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Thermal comfort and overcrowding in bamboo cane-enveloped housing in Portoviejo Confort térmico y hacinamiento en viviendas con envolventes de caña guadúa en Portoviejo

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ABSTRACT The objective was to analyze the relationship between thermal comfort and the occupancy rate of homes with bamboo envelopes in the city of Portoviejo, as well as to understand how these factors influence residents' thermal perception. The research was quantitative. The ASHRAE Thermal Sensation and Satisfaction Scale was applied, based on a sample of 161 urban homes. The results showed that envelope material affects thermal perception, with bamboo being one of the most thermally efficient solutions when compared to concrete. The occupancy rate had no significant statistical correlation with thermal comfort, but it may have an influence. Thus, it is concluded that a bioclimatic design and the use of materials with adequate insulating properties are key when it comes to optimizing the thermal comfort of sustainable homes.

RESUMEN El objetivo fue analizar la relación que hay entre el confort térmico y el índice de ocupación de las viviendas con envolventes de guadúa en la ciudad de Portoviejo, así como saber cómo estas influyen en la percepción térmica de sus habitantes. La investigación fue cuantitativa. Se aplicó la Escala de Sensación y Satisfacción Térmica ASHRAE tomando una muestra de la población incluyendo a las 161 viviendas urbanas seleccionadas. Encontrando que el material de la envolvente afecta la percepción térmica, siendo la guadúa una de las soluciones más eficientes térmicamente si se le compara con el hormigón. El índice de ocupación no tuvo correlación estadística significativa al confort térmico, pero puede influir. Con lo que se concluye que un diseño bioclimático y el uso de materiales con propiedades aislantes adecuadas son clave a la hora de optimizar el confort térmico de las viviendas sostenibles.

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KEYWORDS thermal comfort, overcrowding, *guadúa*, bioclimatic design, occupancy rate

PALABRAS CLAVE confort térmico, hacinamiento, guadúa, diseño bioclimático, índice de ocupación

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1. Introduction

Comfort in homes built with guadua in Portoviejo is a trending topic, alongside the overcrowding many are subjected to. Guadua, an ancient building material, has properties that allow it to regulate the indoor climate and create spaces of well-being for the people who live in them. Recent studies indicate that homes with bamboo exterior structures achieve excellent thermal balance, particularly important in hot, humid climates such as those of Portoviejo (Toala-Zambrano et al., 2021).

Comparative studies have been conducted in Portoviejo comparing guadua houses and traditionally built homes, highlighting their economic viability, sustainability, and thermal comfort. Thus, "The impact of the use of guadua cane in social housing construction" highlights its advantages over reinforced concrete, emphasizing its lower cost, earthquake resistance, and adaptability to local climate conditions (Casanova et al., 2023). Similarly, the study "Analysis of the vernacular guadua cane housing of Manabita, Ecuador" highlights its cultural and heritage significance, recognizing that, although it is not immune to durability issues, it provides suitable living environments (Muentes et al., 2021). Likewise, research on bioconstruction and the sustainable use of guadua cane highlights its relevance to Ecuador's identity and its contribution to improving the living conditions of those who lack terraces or patios in which to play (Vanga et al., 2021).

However, in densely populated urban areas, perceptions of thermal comfort can be influenced by factors such as high population density and housing quality. When buildings are constructed with inefficient materials and house a large number of people in a small space, poorly ventilated interiors, high heat concentration, and increased thermal discomfort due to heat stress can result (Godoy Muñoz, 2012). In response to this, the use of materials such as guadua cane has been proposed as a promising solution for improved thermal management in homes, thanks to its favorable hygrothermal properties and local availability (Largacha and Peñafiel, 2019).

According to ISO 7730 (2014), the key parameters for assessing thermal comfort in living spaces are temperature, humidity, and air circulation. These elements are often subject to significant problems in many overcrowded homes with inefficient structures, highlighting the importance of addressing housing density to improve thermal comfort.

Overcrowding is adding a new challenge to these already complex conditions (Alías and Jacob, 2011). Many families opt for guadua because of its low cost and ease of construction, which often results in small, poorly ventilated dwellings. This results in higher indoor temperatures, increased humidity, and mold problems, which, in turn, significantly affect the quality of life. Although guadua is sustainable, if it is not used with the right materials and techniques, it can compromise well-being, even though it offers earthquake-resistant advantages (Llumiquinga, 2023). In this sense, it is an issue that takes on additional conNotetions when applied to buildings with low thermal capacity materials and poor bioclimatic design, which often force residents to resort to artificial cooling systems, thereby increasing both energy consumption and costs (Castillo et al., 2019).

Given the population density, it is important to note that overcrowding is a condition in which the number of people in a dwelling exceeds its capacity. In other words, a dwelling is considered overcrowded when three or more people occupy the same room (ECLAC and UNDP, 1989). This definition has been widely adopted in the specialized literature (Añazco and Pérez, 2016). For example, the World Health Organization (WHO) establishes a similar threshold, as does the city of New York, which uses a criterion based on square meters: it considers overcrowding to exist when the density exceeds 1 person per 9 m^2 (ECLAC and UNDP, 1989; Añazco and Pérez, 2016). Measuring overcrowding involves not only counting people but also considering privacy and the availability of space. Internationally, there are different methods for assessing overcrowding. One example is the *Longitudinal Study of Households*, which analyzed indicators over time, such as occupancy density (people per room), the number of bedrooms available, and whether these are spacious, comfortable, and suitable for the type of occupant (Spicker et al., 2009).

The city of Portoviejo experiences temperature variations between 21°C and 29°C throughout the year. In Portoviejo, thermal comfort in densely populated urban areas has been steadily improved thanks to the development and integration of bioclimatic design technologies and sustainable materials, such as guadua bamboo (Toala-Zambrano et al., 2022). Although it is an ancestral material in vernacular architecture, it has not found widespread use in contemporary construction, both due to cultural prejudices and the absence of regulations that encourage its use. Therefore, recent studies that highlight its contribution to minimizing internal temperatures and, by extension, to air quality, which is of utmost importance in high-density areas with limited energy resources (Bonilla and Merino, 2017), are significant. It is therefore essential to prioritize the use of local materials with thermoregulatory capacity, as well as regulations aimed at health and sustainability.

Llumiquinga (2023) also highlights the importance of considering solar orientation, cross ventilation, and insulation when building sustainable guadua homes.

Given the above, the objective of this study is to analyze the relationship between thermal comfort and the overcrowding index in guadua-enclosed homes in the city of Portoviejo, and to evaluate its impact on occupants' thermal sensation.

2. Methodology

The Thermal Sensation and Satisfaction Scale, included in ASHRAE Standard 55 (2020) of the *American Society of Heating, Refrigerating and Air-Conditioning Engineers*, was the instrument used to evaluate comfort in urban homes with guadua envelopes. This method reliably captures the perceptions of the inhabitants, accounting for both environmental conditions and the building's thermal characteristics and energy performance.

The survey used in the study was adapted to the climatic conditions of Portoviejo, based on the ASHRAE (2020) methodology, and enabled analysis of residents' thermal perception at different times of day and across different living contexts. Using a quantitative approach, 161 urban residents were surveyed via non-probability sampling, in which participants were intentionally selected according to predefined criteria (Otzen and Manterola, 2017). The QuestionPro platform was used for this purpose, facilitating access to respondents and enabling responses through quality control conducted by 20 interviewers.

For this article, the instrument was structured into four main evaluation dimensions, each composed of specific items to examine different aspects of thermal comfort, the built environment, and overcrowding. The first dimension, "Sociodemographic and participant control data," included nine items on age, sex, weight, height, and thermal habits. The second dimension, "Housing characteristics," was divided into two components: structural characteristics (five items) and architectural and habitability characteristics (six items). The latter evaluated construction quality, structure, height, roof, floor, number of windows, paint, and the use and operating time of daylighting (ASHRAE, 2020).

The third dimension, the "Overcrowding Index," consisted of two items, the number of rooms and the number of inhabitants, according to the criteria of ECLAC and UNDP (1989). It is important to note that this indicator refers to the "condition in which the number of people living in a dwelling exceeds the available space in that dwelling"; that is, overcrowding is defined as an occupancy density equal to or greater than three people per room (ECLAC and UNDP, 1989; Añazco and Pérez, 2016).

Finally, the fourth dimension, "Perception of thermal sensation," included seven items on a thermal sensation scale ranging from "Very hot" to "Cold," allowing us to assess thermal sensation in households (Table 1) (ASHRAE, 2020).

Descriptive and inferential statistical methods were used to analyze the data, including absolute frequencies, percentages, and bivariate correlations using Pearson's test, with a statistical significance threshold of $p < 0.05$. The results were presented in tables.

Perception of thermal sensation	
PMV	**Thermal sensation**
+3	Very hot
+2	Hot
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

Table 1: Wind chill perception scale. ASHRAE (2020)
Note: PMV, "Predicted Mean Vote," used to predict how comfortable people are likely to feel at a given location based on the temperature.

3. Results

3.1. Sociodemographic data and thermal sensation

Table 2 shows the sociodemographic and control characteristics of the study participants. The most numerous age group is 35-44 years old, and participants are mainly men, with heights between 1,60 and 1,69 m and weights between 65 and 74 kg. In addition, they do not suffer from any chronic diseases. Most of the time, they perform activities of moderate intensity, such as their last activity before the interview. The activity lasted 16-30 minutes before the interview, which was conducted between 10:00 a.m. and 12:59 p.m.

The correlational analysis is performed using the p-value. The p-value is a measure that helps us determine whether the results we observe in a study are due to chance. If the p-value is very small (e.g., 0.000), it indicates that the probability of observing what we are not due to chance, but instead to a real relationship.

In this sense, the data obtained reveal that the p-value (0.000) is significantly lower than the threshold of 0,05, indicating that the relationship between wind chill and the time of day when the interview was conducted is not a mere random factor but a statistically significant one. In other words, it suggests that participants' perceptions varied by time of day, perhaps because ambient temperature varied or because people's temperature thresholds differ by time of day.

3.2. Housing conditions and thermal sensation

Table 3 provides a detailed analysis of the structural characteristics of dwellings according to the thermal sensation scale, including construction quality, structure, height, and roof type. The results of this analysis are shown below.

Most respondents consider the construction quality of their homes to be "neutral" (88 cases), although some rate it as "good" (46 cases). This suggests that perceptions of construction quality are balanced, with neither very good nor terrible opinions predominating. Statistical analysis of these data shows no significant differences in terms of thermal sensation (p = 0.850).

In most cases, concrete is the primary material used (70 cases), which was significantly correlated with thermal sensation (p = 0.000); therefore, concrete can significantly influence how occupants perceive temperature. In turn, guadua bamboo is one of the most prominent materials in 64 cases, emphasizing its importance in regional construction.

In 105 cases, most houses have heights ranging from 2.51 m to 2.80 m, followed by heights above 2.80 m in 36 cases, with a p-value of 0.582; thus, we can say that height is not a critical factor in thermal sensation within that range.

Among the roofing materials, concrete slabs are used in 43 cases and zinc with a metal structure in 44 cases, which are the most common. Concrete slabs in particular show a very strong association with thermal comfort (p = 0.000), which would indicate that they offer better insulation compared to other materials.

The results suggest that flooring type can influence occupant thermal comfort, but the relationship is not significant (p = 0.851). Exposed concrete with 38 responses and tile with 55 responses were the most common flooring types, and different patterns were observed on the thermal comfort scale. In particular, wood flooring, with 37 responses, showed a higher frequency of "neutral" and "slightly warm" responses, while marble, with only one response, showed no clear trend. Although the findings suggest that perception may vary depending on the flooring material, factors such as ventilation and the location of the house may play a more important role in occupants' experience of a comfortable thermal sensation.

Regarding the findings on architectural and habitability characteristics according to the thermal sensation scale, Table 4 shows that, to a large extent, the presence of windows influences residents' perception of temperature. In houses with natural ventilation (64 cases), residents reported feeling cooler, suggesting improved thermal regulation and perceived comfort (p = 0.016). In contrast, in 67 cases with limited ventilation and 30 cases with uncertain ventilation, residents reported a greater sensation of heat or thermal neutrality, suggesting that the absence of windows promotes heat retention and increases discomfort.

The findings suggest that wall color could influence how people perceive the temperature in their home. Among those with light-colored walls (76 cases), participants tended to feel warmer where they live. The most likely explanation is that light is reflected more, but the data do not support it (p = 0.071). In contrast, people living in homes with dark-colored walls (12 cases) or who did not know the color of their walls (72 cases) reported temperature sensations in their homes that cannot be explained in the same way and therefore require further study.

Using artificial lighting during the day may influence how temperature is perceived inside the home. Although participants reported their homes were slightly cooler (35 cases), this difference was not statistically significant (p = 0.094). However, in some cases, such as living rooms, artificial lighting led participants to perceive the temperature as warmer, and some even noticed that the temperature in their homes was generally changing. It was also

Sociodemographic data and participants' wind chill								
Variables	**Sample n=161**	**Wind chill scale**						**p-value**
		CA	**CÁ**	**LC**	**NE**	**LF**	**FR**	
Age								
18-24	9	1	4	3	1	0	0	0.156
25-34 years	30	6	14	4	5	1	1	
35-44 years	62	4	16	16	19	7	7	
45-54 years	39	6	8	9	15	0	0	
55 or older	21	4	4	7	5	1	1	
Gender								
Female	66	6	25	15	17	3	0	0.312
Male	95	15	21	24	28	6	1	
Height								
1.30-1.49 meters	3	1	1	0	1	0	0	0.422
1.50-1.59 meters	40	4	8	15	10	2	1	
1.60-1.69 meters	74	13	26	14	18	3	0	
1.70-1.79 meters	41	3	11	8	15	4	0	
1.80 meters or more	3	0	0	2	1	0	0	
Weight								
35-44 KgF	1	1	0	0	0	0	0	0.620
45-54 kgf	11	3	2	3	1	2	0	
55-64 kgf	43	6	12	12	11	2	0	
65-74 KgF	63	3	23	14	18	4	1	
75-84 kgf	33	6	8	8	10	1	0	
95-104 KgF	9	2	1	2	4	0	0	
104 or more KgF	1	0	0	0	1	0	0	
Presence of chronic disease								
Yes	46	4	12	11	16	3	0	0.505
No	86	14	27	21	21	2	1	
Don't know	29	3	7	7	8	4	0	
Intensity of daily activities								
Passive	44	6	16	11	8	3	0	0.769
Moderate	99	13	24	25	30	6	1	
Intense	18	2	6	3	7	0	0	
Intensity of activity prior to the interview								
Passive	49	5	18	11	11	3	1	0.643
Moderate	93	12	22	24	29	6	0	
Intense	19	4	6	4	5	0	0	
Duration of the activity performed prior to the interview								
00 min - 15 min	36	2	10	12	11	0	1	0.438
16 min - 30 min	64	9	21	16	14	4	0	
31 min - 45 min	48	8	12	8	15	5	0	
46 min - 60 min or more	13	2	3	3	5	0	0	
Interview time								
7:00 a.m. – 9:59 a.m.	8	5	1	2	0	0	0	0.000
10:00 a.m. – 12:59 a.m.	85	8	25	22	20	9	1	
1:00 p.m. – 3:59 p.m.	38	8	6	8	16	0	0	
4:00 p.m. – 7:00 p.m.	30	0	14	7	9	0	0	

Table 2: Sociodemographic and control data of participants according to the heat sensation scale. (2020)
Note: H: Hot; W: Warm; SLW: Slightly warm; N: Neutral; SLC: Slightly cool; C: Cool.

Structural characteristics according to thermal sensation scale								
Variables	**n= 161**	**Thermal sensation scale (n=161)**						**p-value**
		CA	**CÁ**	**LC**	**NE**	**LF**	**FR**	
Build quality								
Very good	3	0	2	1	0	0	0	0.850
Good	46	5	15	12	10	4	0	
Neutral	88	11	24	20	29	3	1	
Bad	24	5	5	6	6	2	0	
Structure								
Concrete	70	11	25	12	18	4	0	0.000
Mixed (concrete and wood)	5	0	4	0	1	0	0	
Mixed (concrete and metal structure)	16	3	1	8	4	0	0	
Wood	6	0	0	3	2	0	1	
Guadua cane	64	7	16	16	20	5	0	
Height								
Less than 2.50	19	2	4	9	4	1	0	0.582
2.51–2.80 meters	105	16	31	20	30	7	1	
Greater than 2.80 meters	36	3	11	10	11	1	0	
Roof								
Reinforced concrete slab	43	3	18	8	10	4	0	0.000
Zinc with metal structure	44	10	9	13	12	0	0	
Zinc with metal structure and ceiling or gypsum	11	1	2	3	5	0	0	
Zinc with wooden structure and ceiling or gypsum	5	1	0	2	1	0	1	
Zinc with wooden structure	58	6	17	13	17	5	0	
Floor								
Exposed concrete (troweled)	38	7	12	9	9	1	1	0.851
Tile	24	5	7	4	6	2	0	
Ceramics	55	7	16	17	12	3	0	
Porcelain tile	5	0	1	2	2	0	0	
Marble	1	0	0	0	1	0	0	
Wood	37	2	10	7	15	3	0	

Table 3: Housing conditions: Structural characteristics according to thermal sensation scale. (2020)
Note: H: Hot; W: Warm; SLW: Slightly warm; N: Neutral; SLF: Slightly cool; C: Cool.

observed that the amount of time the light bulbs were on played a vital role. When they had been on for less than an hour, participants generally felt very comfortable or warm, indicating that they had used the light efficiently and that there was a slight variation ($p = 0.026$). However, there were long periods of use, which resulted in a broader range of temperatures, suggesting that artificial lighting could help us feel warmer. Another important finding was that the distance to other buildings and direct light were not significant in this study ($p = 0.146$).

Exposure to morning sunlight influenced indoor thermal sensation, but responses varied depending on the home's orientation. In particular, as expected, the living room received more sunlight and was perceived as warmer ($p = 0.401$), although this correlation was not statistically significant. Overall, these results indicate that the orientation and layout of rooms can affect thermal comfort and, therefore, the well-being and health of their occupants.

3.3. Overcrowding index and thermal sensation

Table 5 presents the distribution of the number of occupants per bedroom in a sample of 161 dwellings, including data on overcrowding. The data show that the number of people per bedroom varies according to household size. Single-person households are rare, but there are two-person households (23 cases), which reflect couples.

In three-person households (27 cases), it is slightly more common to have two bedrooms. With four-person households (54 cases) in three-bedroom homes being the most common option, this could indicate a "traditional" family arrangement. In 34 cases, five-person households need three or four bedrooms more often. Households of six or more people are rare so that we might think of a space problem or that they are underrepresented in the sample.

Table 6 shows the relationship between overcrowding and the heat index scale in homes, using the chi-square test to assess whether the two variables are related. The chi-square analysis found no statistically significant relationship between overcrowding and thermal sensation in our sample: Pearson's chi-square ($p = 0.162$) and the likelihood ratio ($p = 0.066$) support the null hypothesis, suggesting that overcrowding does not directly affect occupants' thermal perception. It should be noted, however, that 72.9% of cells have expected frequencies <5, which is too small for chi-square analysis. Furthermore, the analysis

Architectural and habitability characteristics according to thermal sensation scale

Variables	n=161	Thermal sensation scale						p-value
		CA	CÁ	LC	NE	LF	FR	
Enough windows								
Yes	64	6	27	14	14	3	0	
No	67	14	8	16	23	5	1	0.016
Maybe	30	1	11	9	8	1	0	
Wall painting								
Yes, in light colors	76	12	25	20	17	3	0	
Yes, dark colors	12	1	2	3	4	1	1	0.071
No	72	8	19	16	24	5	0	
Use of headlights during the day								
Use daylight	35	9	10	7	8	1	0	
Bedrooms	23	3	5	5	9	1	0	
Kitchen	15	1	4	5	5	0	0	
Dining room	26	0	6	11	5	4	0	0.094
Room	34	7	10	2	11	3	1	
Bathrooms (SSHH)	27	1	11	9	6	0	0	
Laundry	1	0	0	0	1	0	0	
Spotlight on time								
Less than 60 minutes	83	9	32	21	21	2	0	
From 1 hour to 3 hours	61	7	10	16	20	7	1	0.026
More than 3 hours	15	5	4	2	4	0	0	
Withdrawals from the home								
With minimal setbacks (less than 3 meters)	36	1	14	7	11	3	0	
With comfortable setbacks (3 meters or more)	27	3	11	5	5	2	1	
Semi-detached on one side	30	3	8	7	8	4	0	0.146
Semi-detached on two sides	45	9	8	14	14	0	0	
Semi-detached on three sides	23	5	5	6	7	0	0	
Morning sun								
Bedrooms	49	5	16	12	12	4	0	
Kitchen	24	2	8	6	8	0	0	
Dining room	35	1	8	10	12	3	1	0.401
Living room	52	13	14	11	12	2	0	
Bathrooms (SSHH)	1	0	0	0	1	0	0	

Table 4: Housing conditions: Architectural and habitability characteristics according to thermal sensation scale. (2020)
Note: H: Hot; W: Warm; SLW: Slightly warm; N: Neutral; SLC: Slightly cool; C: Cool.

of the linear trend across categories shows that the trend for overcrowding is less balanced than that for temperature. Therefore, our hypothesis that overcrowding does not have a direct effect on occupants' thermal sensation is not rejected. However, these results suggest that other factors not analyzed in this test may be affecting occupants' thermal sensation.

3.4. Perception of wind chill

The data obtained reveal that the p-value (0.000) is significantly lower than the 0.05 threshold, indicating that the relationship between thermal sensation and the time at which the interview was conducted is not merely a random factor but a statistically significant one. In other words, it suggests that participants' perceptions varied by time of day, perhaps because ambient temperature varied or because people's temperature thresholds differ by time of day.

4. Discussion and conclusions

4.1. Discussion

The findings reveal that the time of day at which the interview is conducted significantly influences perceptions of heat, suggesting that temperature fluctuations from one day to the next affect the thermal range in which a person feels comfortable. This idea is consistent with previous studies indicating that the sensation of comfort is not a fixed concept throughout the day, but varies depending on the ambient temperature and the activity of individuals (ASHRAE, 2020; Rawal et al., 2022; Stasi et al., 2024a; van der Walt et al., 2024; Alonso et al., 2025).

The data indicate that construction type and materials influence thermal perception. Concrete houses are associated with greater heat accumulation, reducing comfort. In contrast, guadua houses received more consistent reviews, suggesting they perform their function more effectively. These findings are consistent with the literature, as guadúa is a material with a low thermal conductivity coefficient, which helps mitigate the effects of summer heat and increase home comfort in hot climates (Valdivia Senociain and Ribera-Barraza, 2022).

In addition, the dwelling's height did not correlate significantly with thermal sensation, but the roof did significantly modify perception. Concrete floors were found to have a significant relationship with thermal comfort, indicating that although they provide insulation, they overheat. These results support previous studies suggesting that roofs made of reflective materials or with good ventilation can better regulate temperatures in hot climates (Banerjee et al., 2022; Kajjoba et al., 2022 and 2024; Rawal et al., 2022; Escobar Carreño et al., 2023).

Overcrowding							
Variables	**# Bedrooms**						**Total**
# Occupants	**1**	**2**	**3**	**4**	**5**	**6**	
1	0	1	1	0	0	0	2
2	16	6	1	0	0	0	23
3	1	27	6	3	0	0	37
4	1	16	30	5	2	0	54
5	0	3	20	9	2	0	34
6	0	1	1	4	2	1	9
7	1	1	0	0	0	0	2
More than 7	0	1	0	0	0	0	1
Total	19	55	59	21	6	1	161

Table 5: Overcrowding: Occupancy and bedrooms. (2020)

Relationship between crowding and thermal sensation			
	Value	**gl**	**Asymptotic significance (2-tailed)**
Pearson's chi-square	43.161a	35	0.162
Likelihood ratio	48.312	35	.066
Linear association by linear	0.020	1	.887
N of valid cases	161		

Table 6: Chi-square test between crowding and heat sensation scale. (2020)

	Perception of wind chill	
Variables	**n= 161**	**%**
Very hot	21	1.04
Hot	46	28.57
Slightly hot	39	24.22
Neutral	45	27.95
Slightly cool	9	5.59
Fresh	1	0.62
Cold	0	0.00

Table 7: Perception of wind chill. (2020)

The study revealed that the presence of windows conditioned perceptions of thermal comfort, with homes with sufficient natural ventilation perceived as hotter, consistent with Stasi et al. (2024a) and Kajjoba et al. (2022). Wall color was not statistically correlated with thermal sensation. However, there was a tendency for light-colored walls in homes to feel cooler. This is because these colors reflect solar radiation and thereby reduce heat accumulation, which aligns with the findings of Rodríguez-Miranda et al. (2021). Artificial light does not influence the overall sensation of heat, unless it is prolonged in spaces such as the living room, where there is a higher perception of heat (Castillo et al., 2019; Toala-Zambrano et al., 2021).

After analyzing solar orientation, the data show that exposure to the morning sun is associated with the thermal sensation. In fact, the living room receives the most sun and is perceived as the hottest. Although this relationship was not statistically significant, the data nevertheless underscore the importance of bioclimatic design, especially when it comes to orienting facades and optimizing shading to achieve thermal comfort in hot climates (Hashemi and Khatami, 2017; Banerjee et al., 2022; Khaksar et al., 2022; Taylor et al., 2023; Stasi et al., 2024b; Kajjoba et al., 2024; Wei et al., 2024).

The results indicate that the crowding index follows a distribution pattern, with a higher concentration of people sharing rooms in three- and four-person rooms. However, the study did not find an association between the number of people per room and thermal perception. Nevertheless, crowding could have an indirect effect through increased body heat production and reduced air circulation, especially in windowless dwellings. Several studies have documented that the concentration of people in enclosed spaces can raise temperatures and degrade air quality (Ascione, 2024; González et al., 2024; Wei et al., 2024; Muñoz-Chavarría, 2021), thereby increasing thermal discomfort. In addition, overcrowding could affect natural ventilation (Escobar Carreño et al., 2023). The results obtained here suggest that variables not studied, such as the orientation of the home, exposure to wind, or the thermal properties of materials, may be modulating this relationship.

The results indicate that most participants perceived the thermal environment as exceeding comfort levels. These results indicate that most of the participants' homes do not meet thermal comfort standards, highlighting the need for passive ventilation options, construction improvements, and interior design conditions to reduce the building's heat gain (Rodríguez-Miranda et al., 2021; Escobar Carreño et al., 2023; Ascione et al., 2024; Wei et al., 2024).

4.2. Conclusions

Guadua bamboo proved to have better thermal performance than concrete; homes built with it had a more uniform distribution of reported thermal sensations. This supports its alternative use in the design of houses for hot climates, preventing heat accumulation indoors. However, its thermal performance can be affected by other architectural elements of the house, such as ventilation and orientation.

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Although no statistically significant relationship was found between the overcrowding index and thermal perception, the number of people could indirectly affect thermal comfort through heat accumulation and indoor air quality. This suggests that, although overcrowding is not a fundamental cause in itself, its combination with inadequate ventilation and deficiencies in the thermal envelope can influence occupants' thermal perception.

Factors such as natural ventilation, the orientation of the dwelling, and the finishes of roofs and walls were shown to influence significantly occupants' thermal sensations. Thus, having multiple windows or choosing roofs with good thermo-reflective properties improves users' perception. These results further highlight the importance of bioclimatic design strategies in guadua buildings to optimize cross ventilation and prevent solar heat from entering the interior.

The results suggest that guadua houses can offer a high degree of thermal comfort when combined with practical design approaches, such as optimizing ventilation, shading to reduce solar radiation, and using materials with low thermal inertia. It also encourages the creation of regulations governing the use of sustainable products to promote designs tailored to a location's climatic conditions, thereby achieving an adequate balance between sustainability, thermal comfort, and habitability in high-density contexts.

5. Recommendations

Although the study used the ASHRAE 55 Thermal Sensation and Satisfaction Scale to measure occupants' thermal comfort, temperature perception is highly susceptible to human factors. It can be biased by factors that are difficult to control. This study should be complemented by continuous monitoring of temperature, air humidity, and air velocity indoors, through the use of sensors and measurements, as well as the use of thermal simulation models, which would allow for a more detailed understanding of thermal variability within homes, as well as the influence of the architectural envelope.

Conflict of interest. The author declares no conflicts of interest.

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