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THERMAL ACCEPTABILITY OF INDIVIDUALS LIVING IN HOUSING VULNERABILITY: A CASE STUDY IN PASSO FUNDO/RS – BRAZIL

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Abstract

Objective: This research aims to investigate and discuss the thermal conditions of a temporary dwelling and the residents' perceptions regarding the thermal environment.
Methodology: It is characterized as an empirical, qualitative, exploratory research of a convenience-defined case study. The thermal evaluation determinants are based on American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE 55, 2020).
Originality/Relevance: Thermal comfort standards typically consider only regular and permanent buildings. This study assesses the thermal conditions of a temporarily constructed dwelling in a region with a subtropical climate and low winter temperatures.
Results: The internal thermal conditions are linked to external temperature variations, and residents' thermal acceptability limits tend to be higher than parameters outlined in adaptive thermal comfort standards.
Contributions: This serves as a pilot study on the thermal conditions of temporary dwellings in the southern region of the country, demonstrating that individuals living in such housing tend to have higher thermal acceptability for cold conditions compared to normative thermal comfort parameters. Meanwhile, the housing's thermal performance aligns with the microclimatic changes in the external environment.

Keywords: thermal comfort, thermal acceptability, temporary housing, housing vulnerability.

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ACEITABILIDADE TÉRMICA DE INDIVÍDUOS QUE VIVEM EM VULNERABILIDADE HABITACIONAL: ESTUDO DE CASO EM PASSO FUNDO/RS – BRASIL

Resumo

Objetivo: Esta pesquisa tem por objetivo investigar e discutir as condições térmicas de uma moradia provisória e as percepções dos moradores quanto ao ambiente térmico.
Metodologia: Caracteriza-se como uma pesquisa empírica, de natureza qualitativa, do tipo exploratória sobre um estudo de caso definido por conveniência. Os determinantes de avaliação térmica estão baseados na American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE 55, 2020).
Originalidade/Relevância: As normativas de conforto térmico consideram somente edificações regulares e permanentes. Este estudo avalia as condições térmicas de uma moradia provisória em precariedade construtiva, inserida em região de clima subtropical, com baixas temperaturas no inverno.
Resultados: As condições térmicas do ambiente interno estão atreladas às variações de temperatura externa e os limites de aceitabilidade térmica dos moradores tendem a ser maiores do que os parâmetros previstos em normativas de conforto térmico adaptativo.
Contribuições: Trata-se de um estudo piloto sobre as condições térmicas de moradias provisórias no sul do país, demonstrando que indivíduos que vivem neste tipo de moradia tendem a ter maior aceitabilidade térmica para o frio em relação aos parâmetros normativos de conforto térmico, enquanto o desempenho térmico da habitação segue as mudanças microclimáticas do ambiente exterior.

Palavras-chave: conforto térmico, aceitabilidade térmica, moradia provisória, vulnerabilidade habitacional.

ACEPTABILIDAD TÉRMICA DE INDIVIDUOS QUE VIVEN EN VULNERABILIDAD HABITACIONAL: ESTUDIO DE CASO EN PASSO FUNDO/RS – BRASIL

Resumen

Objetivo: Esta investigación tiene como objetivo investigar y discutir las condiciones térmicas de una vivienda provisional y las percepciones de los residentes sobre el ambiente térmico.
Metodología: Se caracteriza como una investigación empírica, de naturaleza cualitativa, del tipo exploratoria sobre un estudio de caso definido por conveniencia. Los determinantes de evaluación térmica están basados en la American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE 55, 2020).
Originalidad/Relevancia: Las normativas de confort térmico consideran únicamente edificaciones regulares y permanentes. Este estudio evalúa las condiciones térmicas de una vivienda provisional en precariedad constructiva, ubicada en una región de clima subtropical con bajas temperaturas en invierno.
Resultados: Las condiciones térmicas del ambiente interno están vinculadas a las variaciones de temperatura externa y los límites de aceptabilidad térmica de los moradores tienden a ser mayores que los parámetros previstos en las normativas de confort térmico adaptativo.
Contribuciones: Se trata de un estudio piloto sobre las condiciones térmicas de las viviendas provisionales en el sur del país, demostrando que las personas que viven en este tipo de vivienda tienden a tener una mayor aceptabilidad térmica para el frío en relación con los parámetros normativos de confort térmico, mientras que el rendimiento térmico de la vivienda sigue las cambios microclimáticos del entorno exterior.

Palabras clave: confort térmico, aceptabilidad térmica, vivienda provisional, vulnerabilidad habitacional.

Introduction

There are different perspectives on the concept of adequate housing when considering social, historical, environmental, economic, political dynamics, and limited access to available material and immaterial resources (Fayazi & Lizarralde, 2013).

Inadequate housing conditions extend to the emerging population, comprised of groups of homeless individuals due to environmental catastrophes and social inequalities, as well as informal urban settlement groups constructing inadequate temporary housing with the available material resources, (Ramalhete, 2020), in order to seek better habitability and adaptability conditions, the majority of these dwellings surpass the provisional status, enduring for decades and even generations (Albadra, Coley, & Hart, 2018).

The exposure of individuals in housing vulnerability to climatic conditions tends to be unique among populations and cultures (Moran et al., 2021). The residents' adaptation methods and their ability to withstand temperature changes depend on access to opportunities and the possibilities of making modifications to the built environment in the pursuit of thermal comfort (Nicol & Roaf, 2017), it is also influenced by psychological and physiological adaptation, given the individual thermal experience (Ning, Wang, & Ji, 2016).

However, the number of articles on temporary housing is significantly lower than studies on permanent constructions (Zheng, Wu, Liu, Ding, & Yang, 2022). The majority of individuals living in temporary housing do not feel satisfied with the thermal environment (Albadra et al., 2018; Thapa, Rijal, & Shukuya, 2018; Domínguez-Amarillo, Rosa-García, Fernández-Agüera & Escobar-Castrillón, 2021; Zheng et al., 2022). Users' thermal perceptions depend on psychological, social, and environmental conditions, and the acceptable comfort limits outlined by ASHRAE 55 (2020) may be constrained in defining thermal acceptability in emergency conditions (Nicol, Bahadur Rijal, Imagawa, & Thapa, 2020).

Based on that, this study seeks to address the hypothesis that individuals living in situations of vulnerability tend to be more tolerant of thermal conditions in their environment. The objective is to investigate the thermal conditions of a temporary dwelling and the residents' perceptions regarding the thermal environment. This is an empirical work focusing on a case study of a temporary dwelling in Passo Fundo-RS, constructed with recycled materials and internally lined with Tetra Pak® packaging. The study analyzes data from internal and external temperatures collected in the field and users' responses to the thermal environment, referenced by the ASHRAE 55 (2020) standard on thermal comfort in naturally ventilated spaces.

The article addresses the theme of thermal comfort in temporary dwellings and the thermal adaptability of occupants to the climatic context. In the methodology, two field tests were adopted: temperature measurements and interviews with residents. Based on the results of these stages, the discussion focuses on the relationship of this research with studies published on the topic. Finally, in the conclusion, the study's contributions, limitations, and challenges for future research are presented.

Literature review

The concept of Adaptive Thermal Comfort is determined by the varied experiences, expectations, and behaviors of individuals concerning the climate. Individuals act as active agents in regulating thermal comfort based on their physiological, behavioral, and psychological characteristics, as well as the opportunities for adaptations provided by the design (Nicol & Humphreys, 2002; Humphreys & Nicol, 2018).

The adaptive comfort model serves as a guideline for the ASHRAE 55 (2020) standard, which assesses the thermal comfort of indoor environments in permanent buildings that do not use artificial mechanisms for thermal control. It is based on the association between internal and external temperatures (ASHRAE 55, 2020; Humphreys, Rijal & Nicol, 2013). However, thermal comfort vote scales may not accurately represent individuals' thermal preferences due to the influence of psychological, social, and cultural factors (Nicol & Roaf, 2017).

Local temperature data is more representative concerning individuals' adaptation to external temperature variations (Humphreys; Rijal; Nicol, 2013), when it comes to temporary constructions, the adaptive model is the primary method used in assessing thermal comfort. (Zheng et al., 2022).

Zheng et al. (2022) conducted a review of studies on thermal comfort in temporary buildings and identified that the neutral temperature of dwellings is related to climatic zones, environmental, individual, and structural factors, with the envelope (such as cabins, tents, and containers) being the primary influencing factor in thermal performance. Following the research by Albadra et al. (2018) e Domínguez-Amarillo et al. (2021), which found the low thermal performance and unsatisfactory evaluation of residents in container-type emergency shelters located in hot and humid climates in Jordan and Afghanistan.

Temporary buildings can have their structures thermally optimized using low-cost materials and passive thermal comfort measures based on the climate, such as natural ventilation and shading for temperate regions, and increased thermal inertia of the envelope for colder climates (Sagiroglu & Memari, 2018; Hamdan, Abd-Alhamid & Dabbour, 2021; Zheng et al., 2022).

In a study on the impacts of climate change on low-income housing in Brazil, Nunes e Giglio (2022) demonstrated that natural ventilation is the primary strategy for optimizing thermal performance in constructions, combined with the absorptance and thermal transmittance of the envelope.

Simultaneously, the study by Moran et al. (2021) demonstrated that project adaptations made empirically by residents can lead to unsatisfactory thermal performance.

Residential environments located in rural areas have lower thermal performance due to greater exposure to cold and higher dissatisfaction among residents compared to urban environments (Xiong, Liu & Kim, 2019). These factors are attributed to differences in resident behavior, building typology, and thermal capacity. The study by Xiang et al. (2022) on the impact of heatwaves in China showed that urban areas with physical barriers such as mountains form decentralized patterns of human occupation, presenting different patterns of exposure, sensitivity, and adaptation of individuals to thermal variations. The study observed a greater impact of climate on socially vulnerable areas.

The comfort temperatures of individuals living in naturally ventilated environments are diverse and variable, depending on external temperatures, the diversity of construction materials, and individuals' adaptability to respond to a discomfort event (Humphreys & Nicol, 2018; Tavakoli, O'Donovan, Kolokotroni, & O'Sullivan, 2022).

The study by Thapa et al. (2018) conducted in Nepal, a temperate climate region, demonstrated that thermal acceptability for more than 80% of residents living in temporary shelters was higher than what is defined as the comfort zone for the region. This encompassed a thermal range between 11ºC and 30ºC.

Limiting predefined temperatures as a comfort zone can lead to the exclusion of votes from individuals in extreme or unusual conditions, such as in emergency situations where concerns about thermal comfort become irrelevant. Resilience metrics vary according to thermal conditions, exposure time, types of buildings, and forms of occupation (Nicol, 2019; Nicol et al., 2020; Siu et al., 2023).

Individuals living in housing vulnerability are more exposed to climatic events and imminent environmental risks, with impacts on the health and quality of life of the occupants.

According to Zheng et al. (2022), thermal comfort is one of the primary factors affecting the physical condition and mental health of users. In the adaptive thermal comfort model, thermal resilience considers the relationship between the exposure time to thermal stress and the limit of the occupant's adaptive capacity. However, occupants may be unable to cope with prolonged exposure in more extreme conditions (Nicol, 2019; Tavakoli et al., 2022; Siu et al., 2023).

According to the study by Malik e Bardhan (2023) in India, low-income residents showed lower sensitivity to low temperatures, revealing an inconsistency between average temperatures and thermal acceptability ranges compared to the standards of existing models.

Nicol (2019) suggested the development of research with new definition methods that include different forms and contexts in the assessment of thermal acceptability limits.

Similarly, according to Malik e Bardhan (2023) thermal comfort standards are influenced by economic and sociocultural contexts. The construction of a comfort model should integrate the thermal perception and adaptability of low-income residents through contextualized analyses. The range of temperatures occurring in indoor environments can be considered acceptable depending on their experiences and individual circumstances (Nicol et al., 2020).

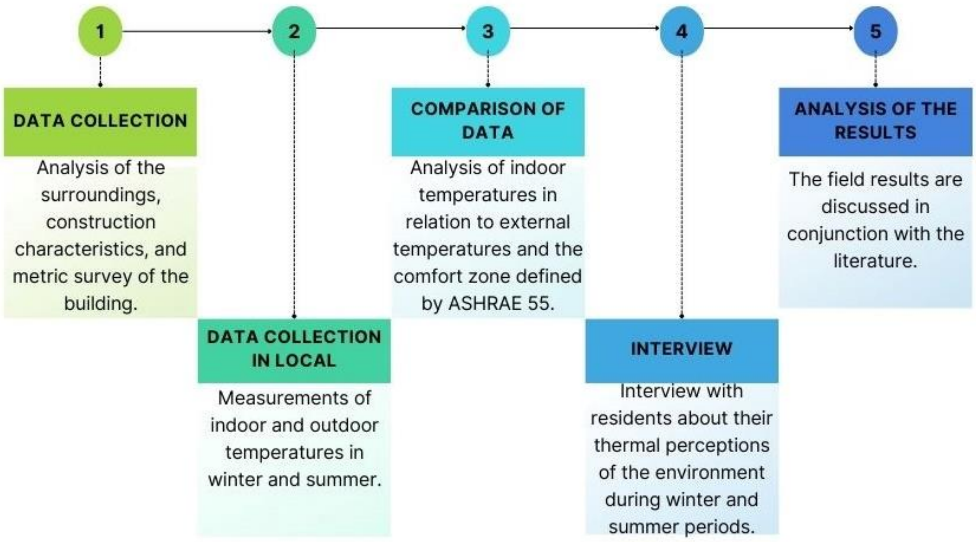
Methodology

The definition of housing was based on the ease of contact with the family and, primarily, on their willingness to participate in the research.

The research methodology was divided into five stages, as described in the research methodology flowchart presented in Figure 1.

Figure 1

Research methodology flowchart



Source: Author's own work (2023)

Guidelines for collecting temperatures in indoor and outdoor environments follow the parameters established by the ASHRAE 55 (2020) standard regarding sensor placement, calibration, and data verification.

Similarly, the formulation of questions was based on the ASHRAE 55 (2020) standard for longitudinal investigations, adapting the questions to a language accessible to the residents.

Climate description

The city of Passo Fundo/RS has a Temperate Climate, of the Subtropical type, with an annual average temperature of 17.70°C and well-distributed rainfall throughout the year.

According to the historical series records from 1981 to 2010 from the National Institute of Meteorology (INMET, 2021), the month of July has lower temperature averages, reaching 12.4°C, a period when cold waves with negative temperatures occur. In contrast, during the summer, the month of January has the highest temperature averages, reaching 22.4°C.

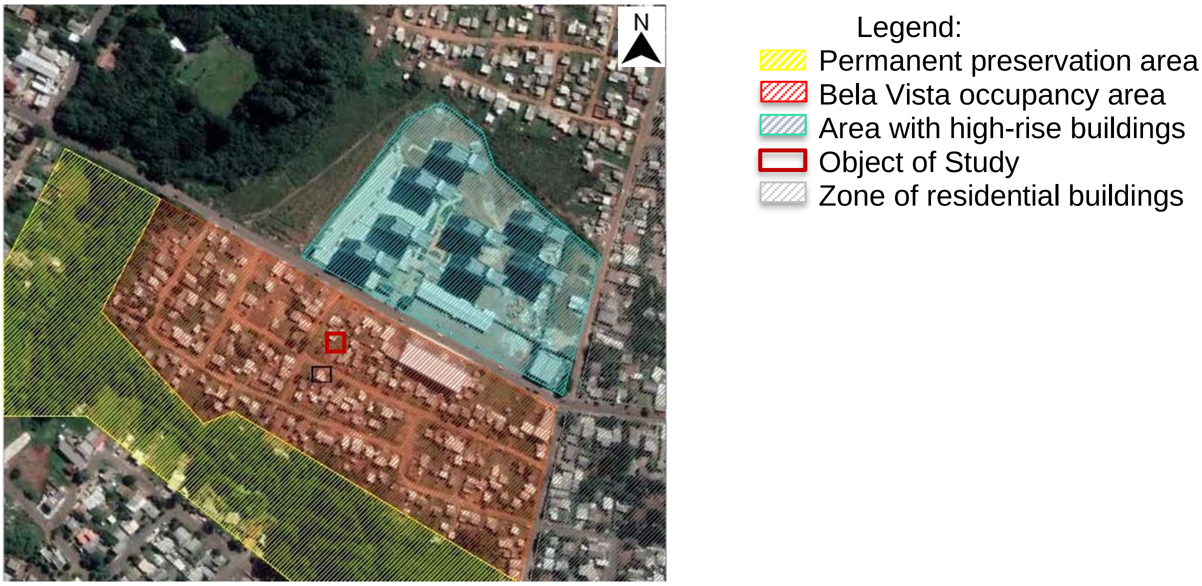
Surrounding area

The occupation area known as "Bela Vista Occupancy" is located near the urban center of the municipality, surrounded by a Permanent Preservation Area (PPA) with large vegetation and the tributary of the Passo Fundo River (Figure 2).

The main access to the occupation is through a main road that divides the occupation area from the area of high-rise buildings.

Figure 2

Urban Surroundings of Bela Vista Occupancy



Source: Author's own work (2022)

The typology of the buildings in the vicinity of the occupancy is predominantly residential, with two-story constructions and vertical blocks built on a plot opposite to the occupancy (Figure 3).

Figure 3

Bela Vista occupancy area

Source: Author's own work (2021)

In the occupancy area, around 150 families are settled, living in dwellings lacking basic infrastructure such as water supply, adequate sanitation, and regular electrical installations.

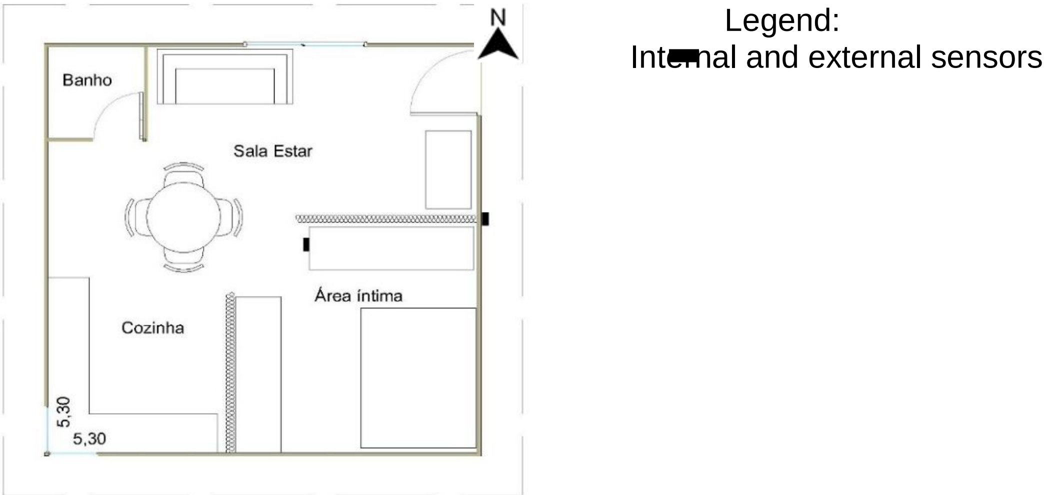
All the houses built in the occupancy are single-story buildings, arranged on regular plots and blocks, with circulation between the block units.

Description of a dwelling in Bela Vista Occupancy (case study)

The dwelling has dimensions of 5.30m x 5.30m (total area of 28.09m²), a ceiling height of 2.50m (average height), and a 0.30m gap from the internal wooden floor to the natural ground. The bedroom and social area are separated by a curtain and a wardrobe, with a single partition wall delineating the bathroom (Figure 4).

Figure 4

Illustrative floor plano f the dwelling



Source: Author's own work (2022)

The main facade is oriented to the North, featuring a primary glass window with a sliding opening system, serving as the main source for illuminating and ventilating the internal space, in addition to the main entrance door, which faces the East facade.

There are two transparent openings in the kitchen area, equipped with a limited opening control mechanism, adapted from a wooden frame and closed with transparent acrylic. According to the floor plan (Figure 4), it is possible to identify the proximity between the main openings, which ends up hindering the air renewal in the internal environment.

Figure 5

External facade (a) and internal environment (b)

(a) (b)

Source: Author's own work (2021)

The construction materials used include reclaimed wood for external walls and a single internal partition for the bathroom, with a thickness of 25.4mm. Fiber cement tiles are used for the roof, and a simple 3mm glass window (Figure 5(a)). The furniture is adapted to the space, situated near the main door, alongside the wood stove — the sole equipment used for heating the environment on cold days (Figure 5(b)).

In Figure 5(b), the interior of the building can be observed with the application of carton packaging. To facilitate installations in homes, volunteers from the BSF Project (2020) developed a modulation with boards formed by packaging, measuring 0.30m in width and 1.10m in length, stapled onto a frame of wooden slats with a thickness of 0.015cm. The floor is made of non-planed wood, allowing thermal exchange between the internal floor and the natural ground due to the gaps.

Data Collection for Temperature

The field data collection followed the normative parameters of ASHRAE 55 (2020), adhering to guidelines regarding the placement of sensors in the environment, calibration, and verification of air temperature and relative humidity records (data on relative humidity will not be analyzed in this study).

The internal equipment was installed in the center of the living/kitchen area, at a height of 1.10m from the floor, following the criterion for locations where occupants stand (ASHRAE 55, 2020).

According to the standard, the recording interval should be between 1 and 5 minutes. The equipment was configured for recordings every 1 minute.

The measurement period was 15 days in both seasons, summer and winter.

Measurement days were conducted as following: during the winter, between July 25, 2021 at 12:00 a.m. and August 11, 2021 at 12:00 a.m. During the summer, between January 5, 2022 at 12:00 a.m. and January 21, 2022 at 12:00 a.m.

The device used for recording temperature and humidity data in the internal environment was the ONSET HOBO® Datalogger model, with a range between -20ºC to 70ºC and humidity up to 100%.

The measurements of external environmental conditions were recorded by the ELITECH® RC-4HC Datalogger model sensor, with a recording range between -40ºC and 85ºC for temperature and a 99% limit for relative humidity.

The external sensor was protected against direct solar radiation incidence on the equipment. The device was placed in a perforated white plastic box, allowing ventilation of the internal space and protection of the equipment against solar radiation. The box was positioned at an average height of 3.00m above the natural ground, protected by the housing's roof.

Before field measurements, all sensors were calibrated. The equipment's margin of error limits is a maximum of 0.5ºC for temperature and +/-5% for relative humidity (ASHRAE 55, 2020). The standard deviation observed in the calibration of the equipment was 0.2 for temperature records and 0.1 for relative humidity records.

Adaptive Thermal Comfort Indices - ASHRAE 55

To estimate the thermal acceptability of the housing's occupants, the criteria of the ASHRAE 55 standard (2020) for naturally ventilated environments were employed.

The parameters described by ASHRAE 55 (2020) were calculated using Equations 1 and 2 below. The calculation utilizes the externally recorded temperatures at the location. Eq. 1 determines the mean limit for cold conditions, and Eq. 2 determines the mean limit for warm conditions (ASHRAE 55, 2020):

$$0{,}31 \times \text{external mean temperature} + 21{,}3 \quad \text{(Equation 1)}$$

$$0{,}31 \times \text{external mean temperature} + 14{,}3 \quad \text{(Equation 2)}$$

Thus, it is possible to assess the percentage of hours in thermal comfort and discomfort based on external temperatures and compare them with internal temperatures, considering a thermal acceptability index for 80% of individuals.

Interviews with residents

In this phase of the research, the goal was to gather information about residents' perceptions of the thermal environment during winter and summer periods.

The interview was conducted with three adult female residents, aged between 20 and 40, during the summer. Due to the wait for approval of the questionnaire's applicability with the residents by the Research Ethics Committee (CEP), there was insufficient time to conduct the interview in both seasons (winter and summer) and during the measurement periods (cross-sectional study), which characterizes a longitudinal investigation of the case study.

The structured interview comprised 10 objective (closed) questions and 2 open-ended questions, adapted to a language close to the social context of the interviewees, ensuring the confidentiality and anonymity of the responses.

The questionnaire model was adapted from the ASHRAE 55 (2020) standard, with questions that could generally express the thermal satisfaction of residents with the environment in winter and summer periods, as well as the causes of thermal discomfort.

The questions include inquiries about thermal perceptions, ways of using the internal space, the main factors that can cause thermal discomfort, and the strategies used by residents to minimize discomfort during these periods.

Results

The field measurement with the sensors during the winter was carried out between July 28, 2021, and August 11, 2021, recording the difference between indoor (SI) and outdoor (SE) temperatures from a central point in the indoor environment, the area where residents spend the most time.

In

Table *1*, it is possible to see the minimum, average, and maximum temperatures recorded during the period. Note the days from July 28 to July 30, 2021, with negative temperatures, considered critical days due to an intense cold wave that affected the region.

Table 1

Mean external (Sensor E) and internal (Sensor I) temperatures for Winter

°C Day	SE Min. Temp.	SE Max. Temp.	SE Mean Temp.	SI Min. Temp.	SI Max. Temp.	SI Mean Temp.	Difference in mean temp. SI - SE
July,28th	0	11,9	4,3	1,4	8,6	5,3	1,0
July,29th	-1,4	10,7	3,5	1,7	10,5	6,2	2,7
July,30th	-3,1	16,1	5,4	0,1	15,0	7,5	2,1
July,31th	4,0	19,4	10,0	5,1	17,8	10,6	0,6
Aug, 1st	5,4	22,7	12,7	9,0	20,5	13,7	1,0
Aug, 2nd	1,8	22,7	10,6	5,1	19,1	12,1	1,5
Aug, 3rd	3,5	20,3	10,9	6,5	19,2	12,6	1,7
Aug, 4th	4,0	20,4	11,8	7,2	19,2	13,3	1,5
Aug, 5th	9,7	22,2	15,2	11,4	20,9	15,7	0,5
Aug, 6th	12,3	22,2	15,9	13,1	21,7	16,8	0,9
Aug, 7th	12,9	25,4	17,8	14,3	23,9	18,6	0,8
Aug, 8th	13,5	28,0	18,7	15,1	26,5	19,7	1,0
Aug, 9th	13,9	28,5	19,9	15,1	26,1	20,1	0,2
Aug,10th	11,1	17,9	14,0	13,8	20,4	16,5	2,5
Aug,11th	5,8	15,7	10,9	8,1	15,8	12,7	1,8
Mean	6,2	20,3	12,1	8,5	19,0	13,4	1,3

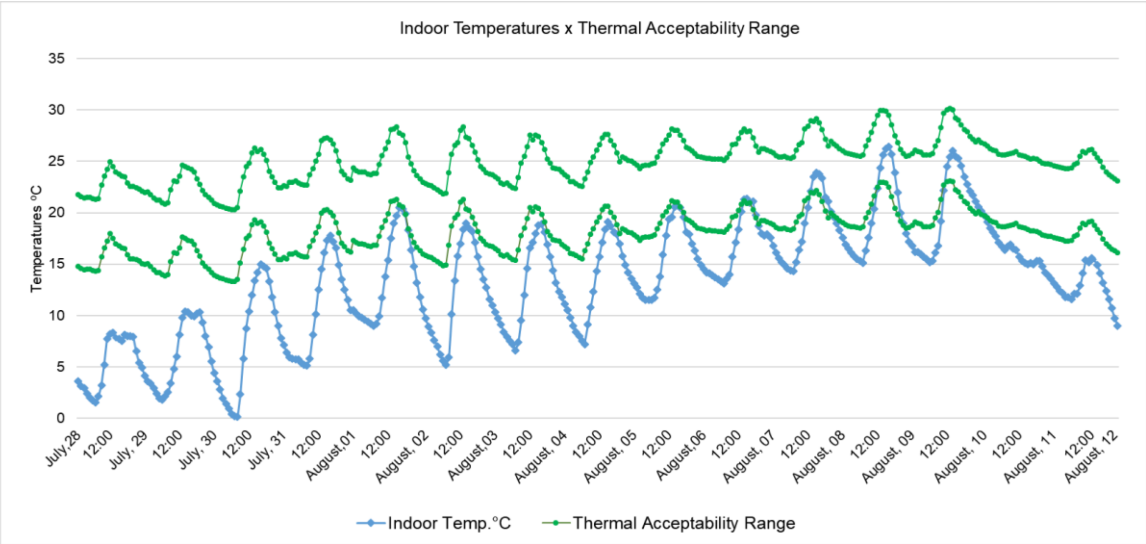
Source: Author's own work (2021)

Observing the proximity of minimum temperatures between indoor and outdoor environments, it is noticeable that this closeness represents the low thermal capacity of the structure, preventing the environment from staying warm for a longer period. During times when the environment remained occupied, such as at night, the thermal difference between the environments reached an amplitude of up to 5°C due to the use of the wood-burning stove to heat the space. However, this condition does not persist throughout the night due to the fragility of the housing structure.

In Figure 6, temperatures indoors were related to the thermal comfort zone defined by ASHRAE 55 (2020).

Figure 6

Thermal acceptability range based on external temperatures (Sensor E) and its correlation with internal temperatures (Sensor I) - Winter



Source: Author's own work (2022)

According to Figure 6, it is possible to identify that for a significant part of the evaluated period, internal temperatures (blue line) were below the considered thermal comfort zone (green lines).

Table *1* demonstrates linearity and minimal thermal difference between the average temperatures of the environments, characteristic of structures with low thermal inertia, like the majority of shelters with a similar construction pattern.

The residents asserted being very dissatisfied thermally with the environment during this period.

According to the interviews, the preference is to be in the living/kitchen area to stay close to the wood-burning stove, as evidenced by the proximity of temperatures between the environments during occupancy hours. The main window remains closed, while the front door of the house is left open during the day.

In addition to using the wood-burning stove while in the living/kitchen area, residents use rugs and tarps on the floor to block the entry of wind through the gaps in the structure. As external temperatures rise, these elements are removed.

All residents believe that the most critical periods of cold occur in the morning and during the night, "from 10 pm until dawn," according to verbal information from one of the residents. For them, the main element of thermal discomfort in the cold is the wooden floor with gaps and the unwanted ventilation that permeates through the openings.

Field measurements during the summer were conducted between January 7, 2022, and January 21, 2022, recording the difference between indoor temperatures (SI) and outdoor temperatures (SE) from the same central point in the indoor environment as in the previous data collection.

Table ***2*** displays the minimum, average, and maximum temperatures recorded during the period. Note the days on January 17 and January 18 with the highest recorded temperatures, considered critical due to an intense heatwave, leading to increased temperatures and low relative humidity, resembling arid climatic conditions.

Table 2

Mean external (Sensor E) and internal (Sensor I) temperatures for summer

°C Day	SE Min. Temp.	SE Max. Temp.	SE Mean Temp.	SI Min. Temp.	SI Max. Temp.	SI Mean Temp.	Difference mean temp. SI - SE
Jan,07th	13,5	28,5	21,3	15,5	29,2	22,2	0,9
Jan,08th	16,0	30,2	22,6	17,7	28,5	23,1	0,5
Jan,09th	15,9	28,1	21,5	17,9	28,5	22,8	1,3
Jan,10th	16,9	32,2	24,2	19,2	32,0	25,0	0,8
Jan,11th	18,1	32,1	25,8	20,7	33,2	26,6	0,8
Jan,12th	13,3	35,3	25,9	17,1	34,0	26,4	0,5
Jan,13th	18,9	35,7	27,9	21,6	35,1	28,1	0,2
Jan,14th	21,5	35,4	26,2	23,8	33,2	27,3	1,1
Jan,15th	20,9	36,1	25,2	23,1	32,2	26,1	0,9
Jan,16th	20,3	37,4	28,3	21,9	35,3	27,9	-0,4
Jan,17th	21,5	38,3	29,2	23,2	36,8	29,2	0
Jan,18th	21,7	38,8	27,2	23,2	35,8	27,6	0,4
Jan,19th	19,9	38,2	27,9	22,5	34,5	28,0	0,1
Jan,20th	21,7	37,9	29,1	23,9	36,6	29,5	0,4
Jan,21th	22,0	38,3	29,5	24,1	37,4	30,1	0,6
Mean	18,8	34,8	26,1	21,0	33,5	26,7	0,5

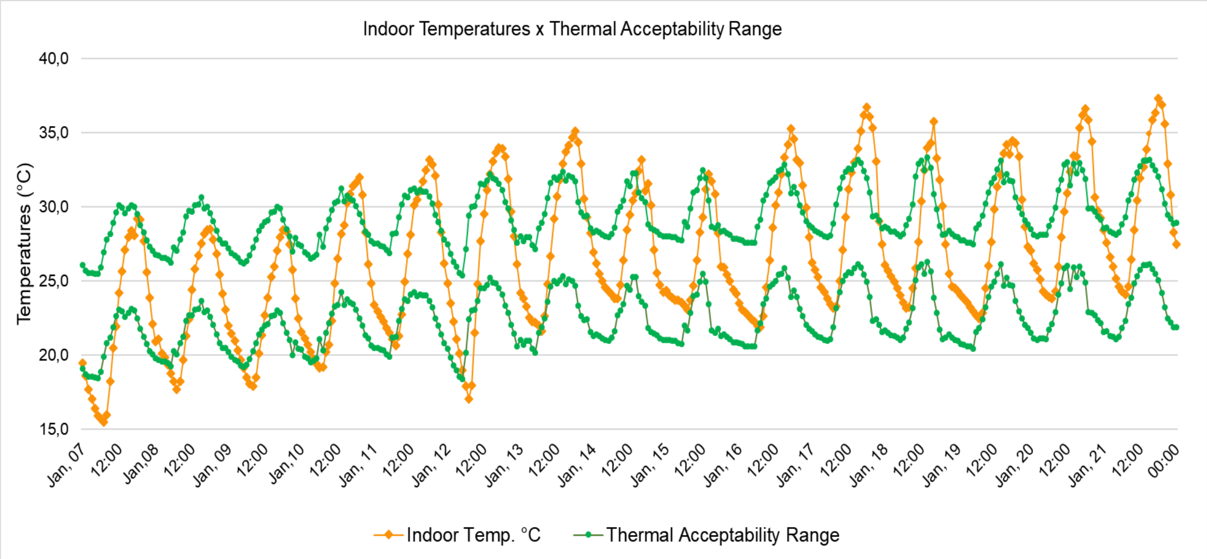
Source: Author's own work (2022)

On January 18th, the external maximum temperature reached 38.8°C, while the internal maximum reached 35.8°C. Although the difference between the average internal and external temperatures is minimal, it is observed that during peaks of external temperature, the internal maximum temperatures showed a difference greater than 3°C on some days, especially on January 17th, 18th, and 19th.

This behavior may be related to the presence of the radiant barrier of aluminum in Tetra Pak® packaging, as it is considered a material with low emissivity, leading to a decrease in heat radiation to the opposite surface, especially during periods of higher heat radiation. Figure 7 shows the relationship between internal temperatures and the thermal comfort zone defined by ASHRAE 55 (2020).

Figure 7

Thermal acceptability range for external temperatures (Sensor E) and the relationship with internal temperatures (Sensor I) Summer



Source: Author's own work (2022)

According to

Figure ***7***, it was possible to verify that the internal temperatures (orange line) were largely within the thermal comfort range (green lines). The linear thermal behavior of temperatures between environments is due to the vulnerable structure of the dwelling. Periods of temperature peaks that exceed comfort conditions, above 32°C, are noticeable.

According to the perceptions of the residents, summer was considered a period of greater acceptability and thermal neutrality.

In extreme heat conditions, residents prefer to be outdoor, especially during the noon hours. During this time interval, surface heating increased due to greater solar radiation incidence, combined with internal heat generation due to cooking activity, contributing to the sensation of thermal discomfort. In periods of extreme discomfort because of the heat, the use of fans does not contribute to cooling the environment, and there is no vegetation in the surroundings that provides any shading for the dwelling.

Discussions

This study's main contribution lies in the analysis of the thermal performance of a temporary, precarious dwelling in the Brazilian context under a subtropical climate, along with the residents' perceptions regarding the thermal environment within their limitations.

The majority of irregular dwellings found in Brazil do not exhibit a standardized project typology, unlike what is commonly found in the literature when defining the term "temporary dwellings/shelters" (Albadra et al., 2018; Sagiroglu & Memari, 2018; Moran et al., 2021). The dynamics of occupations in the country are linked to social inequality and urban poverty, leading to various forms of adaptation to the context. In this case study, residents use Tetra Pak® packaging as internal cladding to mitigate thermal discomfort caused by gaps in the structure.

The main methods applied in research on thermal comfort in temporary housing were utilized in this study, including temperature measurements and interviews with users, despite potential limitations in methodological variables that could be complemented by analyses in future research, such as wind speed around the building.

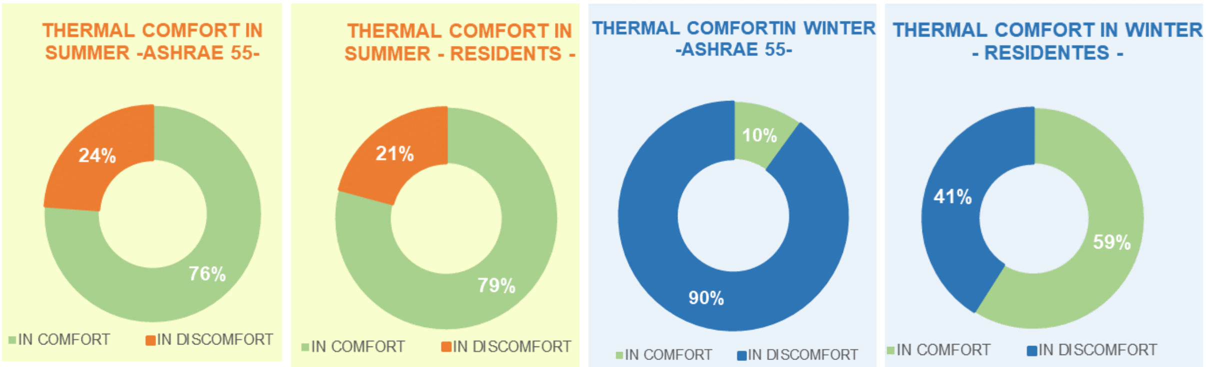
From the results obtained in the field measurements, it was possible to calculate the thermal comfort levels for the indoor environment, as presented in the graphs in Figures 6 and 7.

Additionally, the thermal comfort votes of the residents and their perceptions were transcribed in comparison to the thermal comfort levels defined by ASHRAE 55 (2020).

Figure ***8*** illustrates these comparisons between measurements during summer and winter, highlighting periods that residents identified as lower thermal acceptability.

Figure 8

Thermal comfort and thermal acceptability for summer and winter



Source: Author's own work (2023)

From

Figure ***8***, it is noticeable that during the summer period, the comparison between the ASHRAE 55 results and the intervals of thermal comfort and discomfort reported in the interviews were very close. For this analysis, the period between 10:00 a.m. and 2:00 p.m. was determined as a period of discomfort with heat, according to the residents' descriptions. It was also the period when the highest external temperatures were recorded.

However, the greatest divergence occurred during the winter period because, according to ASHRAE 55 (2020), residents would be in discomfort for 90% of the time. However, interviewees described discomfort with the cold occurring at certain periods of the day (from 10:00 p.m. until dawn), presenting an estimated discomfort of 40%. In this analysis, the interval between 10:00 p.m. and 8:00 a.m. of the next day was determined as the period of greatest discomfort with the cold, as pointed out by the residents, and also when lower external temperatures were recorded.

The application of packaging material is considered the main strategy for thermal comfort, with high acceptability among residents. However, alternative adaptation strategies for heating the environment, such as using a wood stove and placing carpets on the floor during winter, are tactics employed by residents to provide more comfortable periods within the indoor space while staying in the living room/kitchen area.

According to the research by Humphreys and Nicol (2018), thermal comfort temperatures are not static, and individuals' thermal acceptability conditions may span a wider thermal range than established in standards, below 15°C and above 30°C. This scenario is associated with the results shown in Figures 6 and 7, where the average temperatures during the periods of greater acceptability by the residents reached 15°C in winter – a discomfort condition according to ASHRAE 55, where the average temperatures were 21°C in winter – and 26°C in summer, a distribution that falls within the comfort zone.

In Nicol et al. (2020) research, the combinatorial analysis between temperatures and the thermal acceptability of residents demonstrated a thermal range between 11ºC (winter) and 30ºC (summer). These results may also suggest new evidence for a thermal comfort database that is not limited to the standard distribution (Nicol et al., 2020).

The concept of adaptive thermal comfort is central to addressing issues of thermal acceptability and optimizing strategies that increase the adaptive capacity of individuals by including other typologies, different social contexts, and more extreme climatic conditions (Humphreys & Nicol, 2018; Nicol et al., 2020; Zheng et al., 2022).

According to Xiong et al. (2019) Xiang et al. (2022) e Malik e Bardhan (2023), residents in situations of social vulnerability tend to exhibit higher thermal acceptability compared to existing model standards. However, most of the time, people live under the same external climatic conditions (Thapa et al., 2018).

The results also demonstrate that the physical structures of the temporary housing typology are more susceptible to changes in external temperatures, with greater heat loss during the nighttime period (Thapa et al., 2019; Domínguez-Amarillo et al., 2021). The limitation of available material resources leads to solutions considered adequate by the residents, but these may not be ideal for improving their housing conditions (Moran et al., 2021).

Passive cooling measures in the summer and heating measures in the winter prove to be more effective strategies for achieving thermal comfort in housing projects (Xiong et al., 2019).

The optimization of the thermal performance of temporary housing structures for the climate primarily involves increasing the thermal inertia of the envelope. This is limited to materials with low added value and greater availability, such as the use of cellular polyethylene (Sagiroglu & Memari, 2018; Thapa et al., 2019).

In hotter periods, cross-ventilation could facilitate the cooling of the environment. Simultaneously, an appropriate solar orientation guided by technical direction in the project can lead to improvements in the thermal performance of this type of housing (Moran et al., 2021; Hamdan et al., 2021; Nunes & Giglio, 2022).

Access to alternatives to modify the thermal condition of individuals within their environment depends on their social context, coupled with physiological and psychological characteristics, stemming from each individual's thermal experience (Nicol & Roaf, 2017; Nicol & Humphreys, 2018).

Conclusion

Due to lack of research on thermal comfort in temporary housing in Brazil, the most significant contribution of this study was to demonstrate the thermal conditions of a temporary dwelling located in a region with low winter temperatures. The dwelling uses cardboard packaging to optimize thermal comfort in the internal environment, particularly during cold periods.

The main theoretical contribution of this research demonstrated that people living in more precarious housing conditions tend to have higher acceptability to the thermal environment compared to parameters determined by ASHRAE 55 regarding thermal comfort in naturally ventilated environments, as also found in the literature.

The thermal conditions of temporary housing typologies tend to reflect changes in external microclimates, highlighting the importance of related research that demonstrates projections of the impacts of extreme climatic events on populations living in vulnerability.

This study did not intend to claim sole ownership of the results found above. The main practical contributions are related to the limitations of the research itself, following some methodological strategies found in the literature, such as measuring internal and external temperatures and analyzing residents' perceptions of the thermal environment without assessing wind incidence on the building, as well as not including other dwellings and a larger group of people in field evaluations, for example.

This research focused on the thermal differences in the analyzed dwelling, the thermal lag between environments, and residents' perceptions of the internal environment, considering the feasibility conditions of the research and the analytical capacity of the context. However, this is one of the first studies investigating thermal acceptability and performance of temporary dwellings and shows that more studies are needed in order to have advanced discussions within the Brazilian scenario and its cultural, social, and environmental diversity.

Within this perspective for future research, the following methods are suggested:

a) Evaluation of other construction typologies, such as mixed dwellings that use wood and masonry, as they are also employed typologies, within a longer period than 15 days, beyond what ASHRAE 55 (2020) considers as the minimum time;
b) Evaluation of other climatic scenarios within the Brazilian territory. Vulnerable groups living in semi-arid regions, for example, experience extreme heat and low humidity conditions, using local materials available for improving the thermal comfort of their dwellings.
c) For thermal comfort assessments with residents, it is necessary to include a larger number of interviewees highlighting the main factors of thermal discomfort, the strategies adopted to minimize the impact of the climate, both individually and in the building, and in which model and construction characteristics are being evaluated. Since irregular constructions vary widely, this will create a more comprehensive database.
d) Include aspects of wind speed and direction on buildings. In a scenario where there is no artificial air conditioning, wind has a significant impact on the thermal sensation of the occupants.
e) Contemplate studies of prototypes that have similar physical characteristics, and from these models, comparisons can be made, evaluating a model that integrates passive comfort conditioning measures and a model without the adoption of these solutions.

The reduction of housing inequalities needs to include techniques of local interventions with communities, allowing the preparation of these communities for future climate, socio-environmental, and health crises, which are expected to be more frequent.

Therefore, the greater the number of studies on the thermal conditions of temporary housing for vulnerable populations, the more initiatives and participatory actions can help in projects aimed at minimizing the consequences of socio-environmental inequality that affect the most vulnerable populations.

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