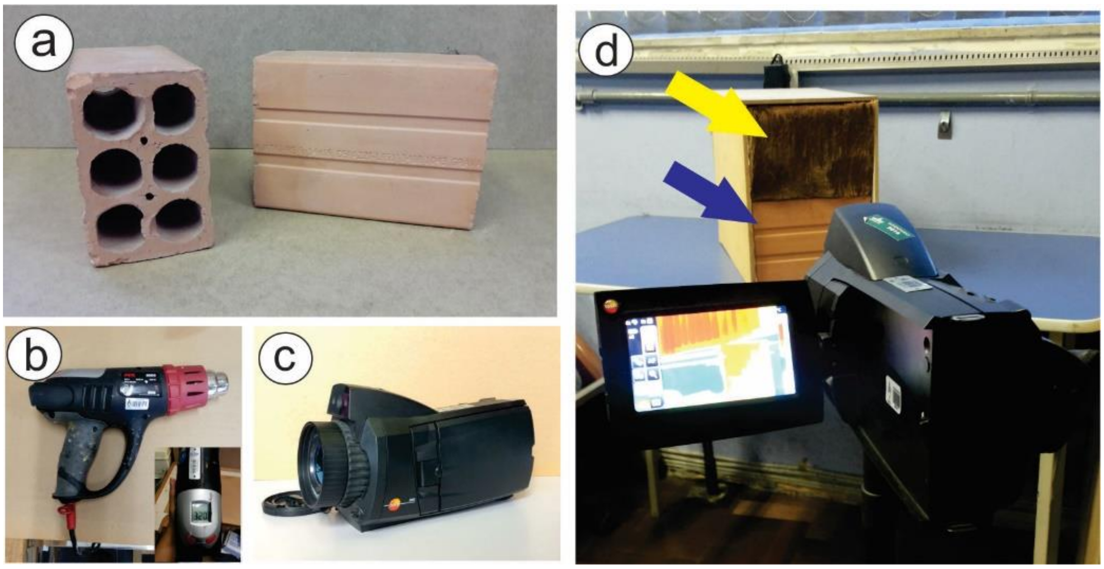

Figure 4. Materials and equipment used in the infrared thermography test: a) ceramic blocks used in the test b) Skil model 8005 blower; c) 350 C Portable Thermograph Imaging Camera Testo 890-2; d) thermograph positioned at 60 cm away from the ceramic blocks capturing thermographic images – the yellow arrow indicates the ceramic block covered by fibrous sheath, while the blue arrow indicates the block without a cover.

III. RESULTS AND DISCUSSION

Acoustic absorption

The obtained data in the acoustic absorption experiments are shown in Figure 5. The graphs show the results for individual samples (A, B and C) and also when associated in two (AB) and three layers (ABC). Table 1 indicates the thickness of each sample.

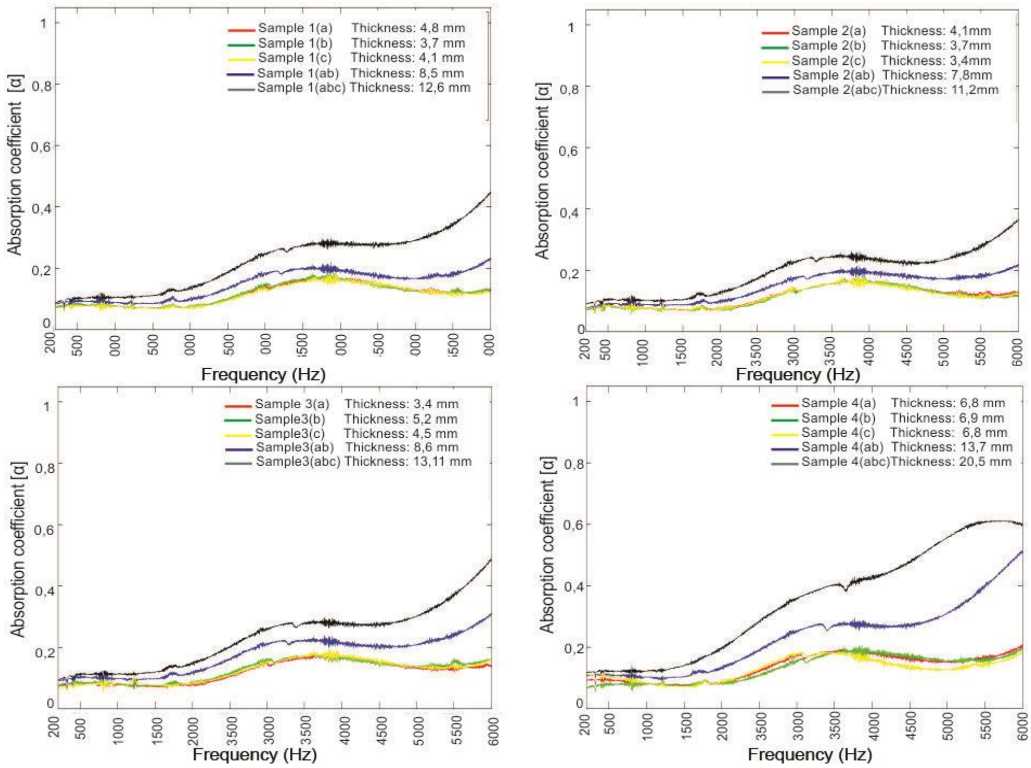

Figure 5. Acoustic absorption graphs of the fibrous sheath samples

The graphs indicate that for samples constituted by a single layer (mean thickness of 4.8 mm), the results were almost identical concerning the sound absorption coefficient, and practically the sound absorption had not occurred. When two layers (AB) were associated (mean thickness of 9.65 mm), a slightly increase of the sound absorption coefficient values were observed. Furthermore, it can be noted that samples constituted by three layers presented the best performance regarding the acoustic absorption when compared to the other samples.

Based on the obtained results, it was observed that sample 4(ABC) was the one which presented the best acoustic absorption, indicating that thickness is a significant factor related to the sound absorption behavior of this material.

The lack of response for lower frequencies can be due to the fact that fibrous/porous materials present low sound absorption coefficients at low frequencies. An alternative for improving sound absorption would be to promote an increase in thickness, since a better low and medium sound frequencies absorption is achieved when a material has higher thickness, or forming a multilayer system [4, 14].

On the other hand, for higher frequencies the sound absorption coefficient ranged from 0.4α up to 0.6α (mean sample thickness of 14.35 mm), thus indicating that the material had absorbed around 40 to 60% of the sound energy.

Although the results indicate low values of sound absorption, when compared with other typical materials for acoustic applications, it must be considered that these were obtained for the single layer samples. In addition, the purpose was to investigate the use of the in natura material, without any kind of processing. Therefore, a cost-benefit analysis should be carried out in order to verify the feasibility of its application when overlapped, or in association with other plant fibers. The combination of fibers constituting mixed panels may produce a material with even better characteristics [5].

Based on the acoustical absorption results, the authors suggest other experiments developed in reverberant chambers, including the association of the material with other vegetable fibers, or increasing its thickness, in order to improve its performance at low frequencies.

Thermal Conductivity

The mean values obtained in the thermal conductivity experiments are presented in Table 1, for each of the analyzed samples.

	Amostra 1A	**Amostra 1B**	**Amostra 2A**	**Amostra 2B**
Média	**0,053**	**0,045**	**0,049**	**0,049**

The experimental thermal conductivity values ranged from 0.045 to 0.053, which were approximately near to those values obtained for insulating materials (0.030 to 0.045) based on NBR 15220-2.

Infrared Thermography

Thermographic images were qualitatively analyzed by using the Testo IRSoft software. Figure 6 shows the real image of the blocks, and their respective thermographic images obtained at room temperature prior to artificial heating.

Initially, the temperature of each material (25.0 °C) and the emissivity index (0.90) were quantified, allowing to observe that there was no major difference between them. It was found only a small temperature difference on the bench (M4, fig 6). In the initial phase of the test a heat leakage had occurred as the material was continuously heated (Figure 6c), however this heat leakage did not affect the area of the test. Attempts were made to establish two read-out points in order to perform all the measurements (read-out point M1 - ceramic block, and read-out point M2 - ceramic block covered with fibrous sheath).

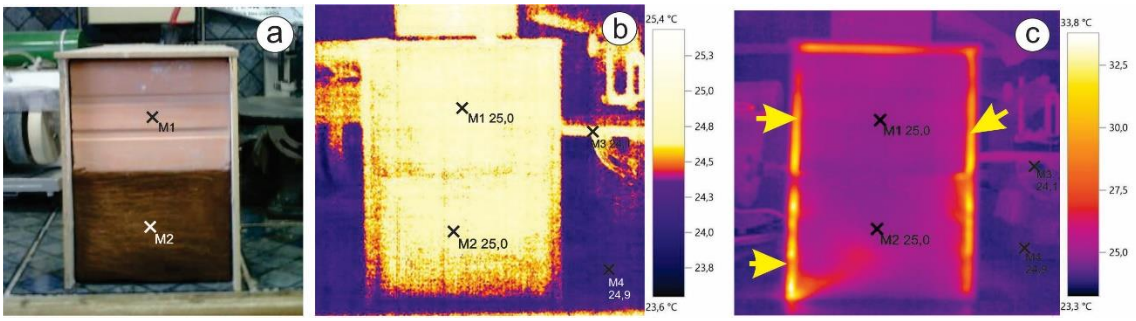

Figure 6. Thermographic images: a) actual images of the blocks, where M1 is the read-out point on the ceramic block without the fibrous sheath, and the M2 is the read-out point on the ceramic block covered with a layer of the fibrous mat; b) thermal images obtained at room temperature before the induced heating; c) beginning of the test indicating the measurements on the ceramic blocks; measurement 1 - M1 - block without fibrous sheath (25 °C); measurement 2 - M2 - block with fibrous sheath (25 °C); yellow arrows – indicate heat leakage; Measurement 3 - M3 - object at the bottom of the test area (24.1 °C); measurement 4 - M4 - bench temperature (24.9 °C).

Table 2 presents the experimental data using samples constituted by one single layer, as well as two and three layers of the fibrous sheath. The samples were disposed on top of one the ceramic blocks and measurements were performed at 10, 30 and 45 min.

Table 2. Registered temperatures for the fibrous sheath samples of the *Livistona chinensis* palm obtained by Infrared Thermography.

Time (min)	One layer of the fibrous sheath Temperature °C Ambient temperature 25,5°C			Two layers of the fibrous sheath Temperature °C Ambient temperature 25,5°C			Three layers of the fibrous sheath Temperature °C Ambient temperature 24,8°C		
	Sheath M2	Block M1	Temperature diference block/sheath	Sheath M2	Block M1	Temperature diference block/sheath	Sheath M2	Block M1	Temperature diference block/sheath
0	25	25	0,0	25	25	0,0	22,7	23	0,3
10	27,6	30,1	2,5	28,6	28,9	0,3	28,6	31	2,4
30	38,5	41,8	3,3	36,9	48,4	11,5	39	64,7	25,7
45	43,9	53,4	9,5	41,7	52,6	10,9	48,2	74,4	26,2

The results in Table 2 indicate that the temperature values presented by M2 (block + sample) and M1 (only block) showed temperature differences in the initial measurement (t = 0 min), when there was a slight difference of the ambient temperature.

The experiment performed at 10 min for the single fibrous sheath layer showed a temperature difference of 2.5 °C between the front part of the M2 and M1 blocks. At 30 min the temperature difference was 3.3 °C and at 45 min it had increased 9.5 °C, indicating that the conduction heat transfer is different along these two blocks.

Concerning the sample constituted by two layers of fibrous sheath, a negligible temperature difference was observed (0.3 °C) during the first 10 minutes of the experiment, whereas after 30 min a significant temperature, difference had occurred (11.5 °C), and at 45 min this difference decreased to 10.9 °C.

Measurements carried out considering samples constituted by three layers of fibrous sheath indicated a temperature difference of 2.2 °C between the two blocks at the first 10 min. After 30 minutes, a significant difference of 25.7 °C was observed, while at 45 min the temperature difference remained at 26.2 °C.

Regarding the number of layers (1, 2 or 3) of the samples on the ceramic block M2, the results had shown that no significant temperature differences were found at 10 min. However, at 30 min the

temperature difference was considerable, increasing from 3.3 °C (1 layer) to 11.5 °C (2 layers) and to 25,7 °C for three layers.
Figure 7 shows the temperature variation profiles for samples constituted with different sheath layers (1, 2 and 3) on the block M2 and the ceramic block M1.

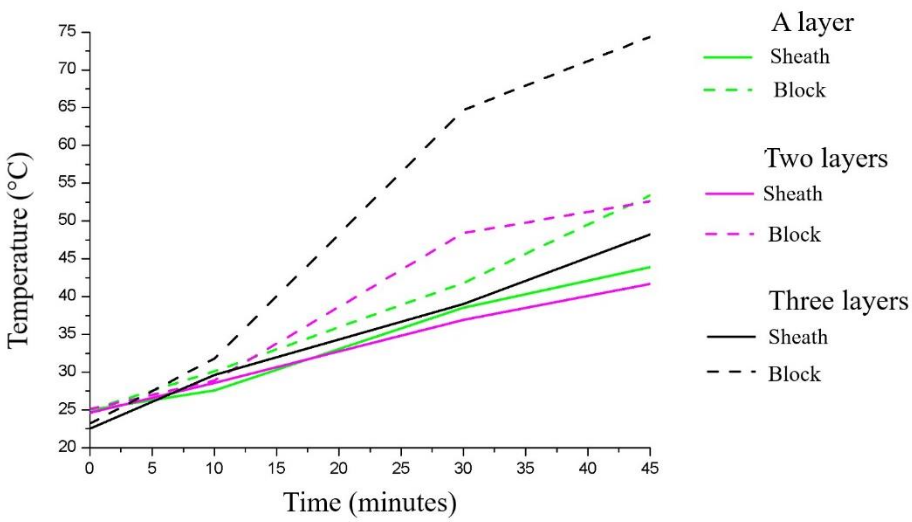

Figure 7. Temperature variation with time for sheath samples (1, 2 and 3 layers) obtained by Infrared Thermography

It can be observed that the amount of layers of the fibrous sheath on the top of the ceramic block had influenced the temperature difference values, when compared with the uncovered ceramic block. This fact was especially significant in case of samples constituted by three layers in this experiment.

IV. CONCLUSION

The experiments performed with the *Livistona chinensis* fibrous sheath indicated a material with a thermal conductivity comparable to insulating materials, which has the advantage of being from a renewable source and can be easily obtained. The thermal measurements indicated that the samples constituted by layers of fibrous sheath on the top of the ceramic block had a lower surface temperature than the uncovered block. This indicates that the material contributed to decrease the heat transfer. In addition, a higher number of fibrous sheath layers increases the thermal resistance of the material, and thus indicates its potential use, in natura form, for thermal insulation.

V. FUTURE WORK

As future work it is suggested the development of thermoacoustical panels, employing an association with other natural fibers, in order to improve the acoustical performance at lower frequencies. It is also suggested a thermal characterization by using a direct sunlight exposure.

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AUTHORS

Jobim, Silvie Janis Mossate. Holds degree in Design - Franciscan University Center (Unifra) end Industrial Production Management - Faculty of International Technology (FATEC). Masters student in Design, student at postgraduate Program in Design, at the Laboratory of Design and Material Selection, in the Federal University of Rio Grande do Sul, Porto Alegre, Brazil. Under the guidance of the PhD Lauren da Cunha Duarte.

Dilly, Jaqueline. Holds degree in Administration – Production Processes, Federal University Pelotas - UFPel. Master in Design, and PhD student, at postgraduate Program in Design, at the Laboratory of Design and Material Selection, in the Federal University of Rio Grande do Sul, Porto Alegre, Brazil. Under the guidance of the PhD Liane Roldo.

Duarte, Lauren da Cunha. Holds degree in Geology, Master degree and PhD in Postgraduate Program in Geosciences Federal University of Rio Grande do Sul, Porto Alegre, Brazil. Professor at Federal University of Rio Grande do Sul in the Materials Engineering Department and also in the Postgraduate Program in Design.