Capter 134

Experimental analysis of a composite thermal wall containing gypsum board and açaí stone residue

Crossref doi https://doi.org/10.56238/devopinterscie-134

Ubiraci Silva Nascimento
Adjunct Professor I of UEMA - (State University of Maranhão/MA/BR). Advisor

Sandra Maria Cruz Nascimento
Teacher PhD from IFMA – Maracanã Campus, São Luís – MA

Willian de Vasconcelos Silva
Student of the Mechanical Engineering course UEMA - (State University of Maranhão / MA / BR). PIBIC/UEMA Scholarship

Alison Sousa Almeida
Student of the Mechanical Engineering course UEMA - (State University of Maranhão / MA / BR). PIVIC/UEMA

1 INTRODUCTION

Currently, environmental issues are gaining more and more accentuated prominence, since the future of humanity is dependent on the actions taken today by man. Great efforts are being spent in the search for knowledge and sustainable alternative solutions that promote development without compromising the environment. Over time, with the advancement of studies and technology, and in return, with the increase in global temperature, the comfort requirements of the population also increased and comfort levels could only be satisfied at the expense of increased consumption of conventional energy to meet the deficiencies of construction. This situation has resulted in an increase in energy consumption in the residential sector, to obtain good thermal comfort. (FRANCO, 2010) .

The advancement of technology has brought several benefits to society in general. On the other hand, population growth has generated an increase in consumption behavior, and caused side effects, thus creating a need for development: sustainable development.

The açaí tree (Euterpe oleracea Mart.) is native to the Brazilian Amazon and the State of Pará is the main center of the natural dispersal of this palm tree. Spontaneous populations are also found in the states of Amapá, Maranhão, Mato Grosso, and Tocantins; and in countries in South America (Venezuela, Colombia, Ecuador, Suriname, and Guyana) and Central America (Panama). However, it is in the region of the Amazon River estuary that the largest and densest natural populations of this palm tree are found, adapted to the high conditions of temperature, rainfall, and relative humidity. (NOGUEIRA, 2005) .

The application of açaí residue to work related to sustainability is of fundamental importance since it is the açaí tree that occurs spontaneously in Brazil and for a large part of the Brazilian population that lives in the states of Amapá, Maranhão, Pará, Tocantins, and Mato Grosso and the main responsible for family income, in addition to serving as food for many Brazilians.

The extraction of açaí can be considered a sustainable activity, fitting perfectly with the policies adopted by the UN for the environment. In 1980, the World Commission on Environment and Development (CMMAD, or Brundtland Commission), implemented the concept of Sustainable Development "as one that meets the needs of the present without compromising the possibility for future generations to meet their own needs." The essence of the idea is to achieve a sustainable world economy. (MARQUES, 2009)

To achieve sustainability, several measures would be necessary. First, society would need to learn to monitor its well-being and environmental conditions. Subsequently, it would need to reduce the time of application of corrective actions, so that the solutions were implemented before the impacts were irreversible. It would also be desirable to minimize the use of non-renewable natural resources, with maximum efficiency and recycling and with consumption below the speed of replacement by renewable resources. As for the latter, he defended the protection of their sources and respect for their rate of recovery. (TEIXEIRA; MILANEZ, 2001).

Collaborating with sustainable development, the search for a material that can be used in buildings that is a thermal insulator has deserved prominence in scientific research, aiming at a material that has the characteristics of good thermal efficiency, good resistance, and low cost.

The recent legislation in force in Brazil has posed new challenges to designers who, to analyze and design buildings to make the most of solar energy, need to know which thermal conditions are preferred by man and at the same time understand the influence that the various typologies of buildings have on obtaining these conditions. It is therefore important that they have methods to predict the thermal behavior of these buildings and to evaluate their thermal comfort.

Specifically in the case of our study, in the Northeast region, due to the high intensity of solar radiation, the heat flow through opaque closures can reach 700 W/m2, representing, therefore, a large portion of thermal load in buildings. The discomfort caused by this situation is well known. The alternatives to face the problem consist of modifications ranging from the conception of the project to the replacement of conventional materials used in civil construction (NASCIMENTO, 2020).

The search for a material that can be used in these buildings that is a thermal insulator has deserved prominence in scientific research, aiming at a material that has the characteristics of good thermal efficiency, good resistance, and low cost (FAQ, 2015).

Thermal comfort depends on physical or environmental variables and also on subjective or personal variables. The main physical variables that influence thermal comfort are air temperature, thermal radiant temperature, air humidity, and relative airspeed. The personal variables involved are activity performed, clothing used, and rate of metabolism of the person. Still, there are the variables of individual characteristics, psychological, and cultural aspects, and habits (NORAIN & KASSIM, 2018).

We define a Thermal wall, as a wall that can prevent blocking the sun's rays and thus not letting the environment heat up. Every wall has some resistance to the sun, but it is possible to make some special treatments to make it more efficient in the work of blocking the sun's rays (ÇENGEL, 2012).

Developed research on composite material for use in civil construction, using plaster mortar and vegetable fiber, intending to obtain a new material that can be used as a coating or sealing element, adding to this property that leads to low thermal conductivity. The tests performed indicated that the thermal properties of the Vegetable Fiber provided a gain of 27.14% in thermal insulation by reducing the thermal conductivity of the compound. (LIMA, 2005).

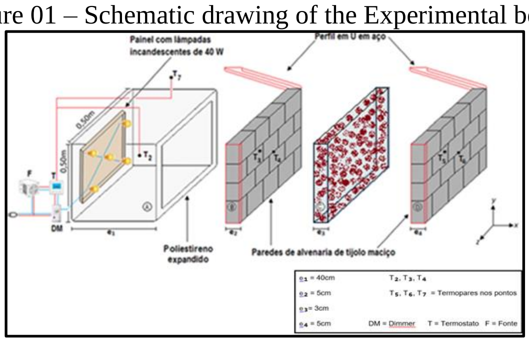
In a dissertation to the Graduate Program at the Federal University of Amazonas, he presented a study on polymeric composites with açaí residue to mitigate thermal effects, where he states that the use of acai residue particles enhances the reduction of environmental impacts generated by agribusiness, providing sectors such as construction with the possibility of producing new, greener materials, also contributing to the mitigation of deforestation forces in the Amazon forest, replacing a part of the wood consumption chain, by actions to reuse materials that generate sustainability indicators in buildings. The same dissertation also states that the high density of particulate panels evidences the potential for application as lining, partitions, and doors, the latter being adapted to situations such as frames for elements of interior architecture. (BARBOSA, 2016).

Finally, an experimental bench will be built with thermal sensors and electronic devices with details and information on the procedures that will be performed, and finally, a comparative analysis will be made with conventional walls in a residence with $100.m^2$

2 METHODOLOGY

The experimental bench was designed and built to determine the thermal behavior of a group of test walls, more precisely, to obtain their thermal conductivities to later be used in numerical simulations. The segments specified below, consist of four independent parts, which for didactic purposes were divided into A, B, C, and D, as shown in Figure 01 (ALMEIDA, 2021).

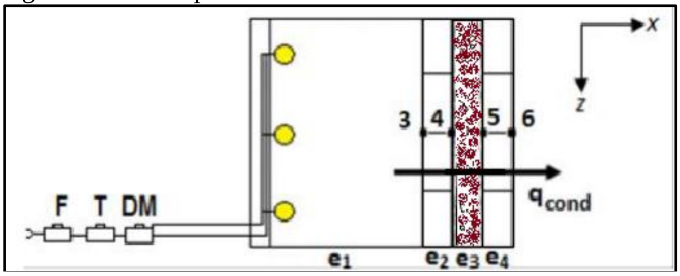
Figure 01 – Schematic drawing of the Experimental bench



Source: Author, 2022.

Part A consists of a box of Expanded Polystyrene of dimensions of (0.50x0.50x0.40) m, where on the left side of dimensions of 0.50x0.50m = 0.25m2, intended for the fixation of 5 incandescent lamps of the nominal power of 40W, fixed in porcelain sockets. The lamps will be distributed evenly throughout the area of 0.25m2, keeping the distances between them at approximately 10 cm. This procedure is because they uniformly simulate solar radiation. The lamps will be connected in parallel coupled to a rotating Dimer, which will allow the variation of their powers. A thermostat will be used as a safety device, to control the maximum temperature, lower than the melting temperature of the Expanded Polystyrene, coupled to a switched source 12 V, 5 A, 60 W, bolt. Figure 02 shows the floor plan with the location of the measurement points.

Figure 02 – Floor plan and location of the Measurement Points.



Source: Author, 2022.

Part **B** will consist of a masonry wall of solid ceramic bricks (5x10x20) cm in the thickness of 5 cm with a square area of 0.50m x 0.50m, woven with cement mortar and sand in the 1:6 trace. Type K thermocouples will be installed in the positions indicated in the Figures. 01 and 02, to measure the aforementioned temperatures. A U-type profile structure of galvanized steel will be designed and made surrounding it, as a frame of 5 cm thick, welded, with the upper part moving, containing hinges, as we can see in Figure 03. The purpose of this frame will be to provide a greater rigidity of the wall, preventing any additional effort, the wall will break.

Figure 03 – Masonry wall with steel angle bracket

Source: Author, 2022.

Part **C** will be built only the frame, which we call the "Cell" of 3 cm thickness that will have a square dimension also of 0.50m x 0.50m, a place where will be placed internally the plate that will be made of the mixture of gypsum and biomass of the residue of the açaí stone. Type K thermocouples will be installed (T3, T4, T5, and T6), and the T4 and T5 will be in contact with the plate and the T3 and T6 on the surfaces of the walls in the direction, from inside the chamber to outside it, that is, from the hot source to the cold source, where through the *Datalogger* the referred temperatures will be measured at these points.

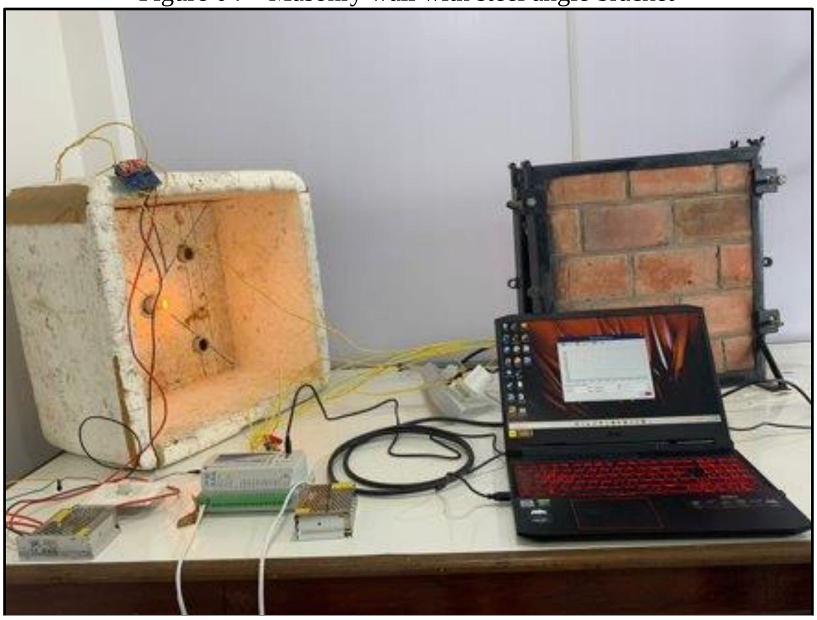
Part **D** will be constructed in a similar way to Part **B**.

On all sides of the bench (B, C, and D), in their respective widths of 5.0 cm, Expanded Polystyrene sheets of 1.00 cm thickness will be used, to avoid the edge effect, heat loss by the sides of the same, isolating from contact with the metal frame.

Finally, two K-type thermocouples were installed at specific points, as a way to evaluate the following temperatures: T2 inside the camera, more precisely in the vicinity of the thermostat measurement, approximately 2.0 cm from the lamp, and T7, without having contact with the skin above the chamber, to measure the ambient temperature.

The experimental bench completed, presented in Figure 04, can be observed initially as the first masonry wall, second, the frame, which we call the "Cell" of 3 cm thickness that will have a square dimension also of 0.50m x 0.50m, a place where the plate that will be made of the mixture of gypsum and biomass of the residue of the açaí seed will be placed internally, third, the other masonry wall and finally an Expanded Polystyrene box of dimensions of (0.50x0.50x0.40) m, where on the right side of dimensions of 0.50x0.50m = 0.25m2, intended for the fixation of 5 incandescent lamps of the nominal power of 40W.

Figure 04 – Masonry wall with steel angle bracket



Source: Author, 2022.

3 FINDINGS

Manufacture of gypsum boards and biomass from açaí stone residue

The samples of the composite will be manufactured with gypsum and biomass of the residue of the açaí seed, in proportions defined by different percentages for each plate, so we use the following percentages of biomass of the açaí seed: 0%, 5%, 10%, 15%, and 20%, the 5 samples will be molded in metallic shapes with dimensions of (50x50x3) cm.

The biomass of the residues of the açaí pits used in the samples of the composites was taken from the açaí tree of the native species, EUTERPE OLERACEA MART., collected in the capital São Luís, located in the State of Maranhão.

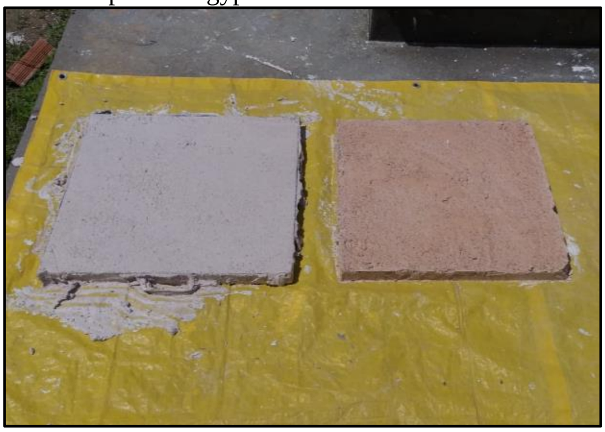
Then, the waste already mentioned was taken to the mechanical crusher, made available by the Institute of Education, Sciences, and Technology of Maranhão (IFMA – Maracanã Campus), and thus we obtain the biomass product in grains, as can be seen by Figure 05.

Figure 05 – Biomass of the residue of the açaí seed

Source: Author, 2022.

Figure 06 homogenizes the gypsum and biomass of the açaí stone residue, emphasizing that 5 plates were manufactured with unique dimensions of (50x50x3 cm) with variation in the percentage of biomass (0%, 5%, 10%, 15%, and 20%).

Figure 06 – Boards composed of gypsum and biomass of the residue of the açaí seed



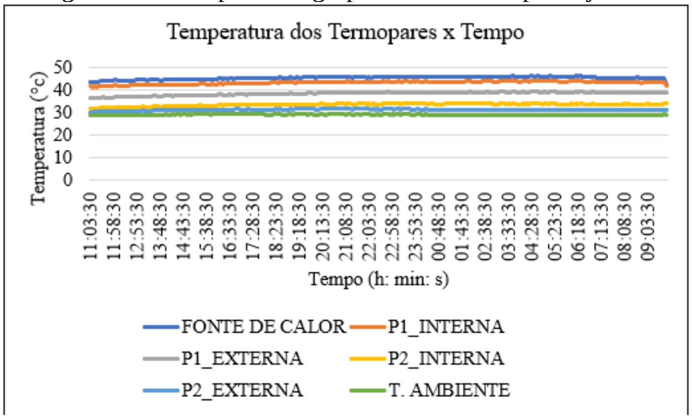
Source: Author, 2022.

Determination of thermal conductivities

In the experiment, an investigation and analysis of the temperatures and thermal conductivity coefficients of the gypsum and fiber boards and the composite wall were performed. After the stage of data collection, we analyzed the results obtained, where the temperatures were collected along the cross-sections of the walls, and then we obtained the arithmetic mean of the same and, in possession of them, thus determine the effective thermal conductivity, as well as the thermal conductivity of the gypsum wall and fiber of the residue of the açaí seed.

Through the accomplishments of the experiments, the following data were obtained through the Datalogger, taking into account the plate with 15% of fiber of plant material in its composition, as can be seen in figure 07.

Figure 07 – Temperature graph of thermocouples by time

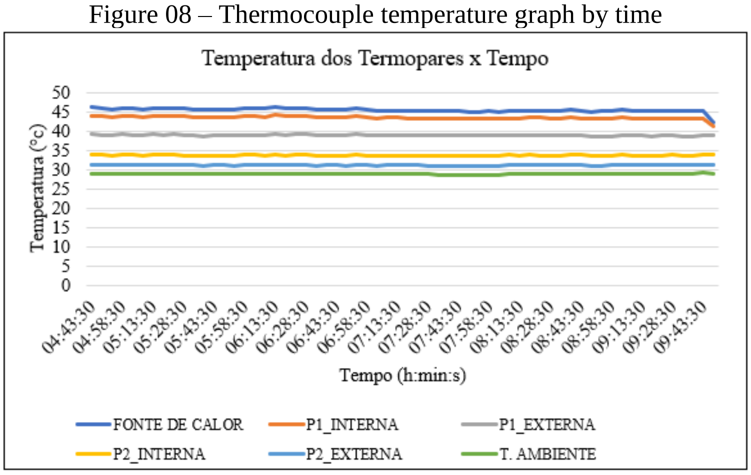


Source: Author, 2022.

The obtainments were started at 11:03:30 a.m. on August 2, 2022, until 9:48:30 a.m. on August 3, 2022, lasting approximately 22 hours, with 274 acquisitions, with intervals of 5 minutes each.

From the data of the 214th acquisition, collected at 04:48:30 on August 3, 2022, it was noted that it had reached the permanent regime and remained until the end of the measurement, presented in the graph of figure 08.

Figure 08 – Thermocouple temperature graph by time



Author, 2022.

Thus, temperature values were collected along the cross-sections of the wall, and the arithmetic mean of the last 60 acquisitions was calculated. These were 43.42°C, 38.82°C, 33.67°C and 31.09°C located respectively in the interfaces, chamber-brick, brick-plaster/fiber, gypsum/fiber-brick and brick-environment, organized from the warm side to the cold side. These values were used to calculate the effective thermal conductivity of the wall and the plaster/fiber wall.

Knowing that the value of the surface area of the wall of 0.25 m2, the total thickness of the wall is 0.13 m, the temperature difference of the mixed wall (T3-T6) = 43.42 – 31.09 = 12.33, K = kef (effective thermal conductivity of the composite wall), of the plaster wall and fiber (T4 – T5) = 38.82 – 33.67 = 5.15, P and the dissipated heat rate 10w (1/4 of the lamp power of 40W.

From the [Eq. 1], it was possible to find the value of the equivalent conductivity coefficient for the composite wall and the plaster and vegetable fiber wall.

$$Q = k \times A \frac{dT}{dx} \qquad \text{[Eq. 1]}$$

Such that,

$$P_{watt} = k \times A \frac{\Delta T}{e} \qquad \text{[Eq. 2]}$$

Where: k = thermal conductivity; P = power; e = wall thickness; A = wall area; T = temperature variationΔ.

Isolating the value of the conductivity coefficient from [Eq. 1] we get,

$$k = \frac{P \times e}{A \times \Delta T} \qquad \text{[Eq. 3]}$$

By substituting the values, one obtains the conductivity of the composite wall:

$$Kpc = \frac{10x0{,}13}{0{,}25\text{x}12{,}33} = 0{,}422\ W/mK$$

Using the same formula, the conductivity of the plaster and fiber wall is calculated, considering only the thickness of the cell part and = 0.03m:

$$Kgf = \frac{10x0{,}03}{0{,}25\text{x}5{,}150} = 0{,}233\ W/mK$$

From the data obtained, it was noted that the result of the thermal conductivity of the gypsum and fiberboard was 0.233 W/mK, which the value was approximated of good insulating materials, such as wood that has a thermal conductivity of 0.12 W/mK, rubber between 0.17 and 0.3 W/mK.

The results of the composite wall for the power of 10W has thermal conductivity equal to 0.422 W/mK, being more insulating than the ordinary brick with 0.6 - 1.0 W/mK.

The same procedure was performed for the other 4 boards composed of gypsum and vegetable fiber of the açaí seed residue, varying only the percentages of the fiber added to the plaster, being used 0%, 5%, 5%, 10%, and 20% in the composition of the plates. Table 01, shows the results obtained from the analyses, we can also observe the results we obtained in the homogenization of the percentages of gypsum and fiber and their respective weights.

Table 01 – Percentages and masses of the 5 plates obtained

ITEM	PERCENTAGES %		WEIGHT OF MATERIALS		PLATE WEIGHT	CONDUT. THERMAL (W/mk)	
EXP.	PLASTER	FIBER (AsM)	MUT GESSO(g)	DRY FIBER (AsM)(g)	DROUGHT(g)	WALL (kp)	.PL. GESSO (kg)
1	100	0	7800	0	8930	0,490	0,295
2	95	5	7410	390	8565	0,434	0,265
3	90	10	7020	780	8370	0,428	0,252
4	85	15	6630	1170	8200	0,422	0,233
5	80	20	6240	1560	7485	0,408	0,209

Source: Author, 2022.

Analysis of the results obtained from the 5 gypsum and fiberboards

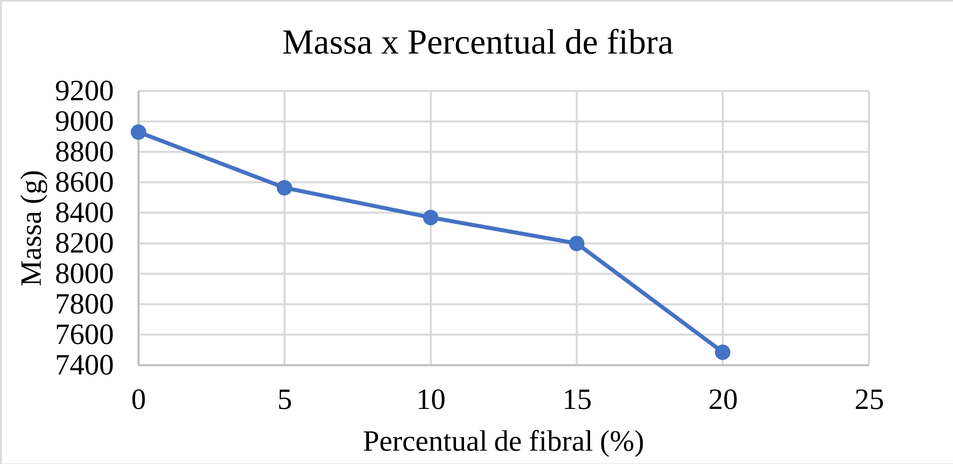
Based on table 02, which relates the mass of the dry plates to the percentage of fiber in the residue, it is noteworthy that the weight of the plate decreases as the fiber is added to the composition of the plate, as can be seen by Figure 09.

Table 02 – Plate mass in grams by the percentage of Fiber

FIBER (AsM)	DRY WEIGHT(g)
0	8930
5	8565
10	8370
15	8200
20	7485

Source: Author, 2022.

Figure 09 – Graph of the mass of the plate in grams by the percentage of fiber



Source: Author, 2022.

Taking into account the thermal conductivity of the composite wall (Kp), we observed in Figure 10 that in the range of 0% to 5%, there was a sharp decrease, while in the intervals of 5% to 15% there was no considerable variation.

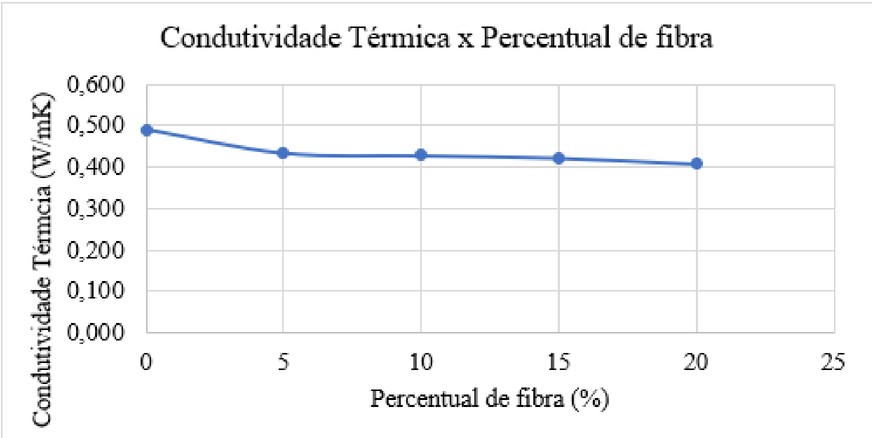
Between 10% and 15% the variation was 0.006 W/mk, and from 15% to 20% was 0.014W/mk, a greater variation when compared to the previous one already mentioned.

Table 03 – Kp of the wall composed by the percentage of fiber

FIBER (AsM)	WALL (kp)
0	0,490
5	0,434
10	0,428
15	0,422
20	0,408

Source: Author, 2022.

Figure 10 – Kp graph of the wall composed by fiber percentage



Source: Author, 2022.

Figure 11 relates the K of the gypsum board with the percentage of vegetable fiber, and residue of the açaí seed, which was added to the composition of the plate.

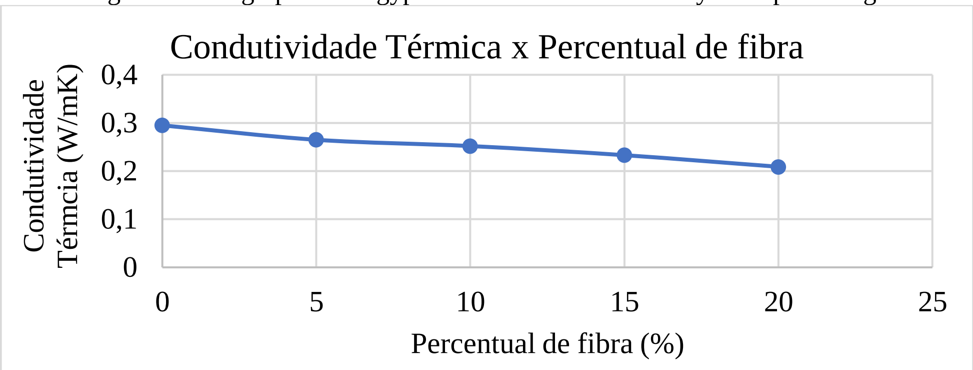
We can conclude that it is feasible to add fiber of up to 20% in the manufacture of gypsum board and vegetable fiber, where the material becomes more thermal insulating, but it must be taken into account that the addition of biomass, thus reduces its mechanical strength.

Table 04 – K of the gypsum board with fiber by the percentage of fiber

FIBER (AsM)	.PL. GESSO (kg)
0	0,295
5	0,265
10	0,252
15	0,233
20	0,209

Source: Author, 2022

Figure 11 – K graph of the gypsum board with biomass by fiber percentage



Source: Author, 2022

In possession of the weights of the dry plates and their volumes that are constant for all plates, we also obtained the values for the respective specific masses, as shown in Table 05, below:

Table 05 – Specific masses of the plates.

FIBER (AsM)	WEIGHT W / DRY(Kg)	VOLUME (m^3)	RÔ (Kg/m^3)
0	8,93	0,0075	1191
5	8,565	0,0075	1142
10	8,37	0,0075	1116
15	8,2	0,0075	1093
20	7,485	0,0075	998

Source: Author, 2022

Comparison of the thermal performance of the wall studied with conventional masonry wall

According to NBR 15220-2, the thermal conductivity of a brick is between 0.7 and 1.05 W/mK. When we observe table 8, which represents the thermal conductivity of the gypsum board with biomass of the açaí stone residue, when we average the values found of conventional brick walls with the addition of biomass 0.240 W/mK, we can conclude that the thermal conductivity of the studied material is better when compared to a conventional masonry brick.

4 CONCLUSION

The plates composed of gypsum and biomass of the residue of the açaí seed, EUTERPE OLERACEA MART., are used to improve the thermal insulation, to protect the internal environments against the variations of high and low temperatures where it can be noticed during the year, thus significantly improving the thermal comfort, in addition to considerably reducing the consumption of electricity to improve the air conditioning of homes.

In this conception, the results obtained lead us to the value of the thermal conductivity of the wall composed of conventional masonry bricks and gypsum board with the residue of the açaí stone, for the average value of biomass addition and 0.423 W/mK, and we can observe that it is below the values obtained when we have a wall composed only of masonry (0.6 to 1 W/mK), this is because of the good performance of the mixture between gypsum and biomass, as an excellent thermal insulator.

The mean value of the thermal conductivity of the gypsum board with the addition of the residue of the açaí seed found was 0.240 W/mK.

Aiming at good results when it comes to thermal insulation, we can conclude that the wall is composed of masonry and plaster with biomass, and is considered an excellent alternative solution for the composition of thermal walls, thus providing optimal thermal conformity, and considering that the environmental aspects and an excellent ecological solution.

REFERENCES

ALMEIDA, Alison Sousa, análise experimental de uma parede térmica mista contendo placa de gesso e fibra vegetal do babaçu, *ATTALEA SPECIOSA MARTIUS*, para determinar o coeficiente de condutividade térmica, São Luís, Faculdade de Engenharia Mecânica, Universidade Estadual do Maranhão, 2021, Relatório Final.

BARBOSA, Andrezza de Melo. Compósitos poliméricos com resíduo de açaí para a mitigação de efeitos térmicos como estratégias eco-alternativas em habitações na Amazônia / Andrezza de Melo Barbosa. 2016.

ÇENGEL, Y. A.; AFSHIN, J.G. Transferência de Calor e massa: uma abordagem prática. Porto Alegre, Editora Mc Graw Hill, 2012. 904p.

FAQ – Imóveis e Construção. Disponível em http://www.faq.inf.br/imoveis-construcao/parede-acustica-e-termica-o-que-e-vantagens-e-como-fazer/. Acessado em 10 de fevereiro de 2022.

FRANCO, FRANCISCO JOSÉ PATRÍCIO. Aproveitamento da fibra do epicarpo do coco babaçu em compósito com matriz de epóxi: Estudo do efeito do tratamento da fibra. Dissertação de Mestrado – Universidade Federal do Rio Grande do Norte, Natal-RN, 2010.

LIMA, João Pinto; Modelagem e Teste de Condutividade Térmica em Placa de Gesso e Fibra Vegetal, Mauritia vinifera Martius, para uso na Construção Civil. Campinas, Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas, 2005, 140 p. Trabalho Final de Mestrado Profissional.

MARQUES, M. E. F.; SILVA, J. L. G. A cadeia produtiva do açaí. Taubaté/SP – Brasil, 2009.

NASCIMENTO, U. S. Borracha de Pneus no Isolamento Térmico de Paredes e Tetos: Modelagem, Validação e Comparação com Paredes Convencionais. 180p. Tese (Doutorado em Engenharia Mecânica) UNICAMP- Universidade Estadual de Campinas. São Paulo, 2020.

NOGUEIRA, O. L.; FIGUEIREDO, F. J. C.; MULLER, A. A. Sistemas de Produção 4. Belém, PA, Embrapa Amazonia Oriental, 2005. 137p.

NORAIN, A.; KASSIM, U. A review on thermal comfort assessment factors for Industrialised Building System (IBS) residences. 2018.American Institute of Physics. AIP Conference Proceedings. https://doi.org/10.1063/1.5066922

TEIXEIRA, B. A. do N.; MILANEZ, B. Contextualização de princípios de sustentabilidade para a gestão de resíduos sólidos urbanos. João Pessoa/PB, 2001. 11p. ABES 21, João Pessoa, 2001. Artigo técnico.