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Heat Transmission and Fractal Dimension of the Representative Materials of the Rural Housing of Tantima, Veracruz.

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Abstract **- The replacement of the traditional materials of rural vernacular housing has occurred gradually, generating discomfort because of the substitution of local materials of natural origin for industrialized elements; Tantima, Veracruz, México is an example of this. To demonstrate that its thermal behavior offers many advantages, this work analyzed the components of a wall of a representative Tantima house: bamboo, wood, and earth. For these, were obtained: the coefficients of thermal diffusivity to apply a theoretical model that allows knowing their thermal profile; through photographs, its fractal dimension was studied to identify the roughness and porosity of its surface. The results were contrasted against the qualities of the cement-sand mortar. The results showed that the mortar presents greater thermal diffusivity, while that of bamboo, wood, and the clay-sand mixture is 20%, 37%, and 42%, respectively. From the studies of the fractal dimension, greater uniformity was found in the clay-sand mix, while the cement-sand mortar presented greater roughness. It was found that, due to the bamboo, the studied wall has good thermal behavior, requiring about 45 hours for the interior temperature to equal the exterior.**

Index Terms **- Alternative materials, Fractal dimension, Thermal behavior, Vernacular housing.**

INTRODUCTION

More than 21% of the Mexican population is concentrated in rural localities, living in vernacular homes in places with less than 2,500 inhabitants [1]. Rural vernacular housing arose out of the need for shelter and protection; Initially, it was built using natural materials, such as stone, wood, bamboo, and earth, that, due to the minimal impact in their obtaining and use, were sustainable. Although the spatial arrangement of the house is preserved, the use of these materials has been abandoned and replaced, generating houses where habitability is compromised.

Substituting these materials involvesrejecting vernacular construction systems due to ignorance of their qualities [2]–[5]. Ignorance associated with the loss of identity of the new generations that, migrating to the city, return influenced by urban architecture and an altered concept of safe and comfortable housing, preferring transculturality, understood as characteristics of urban housing installed in the rural area, as synonymous with status and construction safety.

The present work considers the HuastecaVeracruzana as a study area located in the extreme north of Veracruz, Mexico, between the Cazones and Tamesí rivers, south of the state of Tamaulipas. Initially, the Huastec house had a rectangular floor plan with wooden or bamboo walls, occasionally covered with clay. The walls were reinforced with logs at the corners and at the top, with a sloping roof made of palm leaves. Between deforestation due to poor forest care and the influence of the city, currently, a large number of houses can be found that incorporate materials with characteristics that do not favor thermal comfort, such as concrete blocks and galvanized sheets, and even canvas, rubber, plastic, cardboard, among other waste materials [6], [7]. At the national level, this is reflected in the fact that, of a total of 35,219,141 inhabited homes, 7,531,718 homes were built in rural areas with precarious materials [2], [8].

Studies applied to Huasteca vernacular housing, based on materials such as bamboo, wood, and earth (bahareque), have determined thermal behavior through hygrometric measurements, this being better compared to conventional housing due to the low thermal conductivity of its materials, favoring its habitability, also considering the reduced energy cost due to the absorption of less solar radiation [9]–[11].

The novelty of this research is that the component materials of the wall of the vernacular dwelling are studied directly to quantify the heat transfer and its impact on sustainability, considering it valuable due to the benefit that the result will bring within the National Problems to the improvement of rural or vernacular housing due to the poor quality and precariousness of these.

The literature shows comfort studies applied to urban housing; however, rural housing and rural construction systems have not been fully addressed from a scientific rigor. In this way, it seeks to collaborate in solving the housing problem described in the National Housing Program 2019-2024, with the promotion and development of sustainable rural housing projects, which strengthen the heritage and cultural identity of rural areas to mitigate the social lag.

For this reason, in this article, the corresponding analyzes have been carried out to obtain the heat transfer coefficients of the materials used in the construction, made up of bamboo, cedar wood, and a clay-sand mixture, which are used in a house representative of the Tantima community, in the HuastecaVeracruzana, and with them, evaluate their thermal behavior through theoretical models available in the literature [12], [13], and increase state of the art on comfort and thermal behavior in vernacular architecture, a topic addressed even internationally [14], [15].

On the other hand, it is intended to establish a possible relationship between the morphology of the analyzed objects and their effect on heat transmission since these present complex shapes in nature and cannot be studied or described through Euclidean geometry, using the best method of description and characterization of fractal geometry. The main feature is to assign a non-integer dimension known as the fractal dimension, which will differentiate it from the size established by Euclidean geometry [16].

METHODOLOGY

The methodological process carried out in this study consists of the stages, which are described below:

i. Obtaining the thermal diffusivity coefficients

In the municipal seat of the Tantima, Veracruz, a 10-year-old house was selected, which presents in its walls traditional local materials of bamboo and cedar wood, covered with a homogeneous mixture of clay and clay sand, giving rise to the system called bahareque. This house is located at coordinates 21°19'57.55" N, 97°50' 3.58" W, and is representative of the 395 houses that can be found in the area [17]. Point readings were taken in triplicate from this dwelling with homogeneous materials as described below. Figure 1 shows the dwelling analyzed, which tests were applied to obtain its heat transmission coefficients.

Figure 1 HOUSING ANALYZED, TANTIMA, VERACRUZ. SOURCE: (CONACYTPROYECTPN-2017-5975).

The analysis was carried out directly on its walls, with the support of a KD2 Pro Thermal Conductivity Meter and the SH-1 Sensor;before the measurement, perforation was made with a drill, ensuring that the diameter of the hole coincided with the diameter of the SH-1 Sensor, avoiding the access of air that could alter the result of the measurement; Subsequently, the test was carried out on the materials that make up the wall of the house: bamboo, cedar wood and a mixture of clay - sand, materials that are part of both its structure and its finishes. Figure 2 shows the sequence of the test to obtain the Heat Transfer Coefficients.

Figure 2 OBTAINING THE HEAT TRANSFER COEFFICIENTS. SOURCE: (CONACYTPROYECTPN-2017-5975).

With the records obtained, the following were obtained: The Thermal Diffusivity α, the Thermal conductivity λ, the Thermal Resistance ρ, and the Specific Heat C, in addition to the margin of error in the measurement and the initial temperature of the sample. Additionally, the results were contrasted with the Thermal Diffusivity Coefficient of a cement-sand mortar. This coefficient was obtained from the literature.

ii. Analysis of the fractal dimension

To determine the fractal dimension, the methodology used by [18]was considered, with the pertinent modifications due to the diversity of the material, since samples of bamboo, cedar wood, and cedar wood were considered separately. And the extraction of small volumetric pieces of the clay-sand material; to be observed on one of its faces.

First, the porosity was determined, and later the characterization of the surface of the materials was carried out by the fractal dimension method.

The surfaces were visualized with a Konus College #5302 microscope, WF 15x eyepiece, with 10X magnification. The models were photographed with a Canon EOS Rebel T6 18 Megapixel camera 3" LCD screen 18-55mm/EF 75-300mm lens. The fractal dimension was determined for the patterns formed by counting the box using the J Image v1.40g program. The original images were converted into 8-bit binary to perform the analysis. From there, it was possible to obtain the maximum and minimum size of the nuclei through the position of the cells, thus determining the vertical and horizontal fractal dimensions.

iii. Heat transfer model

The heat transfer process in a wall made of bamboo, cedar wood, and a clay-sand mixture was theoretically evaluated, considering the time it would take to have an internal temperature equal to the external one; and the heat transfer behavior curve through the elapsed time. This through the model of Suárez-Domínguez, E. J., et al. (2015), through the equation:

$$T_{x.t} = T_A + \left[\frac{Aw\beta}{(w^2+\beta^2)}\left(\exp(-t\beta) - (\cos tw) + \frac{\beta}{w}(\sin tw)\right)\left(1 - \frac{x}{x_1} exp\left(-\frac{(x^2 - x_1^2)}{4t\alpha}\right)\right)\right] + A(\sin tw)\frac{x}{x_1} exp\left(-\frac{(x^2 - x_1^2)}{4t\alpha}\right)$$

Where $T_{x.t}$represents the temperature at a distance (x_1) in a certain time (t); T_A represents the outside temperature of the wall, $A$is the constant of adjustment, $w$the hourly part of the day $(w: 1/24)$; β is the heat transfer coefficient, t time,x represents the initial distance of the study, x_1 the final distance of the study andα is the Coefficient of Thermal Diffusivity.

Results And Discussion

From the measurements made to the house with the KD2 Pro Thermal Conductivity Meter and the SH-1 Sensor, it was found that bamboo has a Thermal Diffusivity α of 0.106 mm²/s, cedar wood 0.195 mm²/s, the clay-sand mixture 0.225 mm²/s. **Table 1** shows: Thermal diffusivityα, Thermal conductivity λ, thermal resistance ρ, the specific heat C, the margin of error of the test, and the initial temperature of the sample of the materials analyzed.

TABLE 1
HEAT TRANSFER COEFFICIENTS.

Material	α mm²/s	λ W/mk	ρ °C·c m/W	C MJ/m³k	Err	Temp °C
Bamboo	0.106	0.113	885.6	1.069	0.0006	29.97
Cedar wood	0.195	0.227	441.0	1.165	0.0031	29.20
Mix clay – sand	0.225	0.283	353.2	1.260	0.0400	25.75
Cement-sand mortar	0.530	-	-	-	-	-

From the coefficients shown in the previous table, it is observed that the material with the lowest Thermal diffusivity α is bamboo, concerning it, cedar wood and the clay-sand mixture have higher coefficients of 184% and 212%, respectively. Contrasting with the Thermal diffusivity α of the cement-sand mortar, which in the literature is 0.530 mm²/s [19], this is 500% higher than that of bamboo.The fractal dimension analysis showed the roughness changes of each of the analyzed materials. Figure 3 shows the image captured with the presence of two materials: a mixture of clay-sand and bamboo (left) and a wooden element (right).

Figure 3 Photographs Of The Analyzed Surfaces. Source: (Conacytproyectpn-2017-5975).

The value of the fractal dimension is one of the aspects that allows for measuring the complexity of the elements. This can correlate with other formal properties related to the surface description. In this case, a more excellent uniformity is found concerning the surface, increasing the dimension value for the mixtures but presenting greater uniformity for the clay-based material, probably due to the composition.

In the case of cement-sand mortar, there are two types of grain size of 0.7 micrometers for cement and 0.1 mm on average, respectively, while in the material with clay, there is a range of grain sizes between the two mentioned values. In this case, the materials present a greater uniformity that can be quantified using the values shown in Table 2. Table 2 shows the results of the analysis of the fractaldimension.

TABLE 2
Fractal dimension of cross sections.

Material	Fd	Mistake
Bamboo	1.6698	0.0011
Cedar wood	1.6856	0.0009
Mix clay – sand	1.8339	0.0017
Cement-sand mortar	1.8724	0.0042

The dimension, as can be seen, is between 1 and 2, the first for the smooth ones and the second for others of greater roughness [20], where it is distinguished that the bamboo presents a lower value than that of the bamboo mortar case. These extremes show a different arrangement of the surface components, which explains the heat transfer values obtained: in the bamboo case, there was also the lowest diffusivity value and the highest in the case of mortar. In this way, we find a directly proportional property. The complexity, then, in this case, can work to recognize another property.

It is also notorious that elements such as bamboo have a certain porosity, unlike the mixtures with cement with those of clay. These variations have been observed before in [18]; in this case, they are transferred to other possible values. Subsequently, on the heat transfer model, as described in the methodology of this work, two considerations were taken:

First: Through solving the described equation, a wall of wood and bamboo covered with a clay-sand mixture was analyzed; it was found that the time it would take for the inner face of the wall to reach the same temperature as the outer face is 45 hours.

It is essential to mention that this condition can't be met because the sun exposure cycles are not continuous, and in the worst case, the longest exposure time where a wall is oriented to the west is 4 hours. This represents that the time of exposure to the sun of said wall is less than 10% of that required for the total time in which the interior temperature equals the exterior. Figure 4 shows the thermal lag curve for said bamboo-based wall covered by a clay-sand mixture.

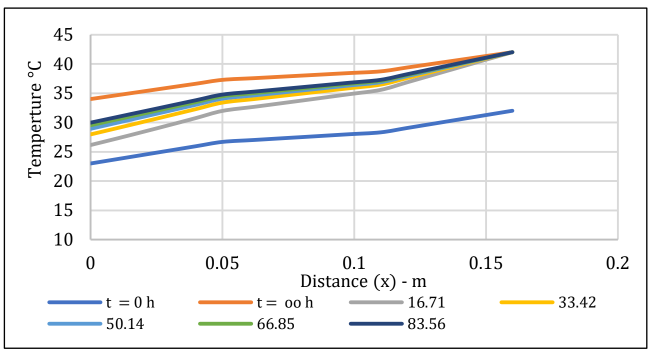

Figure 4 Thermal Lag Curve For The Vertical Element. Own Elaboration.

Second: The equation was used directly to determine the internal and external heat curves, where a thermal delay was observed and, therefore, an internal sinusoidal behavior with a longer wavelength. At the same time, the amplitude of the curve decreases due to the material's low thermal conductivity. Figure 5 shows the thermal behavior of the analyzed materials.

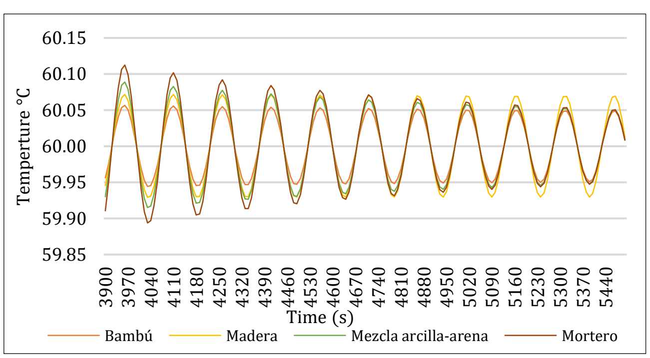

Figure 5 Behavior Of The Interior Temperature. Own Elaboration.

Determining that bamboo is the material that has the most significant thermal retardation; therefore, it offers more habitable and comfortable homes to users. In contrast, the cement-sand mortar and the coatings and construction systems derived from cement present greater thermal conductivity and diffusivity, generating uncomfortable homes, resulting in higher economic expenses for the user to air-condition his home and also negatively impacting sustainability

Conclusions

The substitution of materials in vernacular housing has generated various problems for the inhabitants of the Huasteca, mainly related to comfort inside the buildings; this situation is within the national housing problem, which is sought to be addressed through the development of this investigation. As a novelty, in this article, by means of tests carried out directly in a real case study, the heat transmission coefficients of the original materials constituting the vernacular dwelling of this area of the Mexican Huasteca were obtained for later using a theoretical model to get its thermal profile; and through photographs, the analysis of the fractal dimension was carried out.

From obtaining the temperature transmission coefficients, it is concluded that the material with the highest thermal diffusivity, 0.530 mm²/s, is the cement-sand mortar, an industrialized material. Regarding him, the thermal diffusivity of bamboo is barely 20%, the diffusivity of cedar wood represents 37%, and the clay-sand mixture is 42%.

From the fractal dimension analysis, greater uniformity was found in the clay-sand mixture, while the cement presented greater roughness. The results are consistent with those obtained from applying the theoretical model since the differences in roughness and porosity also contribute to decreased transferred heat.

From the application of the theoretical model, it was concluded that, due to the bamboo, the analyzed wall has favorable thermal behavior since around 45 hours would be required for the interior temperature to equal the exterior and due to the short exposure time of the element to the sun, the inside temperature would never reach the outside temperature. The results are consistent with those obtained in the fractal dimension analysis.

In this way, it is possible to affirm that, through the promotion of vernacular materials, coatings, and construction systems, it is possible to create comfortable spaces that adapt to the style of rural areas and generate lower air conditioning costs, seeking better quality of life and, in this way, resume the cultural identity of the rural areas of Mexico.

Recommendations

To close this article, it is recommended that the research be replicated to the different plant species in Huasteca to determine the material that offers the most excellent thermal retardation.

It is also suggested to carry out hygrothermal monitoring of the materials to compare the results obtained in this article through the theoretical model with the temperature obtained in the physical monitoring. This will increase research and literature on vernacular architecture and alternative sustainable materials.

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