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Tesis

Use of biopanels in bagasse-derived ceilings for thermal comfortin homesin the Sierra-Altoandina, Aramachay, Jauja

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Vladimir Simon Montoya Torres

Para optar el Título Profesional de
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Use of Biopanels in Bagasse-derived Ceilings for Thermal Comfort in Homes in the Sierra - Altoandina, Aramachay, Jauja

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Abstract The research evaluates the effectiveness of bagasse as a residual organic material and its implementation as a roofing solution for housing in high Andean areas, knowing and interpreting the circumstances of the Aramachay - Jauja annex, from the climatological issue to the economic status of the local population. The methodology was experimental; quantitative and qualitative data were collected, to address figures such as thermal levels, in addition to the results of the instruments (anemometer and thermo hygrometer) to measure the temperature and humidity throughout the experimental part; on the other hand, qualitative information was handled based on surveys and interviews with the residents of the annex to better interpret their feelings and context, in addition to obtaining relevant data such as their economy. A diagnosis of the environment and analysis of materials are contemplated; from these, we will know the different problems, effects and thermal needs inside the houses that the settlers are facing, in addition to the properties of the materials that will serve as conglomerating elements with the bagasse, cement, gypsum, paste and sugarcane slime were considered. Afterwards, the results of the feasibility of the resulting mixtures are evaluated, in addition to their implementation in a modular space and finally, the temperature and humidity figures are taken every three hours in the span of a whole day (24 hours). It was determined that the biopanels used as covers provide a slight thermal degree to the interior of the module and the mixture with the best favorable effect was bagasse, stalk slime and paste; in spite of highlighting more, the desired thermal comfort index was not reached. We can affirm that the use of heat regulating systems such as the trombe wall or the covering proposed in this article does not cover the thermal comfort degrees due to its isolated and individual use, but if a housing design that considers all these unified elements is taken into account, it would clearly have a better response; besides, it would remain as a tentative precedent in social housing in high Andean zones.

Keywords Thermal Comfort, Ceiling, Bagasse, Paste, Thermal Cover, Biopanels, Trombe Wall, Cold Climates

1. Introduction

The Peruvian high Andean zone [1] is characterized by its cold and harsh climate; its inclement environment in the winter season causes severe damage to the health of the inhabitants [2], especially those living in the communities located at higher altitudes, as these are the most vulnerable sectors with the lowest economic resources in general. The community of the Aramachay annex [3] corresponds to the district of Sincos [4], province of Jauja [5], in the Mantaro Valley and is located at an altitude of 3750 meters above sea level. When evaluating the characteristics of the area, we can affirm that the inhabitants of Aramachay are in constant proximity to meteorological hostility (table 1) [6],

with the months of May, June, July, August and September having the lowest temperatures, reaching temperatures below 0°C. This panorama causes serious respiratory illnesses in the inhabitants, in addition to economic damages with losses in agriculture and livestock; it is worth mentioning the issue of housing, since their rest and shelter spaces must have an optimal degree of thermal comfort [7] to protect them from the cold. The roofs of the area's houses play an important role in providing protection from atmospheric phenomena such as rain, hail and freezing wind, especially at night; in view of this problem, it can be seen that the inhabitants continue to use "simple" materials such as roof tiles or *calaminas*. However, these materials are not the most optimal when it comes to the thermal issue. A detail that determines the acquisition of these ineffective materials is the low economy of the people of Aramachay; this deficit is serious in the country [8] since the Peruvian government programs to cover the conditioning of homes to withstand the cold in high Andean areas [1], such as the National Rural Housing Program (PNVR) only covered 32.47% of vulnerable populations in 2019.

Table 1. Relative temperature table by month – Aramachay, Jauja.

	Minimum temperature	Mean temperature	Maximum temperature	Mean wind (km/h)
January	0°C	5°C	10°C	6 km/h
February	1°C	5°C	10°C	5 km/h
March	0°C	4°C	10°C	5 km/h
April	0°C	4°C	11°C	5 km/h
May	-2°C	3°C	12°C	6 km/h
June	-3°C	2°C	10°C	6 km/h
July	-3°C	1°C	10°C	7 km/h
August	-2°C	2°C	10°C	7 km/h
September	-1°C	4°C	11°C	7 km/h
October	0°C	5°C	12°C	6 km/h
November	0°C	5°C	12°C	6 km/h
December	0°C	5°C	11°C	6 km/h

For this reason, it is considered that this research has a social purpose since it contributes to thermal regulation in vulnerable housing [9] and provides a viable economic option for the inhabitants of Aramachay.

Due to the lack of action and advice from governmental entities in the development of optimized housing in the area hit by the freezing waves, the issue of informal self-construction [10], a problem that affects the quality of life of the user, threatening the safety and health factor, especially in the construction of a house with impractical materials to withstand the prevailing climatic factors, has arisen. Thermal comfort in a house [11] is variable due to multiple factors, whether external to the space, such as wind speed, humidity or precipitation; or internal, such as activities, metabolic rate or the clothing of the individuals inside the enclosure. According to Poma [12], the comfort range can be evaluated by implementing the psychrometric abacus of Givoni [13], a tool for estimating the thermal comfort to which a given environment should aim, and recommendations are made to reach this range if the conditions are not the most favorable. In addition, a previous analysis was developed with this tool to have a diagnosis of thermal comfort [9] in the months with the highest index of cold in Aramachay (**Figure 1**); with the application of the data, we can visualize that the main recommendations are the incorporation of conventional heating [14] and the use of solar passive [15] in the houses. Emphasizing the economic situation of the population [16], some are shepherds and farmers with activities that barely help them to subsist [1]; few have the ability to implement heating equipment in their homes, but it is possible to mitigate and reduce a percentage of the impassive temperature with the use in coverings made of biothermal materials that have some degree of thermal regulation [17].

Bagasse or *maloja* [18] is the residual material that is generated after squeezing sugar cane and turns out to be a good option due to its characteristics, such as its low density and high hardness; regarding its acquisition, it is an element that does not require industrial processes; therefore, this material is proposed for its reuse value, and its value as raw material contributes to several sustainable development goals [19], applying a contribution to the following goals: health and well-being - SDG 3, by minimizing negative climate factors that impact on housing and population; sustainable communities SDG - 11, by providing a research precedent on the use of easily accessible materials in roofs of homes in vulnerable areas and of limited socio-economic status; sustainable production and consumption SDG - 12, by using bagasse as a residual element in coverings.

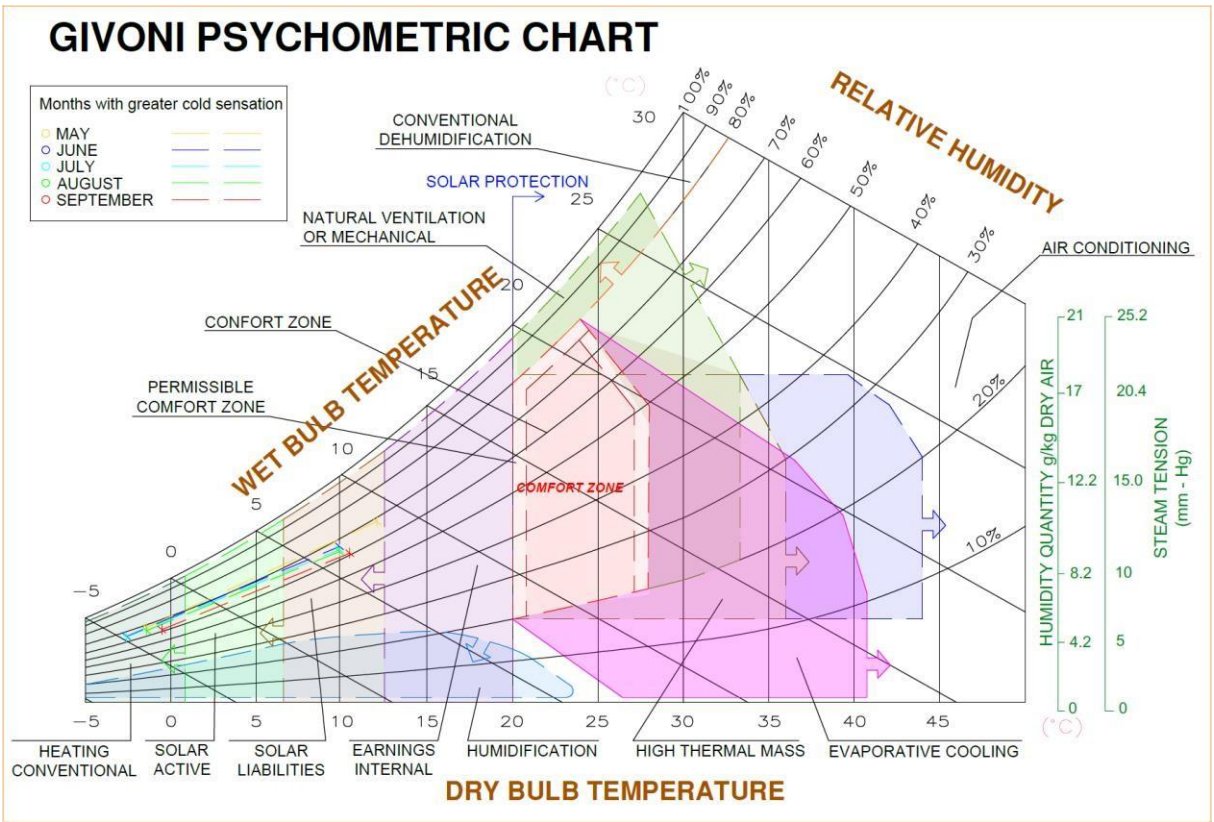

Figure 1. Givoni Psychometric chart, Aramachay - Intense cold months. - realized in Autocad.

Bagasse, due to its fibrous components, is optimal for the construction of enclosure structures; however, in order to achieve greater consistency, cohesion and percentage of thermal insulation [17], an additional material is required. For this purpose, the following malleable and conglomerating substances are proposed [20]: cement, gypsum, paste and bagasse slime with paste coating, since they facilitate the possibility of adherence when drying, in addition to the fact that they are more affordable to obtain.

2. Materials and Methods

2.1. Study Design

This research has an experimental nature [21]. Hernandez et al. mention that this type of study is used when the researcher intends to establish the possible effect of a manipulable cause, to establish influences; the tests will determine the performance of thermal regulation [9] of the materiality combined with bagasse. Subsequently, thermal prototypes [7] will be developed and installed in the housing modules to perform the measurement tests in order to verify their temperature behavior inside and outside the modular space.

2.2. Authorship

The research of Ceballos [22] at the National University of Loja Ecuador presented the thesis to demonstrate that by using mixtures of Portland cement and sugar cane bagasse fibers, implementing an alternative production technology is considerably durable and competitive with adequate physical and mechanical properties for the construction of lightweight panels used in the elaboration of walls in residential buildings; in the methodological part, an analysis of the design of the mixture is carried out, in which the variable water-cement (A/C) and fiber cement (F/C) ratios and their influence on the physical and mechanical characteristics of the manufactured elements are considered.

Peña and Roman [23] emphasize the problem of cold at the national level, for this reason, they dedicated their efforts to develop a model of natural insulation to mitigate the cold and frost. Through surveys applied to 240 people in the town of Cupisa, it was possible to better understand the impact of cold weather on the population, and a model was created using natural fibers, synthetic glue, sawdust and geogrids. After the final evaluation of the prototypes, it was concluded that the freezing temperature decreased by 26% inside the houses, a striking aspect due to the low cost of creation and the reuse of residual material [24].

Castro [25] explains that her research efforts were to improve the circumstances of vulnerable populations in the face of the harsh climate [6], especially to give quality of life to children and the elderly. The author ventures into the development of a prototype of a bioclimatic rustic home with sustainable and thermal characteristics; through her

scientific effort, it was concluded that the physical and thermal properties of the materials have an important role in comfort; but it is necessary to continue innovating in terms of its components and its implementation "in situ" to consolidate a better combination that can provide thermal comfort to its users.

2.3. Method

The research has an experimental and exploratory connotation [30], where qualitative and quantitative data will be obtained, therefore, the mixed approach is considered; this was done because there is descriptive information such as the perception of the inhabitants of Aramachay [3] and their relationship with their living space, on the other hand, measurable data such as the physical properties of the proposed materials and the temperature level resulting from the panels installed in the module are handled. The sugar cane residue [18] is the base product for the elaboration of the panel models which, together with the other selected components, will be evaluated for their subsequent physical quality and thermal response. The use of bagasse is proposed because of its fibrous qualities and because it is biodegradable and with a correct treatment, it can be an optimal sustainable and economical construction element.

As a complement to bagasse, components that have been part of scientific and academic proposals of the same nature are proposed to regulate temperature in an inexorable climatic environment. The design and manufacture of biopanels are the result of the experimental aspect. Low-cost and easy-to-obtain binder materials (**Figure 2**) were chosen because this proposal aims to reduce the gap between the quality of housing and the economic capacity of a vulnerable demographic group in the Jauja annex; among these materials are: cement [26], gypsum [27], flour paste [28] and cactus slime [29].

Universidad Continental	MATERIALS AND TEST INSTRUMENTS CHART				
01. MATERIALS					
01.01. Components to analyze					
Characteristics of the materials	***1- A. Bagasse (Base Material)Saccharum officinarum***	***1-B. Cement***	***1-C. Gypsum***	***1-D. Flour paste***	***1-E. Penca slime***
01. 01.01 FORMAT	-	0.60 x 0.30 mtrs.	0.60 x 0.30 mtrs.	0.60 x 0.30 mtrs.	0.60 x 0.30 mtrs.
01. 01.02 DENSITY	0.65 kg	1.44 kg	2.32 kg	0.45 kg	0.21 kg
01.01.03 THICKNESS	-	0.50			
01. 01.04 HUMIDITY PERCENTAGE	30%	0%	0%	90%	95%
01. 01.06 PRICE	1.32 USD - (5.00 PER)	1.06 USD - (4.00 PER)	3.31 USD - (12.50 PER)	1.32 USD - (5.00 PER)	1.32 USD - (5.00 PER)
01. 01.07 TEST PHOTOS					
02. INSTRUMENTS					
	Brand:	UNI-T		Brand:	BENETECH
	Model:	UT363		Model:	UT363
2-A. Anemometer	Measuring capacity:	0 a 30 m/s	2-B. Digital Thermohygrometer	Measuring capacity:	Ambient temperature: -10 to 50 °C | Ambient humidity: 0 to 99.9% RH

Figure 2. List of materials and test instruments chart. - Excel

Based on previous research [30] such as that conducted by Castillo, Borja and Sotomayor, the proposal to create thermal panels based on recycled or biodegradable materials for implementation in low-income housing is a viable option to expand the use of recycled products for sustainable construction purposes; as well as this exploratory background, cardboard and cork stoppers were used due to their easy acquisition, low cost and being a material considered "waste".

Bagasse is the waste of sugar cane, which is consumed for its sweet extract and is sold in a considerable amount in the commercial urban area of Huancayo and Jauja (markets), the latter being the area closest to the Aramachay annex, districts that generate large flows of movement at the regional level, so this biodegradable material exists in abundance that can be given a second use from the constructive vision and serving as an element connected to others. Therefore, as a basic part of the experiment, it was taken into account that since it is an element that will be installed on the roof, it must have a greater length of an edge, since the upper area of the infrastructure has a predominant span of 3 meters in some of its faces; therefore, a mold was created to put the amalgam of elements and materials already mentioned. Some of them have an industrial origin and others are organic elements, but based on this difference we will have comparative results to see the efficiency and thermal behavior of each one.

Constructive aspects were taken into account for the pre-dimensioning of the panel, such as the type of housing for which this prototype is designed; the dimensions of the module at the perimeter level should not exceed 1 meter in length; the thickness should not exceed 20 cm; the weight of the module should not exceed 3 kg, and it should be easy to implement with its proper fixing accessories. [31]

The resulting multiple mixtures were placed in molds constructed from the wood of the following dimensions: 0.6 mtrs. long. x 0.3 mtrs. wide x 0.05 thick, having a total volume of 0.009 m^3. Once the drying process of the samples was concluded, we proceeded to evaluate their physical properties and subsequently their thermal behavior in the module (Figure 3). Through the use of two measuring instruments, an anemometer to calculate wind forces and a thermohygrometer to evaluate the climatic conditions of the environment, data were obtained from the calorific panorama implementing the resulting prototypes; it should be noted that the temperature measurement was taken in a period of 3 hours during one day (24 hours) based on the recommendation given by Espinoza [9].

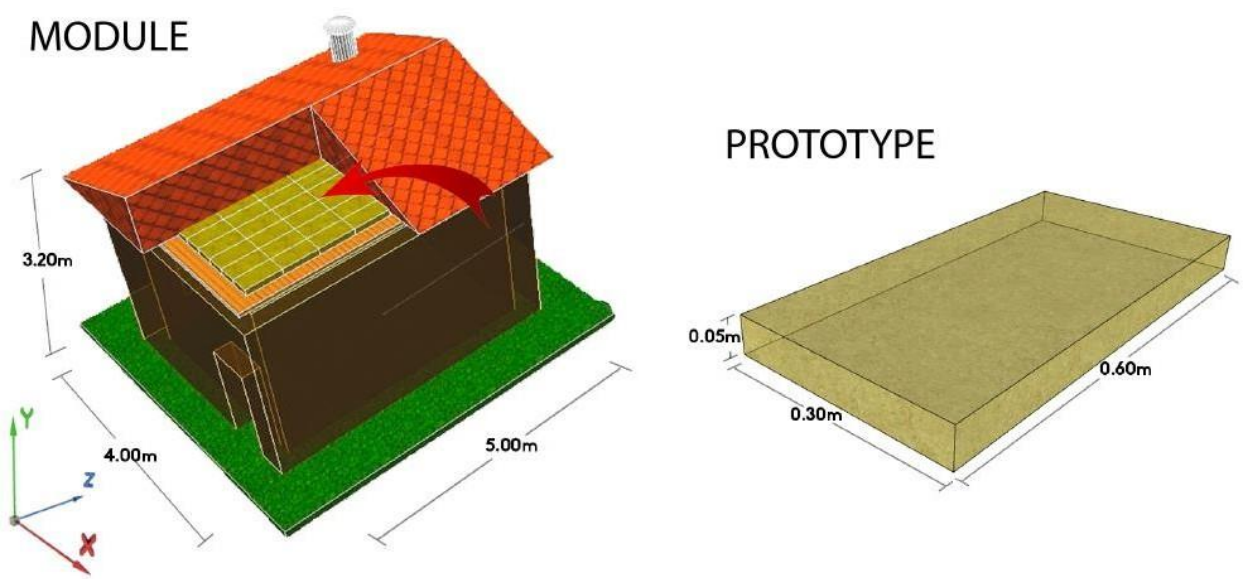

Figure 3. Module and prototype dimensions analyzed. - SketchUp

3. Results

Knowing the context of an area [32] is the first step to consider hypotheses according to the situation, it facilitates understanding the feelings of the inhabitants; therefore, surveys were conducted with 60 inhabitants. The qualitative information gathered validates the months in which the greatest misfortune is suffered under the climatic conditions (May to September) [6], in addition to reaffirming that the use of low-quality roofs (*calaminas*) [9] is due to the low economic possibilities of the average inhabitant (less than 200 $ - 750.00 PER) [1], in addition to affirming that the predominant material is adobe in walls.

The pieces from the tests were integrated into a housing module and data was taken with the instruments, obtaining information on the temperature outside and inside the module, thus verifying the margin of thermal difference and effectiveness of the pieces.

The cement and bagasse (**Figure 4**) showed not so favorable results as a thermal barrier; the average calorific value inside the module in the established hourly range gives us a total of 94.6 °C while outside the module we have 91.6 °C. The difference is notoriously minimal of 3 °C, validating that this model does not have the necessary properties to protect the house from the cold climate. The relative humidity [33] - average inside the module is 68.1%, during the data collection process, and the final weight of the panel is 3.50 kg.

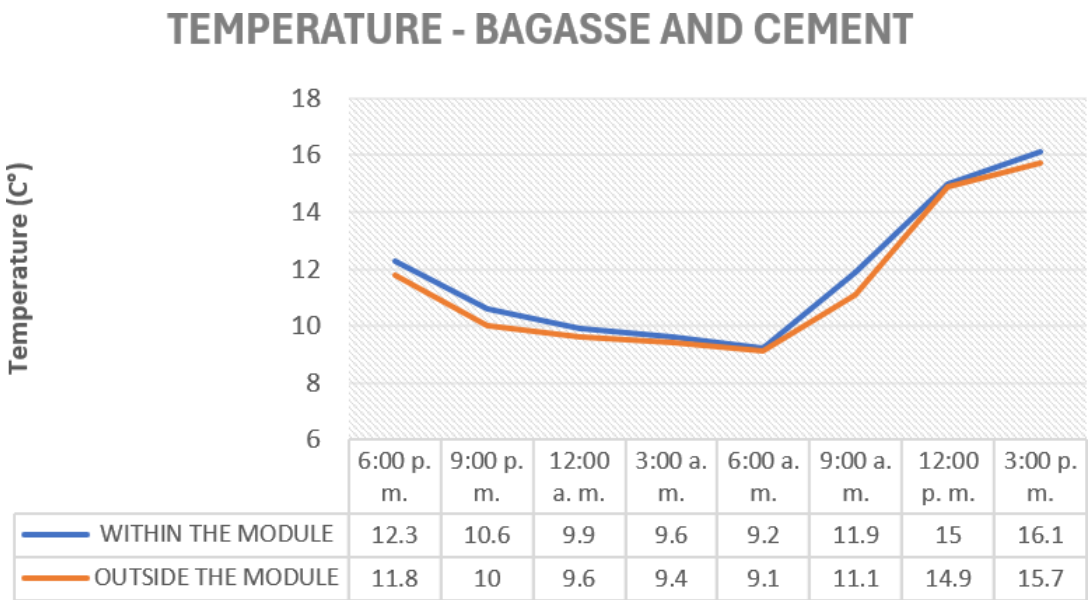

Figure 4. Test 01 – Temperature (Bagasse and cement). – Excel.

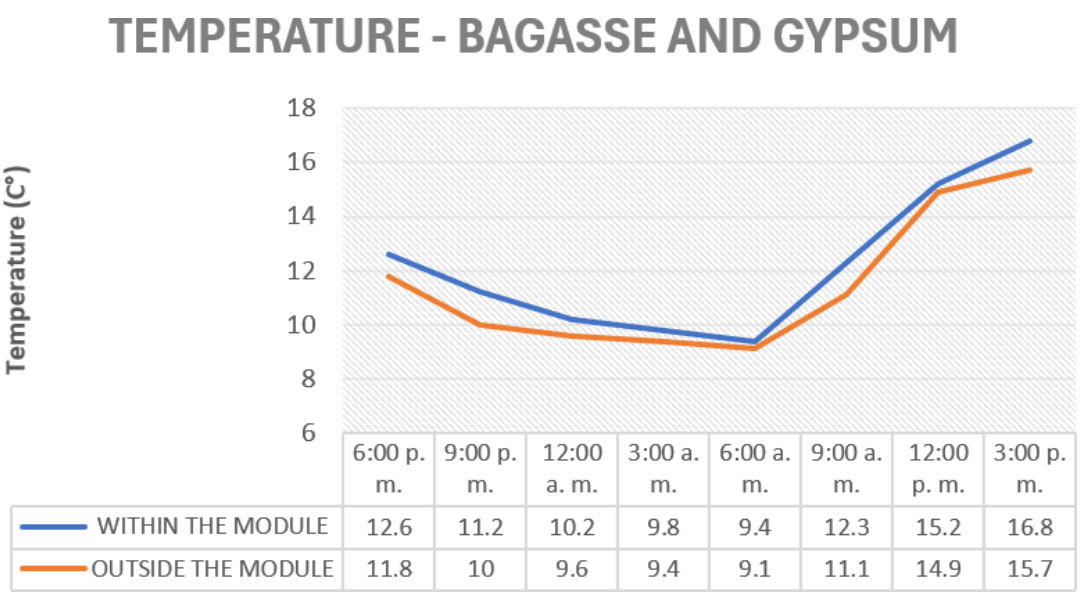

Figure 5. Test 02 – Temperature (Bagasse and gypsum). – Excel.

The melting of gypsum and bagasse (**Figure 5**) showed unfavorable results; the average calorific value inside the module gives us a value of 97.5 °C; on the other hand, outside the module we have 91.6 °C, and the minimum difference is 5.9 °C. This mixture does not meet the necessary heating properties to safeguard the housing. The relative humidity - average inside the module is 67.2%, and the final weight of the individual panel is 3.40 kg.

The combination of the paste and bagasse (**Figure 6**) presents an improvement in the thermal reception; inside the module gives us an average value of 100.8 °C; on the other hand, outside the module we have 91.6 °C and the difference is 9.2 °C, improving the response of the thermal aspect. The relative humidity - average inside the module is 66.2%, and the final panel weight is 2.60 kg.

Lastly, three materials were used together: the slime of the stalk, the paste and the bagasse (**Figure 7**), the most remarkable of the prototypes. The average calorific value inside the module gives us a value of 103.9 °C; on the other hand, outside the module we have the value of 91.6 °C and the difference is 12.3 °C, having the best result of calorific reception. The relative humidity - average inside the module is 65.4%, and the final weight of the individual panel is 2.00 kg.

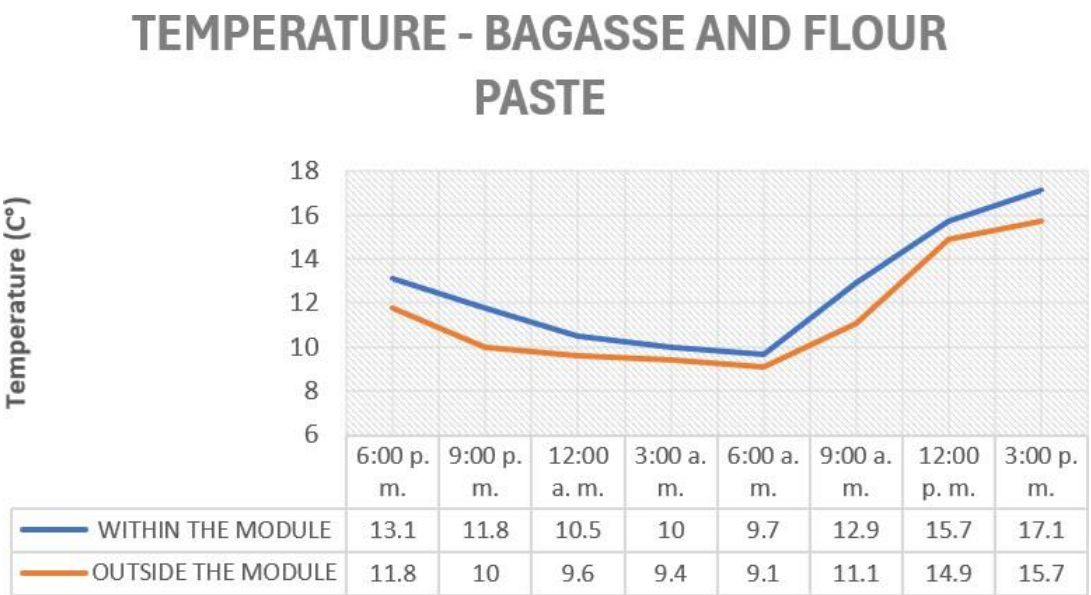

Figure 6. Test 03 – Temperature (Bagasse and flour paste). – Excel.

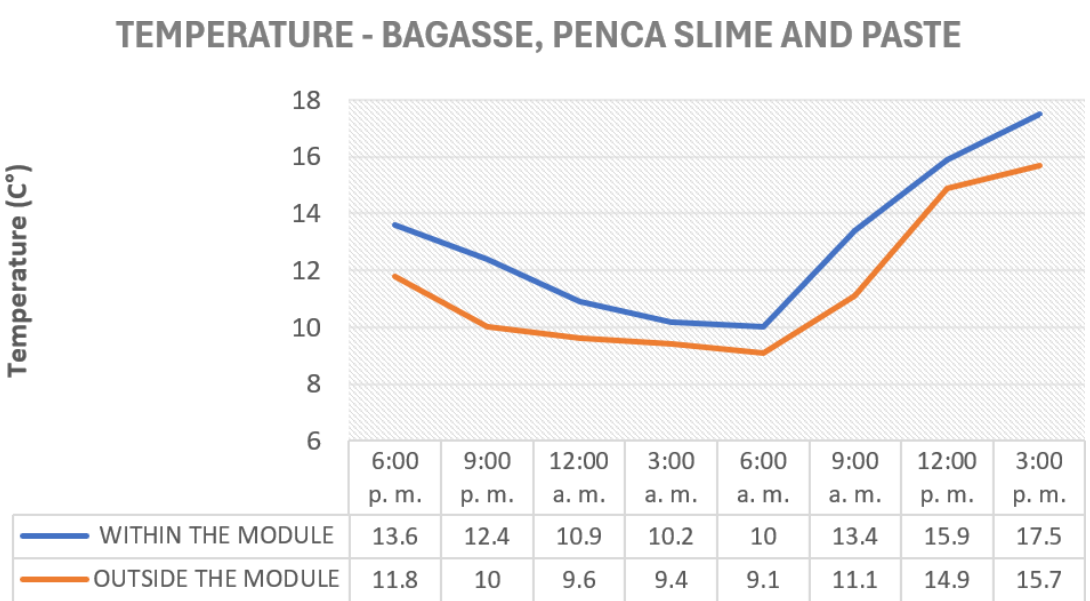

Figure 7. Test 04 – Temperature (Bagasse, penca slime and paste). - Excel

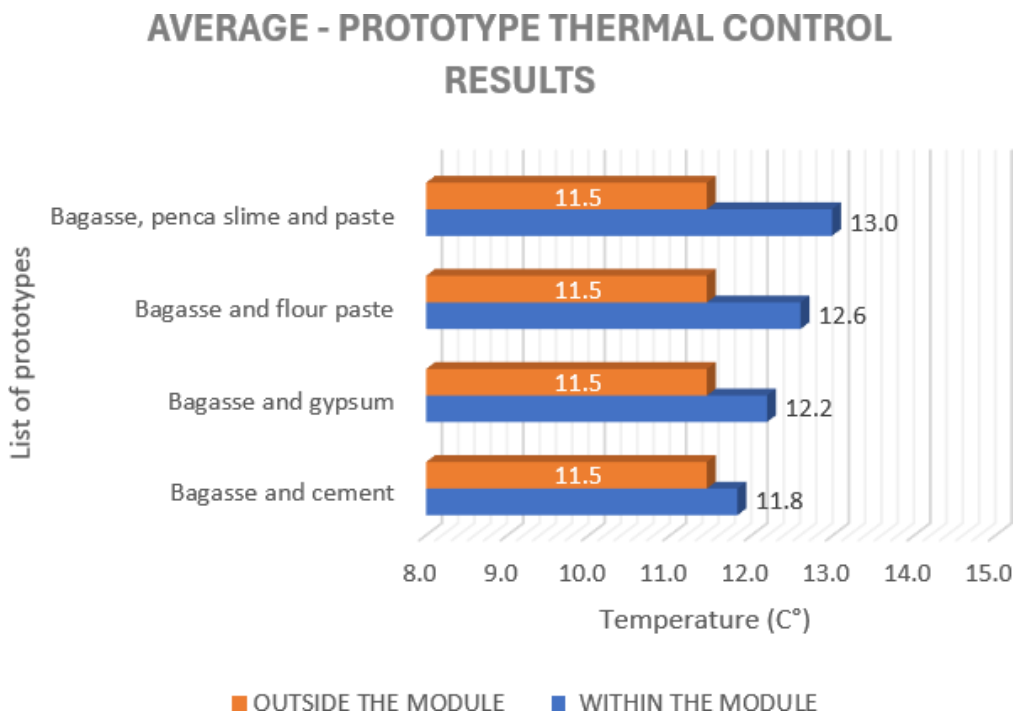

Figure 8. Thermal averaging – prototypes. – Excel

Based on the tests, **Figure 8** shows the effectiveness of each model measured in the module, and the measurement was carried out in Aramachay during a whole day with a three-hour interval. The average temperature outside was 11.45 °C while, in the measurement inside the module, the combination with the lowest effectiveness was bagasse with cement consolidating at 11.83 °C and the one that obtained the best result was the mixture of bagasse, sugarcane slime and paste with a value of 12.99 °C. Despite the results, the highest thermal value does not reach 16 °C [34], considered the recommended thermal comfort zone.

4. Discussion

Wuan & Duan [35], state that comfort is closely related to the thermal comfort index, where data such as temperature and humidity in a balanced state provide well-being to the space; in their research they focused their investigative vision on the thermal measurement of an office at the University of Cincinnati. They used the "Autodesk" CFD system to regulate ventilation to produce thermal comfort maps that encompass the data collected during their simulation. Unlike this research, the whole picture is far from the modern atmosphere that Wuan & Duan touched upon, yet the comparative nature of thermal comfort is what unites them; the analysis of the offices in two seasons resembles the data collection that was done, not by using a thermostat, but by evaluating the thermal effectiveness of the bio-panels. In the case of the offices during the summer, the relative percentage reached 16.8 °C and in winter 12.6 °C and compared to the case of the Andean housing module, the values reached 13 °C and 11.8 °C. Although the first pair of thermal data are higher, they have strong limitations with the thermostat system in terms of the permanent comfort system, likewise, the thermal system with the panels does not have such a significant impact on the heating comfort, but it does have a degree of reduction of the external cold to the interior habitat. One thing to note about the proposed experimental model is that it does not depend on energy to be functional; its properties are those that provide a certain margin of protection in the ceiling.

In a national perspective, Gonzalez [7] conducted his studies in an area of much greater cold than Aramachay; his proposals for constructive solutions were measured with statistical control charts indicating that the use of organic materials is a good opportunity to implement a sustainable theme in high Andean housing; using bamboo or worked earth would look for the best combination between external and structural materiality. Although the proposed mixtures and their results are part of the local pioneering experiments for the topic of thermal roofs of easy accessibility and implementation, they are an advance in focusing on the best fusion of materials for protection against cold in high Andean houses. On the other hand, Espinoza [9] contributes with his results to a list of constructive considerations for social housing in high freezing zones; at the ceiling level, it is worth considering not having much height from the base to the ceiling to prevent heat from accumulating in the upper part; in the experimental module that has a height of 3.20 meters, a reduction could be made to integrate this observation. The author proposes the use of solar heating, a system that would add the sustainable and thermal aspect, but the drawback for its integration in homes would be the

economic issue [36]; in a regional market, the value of solar heating is $ 413.45 - 1540.00 PER, remembering that the average value of the cost of living of the inhabitant of the annex is less than $ 200. The situation of the management of more complex technologies is a topic to be further deepened by the economic issue, a detail that can be of greater scope with programs of the Peruvian government.

5. Conclusions

In conclusion, it is worth mentioning that the results of the proposed combinations of materials do not reach the degree of relative thermal comfort, although it is noteworthy that they do help to slightly mitigate the cold (**Figure 9**).

Although the performance did not reach the expected degree of comfort, there are relevant aspects worth highlighting. The first is that the bagasse is a material of mooring and fusion with the sugar cane slime and the paste is interesting for its thermal properties. In addition, the individual weights of the bio panels do not exceed 4kg. So, we can conclude that they are light and their incorporation does not suppose an excess of load for the cover of the house and based on their economic study, they are the most accessible option for these alternative organic materials for the economically precarious social groups of the Peruvian highlands.

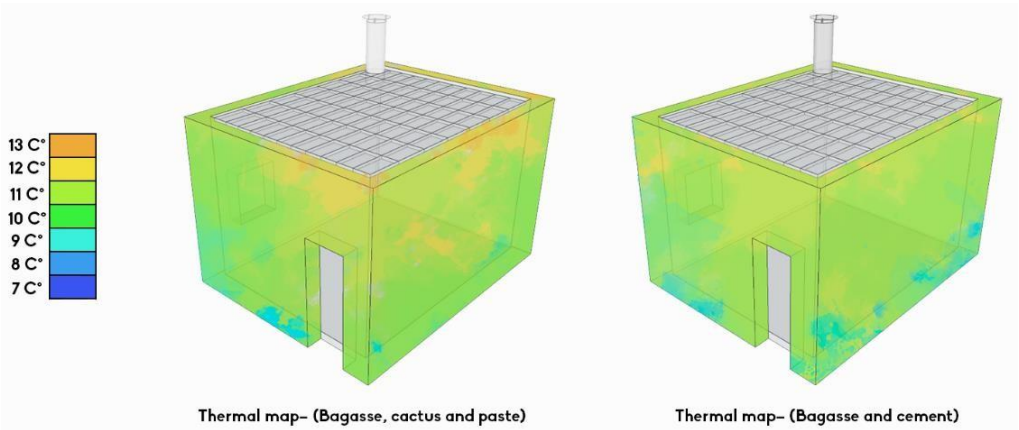

Figure 9. Thermal map - Major result (Test 04) and minor result (Test 01) - SketchUp

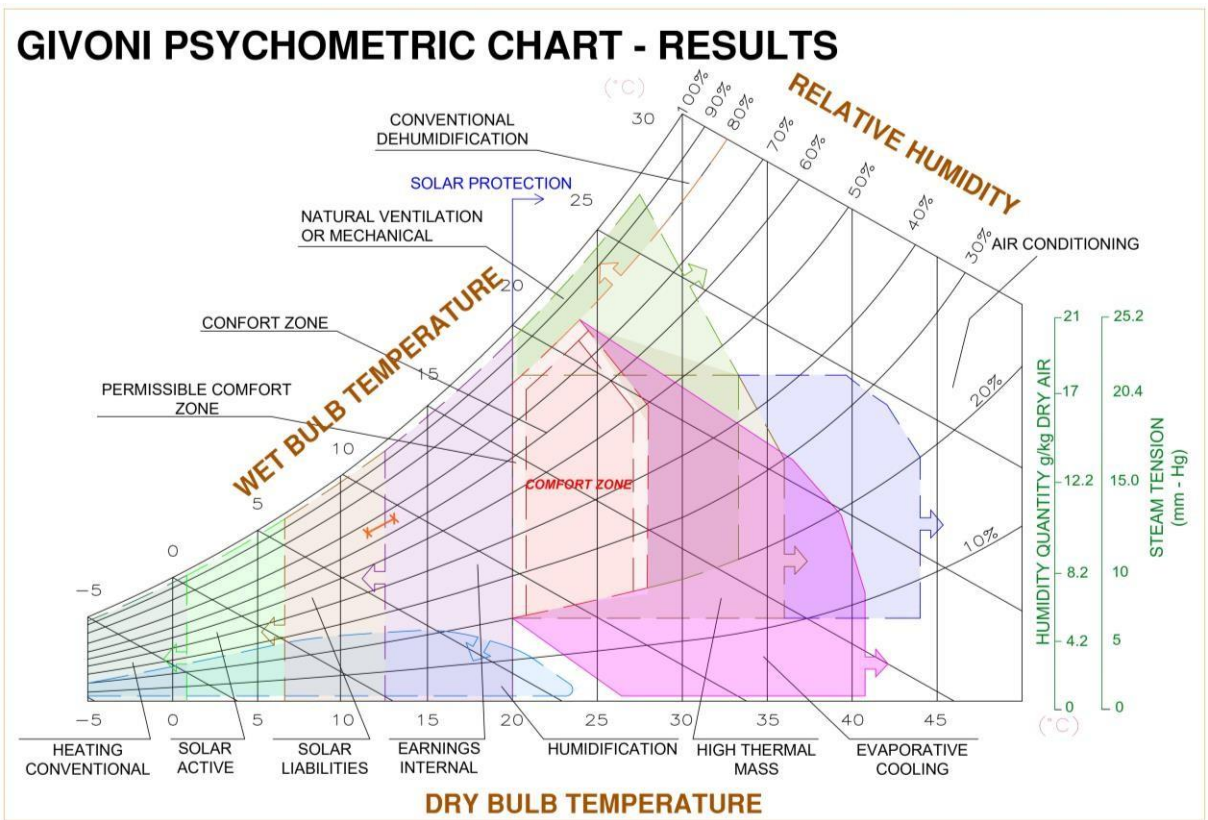

Figure 10. Givoni Psychometric Chart - Results, Aramachay - realized in Autocad.

It can also be asserted that thanks to the graph of Givoni [13] it can be seen that the levels of effectiveness of these experiments where temperatures were in a range of 11.8 °C to 13 °C and average humidity of 66.75 RH (**Figure 10**), which unlike the local primary meteorological data, are significantly lower.

This gives way to a broad reflection on the implementation of constructive elements in high Andean houses and this has been a constant experiment; as well as the trombe walls [37] which are protection for the cold in Peru are not the most successful solution in their entirety. In the course of the research, from the results and examining investigations of the same nature (materials and thermal systems for high Andean housing), it is evident that the individuality of each one of them is a perpetual obstacle, especially if there are proposals for a social housing model that has to meet the thermal comfort requirements for the users. As a recommendation, for future work with the same objective, multiple thermal insulation elements should be used and tested in the same simulation to determine with data how they affect the environment, consolidating the expected state of comfort. Likewise, governmental entities should join efforts and constant interest to strengthen support programs for vulnerable populations that continue to suffer from freezing waves in their homes.

The results suggest that the use of biopanels composed of bagasse, baba de penca and engrudo has the potential to improve thermal comfort in Andean dwellings. Although the panels did not reach the optimal level of comfort, they present an economical and sustainable option for vulnerable communities. Future studies could explore additional combinations and evaluate implementation in real conditions to validate their effectiveness.

Acknowledgements

We are grateful to the experts, authorities, researchers and colleagues for the availability of the data that have made this research possible.

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