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THERMAL PERCEPTION OF USERS IN THE VERNACULAR HOUSING OF THE URO COMMUNITY OF LAKE TITICACA IN PERU

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PERCEPCIÓN TÉRMICA DE USUARIOS EN LA VIVIENDA VERNÁCULA DE LA COMUNIDAD URO DEL LAGO TITICACA EN PERÚ

PERCEPÇÃO TÉRMICA DOS USUÁRIOS NA HABITAÇÃO VERNACULAR DA COMUNIDADE URO DO LAGO TITICACA, NO PERU

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RESUMEN

El objetivo de la siguiente investigación fue realizar un estudio de campo, para conocer la percepción térmica de los usuarios de la vivienda vernácula en clima frío de la región Altoandina peruana. Las unidades analizadas fueron viviendas construidas en base a "totora" de la comunidad Uro. El estudio de campo desarrollado consistió en caracterizar el desempeño térmico de la vivienda, determinar la superficie corporal y aislamiento de ropa, valorar la sensación, preferencia y aceptabilidad térmica, determinar las estrategias de ajustes personales y calcular la temperatura neutra. Se recogieron 78 encuestas válidas en dos períodos estacionarios (verano e invierno). Los resultados revelan que, los usuarios de la vivienda se encuentran incómodos. La preferencia apunta a ambientes más cálidos y secos. La temperatura neutra en verano fue de 19.62 °C y en invierno de 21.98 °C. Los habitantes del lugar evidenciaron tener la expectativa que el ambiente puede mejorarse térmicamente con mayor aislamiento.

Palabras clave
vivienda vernácula, confort térmico, percepción térmica, condición climática.

ABSTRACT

The objective of this work was to conduct a field study to determine the thermal perception of users of vernacular housing in the cold climate of the Peruvian High Andean region. The units analyzed were houses built by the Uro community using "totora" (bulrush reeds). The field study characterized the dwelling's thermal performance, determined body surface area and clothing insulation, assessed thermal sensation, preference, and acceptability, determined personal adjustment strategies, and calculated the neutral temperature. Seventy-eight valid surveys were collected in two periods (summer and winter). The results reveal that the dwelling's users are uncomfortable. The preference points to warmer and drier environments. The neutral temperature was 19.62 °C in summer and 21.98 °C in winter. However, the inhabitants had the expectation that the environment could be thermally improved with more insulation.

Keywords
vernacular housing, thermal comfort, thermal perception, climate conditions.

RESUMO

O objetivo da pesquisa a seguir foi realizar um estudo de campo para descobrir a percepção térmica dos usuários de habitações vernaculares no clima frio da região dos Altos Andes peruanos. As unidades analisadas foram moradias construídas em "totora" da comunidade Uro. O estudo de campo consistiu em caracterizar o desempenho térmico da habitação, determinar a área de superfície corporal e o isolamento das roupas, avaliar a sensação, preferência e aceitabilidade térmica, determinar as estratégias de ajuste pessoal e calcular a temperatura neutra. Setenta e oito questionários válidos foram coletados em dois períodos sazonais (verão e inverno). Os resultados revelam que os usuários da residência não se sentem confortáveis. A preferência é por ambientes mais quentes e secos. A temperatura neutra no verão foi de 19,62 °C e de 21,98 °C no inverno. Os habitantes do local evidenciaram a expectativa de que o ambiente possa ser melhorado termicamente com mais isolamento.

Palavras-chave:
habitação vernacular, conforto térmico, percepção térmica, condição climática.

INTRODUCTION

The High Andean region of Peru has a cold tundra and glacial climate, high solar radiation, low annual thermal oscillation, and high diurnal thermal oscillation. Due to this climatic variability, the thermal behavior of buildings is different, and the altitude greatly influences it (Molina et al., 2023). In this context, the Uro community faces discomfort, respiratory diseases, and even death during the winter period. To mitigate this situation, the locals usually wear thick clothes to protect themselves from the cold. According to records of the SENAMHI (National Meteorology and Hydrology Service of Peru), the average outdoor temperature in the community drops to 3.50 °C in summer and -1.60 °C in winter, which shows the location's adverse climate.

The Uro community is located on Lake Titicaca, considered the world's highest navigable lake at 3800 meters above sea level. It is an ancient people whose existence dates back to before 500 A.D. Its life is intimately linked to the lake and its resources. Of the total population, 60% are settled on floating islands, and the rest live on dry land. The "Totora" or Southern Bulrush (Schoenoplectus Tatora) is the primary means of subsistence (Aza-Medina et al., 2023, p. 2; Hidalgo-Cordero et al., 2023) whether the material is arranged loosely, braided, or woven like blankets, or in the construction of artificial islands, houses, boats (Hidalgo-Cordero & Aza-Medina, 2023, p. 2; Hýsková et al., 2020).

Significant studies have been carried out on thermal comfort in vernacular dwellings in low-altitude regions (Costa-Carrapiço et al., 2022; Malik & Bardhan, 2022; Widera, 2021). However, few studies were found in high-altitude regions, so it is necessary to investigate, considering that thermal comfort is one of the essential parameters that can provide information for the adaptation of strategies in housing due to its impact on human health, productivity, quality of interior space, and the reduction of energy consumption (Malik & Bardhan, 2022). Providing information to improve housing is crucial and challenging because it depends on many factors that require field studies, such as climatic, psychological, physiological, and cultural aspects (Abdollahzadeh et al., 2023). Therefore, a fundamental issue in conducting field studies is determining the thermal perception of a house's users of temperature changes inside the room (Camuffo, 2019, p. 15).

According to Chang et al. (2021), vernacular housing studies are primarily focused on climate adaptation, which aims to provide climate-adaptive and energy-efficient passive design strategies. Similarly, Xiong et al. (2019) indicate that thermal comfort in vernacular housing focuses on users' adaptability to the climate to provide acceptable thermal environmental conditions. Therefore, vernacular dwellings are places where users adapt to the climate. Hence, improving the internal conditions of the dwelling is required.

In this context, this study aimed to conduct a field study to determine the thermal perception of users of vernacular housing in cold climates typical of the Peruvian High Andean region and provide information on their thermal perception to recommend adaptive strategies to improve their internal conditions.

METHOD

STUDY AREA

The Uro Community

The study area was defined as the Uro community in the department of Puno, Peru, on Lake Titicaca, with a south latitude of 15° 49'14", a west longitude of 69° 58' 12", and an altitude of 3900 meters above sea level. The community is located on floating islands built with "Totora," 5 km from the port city of Puno. The Uros Islands comprise more than 100 units organized in an aligned strip, accessed in the center, and divided into two north and south zones (Figure 1). The islands focused on housing are the most common. These are in a crescent shape with a central space that acts as a yard.

The Uro community's vernacular housing

Its one-floor housing is characterized by its compact shape. The roof is gabled, and the door is used to ventilate the room. The floor is usually boarded with wood or loose reeds and raised 50 cm above the level of the island to prevent moisture entry (Figure 2a). "The structure comprises 2-inch wooden slats recessed with nails" (Steffens et al., 2017, p. 2), which serve as a support (Figure 2b). The house's walls consist of blankets of hand-woven Totora "kesanas," which have an approximate thickness of 3 inches. It was confirmed that the weaving technique of the walls varies compared to that of the roof. In the latter, even longer Totoras were found with a different braiding technique (Figure 2c).

The house has undergone changes with the passage of time. In its beginnings, it had a circular floor plan and a conical roof (Figure 3a). Currently, it has a rectangular or square floor plan (Figure 3b). In addition, modern materials, such as metal sheets, wooden sheets, and plastic, are incorporated into ceilings and walls,

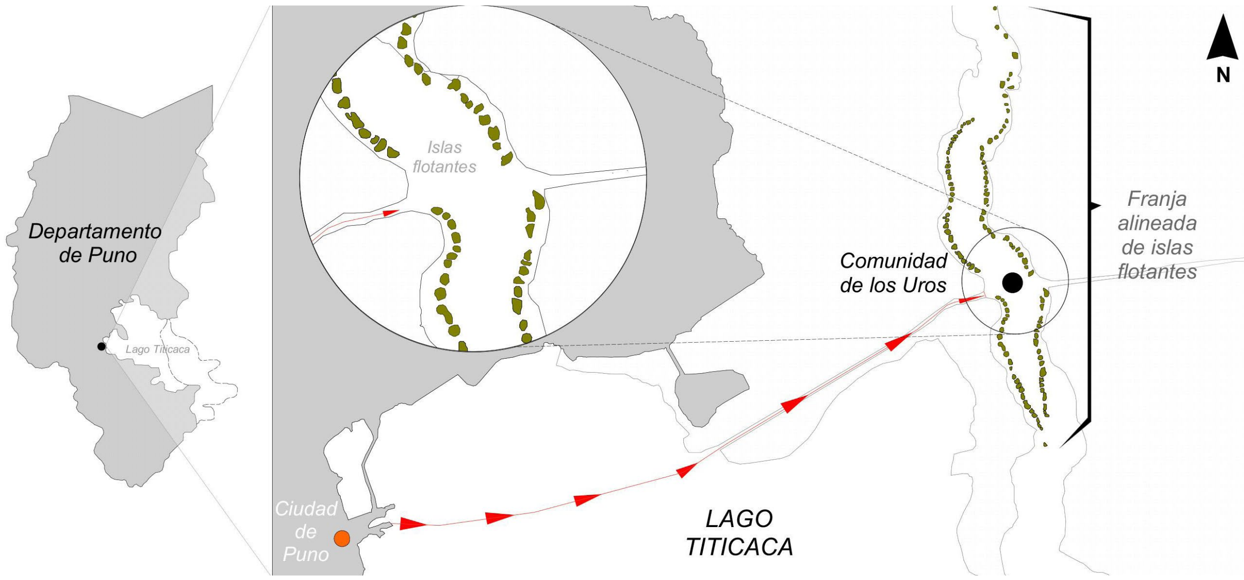

Figure 1. Floating Islands - location. Source: Preparation by the authors.

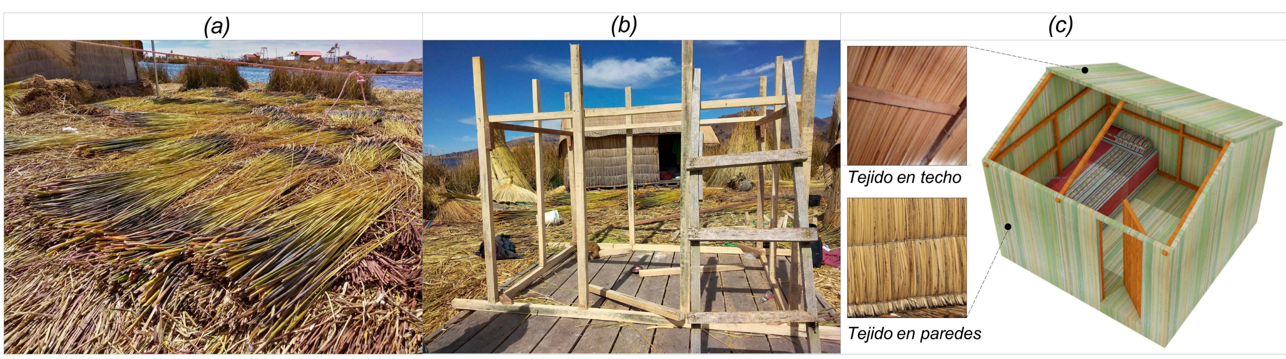

Figure 2. Uro Dwelling - Assembly. Source: Preparation by the authors.

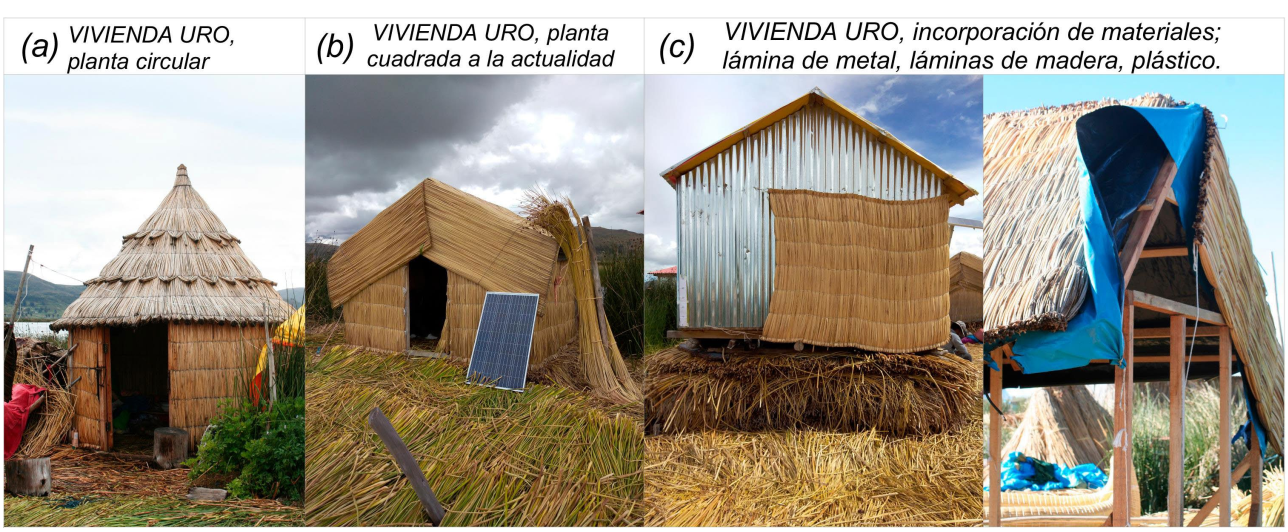

Figure 3. Evolution of shape and materials. Source: Preparation by the authors.

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Figure 4. Interior and exterior photos of the vernacular dwellings. Source: Preparation by the authors.

Table 1. Sample size. Source: Preparation by the authors

Description		Total		Summer		Winter	
		n = 78		n = 50		n =28	
		Sample	Percentage	Sample	Percentage	Sample	Percentage
Gender	Female	52	67%	33	66%	19	68%
	Male	26	33%	17	34%	9	32%

disfiguring the indigenous version (Figure 3c).

The internal use of the buildings is mainly as a multi-purpose room, fulfilling the roles of kitchen, storage room, and bedroom, handling the basic needs in one place (Figure 4a) and, in other cases, as a bedroom (Figure 4b).

SAMPLE SIZE

To determine the sample size, non-probability sampling was used in each study period, considering the availability and willingness of users to participate (Table 1).

FIELD STUDY

Surveys were carried out alongside measurements of the house's thermal performance for seven days: five days in the summer (06/01/22 to 01/13/22) and two days in the winter (07/15/22 to 07/16/22). 21 islands of the Uro community were taken as a study due to accessibility. The ASHRAE 55-2017, ISO 7730, ISO 10551, and ISO 7726 standards and norms were used (ANSI/ASHRAE 55, 2017a, pp. 8-19; ISO 7726, 1998, p. 23; ISO 7730, 2005; ISO 10551, 1995) and 78 valid responses of sensation, preference, and thermal acceptability were collected. 50 people were interviewed in 40 dwellings in the summer period and 28 people in 19 dwellings in the winter period. The participants were men and women aged between 18 and 60 years.

DWELLING'S INTERNAL THERMAL PERFORMANCE

Air temperature, relative humidity, globe temperature, and wind speed data were recorded. Two pieces of equipment were placed; a heat stress meter and a hot wire thermo-anemometer (Figure 5b). The measurements were taken with the doors closed, and

(a)

(b)

Measument content	Operation range	Accuracy
Temperatura de aire (R6250)	0 a 50 °C	±0.8 °C
Resolución		0.1°F/°C
Humedad relativa (R6250)	5 a 95%	>70% HR: ±(3% rdg+1%HR)
Resolución		0.1% HR
Temperatura de globo (R6250)	0 a 80 °C	±0.6 °C
Temperatura de aire (R4500)	0 a 50 °C	±0.8 °C
Velocidad de aire (R4500)	0.2 a 25 m/s	±0.2 m/s
Resolución		fpm: 1m/s, km/h
Diámetro de Globo negro: 2.9" (75mm)		

(c)

Figure 5. Measurement, surveys, and location of equipment. Source: Preparation by the authors.

the recording was done from 9 am to 3 pm. The devices were placed in the center of the room at a height of 1.10 meters from ground level and 0.5 meters from the user (Figures 5a and 5c). The recording was performed at 5-minute intervals for the heat stress meter and 2 minutes for the hot wire thermo-anemometer. In parallel, information on thermal perception was collected from surveys.

After recording the field data, the operating temperature (OT) was calculated, as it is a weighting of the average radiant temperature of the enclosures and the dry air temperature, considering that both contribute to the room temperature with their radiant and convective heat transfer coefficients (Equation 1).

$$t_o = At_a + (1 - A)\, t_r$$

Where: t_o is the operating temperature, A=Constant as a function of the air velocity, t_a is the air temperature (°C), and t_r is the average radiant temperature (°C).

This procedure was carried out for each of the studied houses. The operating temperature (OT) and humidity variables were correlated for data analysis to show scatter plots.

User's body surface area and clothes insulation

To determine the body surface area, information was collected about their previous activity, food intake, and general aspects such as gender and age. Then, the user's height and weight were measured (Table 2), considering the mathematical model of Mosteller (Equation 2).

Regarding the insulation index (Clo), a list of typical

$$Superficie\ corporal\ (m^2) = \sqrt{\frac{altura\ (cm) x peso\ (kg)}{3600}}$$

Table 2. General information of the users. Source: Preparation by the authors.

Season	Gender	Sample size	Height (cm)	Weight (kg)
Summer	Men	17	165.29	88.37
(January)	Women	33	152.27	77.26
Winter	Men	9	161.22	75.92
(July)	Women	19	151.79	71.24

garments that included 20 options was provided (Figure 6). The data obtained were processed on an Excel spreadsheet, making a sum total per user.

Thermal sensation, preference, and acceptability

For thermal sensation and preference, 7-point rating scale surveys were used, and for acceptability, dichotomous surveys with acceptable and unacceptable ratings were used (Table 3). Between 9 and 14 surveys

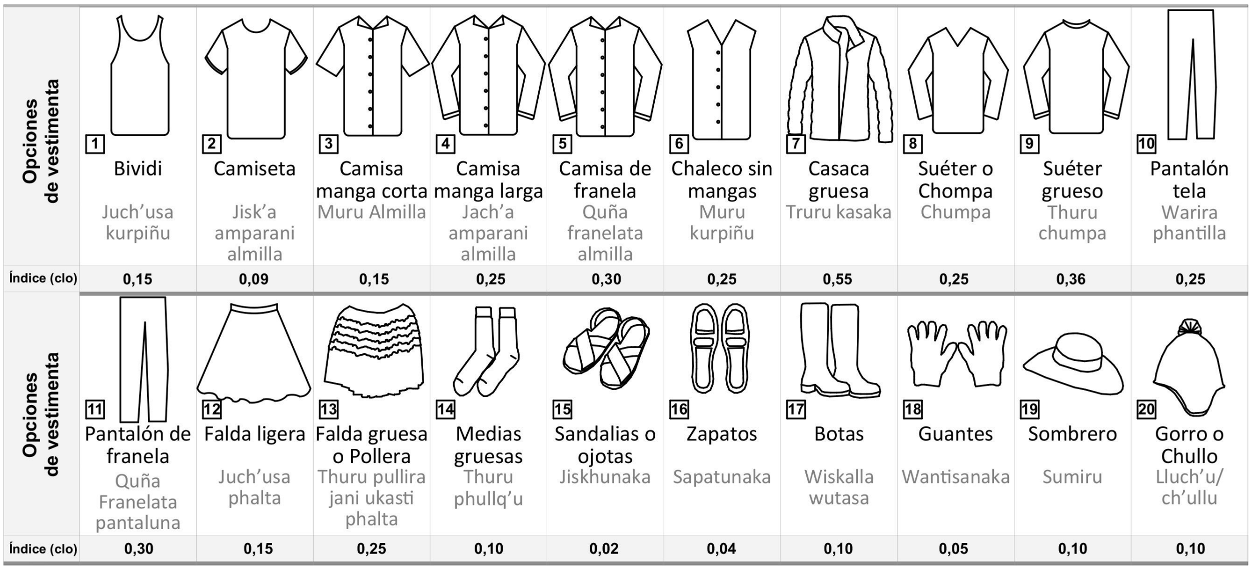

Figure 6. Clothing options. Source: Preparation by the authors and translation into Aymaran by CELEN-UNAP professor, Miriam Jiménez

Table 3. The assessment scale used. Source: Adapted from ASHRAE and ISO 10551 (1995).

Scale	Sensation		Preference		Acceptability
	How are you feeling at the moment regarding temperature and humidity?		How would you rather be right now?		Do you thermally accept this environment at the moment?
	Temperature	Humidity	Temperature	Humidity	Temperature
-3	Very cold	Very dry	Much colder	Much drier	
-2	Cold	Dry	Colder	Drier	
-1	Slightly cold	Slightly dry	Slightly colder	Slightly drier	
0	Neither hot, nor cold	Neither wet, nor dry	No change	No change	Acceptable
1	Slightly warm	Slightly damp	Slightly warmer	Slightly damp	Unacceptable
2	Hot	Humid	Hotter	More humid	
3	Very hot	Very humid	Much hotter	Much more humid	

were conducted daily from 10 a.m. to 4 p.m. Users were asked to perform a sedentary activity (1.2 met) for 20 minutes before responding.

Answers were taken orally and recorded in the questionnaire. A support booklet with the rating scales was used for better visualization. The questions for the answers about thermal sensation and preference regarding temperature and humidity were: How are you feeling right now regarding temperature and humidity? and, how would you rather be right now? For acceptability, the question was: At this moment do you thermally accept this environment? (Table 3). The questionnaire was translated into the Aymaran language (the users' original language) for greater understanding. An Excel spreadsheet was used for data processing. The descriptive statistical method of frequency distribution was used to show the graphs in both study periods.

Personal adjustment strategies

The personal adjustment strategies were used for two conditions (cold and heat) in both males and females. Information was collected by means of 9-point rating scale surveys (ISO 10551, 1995) (Table 4). The information was processed on an Excel spreadsheet. Descriptive statistics of frequency distribution were used to show the graphs. The purpose was to determine which strategy users use most frequently and what modifications they suggest to remain in a state of comfort.

Calculation of neutral temperature

The house's neutral temperature was calculated using the Griffiths method (Griffiths, 1991). The regression constant obtained from the field data was applied for the calculations. This was obtained

Table 4. Personal adjustments. Source: Preparation by the authors.

En relación al frío, ¿Qué acciones realiza para mantenerse en una temperatura agradable?									En relación al calor, ¿Qué acciones realiza para mantenerse en una temperatura agradable?								
1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Aumentar la cantidad de ropa.	Usar	Beber bebidas calientes.	Comer comida caliente.		Cerrar la puerta.	Calefactor eléctrico.	Ninguno.	otros	Usar ropas ligeras.		Beber bebidas frías.	Comer comida	Salir al aire libre.	Abrir la puerta.	Usar ventilador eléctrico.	Ninguno.	Otros.

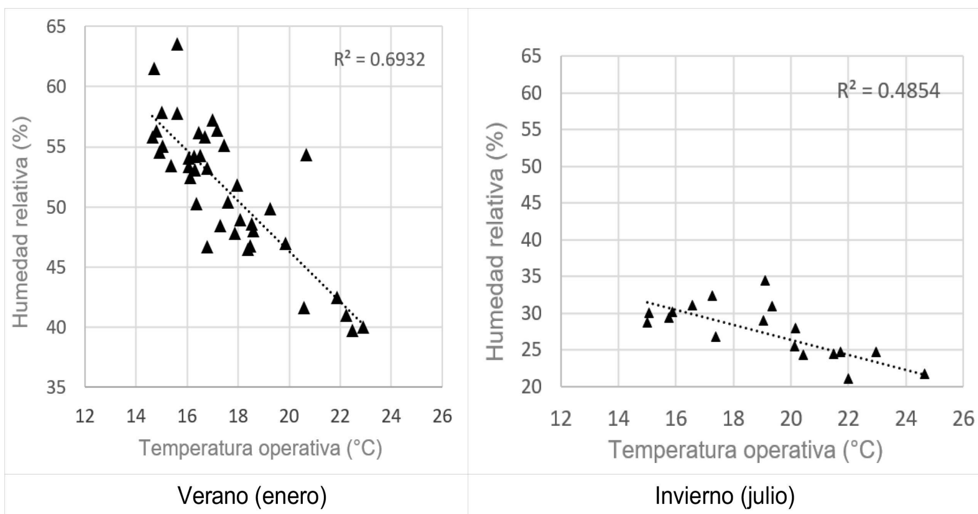

Figure 7. Scatter diagram of the thermal performance of the house. Source: Preparation by the authors.

by correlating the operating temperature variable and the thermal sensation votes using the Pearson coefficient statistic[1]. The constant of 0.33 proposed by (Fanger, 1970) and the universal constant of 0.50 proposed by Humphreys and Nicol (Humphreys & Nicol, 1970) were also used. Considering the dataset collected onsite, the neutral temperature was estimated for the house users. Equation 3 was used to calculate this.

$$T_n = T_o - \left(\frac{VST}{\alpha}\right)$$

Where: Tn is the neutral room temperature (°C); To is the indoor operating temperature (°C); VST is the thermal sensation vote (dimensionless); α is the Griffiths user constant/thermal sensitivity (°C-1).

RESULT

DWELLING'S INTERNAL THERMAL PERFORMANCE

The scatter diagram shows the dwellings' thermal performance in the study periods. The correlation is low for winter and medium for summer, suggesting a tendency for high spread (Figure 7). In the summer, an operating temperature (OT) of 17.50 °C and a predominant relative humidity of 51.5% were observed. On the other hand, in the winter period, the OT is around 19.20 °C, and the relative humidity is 27.16%.

USER'S BODY SURFACE AREA AND CLOTHES INSULATION

The average calculated body surface area for women was 1.80 m², and for men, it was 2.01 m². The average insulation value indicates 1.25 clo for women and 0.86

1 Coefficient that measures the correlation between 2 variables (operating temperature and thermal sensation votes)

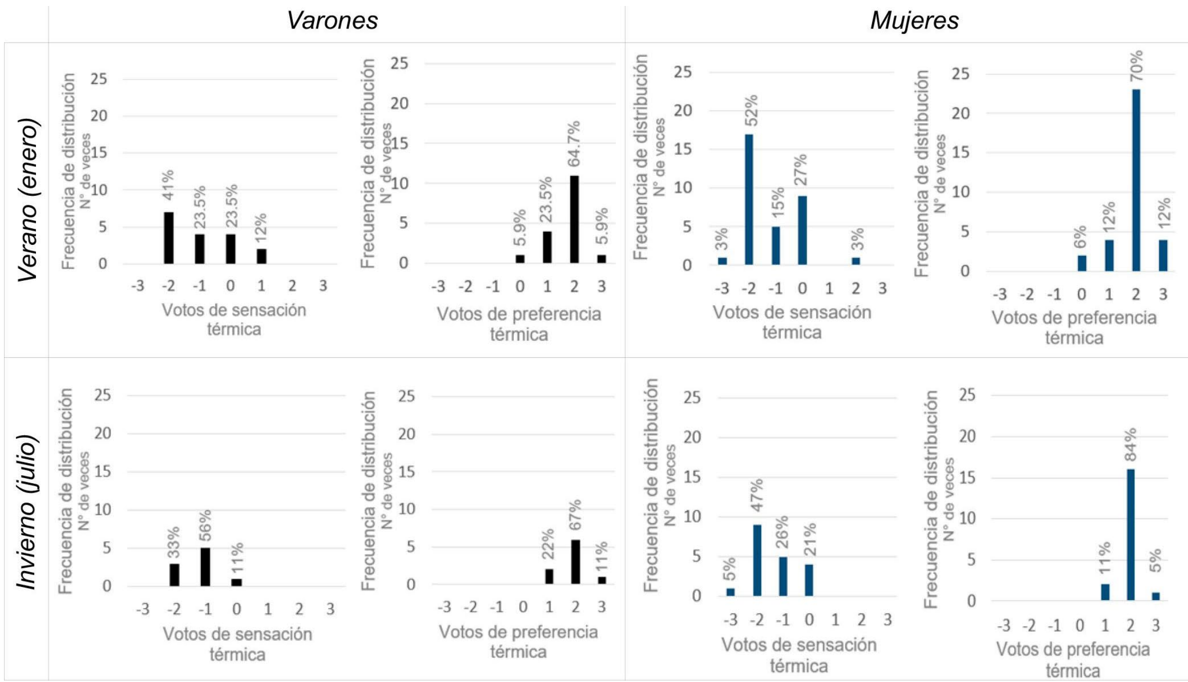

Figure 8. Frequency of thermal sensation and preference votes. Source: Preparation by the authors.

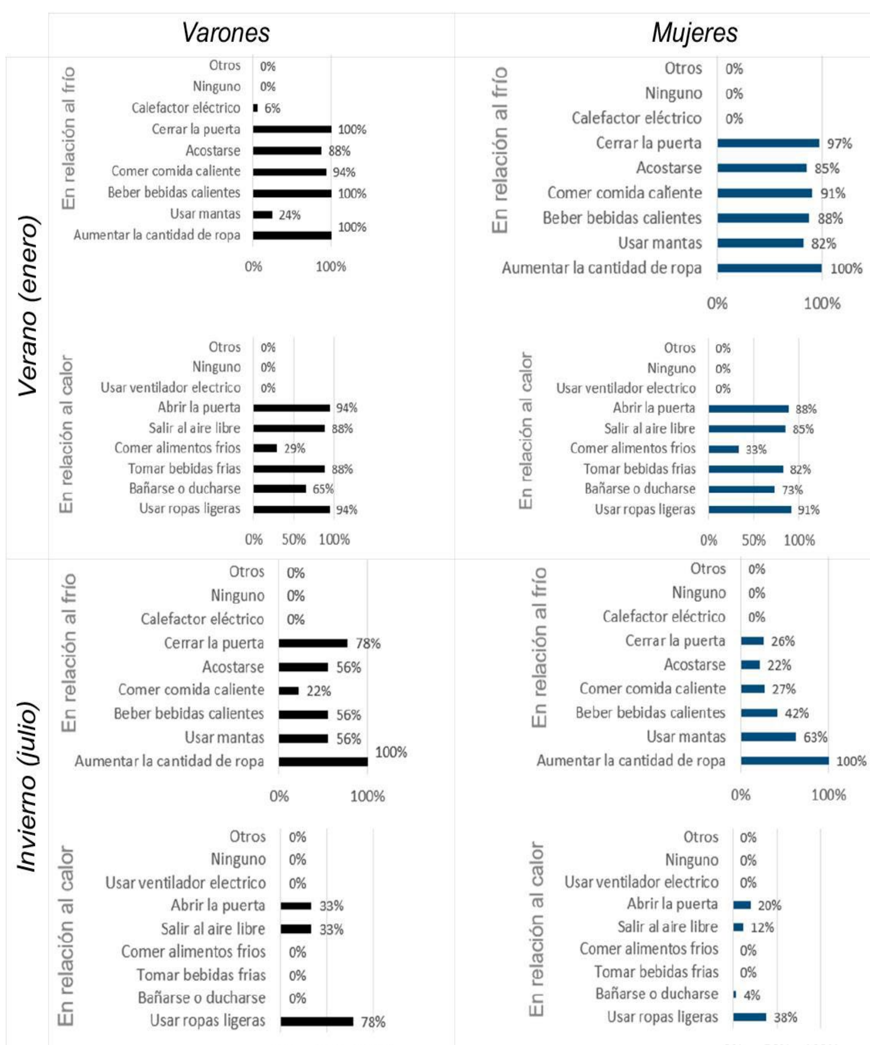

Figure 9. Personal adjustment strategies. Source: Preparation by the authors

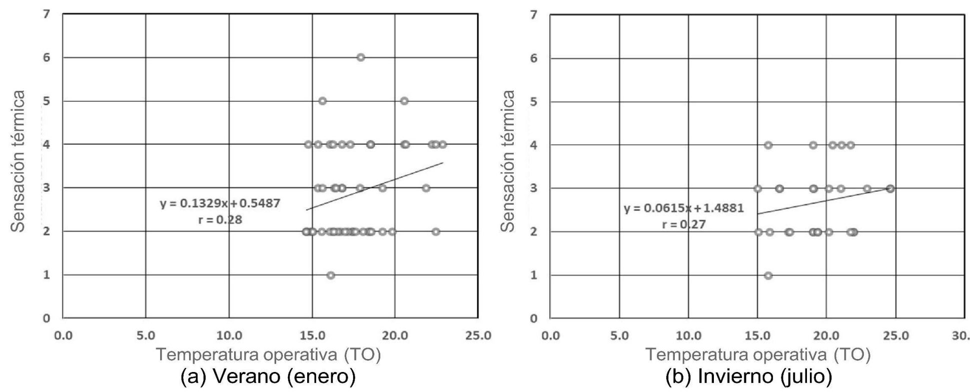

Figure 10. Correlation between the operating temperature and the thermal sensation. Source: Preparation by the authors

Table 5. Neutral temperature and Griffiths constant, SD = Standard deviation, r= correlation coefficient. Source: Preparation by the authors.

Season	Operating temperature (°C)	Griffiths (°C)			
	Mean	0.13	0.06	0.33	0.50
Summer	17.55	25.54	34.87	20.69	19.62
SD		9.97	10.13	4.04	2.96
Winter	19.34	29.50	41.36	23.34	21.98
SD		5.89	6.33	3.29	2.88

clo for men in the summer, while it is 1.01 clo for women and 0.90 clo for men in the winter. This means that in summer, the inhabitants wear more clothes than in winter. This could be because in the summer, there is intense rainfall in the study area, and people need to get warm.

THERMAL SENSATION, PREFERENCE, AND ACCEPTABILITY

The three main thermal sensation assessment scales (Humphreys et al., 2016, cited by Mino-Rodriguez et al., 2018, p. 9) were assumed to be a comfort zone. These consider that a person feels comfortable when the thermal perception responses are (-1) "slightly cold," (0) neutral, or (+1) "slightly warm."

Users, both women and men, concentrate their answers in the category Cold -2, Slightly cold -1, which suggests thermal discomfort because the cold rating is outside the comfort zone. Thus, it is also shown that the thermal preference votes tend towards the category No change 0, Slightly hotter +1, Hotter +2, and Much hotter +3 in both study periods, so a tendency towards warmer environments is observed (Figure 8).

Regarding acceptability, 36% of the respondents indicated that yes, and 64% that they do not accept the environment thermally in the summer season. For the winter season, 28.6% indicated yes and 71.4% no.

PERSONAL ADJUSTMENT STRATEGIES

The strategy regarding the coldest period is to increase the amount of clothing. In this aspect, both men and women coincided in the two seasons studied. The strategies for staying at a cooler temperature in both seasons for both men and women have been to wear light clothes and open the door (Figure 9). The personal adjustments regarding summer and winter are pretty similar for men and women. The occupants point out that changes to the house are necessary. They indicate that they would prefer that the houses be warmer and that less wind enters inside because not all houses have the same amount of Totora blankets.

NEUTRAL TEMPERATURE

The Griffiths constant result for the thermal sensitivity of the house users in the summer period was 0.13 and for winter 0.06. These values are minimal compared to those found in previous field studies (Figure 10). Constants of 0.33 and 0.50 were used, and they are widely used in specialized studies on thermal comfort. The neutral temperature calculated with the constant 0.50 for the summer period was 19.62 °C, and 21.98 °C for winter, with a low standard deviation, so the study assumes these calculated values as neutral temperature (Table 5).

DISCUSSION

The house's internal thermal performance was at an average operating temperature of 17.50 °C in summer and 19.20 °C in winter. Meanwhile, the average outdoor temperature recorded in summer was 3.50 °C and in winter -1.60 °C. The differences are significant, which suggests adopting envelope isolation strategies from the outside.

Thermal sensitivity indicates that users are in discomfort, which may be due to the influence of external weather conditions. More than 60% of users do not accept the room, which suggests a natural desire for warmer environments. According to Xiong et al. (2019), people have to stay indoors with heating equipment in cold areas. However, the Uro community does not have the resources to obtain these mechanical systems, so they wear thick clothes day and night. During the day, the room serves as a kitchen, which is part of the community tradition and can improve its comfort.

Due to the thermal unacceptability, it is necessary to adopt strategies that improve the house's thermal comfort. In cold weather, according to Nie et al. (2019), passive solar heating can reduce the effect of cold and improve energy efficiency, thus improving room temperature. On the other hand, Qiao et al. (2019) point out that the insulation of walls and ceilings with materials with high thermal storage is an adaptive strategy for cold climates. Therefore, the use of solar energy is suggested, along with strategies that involve the improvement of the thermal envelope and airtightness. These include 1) the use of buffer spaces such as corridors, terraced greenhouses, etc., 2) using materials with a large thermal storage capacity, and (3) the dynamic use of housing in the different seasons to take advantage of the climate.

The calculations show a neutral temperature of 19.62 °C for summer and 21.98 °C for winter, with neutral temperatures being determined in similar studies. Rijal et al. (2010) found temperatures of 21.10 °C and 15.30 °C for summer and winter, respectively. Comparatively, the neutral temperature for summer does not present significant differences. However, for winter, the temperature found in this study is higher due to the high solar radiation during the day (5.9 kWh/m^2), which makes it possible for housing to be heated in the daytime schedule. Similarly, Mino-Rodriguez et al. (2018) found an average neutral temperature of 23.40 °C. This value is close to this study and provides consistency to the results. On the other hand, the neutral temperatures found are close to the design temperature of 22 °C according to the ASHRAE 55-2017 standard. However, it is essential to note that the survey's information is for the daytime schedule. Solar radiation is high, especially in winter, so temperatures could drop significantly if the night records were taken. This suggests that thermal neutrality may not be sufficient to identify the thermal comfort needs of users.

Thermal comfort in indoor environments plays a vital role in energy consumption. However, state policies often do not take this into account. This work provides a better understanding of users' thermal comfort for vernacular dwellings in the Uro community, which would help to adopt strategies to improve the dwellings.

The main limitation of the research was the number of people surveyed. This was mainly due to the fact that they did not have time and were not willing to answer the survey. On the other hand, the data collection times were also an impediment because information could only be collected during daylight hours.

CONCLUSIONS

This study highlights users' thermal perception. The vernacular housing is in a state of thermal vulnerability, and the shape must return to the knowledge used in the past, where compactness was taken into account, offering a better response to the climate. The current materiality does not satisfy users' needs despite their adaptive responses to find comfort, such as the constant renewal of the material. In response, the occupants do not thermally accept the dwellings in the daytime, both in the summer and winter seasons. At night, users have to take additional measures to insulate the house, with the envelope being a pivotal point to treat and improve. The neutral temperature value in winter is above the summer period.

The improvements point towards the insulation of the thermal envelope to achieve warmer and drier rooms, the improvement of airtightness with more Totora blankets, and better braiding techniques. This study can be considered an initial study to subsequently conduct studies aimed at the thermal improvement of housing, with in-depth simulations, and technological improvements that involve using Totora, typical of the Uro community.

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