ANALYTICAL AND NUMERICAL STUDY OF A MIXED THERMAL WALL CONTAINING PLASTERBOARD AND BABASSU PLANT FIBER

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ABSTRACT
In this study, concepts of thermal conductivity and heat transfer applied to thermal walls were used, exploring the fact that thermal conductivity varies from material to material, thus providing an opening in the range of studies in the area of mathematical and numerical analysis of this variation. For this, the project presents the development of a code in MATLAB, applying the MDF- finite difference method in the explicit model, starting from the discretization of the thermal heat diffusion equation, where the simulations were carried out

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from data obtained from the thermophysical properties of existing materials in the literature, as well as from the data obtained experimentally from another parallel study to this one, where the thermal conductivities and specific mass of the gypsum boards with different additions of babassu fiber biomass were used. The analyses were concentrated to evaluate the effects on the variation of the percentage of biomass added to the plasterboards, wall thickness, color of the paint of the external wall, in addition to analyzing and comparing the efficiency of walls made with different types of materials. With the results of this study, we intend to contribute with another construction alternative, emphasizing the thermal aspect.

Keywords: Numerical Analysis. Babassu biomass. Plaster. Sustainability.

INTRODUCTION

In this study we present an alternative use of the addition of babassu palm leaf fiber to plaster molded in plate shapes, as a construction alternative, as a filling of a mixed wall of traditional masonry of solid bricks, in order to numerically evaluate its performance, emphasizing the thermal aspect. It will be structured in such a way that initially a bibliographic review of the state of the art will be carried out by consulting several current articles that address the subject, then we will present a numerical model containing governing equations, initial conditions, boundary conditions and resolution method (PATANKAR, 1980).

Babassu is the common name of several species of the genus Attalea (A. speciosa, A. brasiliensis), which occur both in the Amazon forest and in the Cerrado biome. It consists of a robust and imposing palm tree with an isolated stem (trunk) up to 20 meters in height and 25 to 44 centimeters in diameter, with 7 to 22 leaves measuring 4 to 8 meters in length (SILVA and TASSARA, 1991; HENDERSON, 1995; LORENZI 1996 et al., BRANDÃO et al., 2002).

This species has several synonyms cited in the literature, such as: Attalea apoda Burret; A. camposportoana Burret; A. lydiae (Drube) Barb. Rodr.; A. puxuna Barb. Rodr.; Orbignya barbosiana Burret; O. huebneri Burret; O. macropétala Burret; O. macrostachya Dr.; O. martiana Barb. Rodr.; O. oleifera Burret; O. phalerata Mart.; O. pixuna (Barb. Rodr.) Barb. Rodr.; O. speciosa (Mart. ex Spreng.) Barb. Rodr. (LORENZI et al., 1996; BRANDÃO et al, 2002. It is popularly known as: babaçu, babassu, baguaçuí, uauaçu, aguaçu, bauaçu, coco-de-macaco, coco-de-palmeira, coco-naiá, coco-pindoba, pindoba, guaguaço, baguaçu, auaçu (SILVA and TASSARA, 1991; LORENZI et al., 1996; BRANDÃO et al, 2002).

The babassu coconut is a native product of Brazilian lands, which, according to economists, ecologists and bioenergy specialists, can be considered a privilege, since the use of babassu is integral, from its leaf to the seed, being, therefore, a product of representativeness for the economy. It is of fundamental importance to work with the babassu coconut because it is a subsistence material both for the breakers and for the Brazilian industry, with the possibility of being an artisanal and industrial material at the same time. Its by-products are sold both in open markets and in the foreign market. Observing the product we investigated, we realize that, in addition to its beauty, this cocal brings hope to the population that knows how to extract from it: milk, oil, charcoal, among others. As we have mentioned before, the process of babassu by-products has expanded a lot and the culture created from the manual work, carried out by the breakers, allows us to glimpse the need to create a glossary through which one can have access to the lexicon referring to the product, as well as to the industrial or artisanal process originated from this vegetable. The process to which the babassu coconut is subjected has undergone several modifications and innovations in its methods, in addition, the differences between the manual and the industrial process are noticeable. Such changes, innovations and differences entail changes in the terms used. New terms are created to designate actions, objects and things used in the performance of work. In this sense, it is necessary to observe that there is material that can facilitate the understanding of techniques, methods and objects so that the use and functionality of the product are intense. (LUCENA, J. M., 2008)

Borges et al. (2018), in a feasibility study of the production of soil-cement bricks with civil construction waste and babassu coconut fiber, developed a work motivated to assist low-income communities that aim to build masonry houses close to the areas of babassu extraction and taking into account the need to use resources that are renewable and recyclable natural sources. Through verification of the feasibility of producing a soil-cement brick, having as raw materials the babassu coconut fiber and the construction and demolition waste type A, from the comparison of results obtained through the literature. Analyzing the classes referring to basic tests about conventional bricks.

Silva et al. (2004), presented at the III National Congress of Mechanical Engineering in Belém-PA, a paper entitled "coconut fibers as an inducer of thermal insulation in soil-cement bricks", where they used coconut shell fiber powder as aggregate in the composition of soil-cement bricks. Bricks were manufactured in a concentration of 6% powder about cement. Tests were carried out for the analysis of mechanical strength (compression) and determination of thermal conductivity, based on ABNT and ASTM standards, respectively. Compared to conventional cement soil bricks, considered standard in the development of the research, soil-cement bricks with aggregate showed reduced thermal conductivity without compromising mechanical resistance. The results point to the possibility of using this alternative to reduce the thermal load in low-income housing, thus contributing to reduce thermal discomfort in housing located in regions with a high insolation index, as is the case of the Northeast of Brazil.

Still from the perspective of the feasibility study of the use of babassu coconut fiber in soil-cement brick formulations, another work analyzed the characteristics of ecological bricks made with babassu coconut fiber to meet the acceptance criteria by standard for good mechanical resistance, water absorption, durability and thermal comfort of ecological bricks. The levels of fiber addition applied in this research were 0%, 0.5%, 1%, 1.5% and 2% in a mass used in the production of ecological bricks. The adopted trait of 7/1 for the proportion of soil about cement. The specimens were made in standard size in a simple manual press. Technological tests of water absorption and mechanical resistance were carried out on the specimens, following the standards of ABNT 8491:2012, for a curing period at the ages of 7, 14, 21 and 28 days for the wetting of the soil-cement brick. Characterization tests of the raw materials were also carried out, such as: granulometry, consistency limits, X-ray diffraction and X-ray fluorescence, as well as a study of the comparison of the thermal comfort promoted by the bricks produced with and without the addition of fiber. The results showed that the addition of babassu coconut fiber in the soil-cement brick positively influences mechanical strength, thus obtaining an appropriate material for the masonry construction system without structural function (CARVALHO, 2019)

In a work entitled "use of the fiber of the epicarp of the babassu coconut in composite with epoxy matrix: study of the effect of the fiber treatment", the chemical-physical characteristics of the fiber from the epicarp of the babassu coconut (Orbignyda Phalerata) were analyzed, and the main contents of the fiber constituents were determined: insoluble Klason lignin, cellulose, holocellulose, hemicellulose and the contents of ash and moisture. A study of the superficial modification of the epicarp fibers of babassu coconut was carried out under the effect of chemical treatment by alkalinization, in an aqueous solution of NaOH at 2.5% (w/v) and 5.0% (w/v), aiming to improve the matrix/reinforcement compatibility in composite with the epoxy matrix. The results of the modifications that occurred in the fibers were studied using thermogravimetry (TG) and differential scanning calorimetry (DSC) techniques. The results found in the thermal analyses in samples of fibers without chemical treatment and in samples of fibers treated by alkalinization show that the proposed chemical treatment increased the thermal stability of the fibers and provided an increase in the surface area of the fibers, parameters that improve the fiber/composite adhesion (FRANCO, 2010).

According to Çengel's (2012) definition, a thermal wall can block the sun's rays, not letting them heat the internal environment. Every wall has some resistance to the sun, but it is possible to do some special treatments to make it more efficient in the tasks of blocking the sun's rays.

Lima (2005) developed a research on composite material for use in civil construction, using plaster mortar and vegetable fiber, to obtain a new material that can be used as a coating or sealing elements, adding to this property that leads to low thermal conductivity. The tests carried out 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.

The relevance of this project is very great and comprehensive, considering that it deals with a current environmental problem and associates a new technology to solve thermal comfort problems in a sustainable way, saving energy and reducing environmental impacts.

METHODOLOGY

Several numerical methods can be used for the case in question, among them: finite differences, finite elements and finite volumes. The first corresponds to the simplest of the three and easiest to implement computationally, but it has some difficulty and imprecision of the mesh when treated for multiple bodies in contact. While the others have better adaptation to the study of multiple bodies in contact or in discontinuities along a body studied, but more laborious and complex computational implementation.

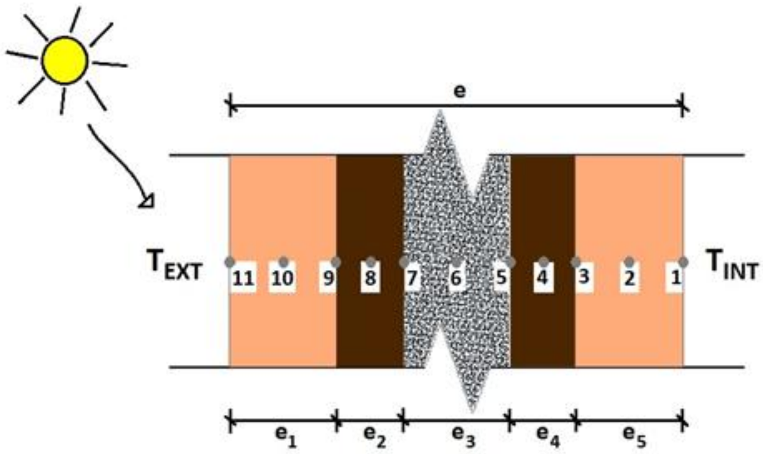
Given this and for the sake of simplification, we will discretize and implement the mathematical model by **the MDF – Finite Difference Method**.

We started the modeling from the equation of one-dimensional thermal diffusion in transient regime for the conduction of heat along a wall without internal heat generation. This equation is called Parabolic Partial Differential Equation and, for the case under study, it is of the nonlinear type since the boundary conditions are functions of the independent variable time, since it is assumed that the incident solar radiation on the surface of the external wall and the daily environmental temperature vary throughout the hours of the day. Due to these characteristics, it is necessary to use a numerical method to obtain the solution of the equation. Thus, it was decided to use MDF with Explicit Scheme due to its simplicity, vast available literature and satisfactorily representing unidirectional heat transfer phenomena.

The use of the method boils down to working the phenomenon in a discrete domain of points, whose equations are linear and simpler to solve than if they were worked in the continuous domain. Thus, an important step of the method is the discretization step of the heat diffusion equation to the points inside the wall body and at the internal and external borders of the wall. And, taking into account that our wall is made up of more than one material arranged in layers, we have to admit each layer as a body with two borders, which makes the process much more complex and laborious.

We will use the following figure to illustrate a mixed wall that was initially designed to be composed of two outer layers of bricks, a central layer of babassu coconut fiber and two thin layers of plywood that surrounds the layer of fiber. In this way, we will have 05 (five) layers and 11 (eleven) points of interest to be considered for the elaboration of mathematical modeling and subsequent simulations.

Figure 1 - Composition of the composite wall with points of interest



Source: Authors (2020)

It should be noted that, although we used an algorithm for five layers, only three were used, replacing the wood layer with masonry in the simulations of the results. For our study, the layers of the masonry walls were considered to be homogeneous

Thus, we now consider:

- Each constituent layer of the elements of our wall and ceiling is homogeneous and isotropic;
- The thermal properties of the materials that constitute them do not vary with temperature;
- There are no heat sources inside the elements;
- There are no considerations or infiltration of moisture into the elements;
- The border conditions are symmetrical.

RESULTS AND PARTIAL DISCUSSIONS

DISCRETIZATION OF THE THERMAL DIFFUSION EQUATION

To begin the discretization process, we need to emphasize that our thermal wall is composed of a flat surface subject to incident solar radiation, convection on the surface of the external and internal wall, conduction through the wall, conduction between the internal borders of the walls and pure conduction between the plaster wall. Considering the uniform initial temperature, constant physical properties of the construction materials, convective heat transmission coefficient, internal and external faces, constant, wall without humidity, and constant internal air temperature.

To obtain the governing equation of the problem, we will take as a basis the formulation of finite differences (PATANKAR, 1980).

By the definition of derivative:

$$\frac{\partial f}{\partial x} = \frac{f(x + \Delta x) - f(x)}{\Delta x} \quad (3.1)$$

If we make the first derivative by the truncated Taylor series (x+ Δx around x) and also the first derivative truncated in n=1. And rearranging the equation obtained, we will achieve an equation similar to the definition of the derivative (3.1) below:

$$\frac{\partial T(x)}{\partial x} = \frac{T(x + \Delta x) - T(x)}{\Delta x} \quad (3.2)$$

Making the second derivative for the point m:

$$\left.\frac{\partial^2 T(x)}{\partial x^2}\right|_m = \frac{\left.\frac{\partial T(x)}{\Delta x}\right|_{m+1/2} - \left.\frac{\partial T(x)}{\Delta x}\right|_{m-1/2}}{\Delta x} \quad (3.3)$$

Constituting $\left.\frac{\partial T(x)}{\Delta x}\right|_{m+1/2} = \frac{T_m - T_{m-1}}{\Delta x}$; $\left.\frac{\partial T(x)}{\Delta x}\right|_{m-1/2} = \frac{T_{m+1} - T_m}{\Delta x}$ (3.4)

We will use the substitution of equation (3.4) in equation (3.3), we will get:

$$\left.\frac{\partial^2 T(x)}{\partial x^2}\right|_m = \frac{\frac{T_m - T_{m-1}}{\Delta x} - \frac{T_{m+1} - T_m}{\Delta x}}{\Delta x} \quad (3.5)$$

Achieving then:

$$\frac{\partial^2 \boldsymbol{T}(\boldsymbol{x})}{\partial \boldsymbol{x}^2} = \frac{\boldsymbol{T}_{m-1} - 2\boldsymbol{T}_m + \boldsymbol{T}_{m+1}}{\Delta \boldsymbol{x}^2} \quad (3.6)$$

For the case involving heat conduction in transient regime, which results from the energy equation (first law of thermodynamics) and the Fourier equation for diffusion heat flux terms, we have the governing equation of the problem:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{e_{ger}}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \quad (3.7)$$

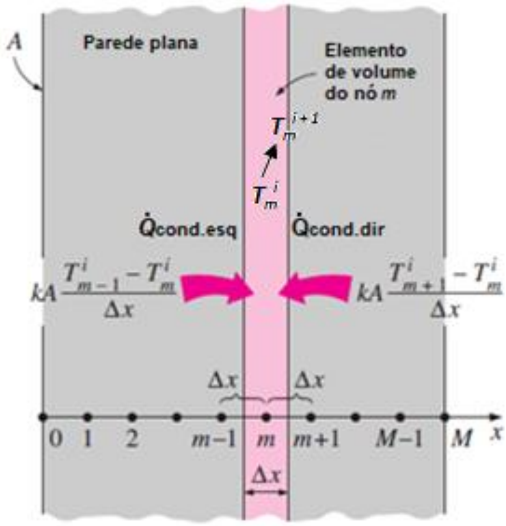
For the case of heat conduction in a one-dimensional transient regime in a flat wall and without heat generation, we have the following equation:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad (3.8)$$

Discretization within each layer

Discretization for the inner knots, which are the points (2; 4; 6; 8 and 10) of Figure 1, making the appropriate energy balances for the explicit method, is as follows, as shown in Figure (2) and Equation (3.9):

Figure 2 - Dots inside the mesh



Source: Çengel (2012), adapted

Substituting in the previous equation and performing the energy balance, we obtain the equation:

$$kA\frac{T_{m-1}-T_m}{\Delta x} + kA\frac{T_{m+1}-T_m}{\Delta x} = \rho A \Delta x C_p \frac{T_m^{i+1}-T_m^i}{\Delta t} \qquad (3.9)$$

Multiplying by Δx/(kA), we get:

$$T_{m-1} - 2.T_m + T_{m+1} = \frac{\rho.\Delta x^2}{k} c_p \frac{T_m^{i+1}-T_m^i}{\Delta t} \qquad (3.10)$$

Para: $(\alpha = \frac{k}{\rho . c_p})$, fica: $$T_{m-1} - 2.T_m + T_{m+1} = \frac{\Delta x^2}{\alpha \Delta t}(T_m^{i+1} - T_m^i) \qquad (3.11)$$

Sendo $(\tau = \frac{\alpha \Delta t}{\Delta x^2})$, teremos: $$T_{m-1} - 2.T_m + T_{m+1} = \frac{T_m^{i+1}-T_m^i}{\tau} \qquad (3.12)$$

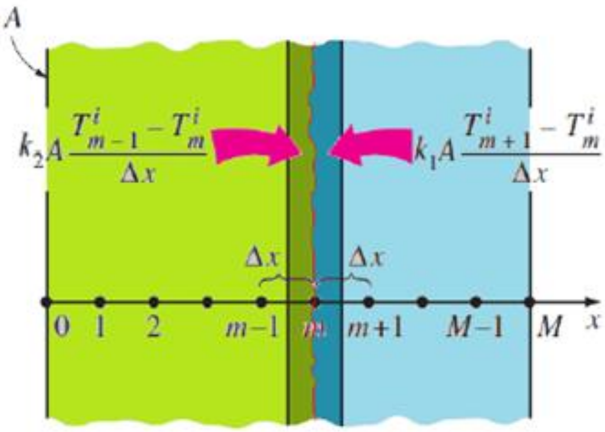
Reorganizing and explaining the term of interest, we have:

$$T_m^{i+1} = (T_{m-1} - 2T_m + T_{m+1})\tau + T_m^i \qquad (3.13)$$

Discretization between different layers

For the problem of heat conduction between walls of different materials, we have the points (3; 5; 7 and 9) of Figure 1, where we have to assume for this discontinuity, the change of material from one plate to another and that the knot of the mesh is at the exact point between the two bodies, as shown in Figure 3 below.

Figure 3 - Knot between the two plates



Source: Çengel (2012), adapted

We then have the conduction between two different materials k1 and k2:

$$k_1 \frac{T_{m-1} - T_m}{\Delta x} + k_2 \frac{T_{m+1} - T_m}{\Delta x} = \rho_1 \frac{\Delta x}{2} C_{p1} \frac{T_m^{i+1} - T_m^i}{\Delta t} + \rho_2 \frac{\Delta x}{2} C_{p2} \frac{T_m^{i+1} - T_m^i}{\Delta t} \qquad (3.14)$$

Reorganizing:

$$k_1 \frac{T_{m-1} - T_m}{\Delta x} + k_2 \frac{T_{m+1} - T_m}{\Delta x} = \left(\rho_1 \frac{\Delta x}{2} C_{p1} + \rho_2 \frac{\Delta x}{2} C_{p2}\right) \frac{T_m^{i+1} - T_m^i}{\Delta t} \qquad (3.15)$$

That isolating the term of interest, we have:

$$T_m^{i+1} = \left(k_1 \frac{T_{m-1} - T_m}{\Delta x} + k_2 \frac{T_{m+1} - T_m}{\Delta x}\right) \frac{\Delta t}{\left(\rho_1 \frac{\Delta x}{2} C_{p1} + \rho_2 \frac{\Delta x}{2} C_{p2}\right)} + T_m^i \qquad (3.16)$$

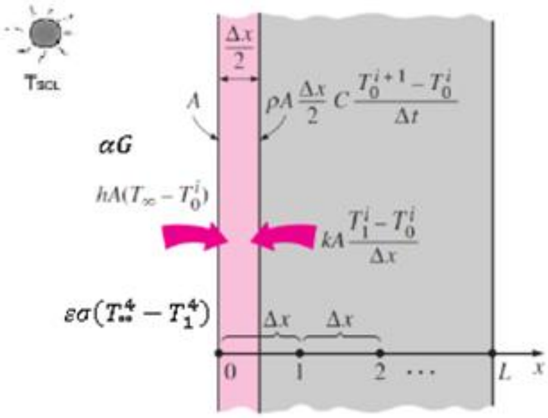
Discretization of the external face border

In the discretized equation for node **(11)** of Figure 1, located at the contour of the outer wall, we assume the condition of natural convection of air, radiation given by the

Stefan-Boltzmann law and solar radiation, we have the net rate of energy that crosses the face of the infinitesimal element and given by equation (3.17), where G is the global radiation (solar radiation), is the absorptivity, is the emissivity, *Tsky* is considered as the ambient temperature and *To* is the surface temperature of the wall, according to (Çengel, 2012) and also observing in figure 4:

Figure 4 - Node condition at the outer border

$$Q = \alpha G + \varepsilon\sigma(T_{céu}^4 - T_0^4) + h(T_{amb} - T_0) \qquad (3.17)$$



Source: Çengel (2012), adapted

Assuming the conduction condition coming from the posterior node next to equation (3.17), we have:

$$\alpha G + \varepsilon\sigma(T_\infty^4 - T_0^4) + h(T_\infty - T_0) + k\left(\frac{T_1 - T_0}{\Delta x}\right) = \rho\frac{\Delta x}{2}C_p\frac{T_0^{i+1} - T_0^i}{\Delta t} \qquad (3.18)$$

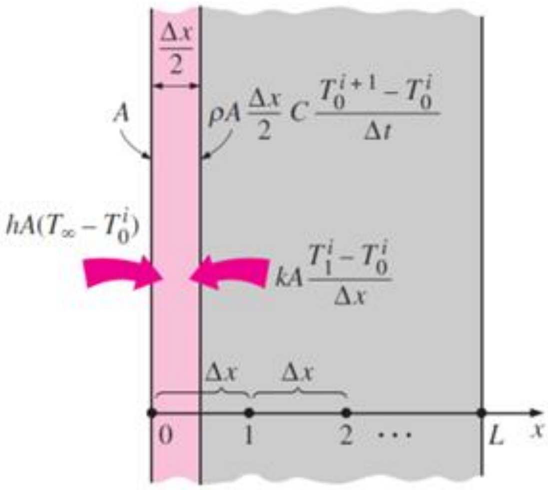
Isolating the term and rearranging the equation, we have:

$$T_1^{i+1} = \left(k\frac{(T_1 - T_0)}{\Delta x} + h(T_\infty - T_0) + \epsilon\sigma(T_\infty^4 - T_0^4) + \alpha G\right)\frac{2\Delta t}{\rho\Delta x C_p} + T_0^i \qquad (3.19)$$

Discretization of the border of the inner face

Finally, we have the discretized equation for point **(1)** of Figure 1, situated at the boundary of the inner face, as shown in Figure 5, boundary nodes, assuming that the only transfer on the surface occurs by purely natural convection, as shown in the following equation:

Figure 5 - Discretization at the inner boundary of the environment.



Source: Çengel (2012)

$$h_A\,(T_\infty - T_0^i) + k.A.\frac{T_1^i - T_0^i}{\Delta x} = \rho.A.\frac{\Delta x}{2}\,c_p\frac{T_0^{i+1} - T_0^i}{\Delta t} \qquad (3.20)$$

Multiplying by

$$\cdot\left(\frac{2\Delta x}{k.A}\right) \rightarrow \frac{2h\Delta x}{k}(T_\infty - T_0^i) + 2.\,(T_1^i - T_0^i) = \frac{\rho.\Delta x^2}{k}\,c_p\frac{T_0^{i+1} - T_0^i}{\Delta t} \qquad (3.21)$$

Towards:

$$:\left(\alpha = \frac{k}{\rho.c_p}\right) \rightarrow \frac{2h\Delta x}{k}(T_\infty - T_0^i) + 2.(T_1^i - T_0^i) = \frac{\Delta x^2}{\alpha\Delta t}(T_0^{i+1} - T_0^i) \qquad (3.22)$$

Doing (□ =), we have $\frac{\alpha\Delta t}{\Delta x^2}$□$\frac{2h\Delta x}{k}$ (T_∞□T_0^i) + 2.() = (3.23)$T_1^i - T_0^i \frac{T_0^{i+1} - T_0^i}{t}$

Organizing:

$$:T_0^{i+1} - T_0^i = \tau\left[\frac{2h\Delta x}{k}(T_\infty - T_0^i) + 2.\,(T_1^i - T_0^i)\right] \qquad (3.24)$$

Isolating the term of interest:

$$T_0^{i+1} = (T_0^i - 2.\tau.T_0^i - \tau.T_0^i\,\frac{2h\Delta x}{k}) + 2.\tau.T_1^i + 2.\tau.\frac{h\Delta x}{k}.T_\infty^i \qquad (3.25)$$

Which in simplified form is:

$$\boldsymbol{T_0^{i+1} = (1 - 2.\tau - \tau.\frac{2h\Delta x}{k}).T_0^i + 2.\tau.T_1^i + 2.\tau.\frac{h\Delta x}{k}.T_\infty^i} \qquad (3.26)$$

Stability Criterion

The implementation of the explicit method is easier and faster to be carried out, but it is an unstable method and for its use, the stability criterion must be considered to prevent the solutions from oscillating or diverging from the real solution. All finite difference equations were analyzed and the procedure for choosing the most restrictive stability criterion was used for the calculation and was automated within the program.

Once the number of points and a uniform spacing between the consecutive nodes have been determined, the time step must satisfy the following relation:

$$\Delta t \leq \frac{\Delta x^2}{2\alpha}, \quad onde\ \alpha = k/\rho.\mathrm{Cp} \tag{3.27}$$

This relationship depends on the thermal diffusivity of the material and the spacing of the mesh.

RESULTS OF THE SIMULATIONS

Several numerical simulations were carried out to evaluate the effects of the variation in the percentage of biomass, thickness of the internal layer, color of the paint of the external wall and the effects of the different types of materials that can be applied for comparison purposes with the mixed board of gypsum and babassu coconut fiber. The data on solar radiation and ambient temperature were obtained from INMET (National Institute of Meteorology). For these simulations, experimental data were used at the values of 0.25 W/m.K for the thermal conductivity of the babassu plate, as well as a specific mass of 1107 Kg/m³ and specific heat of 1090 J/Kg.K, data obtained by Çingel (2012).

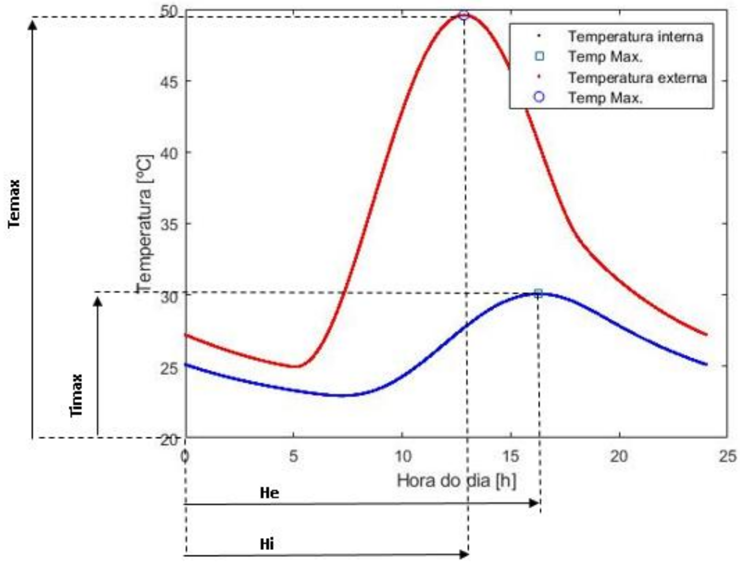
Simple masonry wall

Initially, the simulation was carried out with a simple wall of common ceramic brick of 15cm thickness with thermal conductivity of 0.72 W/m.K, specific mass of 1922 Kg/m³, specific heat of 835 J/Kg.K, absorptivity of 0.63 and emissivity of 0.93.

In Figure 6 we can observe the external and internal temperature of the wall throughout the 24 hours of the day, highlighting the maximum temperature on the external wall, reaching 49.58 ºC, occurring around 1:00 pm and on the internal wall with a peak of 30.08ºC around 4:30 pm. Through the result, we can observe a delay in the temperature peak (RET= difference in the time when the maximum temperature occurs in the external wall in relation to the internal one), caused by the resistance and thermal conductivity of the material along the wall. Another analysis that can be obtained is the decrement factor (RT*= ratio between the maximum temperature of the inner wall and the maximum temperature of the outer wall).

The values obtained for RT= 0.607 and RET=3.44h.

Figure 6 - Temperature of the single wall throughout the day.



Source: Authors (2020)

Composite wall with percentages of babassu fiber biomass

For the wall composed of biomass, 5cm of masonry was considered for each wall with the internal layer filled with 3cm boards with different percentage additions ranging from 0 to 20%, totaling a total thickness of 13cm.

From the simulations we were able to obtain figure 7, which shows that the decrement factor is reduced as the percentage of biomass added to the plate increases, with the maximum reduction to 10% of additive biomass. This leads us to conclude that the percentage of efficiency of the composite wall with the addition of 10% of biomass compared to the composite wall with gypsum board without the addition of it was 13.57% in reducing the thermal load for the interior of the environment.

Figure 7 - Effect of the variation in the percentage of biomass in the composite wall on the values of RT* and RET

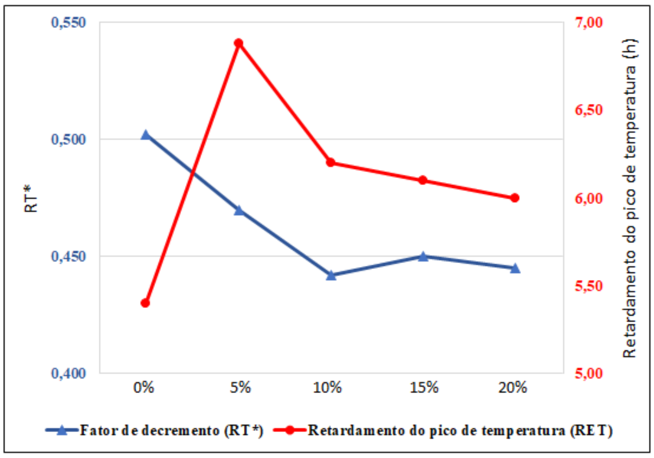


Table 01 – Percentage of biomass applied to gypsum boards

GYPSUM BOARD BIOMASS	RT*	RET
0%	**0,502**	**5,40**
5%	**0,470**	**6,88**
10%	**0,442**	**6,20**
15%	**0,450**	**6,10**
20%	**0,445**	**6,00**

Source: Authors (2021)

Variation of the internal thickness of the composite wall with babassu fiber biomass

For these simulations, the same conditions as those made above were used, only varying the internal thickness where the mixed plasterboard and babassu fiber is located.

In Figure 8, for the decrement factor RT*, we observe that the greater the wall thickness, the greater the thermal resistance, reducing the heat transfer rate and consequently reducing the maximum temperature of the internal surface. The time interval defined as the time at which the maximum temperature reaches the inner surface increases with increasing wall thickness (Peak Temperature Delay). We can see that the reduction in the thermal load when the wall thickness is increased from 12 to 25cm is 34.31%.

Figure 8 - Effect of the variation in the thickness of the composite wall on the values of RT* and RET

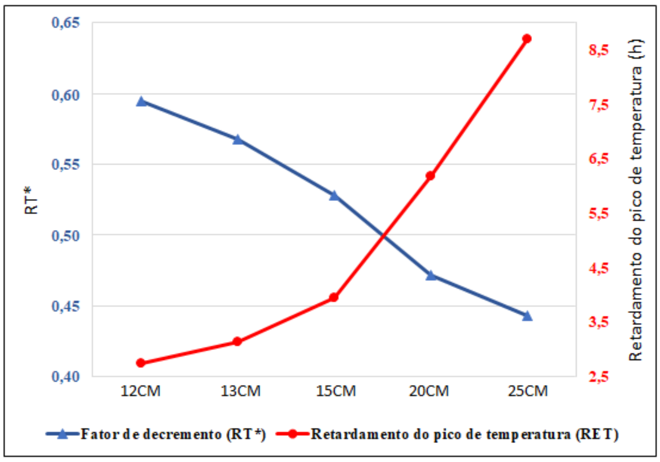


Table 02 – Variation in the thickness of the composite wall with the addition of biomass at 20%

THICKNESS	RT*	RET
12cm	**0,595**	**2,74**
13cm	**0,568**	**3,14**
15cm	**0,528**	**3,96**
20cm	**0,472**	**6,18**
25cm	**0,443**	**8,69**

Source: Authors (2021)

Color variation of the outer surface of the composite wall

For these simulations, the same conditions as those made above were used, using the standard composite wall of 13cm thickness.

We can observe in Figure 9 that because walls painted with light colors reflect more and dark walls are more absorbent, more variations in the values of the decrement factor are perceived, and the peak temperature delay has hardly changed. We can see that between external walls painted white and black, just the option to paint white, we already have a 30% optimization in the comfort of the internal environment.

Figure 9 - Effect of the color variation of the exterior wall paint on the values of RT* and RET

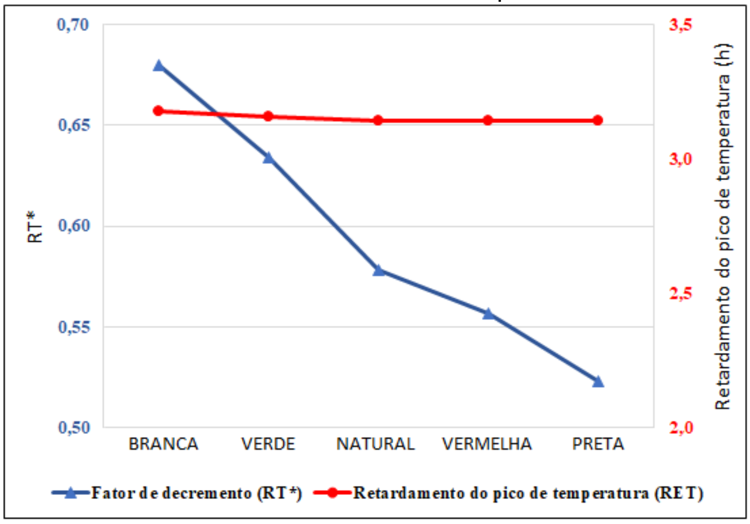


Table 03 – Variation in the color of the painting of the external wall

COLORS	RT*	RET
WHITE	0,68	3,18
GREEN	0,634	3,16
NATURAL	0,578	3,14
RED	0,557	3,14
BLACK	0,523	3,14

Source: Authors (2021)

Variation in materials used

For this simulation, four different types of materials were analyzed: The standard composite masonry wall simulated above, the wall with external wooden faces with thermal conductivity of 0.19 W/m.K, specific mass of 545 Kg/m³ and specific heat of 2385 J/Kg.k and the biomass board with thermal conductivity of 0.25 W/m.K, specific mass of 1107 Kg/m³ and specific heat of 1090 J/Kg.k.

In Figure 10, we can analyze that the materials are organized increasingly about thermal conductivity, from left to right, and with the increase in the thermal conductivity of the materials, the heat flow to the inner surface of the wall increases, decreasing the delay of the peak temperature (RET) and increasing the decrement factor (RT*).

When comparing wooden and concrete walls, we can see that the first is around 35% more thermally comfortable.

Figure 10 - Effect of variation in the type of wall material on RT* and RET values

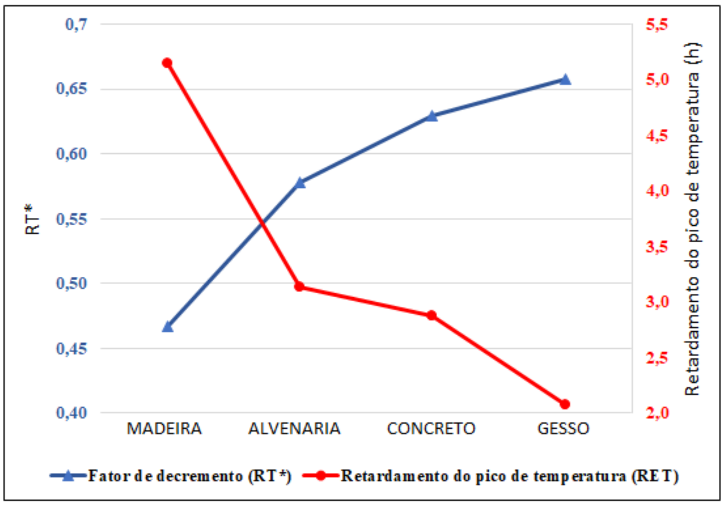


Table 04 – Variation in the type of wall construction material

CONSTRUCTION MATERIALS	RT*	RET
WOOD	**0,467**	**5,15**
MASONRY	**0,578**	**3,14**
CONCRETE	**0,629**	**2,87**
PLASTER	**0,658**	**2,08**

Source: Authors (2021)

CONCLUSION

With an increase in the thickness of the walls, as well as the use of materials with low thermal conductivity characteristics, they slow down the flow of heat along the composite wall, increasing the peak temperature delay, improving the thermal comfort of the internal environment, and consequently, reducing the use of electricity to connect air conditioners and fans.

The use of other types of materials in civil constructions can be interesting from the point of view of thermal comfort, since construction materials generally have relatively high thermal conductivity, being a better conductor of heat, increases the heat flux to the inner surface of the wall, reducing the delay of the temperature peak and increasing the decrement factor, and consequently, increasing energy expenses.

Given the results exposed, we can consider that the layer of babassu coconut fiber was essential in the thermal insulation of the mixed wall, considering the differences found in the simulations.

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