parc pesquisa em arquitetura e construção
research in architecture and construction
ISSN 1980-6809 | https://doi.org/10.20396/parc.v17i00.8679710

Assessment of User Thermal Resilience in Social Housing

Talita Marini Brandelli [1]
Universidade Federal de Pelotas, Pelotas, RS, Brazil

Nébora Lazzarotto Modler [2]
Universidade Federal da Fronteira Sul, Erechim, RS, Brazil

Luiz Antonio dos Santos Franz [3]
Universidade Federal de Pelotas, Pelotas, RS, Brazil

Thaísa Leal da Silva [4]
Atitus Educação, Passo Fundo, RS, Brazil

Júlia da Cruz Lopes [5]
Universidade Federal de Pelotas, Pelotas, RS, Brazil

Eduardo Grala da Cunha [6]
Universidade Federal de Pelotas, Pelotas, RS, Brazil

Nirce Saffer Medvedovski [7]
Universidade Federal de Pelotas, Pelotas, RS, Brazil

Abstract

The replication of Social Housing (SH) units without considering regional climatic specificities often compromises thermal performance and residents' well-being. This study proposes and tests a method to assess users' thermal resilience, understood as their ability to adapt to indoor thermal conditions through behavioral and perceptual adjustments. A pilot study was conducted during the summer in a housing complex located in Pelotas, southern Brazil, integrating three analytical dimensions: (a) thermal comfort level calculated according to ASHRAE Standard 55 (ASHRAE, 2020); (b) users' thermal perception; and (c) artificial acclimatization strategies adopted. The methodology included thermal monitoring of buildings using sensors and the administration of a questionnaire to residents. The results revealed a discrepancy between objective and subjective assessments: although indoor environments remained within the ASHRAE Standard 55 comfort zone for more than 82% of occupied hours, between 79% and 83% of residents reported heat-related discomfort, indicating that the standard's upper threshold may not represent local comfort conditions. The proposed qualitative matrices enabled the classification of users as resilient, non-resilient, or typical, showing that most rely on artificial cooling to achieve comfort and are therefore non-resilient. The study contributes to advancing research on thermal resilience by introducing a user-centered method that integrates physical measurements and perceptual data. This approach broadens the understanding of adaptive behavior in social housing and supports the development of design and evaluation strategies suitable for subtropical climates.

Keywords: thermal comfort, thermal resilience, user resilience, Social Housing.

Avaliação da Resiliência Térmica do Usuário em Habitação de Interesse Social

Resumo

A replicação de unidades de Habitação de Interesse Social (HIS) sem considerar as especificidades climáticas regionais frequentemente compromete o desempenho térmico e o bem-estar dos moradores. Este estudo propõe e testa um método para avaliar a resiliência térmica dos usuários, compreendida como a capacidade de adaptação às condições térmicas internas por meio de ajustes comportamentais e perceptivos. Um estudo piloto foi conduzido durante o verão em um conjunto habitacional de Pelotas (RS), integrando três dimensões analíticas: (a) nível de conforto térmico calculado conforme a norma ASHRAE Standard 55 (ASHRAE, 2020); (b) percepção térmica dos usuários; e (c) estratégias de aclimatação artificial utilizadas. A metodologia incluiu o monitoramento térmico das edificações através de sensores e aplicação de questionário com seus usuários. Os resultados revelaram uma discrepância entre as avaliações objetivas e subjetivas: embora os ambientes internos tenham permanecido dentro da zona de conforto da ASHRAE Standard 55 por mais de 82% das horas ocupadas, entre 79% e 83% dos moradores relataram desconforto por calor, indicando que o limite superior da norma pode não refletir as condições locais de conforto. As matrizes qualitativas propostas permitiram classificar os usuários como resilientes, não resilientes ou típicos, mostrando que a maioria depende de resfriamento artificial para alcançar conforto, sendo, portanto, não resiliente. O estudo contribui para o avanço da pesquisa em resiliência térmica ao introduzir um método centrado no usuário, que integra medições físicas e dados perceptivos. A abordagem amplia a compreensão do comportamento adaptativo em habitações de interesse social e apoia o desenvolvimento de estratégias de projeto e avaliação adequadas aos climas subtropicais.

Palavras-chave: conforto térmico, resiliência térmica, resiliência do usuário, Habitação de Interesse Social.
Financiamento: Não aplicável.

CC BY

Conflitos de interesse: Os autores certificam que não têm interesse comercial ou associativo que represente um conflito de interesses em relação ao manuscrito.
Aprovação ética: Esta pesquisa foi aprovada pela Plataforma Brasil/Comitê de Ética em Pesquisa sob o número de protocolo CAAE 65363922.7.0000.5317.
Disponibilidade de dados e material: Não aplicável.
Histórico: submetido em 25.04.2025, aprovado em 13.06.2025, publicado em 20.07.2026
Editores Responsáveis: Arthur Santos Silva, Felipe Corres Melachos

1. Introduction

The demand for homeownership in Brazil is largely dependent on public policies aimed at addressing deficiencies in the housing sector, providing incentives and financial resources. These policies not only ensure the right to housing but also drive economic growth, recognizing adequate housing as fundamental to the country's development. An example is the federal program "Minha Casa Minha Vida" (MCMV), initiated in 2009, which aims to meet the demand for homeownership among the low-income population. However, the prioritization of real estate market interests by MCMV has led to some limitations in the quality of Social Housing, such as low-quality architectural designs and construction techniques (Amore; Shimbo; Rufino, 2015; Pinto, 2016; Bortoli, 2018; Araujo, 2020).

These limitations result in issues such as dimensional inadequacies, construction defects, and thermal discomfort, leading residents to employ adaptation solutions such as alterations to the layout or excessive use of air conditioning (Villa; Oliveira, 2021; Bavaresco et al., 2021; Wang et al., 2019). These strategies for adapting and transforming the built environment can also be seen as the resilience capacity of individuals to anticipate, adapt to, and transform the inhabited space as a means of preservation against adversities (UN-Habitat, 2022).

Currently, the built environment is more vulnerable than ever to the impacts of climate change, therefore, incorporating resilience requirements into the built environment is essential, and this transformation into a more resilient environment can enable individuals to have the capacity to withstand and adapt in response to any disturbance that may occur, in the short or long term (Al-Humaiqani; Al-Ghamdi, 2022).

Bortoli and Villa (2020) argue that, due to climate change being prominent among the current challenges of our planet, it is essential for Social Housing to be resilient and capable of adapting to the local climate. It can be stated that the resilience to climate change in housing will be greater the deeper the understanding and awareness of the topic (Nunes; Giglio, 2022). In this context, the study of resilience begins from a thermal perspective.

The present research considers thermal resilience as the capacity of a building to maintain internal temperatures within pre-established limits or to enable adaptability of individuals, supported by Schweiker (2020).

Therefore, the present study aims to assist in the analysis of thermal resilience by creating qualitative matrices within a Post-Occupancy Evaluation. Supported by Tavakoli et al. (2022), Zhao, Lian, and Lai (2021), Schweiker (2020), and Lomas and Giridharan (2012), the present research acknowledges that the adaptive thermal comfort model can be used to assess user thermal resilience.

Overall, the model captures resilient behavior of the user. Therefore, the evaluation of the present study is based on the adaptive model of ASHRAE Standard 55 (ASHRAE, 2020). The focus is on analyzing the resilient behavior of building occupants under normal operating conditions, seeking to understand how they accept and experience thermal discomfort and adapt passively or actively.

The contribution of the present work is the presentation of a method to determine the user's thermal resilience based on the integration of the environment's thermal comfort level, calculated from ASHRAE Standard 55 (ASHRAE, 2020), in the thermal comfort level perceived by users, and in the artificial acclimatization strategies used by them.

2. Theoretical background

The expression “resilience” has been a topic of focus in the last decade, is used in different domains of literature and science (D’Agostino et al., 2023; Tavakoli et al., 2022; Attia et al., 2021; Schweiker, 2020; Martin; Sundley, 2015; Pickett et al., 2014). Initially associated with the ability to return to balance after disturbance, resilience began to focus on a dynamic approach in other areas of knowledge, highlighting the ability to adjust to changing conditions and respond to different pressures (Hassler; Kohler, 2014; Laboy; Fannon, 2016). Currently, it is also applied to evaluate the persistence of people, objects or systems in the face of challenges, highlighting the ability to transform difficulties into positive opportunities (Garcia; Vale, 2017). Although definitions vary, there is a correlation between contexts and fundamental principles, which remain consistent over time, being adapted by different disciplines to meet their specific needs (Tavakoli et al., 2022).

The increase in temperature, driven by climate change, is a global concern, therefore, buildings play a crucial role in protecting their occupants (Samuelson; Baniassadi; Gonzalez, 2020). From the above, it is noted that the thermal resilience approach is essential to assess the climate mitigation and adaptation potential of buildings in cities (Samuelson; Baniassadi; Gonzalez, 2020; Siu et al., 2023). Schweiker (2020) defines thermal resilience in the case of a building as the ability to maintain internal temperatures within established limits or allow people to adapt.

Based on the literature review conducted on thermal resilience, it is evident that the risk of overheating is being studied in buildings both without mechanical cooling (Lomas; Giridharan, 2012) and in well-insulated buildings during extreme events such as power outages in summer, for example (Ozkan; Good, 2022; Kesik; O'Brien; Ozkan, 2020; Baniassadi; Heusinger; Sailor, 2018; Fosas et al., 2018).

Siu et al. (2023) and Ji et al. (2023) highlight the need to assess and quantify the thermal resilience of buildings to extreme weather conditions, particularly in relation to power outage events. D’Agostino et al. (2023) propose metrics for quantifying passive and active thermal resilience, depending on location and climate. The method developed was tested in five European climatic zones using computational simulation, under normal operating conditions and during an extreme event.

In another line of study on thermal resilience, there is a focus on urban heat resilience (Lim et al., 2022; Croce; Vettorato, 2021; Diz-Mellado et al., 2023; Xiang et al., 2022). Another line of study focuses on resilient cooling and the passive survivability of the buildings, studied by Ahmed, Kumar, and Mottet (2021), Miller et al. (2021), López-García et al. (2022), Samuelson, Baniassadi, and Gonzalez (2020), and Borghero et al. (2023). Jha, Miner, and Stanton-Geddes (2013) and Cox (2023) address resilience from the perspective of system management.

Many studies discuss retrofitting and its relationship with resilience (Borghero et al., 2023; D’Agostino et al., 2023; Ji et al., 2023; Lomas and Giridharan, 2012). According to the authors, retrofitting plays an important role in improving building envelope performance and contributes to strengthening resilience, even in the face of climate change.

There is a gap in the literature regarding metrics capable of quantifying resilience promotion (D’Agostino et al., 2023). According to Tavakoli et al. (2022), analysis of building-related resilience is divided into five groups: resilient building design; resilient systems; resilient cooling; resilient cities; and resilient occupant behavior. Schweiker (2020) further notes that research analyzing personal resilience is scarce, emphasizing that building flexibility and occupants' adaptive capacity are crucial factors for resilience. Therefore, the current study focuses on resilient occupant behavior within the built environment. It is important to highlight that, whenever the term "resilient" is used in this work to describe user behavior, it refers to their ability to adapt to internal thermal conditions through behavioral and perceptual adjustments.

Thermal comfort requirements and preferences vary significantly among occupants of different age groups, income levels, and health vulnerabilities (Hong et al., 2023). According to the authors, the thermal resilience of buildings can be assessed by monitoring the outdoor climate, the indoor thermal environment, and occupants’ comfort. To this end, monitoring temperature and humidity using sensors is considered the most appropriate approach for evaluating existing buildings.

Based on a literature review study (based on 22 articles and four databases), Peri et al. (2025) point out that current research still neglects the importance of learning more about the thermal resilience of building occupants, which, to some extent, interferes with the proposal of strategies to ensure people's health and well-being in the face of extreme temperatures caused by climate change. According to the authors, a building's performance is influenced not only by its design, installed systems, and the local climate, but also by the behavior of the people who live in or use it. Thus, it is justified to further investigate how occupants naturally adapt to the places through their behaviors.

Furthermore, Peri et al. (2025) emphasize that, in research on the thermal performance and thermal resilience of buildings, occupants are generally conceptualized as passive thermal loads, with little attention given to how they seek to adapt. In the few cases where adaptive behaviors are considered, research is generally limited to observing the opening and closing of windows, the adjustment of blinds, and the use of fans. According to the authors, other adaptive practices related to clothing, such as choices and changes of garments, are rarely addressed.

This reinforces the relevance of user-centered approaches, such as the one proposed in this study, which integrate behavioral, perceptual, and environmental dimensions to assess thermal resilience more comprehensively.

According to Kesik, O'Brien, and Ozkan (2020), special considerations for thermal resilience in Social Housing are necessary to protect vulnerable communities. Villa, Bortoli, and Oliveira (2021) also note a lack of research specifically targeting resilience in Social Housing. Given the above, there is a recognized importance in studying and assessing thermal resilience in Social Housing, especially considering the historical quality issues of housing delivered through the MCMV program in Brazil.

In the Brazilian context, several studies have contributed to the understanding of resilience and thermal performance in Social Housing. Nunes and Giglio (2022), for example, examined the sensitivity of building design variables to diverse environmental and climatic conditions, emphasizing the need to integrate climate change considerations into design decisions to promote resilient built environments. In turn, Villa and Oliveira (2021) developed a digital Post-Occupancy Evaluation (POE) method focused on resilience, addressing attributes such as environmental comfort, flexibility, and well-being. Their approach combines user feedback and digital tools to identify vulnerabilities and guide more adaptive housing design strategies. Meanwhile, Bavaresco et al. (2021) conducted a systematic review of energy performance in Brazilian Social Housing. Their findings indicate that standardized designs and limitations of adaptation to local climates compromise thermal efficiency and occupant comfort, while also highlighting the importance of incorporating passive design strategies and user-centered approaches to improve energy efficiency and overall housing quality.

Common metrics include passive habitability, overheating threshold, and thermal autonomy, but a lack of standardization persists due to scant guidance in technical standards and codes (Kesik; O'Brien; Ozkan, 2020). Homaei and Hamdy (2021) propose a comprehensive metric considering building and occupancy characteristics. Concomitant to the above, López-García et al. (2022) propose innovative methods to audit heat resilience in buildings, using real monitoring data to assess internal overheating.

According to Schweiker (2020), the widely accepted definition of thermal comfort is provided by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), which describes it as "the condition of the mind that expresses satisfaction with the thermal environment and is assessed by subjective assessment". This standard is applicable in the assessment of thermal comfort, relating external and internal temperatures to determine whether the desired conditions have been achieved (ASHRAE, 2020).

The adaptive approach to thermal comfort recognizes a range of acceptable temperatures, avoiding a single definition of comfortable temperature (Nicol et al., 2020). In this context, Siu et al. (2023) highlight different thermal tolerances, influenced by factors such as age, health and acclimatization. Adaptive models, developed in recent decades, highlight the resilience of occupants to thermally adjust (Zhao; Lian; Lai, 2021).

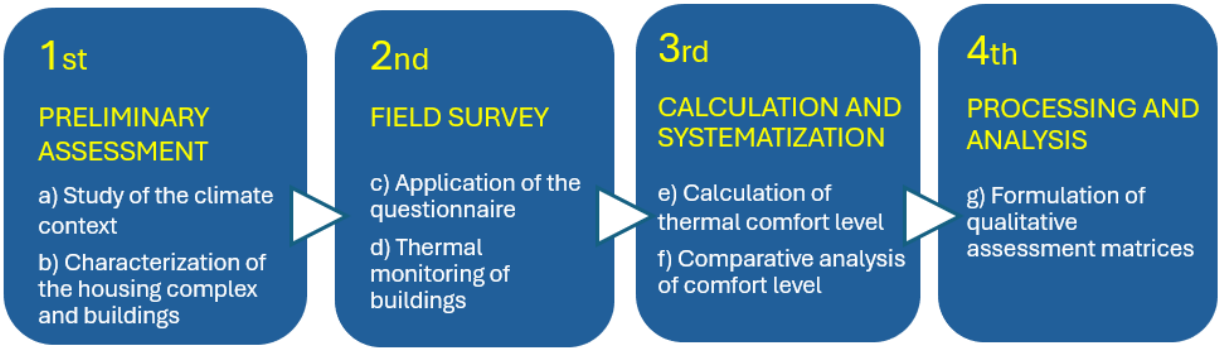
Schweiker (2020) highlights three parameters for analyzing human resilience: resistance, coping capacity, and recovery capacity, emphasizing the need to define measures to evaluate influencing factors. Nicol et al. (2020) highlight that the assessment of thermal resilience is linked to the diversity of construction materials and individual expectations, being influenced by social, cultural, physiological, and psychological factors.

3. Method

This research is exploratory with a qualitative and quantitative approach. In methodological terms, it is based on the Post Occupancy Evaluation (POE) procedures. The research[1] had four main stages, as shown in the Flowchart in Figure 1, namely: (a) preliminary assessment, related to the collection of information about the housing complex, and the study of the characteristics of the local microclimate and buildings (construction techniques and wrap materials); (b) field survey, consisting of a questionnaire with residents of housing units and thermal monitoring of buildings using sensors; (c) calculation of the thermal comfort level according to the criteria established in ASHRAE Standard 55 (ASHRAE, 2020), and data systematization; (d) processing and analysis of results, which resulted in the formulation of qualitative assessment matrices.

The procedures developed in each stage of the methodology are presented in detail below, as summarized in Figure 1.

Figure 1 - Flowchart characterizing the research stages.



Source: Authors, 2024.

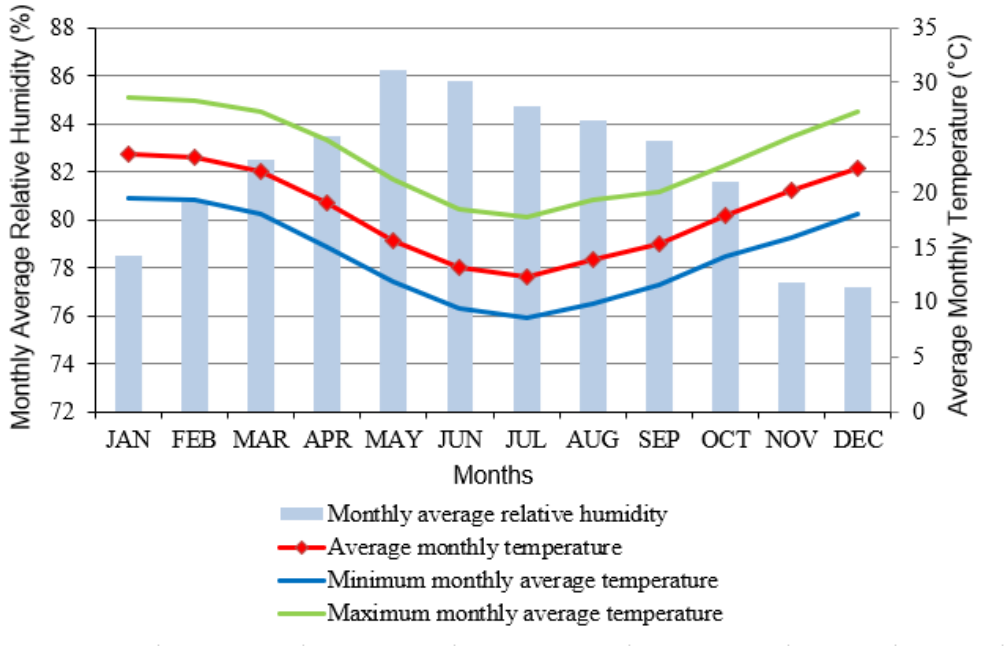
3.1. Study of the climate context

The housing complex[2] studied in this research is located in Pelotas[3], in the State of Rio Grande do Sul, located in the Southern Region of Brazil belongs to Bioclimatic Zone 2R, according to the categorization of the Brazilian Standard for Thermal Performance of Buildings – NBR 15220-3 (ABNT, 2024). The city of Pelotas is located at an altitude of approximately 9 meters, and it has a predominant humid subtropical climate (type Cfa), according to the Köppen–Geiger climate classification (Nimer, 1989; Grimm, 2009).

Figure 2 presents the values of monthly average relative humidity, monthly average temperature, monthly minimum temperature, and monthly maximum temperature corresponding to the climatological normals of 1991-2020, according to data from the Pelotas meteorological station (INMET, 2024).

[1] This research was approved by the Brazil Platform/Research Ethics Committee under the Certificate of Presentation for Ethical Consideration (CAAE) number 65363922.7.0000.5317. All interviewees signed the Free and Informed Consent Form, authorizing the anonymous use of their responses.
[2] Residential Moradas Pelotas 2, built by NEX GROUP Incorporadora.
[3] Pelotas has an estimated population of 325,685 inhabitants in 2022, according to data from the Brazilian Institute of Geography and Statistics – IBGE (2022).

Figure 2 - Monthly average values of relative humidity, air temperature, minimum temperature and maximum temperature in Pelotas/RS/Brazil.



Source: Brandelli, 2024, p. 87.

According to the graph presented in Figure 2, average relative humidity values throughout the year predominate in the range of 77% to 85%. May is the month with the highest relative humidity (86.2%), while December has the lowest percentage (77.2%). The high humidity condition combined with the occurrence of periods of mild temperature means that the thermal sensation of cold prevails. In the Pelotas region, according to data from the Projeteee platform[4], it is estimated that in 74% of the hours of the year there is discomfort due to cold, in 12% there is discomfort due to heat and in only 15% there is a condition of thermal comfort.

3.2. Characterization of the housing complex and buildings

It is a horizontal housing complex considered Social Housing, which has 492 semi-detached single-story units.

[4] Projeteee is a publicly accessible platform that presents climate data for several Brazilian cities. Available at: http://www.mme.gov.br/projeteee/dados-climaticos/ Accessed on: April 25, 2024.

Figure 3: Floor plan of the semi-detached housing units that make up housing complex.



Source: Brandelli, 2024, p. 62.

The main bedroom has lighting/ventilation facing the front facade, while the living room/kitchen opens towards the back of the lot (Figure 4).

Figure 4: Semi-detached housing units: front facade of corner housing (left) and side facade (right).



Source: Brandelli, 2024, p. 63.

As for construction materials, the buildings were built with reinforced concrete fence panels cast in situ, with the external and internal walls measuring 8 cm and 10 cm, respectively. The seals, both internal and external, are covered with a layer of textured acrylic paste (Nex Group real estate developer).

The dimensions of the walls comply with the minimum established by the Brazilian standard NBR 16055 (ABNT, 2022), which establishes the criteria for cast-in-place vertical concrete seals. The foundation is of the raft type and serves as the basis for laying the internal floor. The coverage is uniform and extends over the two semi-detached units. As for materials, the roof consists of ceramic tiles, galvanized steel structure, and internal plaster lining.

The evaluation of the building envelope's thermal and ventilation performance was conducted according to the Brazilian performance standard NBR 15575 (ABNT, 2021). Table 1 indicates that both the external walls and the roof exceed the maximum thermal transmittance (U-value) limits established by the standard, which reflects the low thermal resistance of the envelope.

Table 1 – Thermal performance of the envelope according to NBR 15575

Component	NBR 15575 Requirment	Calculated
External walls	U ≤ 2.5 W/(m²K)	U = 4.41 W/(m²K)
Roof	U ≤ 2.3 W/(m²K)	U = 3.26 W/(m²K)

Source: the authors.

Regarding natural ventilation (Table 2), the openings in the bedrooms and the living room/kitchen meet or exceed the minimum requirements, whereas the bathroom is slightly below the recommended area.

Table 2 – Ventilation according to NBR 15575

Room	NBR 15575 Requirement (A ≥ 7%)	Calculated
Bedroom 1	A ≥ 0.61 m²	A = 0.72 m²
Bedroom 2	A ≥ 0.56 m²	A = 0.72 m²
Living room/Kitchen	A ≥ 1.33 m²	A = 2.26 m²
Bathroom	A ≥ 0.20 m²	A = 0.18 m²

Source: the authors.

These results indicate that, although ventilation conditions are generally adequate, the thermal performance of the envelope may contribute to increased indoor heat gain.

3.3. Application of the questionnaire

The questionnaire was administered in person by the researchers on April 5th and 8th, 2023. In total, 30 residents agreed to participate. The questionnaire was answered individually by each resident during a researcher's visit to the residence. In case of doubt about completing it, the researcher explained the questions. In general, the application lasted around 30 minutes.

The questionnaire, of a qualitative nature, had 25 structured and closed questions, covering three parts, each with a set of questions.

- First part: Recording user demographic data.

- Second part: Recording the user's perception regarding the level of thermal comfort in the living room/kitchen and bedroom, in the morning, afternoon, and night shifts, throughout the summer, winter, and autumn/spring seasons.

To record thermal perception, the interview was designed based on the seven-point scale defined by the international standard ISO 10551 – Ergonomics of the physical environment – Subjective judgment scales for assessing physical environment (ISO, 2019). The seven-point thermal sensation scale is also recommended by ASHRAE. According to Fanger (1970), the ASHRAE seven-point scale is used to determine people's actual thermal sensations.

A color-referenced scale was provided during the interview process to assist respondents in accurately interpreting the thermal sensation levels (Figure 5). The structured interview form is available in Brandelli (2024).

Figure 5 – Seven-point thermal sensation scale presented during the interview



Source: Brandelli, 2024, p. 64.

- Third part: Use of artificial acclimatization strategies used by the user to achieve thermal comfort, such as the use of air conditioning units and fans.

All respondents signed the Informed Consent Form (ICF), allowing the responses to be used anonymously.

3.4. *Thermal monitoring of buildings*

Monitoring the thermal condition of buildings included measuring the operating temperature of indoor environments for prolonged periods using sensors such as HOBO® Datalogger - ONSET.

Firstly, the calibration of the sensors used in the research was measured. To this end, according to the procedure used by Silva (2017), the equipment was conditioned in a thermal box for 72 hours and programmed to capture the temperature every 10 minutes for three days.

For this pilot study, 3 buildings in the housing complex were monitored, with each housing receiving two sensors, one installed in the living room/kitchen and the other in the main bedroom. In order to collect external temperatures, an external sensor was also installed, which was fixed to the outside of a wall in one of the buildings. Monitoring took place from February 2nd to 24th, 2023, with hourly measurements, which corresponds to 22 days and 528 hours.

The buildings studied are located on the same solar orientation axis (Northeast/Southwest). However, they differ in terms of positioning (middle of row or corner), as highlighted in Figure 6 by the letters A, B, and C, in terms of ventilation characteristics and acclimatization (natural or hybrid), and also regarding occupation (adults with/without children), as shown in Table 3.

Figure 6: Implementation of a housing complex with the buildings monitored for the Pilot Study.



Source: Brandelli, 2024, p. 78.

Table 3 – Characteristics of monitored residential units.

Housing	Position	Ventilation	Occupants
House A - sensors 1 and 2	corner	hybrid ventilation	single-parent family (father or mother + children)
House B - sensors 3 and 4	middle of row	hybrid ventilation	single-parent family (father or mother + children)
House C - sensors 5 and 6	middle of row	natural ventilation	dual-income, no kids

Source: Authors, 2024.

The sensors were installed at a height of 1.20 m from the floor, on the side of cabinets or walls, in accordance with Curcio (2011), and were protected from direct solar radiation (Figure 7).

Figure 7 – Sensors installed in the bedroom (left) and living room (center), and approximate view of the equipment (right).



Source: Brandelli, 2024, p. 70.

It should be noted that the environmental measurements were not conducted simultaneously with the interviews. This decision resulted from both logistical constraints during fieldwork and the methodological approach adopted, which aimed to understand the residents' overall thermal experience within the dwelling rather than their instantaneous thermal sensation.

3.5. Calculation of thermal comfort level

The results from the monitoring were analyzed based on the adaptive thermal comfort index of ASHRAE Standard 55 – Thermal Environmental Conditions of Human Occupancy (ASHRAE, 2020)[5], in order to measure the level of thermal comfort in the long-term indoor environments studied.

ASHRAE Standard 55 (ASHRAE, 2020) defines the operating temperature limits to characterize a local Thermal Comfort Zone[6]. The neutral operating temperature is calculated from the average weekly or monthly external air temperature, allowing a tolerance range of ±3.5°C for conditions of thermal satisfaction for 80% of users. In the present study, the monthly average was used.

Indoor operative temperature results from the combined effects of air temperature and mean radiant temperature, and it also varies according to air velocity (Santo; Alvarez; Nico-Rodrigues, 2013). The sensors used in this study measured only indoor air temperature. For simplification, it was assumed that the indoor operative temperature was equal to the indoor air temperature and that the air velocity inside the building did not exceed 2 m/s.

According to the external temperatures measured during the pilot study period, an average temperature of 25.1°C was reached. The calculated neutral operating temperature for the period is 25.6°C. Therefore, the upper and lower limits of the comfort zone are, respectively, 29.1°C and 22.1°C, according to ASHRAE Standard 55 (ASHRAE, 2020).

The internal operating temperature measured hourly was then compared with the limits of the comfort zone in order to obtain the number of hours in thermal comfort of the environment, the number of hours of discomfort due to cold and heat, as presented in the section that follows.

[5] The research began in 2022, at which time the most up-to-date version of ASHRAE Standard 55 was the 2020 edition; therefore, this version was adopted for the study.
[6] The ASHRAE 55 (2020) standard allows the calculation of the number of hours per year within the comfort zone, observing an average relative humidity rate of 50%, and temperatures below 35°C.

3.6. Comparative analysis of comfort level

To analyze the results, two approaches were considered, which are described below. Firstly, based on the results of the assessment of the level of thermal comfort obtained from the procedures of ASHRAE Standard 55 (ASHRAE, 2020), which defined the percentage of hours in which the environments surveyed offer comfort, discomfort due to cold, or discomfort due to heat to their occupants. A comparison was made between these results and the thermal sensation of users, obtained through questionnaires.

This comparison made it possible to analyze whether the comfort zone recommended by the standard is consistent with the perception that users reported in the questionnaire. It also made it possible to observe the impact of acclimatization measures on thermal comfort conditions.

Also, with a view to the results of the evaluation according to the standard and based on the questionnaire, the second analysis approach sought to compare the 3 buildings researched with each other. Thus, the results were analyzed from a unit located on the corner (House A, with hybrid ventilation), and two units located in the middle of a row (House B, with hybrid ventilation, and House C, with natural ventilation). This analysis sought to verify whether solar exposure on facades (in greater or lesser intensity) causes changes in the comfort condition of internal environments.

3.7. Formulation of qualitative assessment matrices

The analysis of the results also involved the formulation of qualitative user assessment matrices. The matrices were constructed based on the observation of three parameters: (a) the level of thermal comfort of the environment based on ASHRAE Standard 55 (ASHRAE, 2020); (b) the user's thermal perception; (c) the artificial acclimatization strategies employed by the user, the latter collected from the questionnaire.

The design of the matrices was based on the understanding that the combination of these three parameters characterizes three types of users: (a) Non-resilient, which corresponds to those users who have the perception of thermal comfort and still use artificial acclimatization strategies; (b) Resilient, someone who perceives discomfort, however chooses not to use artificial acclimatization measures; (c) Typical, which corresponds to that user who has an expected behavior, that is, when the environment is thermally comfortable he does not use acclimatization, and when the environment is thermally uncomfortable, he uses acclimatization. These classifications and conceptualizations characterize the core of the proposed method.

The different possibilities for parameter combinations generated eight qualitative assessment matrices, as shown in Table 4.

Table 4. Qualitative assessment matrices regarding users' thermal resilience.

Matrix	Level of thermal comfort of the environment / ASHRAE Standard 55-2020	User's thermal perception	Artificial acclimatization strategies	User's resilience classification
1	Comfortable	Comfortable	Yes	Non-resilient
2	Uncomfortable	Comfortable	Yes	Non-resilient
3	Comfortable	Uncomfortable	Yes	Non-resilient
4	Uncomfortable	Comfortable	No	Resilient
5	Comfortable	Uncomfortable	No	Resilient
6	Uncomfortable	Uncomfortable	No	Resilient
7	Comfortable	Comfortable	No	Typical
8	Uncomfortable	Uncomfortable	Yes	Typical

Source: Brandelli, 2024, p. 74.

The first column of Table 4 refers to the qualitative assessment matrix generated, the second column concerns the level of thermal comfort of the environment defined based on the ASHRAE Standard 55 (ASHRAE, 2020) method, corresponding to comfort or discomfort; the third column expresses the user's thermal perception in relation to the researched environment; the fourth column refers to the use of artificial acclimatization strategies by the user, expressed by Yes or No; and the fifth column, finally, defines the user's classification as non-resilient, resilient or typical.

The central conceptual assumption is that users' thermal resilience refers to their ability to maintain satisfaction—or at least tolerance—when exposed to thermal discomfort, prioritizing adaptive and passive behavioral responses over the use of artificial strategies.

Accordingly, individuals who reported thermal discomfort but did not activate any artificial acclimatization strategies were classified as resilient, as they demonstrated adaptive behavior through acceptance, habit adjustments, or passive measures (e.g., clothing adaptation or window management). Conversely, individuals who reported feeling comfortable while still using air conditioning or fans were classified as non-resilient, as their comfort depended on technological support rather than adaptive behavior. The typical category comprises users whose actions align with the expected adaptive model (i.e., use of acclimatization strategies under discomfort and no use under comfortable conditions).

This approach makes it possible to relate thermal resilience not only to physical conditions but also to subjective adaptive capacity and cultural patterns of thermal comfort.

4. Results and discussions

This section presents the results obtained regarding the assessment of the level of thermal comfort according to ASHRAE Standard 55 (ASHRAE, 2020), carried out from the thermal monitoring of buildings through sensors, the application of the questionnaire with users living in the housing complex, and the results systematized in the form of qualitative assessment matrices.

4.1. Results of the questionnaire application

When analyzing the results of the questionnaire application, a descriptive analysis is initially presented. Subsequently, an interpretative analysis is presented, characterizing evidence that justifies the illustrated data. The results of thermal perception regarding the level of comfort in summer are presented in Table 5.

Table 5. Percentage values related to residents' thermal perception responses.

Shift	Bedroom							Living room						
	VC*	C*	SC*	C*	SW*	W*	VH*	VC*	C*	SC*	C*	SW*	W*	VH*
Morning	0%	0%	0%	28%	21%	28%	24%	0%	0%	0%	55%	21%	21%	3%
Afternoon	0%	0%	0%	17%	3%	45%	35%	0%	0%	0%	21%	31%	24%	24%
Night	0%	0%	0%	21%	21%	41%	17%	0%	0%	0%	31%	34%	24%	10%

* Thermal perception scale composed of Very Cold (VC), Cold (C), Slightly Cold (SC), Comfortable (C), Slightly Warm (SW), Warm (W), Very Hot (VH).
Source: Authors, 2024.

It is observed that during the afternoon shift, 83% of user-respondents consider the bedroom to be uncomfortable due to the heat, with 35% of these classifying it as very hot. Heat discomfort also predominates in responses relating to the living room, in which 79% of respondents report feeling discomfort due to heat. It is noted that the bedroom is considered very hot by more residents compared to the living room for the same period of the afternoon.

During the night, the bedroom is seen as very hot by 17% of respondents and as hot by 41% of them, which is equivalent to a total of 58% of users who consider the bedroom to be uncomfortable due to the heat.

For 55% of respondents, the most comfortable environment indicated by residents was the living room during the morning shift. The bedroom in the morning is considered uncomfortable due to the heat by the majority of residents (73%).

The results regarding users' adaptation strategies regarding the use of air conditioning equipment and fans are presented in Tables 6 and 7.

Table 6. Percentage values relating to adaptation responses due to the use of air conditioning by residents.

Use of air conditioning equipment	Bedroom			Living room		
	Morning	Afternoon	Night	Morning	Afternoon	Night
Do not use	80%	67%	47%	73%	63%	63%
Full shift	13%	20%	40%	13%	23%	13%
Half shift	7%	13%	13%	13%	13%	23%

Source: Authors, 2024.

Table 7. Percentage values related to residents' adaptation responses due to fan use.

Use of fan equipment	Bedroom			Living room		
	Morning	Afternoon	Night	Morning	Afternoon	Night
Do not use	70%	63%	30%	67%	57%	57%
Full shift	23%	33%	60%	33%	43%	43%
Half shift	7%	3%	10%	0%	0%	0%

Source: Authors, 2024.

Regarding users' adaptation strategies regarding the use of air conditioning equipment and fans, the results show that, in the summer, the majority (53.3%) use air conditioning at night in the bedroom, with 40% of respondents. They use the air conditioning throughout the night. There is no report of the use of air conditioning equipment during the morning and afternoon periods in this environment. As for fan use, 70% of users use the equipment in the bedroom at night, 60% of them throughout the night.

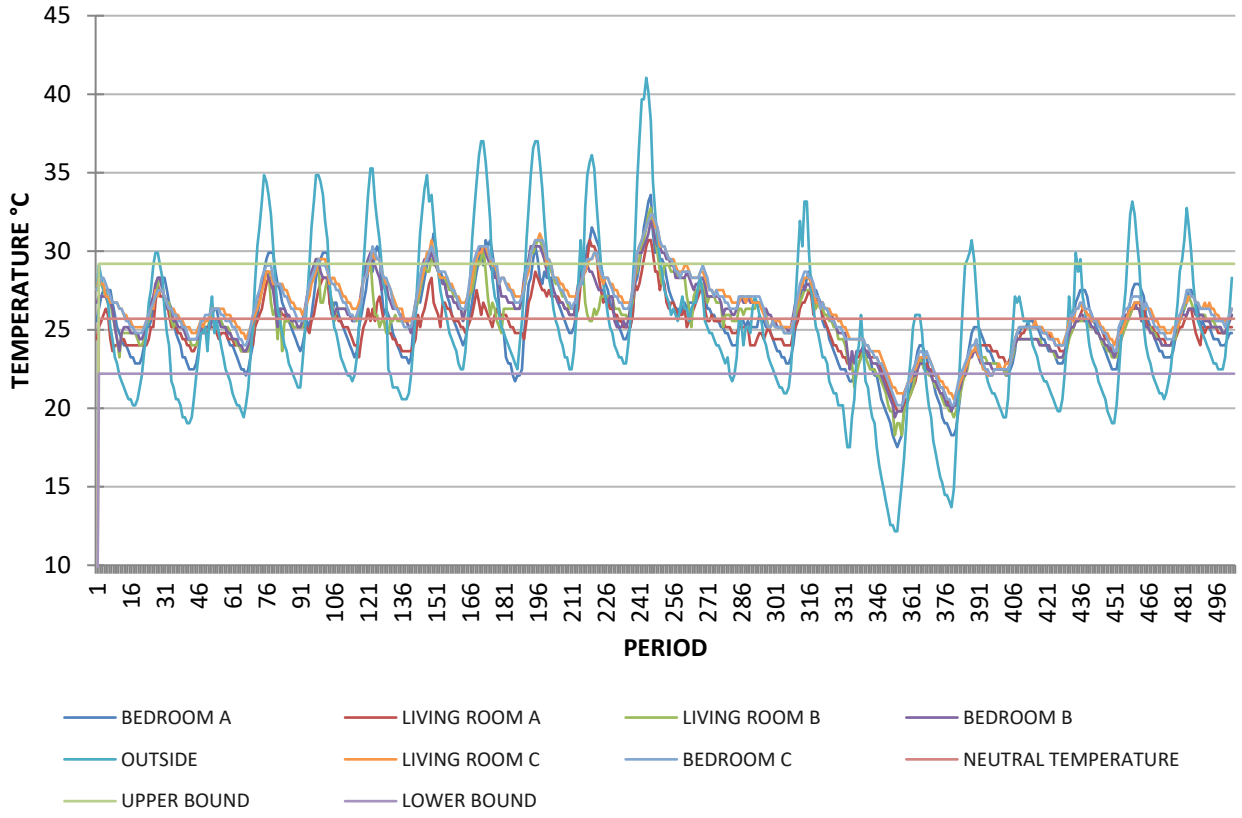
In the room, the use of the air conditioning system is lower among users, approximately 33%, although 23.3% of respondents do not have air conditioning systems. Regarding the use of the fan, 43.3% of respondents use the fan throughout the afternoon and throughout the night in the environment.

The questionnaire also included questions about the acclimatization strategies used by residents in the living room and bedroom, which included questions about the management of openings (whether they use windows and doors open, partially open, or closed), and about the use of blinds and curtains, every shift and every season. However, it was not possible to include these responses in the systematization of results, given the difficulty of isolating such acclimatization variables. This difficulty, therefore, is a limitation of this study.

4.2. Results of thermal comfort level assessment

The results of thermal monitoring of House A (corner), House B (middle of the row), and House C (middle of the row), as well as the neutral operating temperature of the analyzed environments and the upper and lower limits of the comfort zone, are presented in Figure 8.

Figure 8 – Results of thermal monitoring and assessment of the thermal comfort level (ASHRAE Standard 55) of Houses A, B and C.



Source: Brandelli, 2024, p. 80.

As seen in Figure 8, the highest external temperature for the period was 41.1°C and the lowest was 12.2°C, which consists of a thermal amplitude of 28.9°C. The average maximum internal temperature was 32.3°C, and the average minimum internal temperature was 19.3°C.

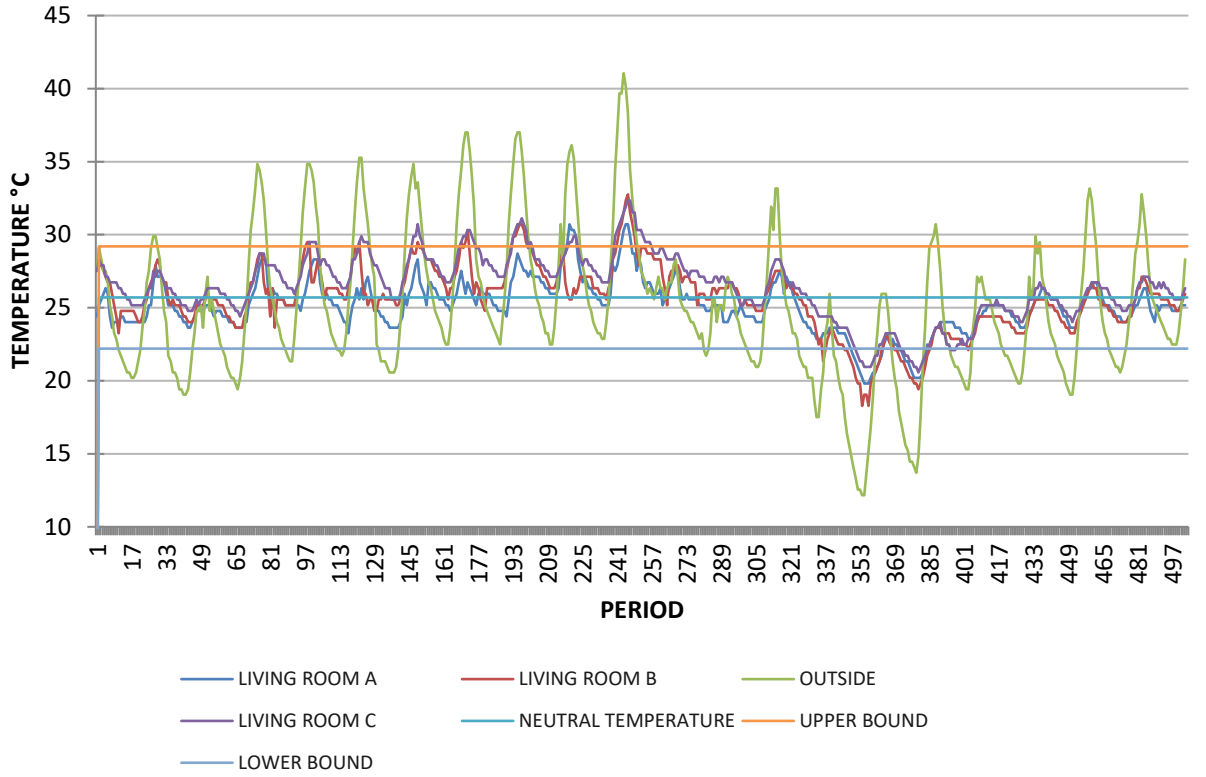
According to the external temperatures measured during the research period, an average temperature of 25.1°C was reached. Therefore, the calculated neutral operating temperature for the period is 25.6°C, according to the calculation procedure indicated by ASHRAE Standard 55 (ASHRAE, 2020). Therefore, the upper and lower limits of the comfort zone are, respectively, 29.1°C and 22.1°C, representing 80% of users' thermal satisfaction (ASHRAE, 2020).

The bedroom/House A presented a greater thermal amplitude compared to all other environments (living rooms and bedrooms). The highest temperature in the bedroom/House A was 33.6°C, the lowest was 17.5°C, which corresponds to a thermal amplitude of 16.1°C. Living room/House A presented a thermal amplitude of 10.9°C.

The temperature range in the living room/House B was 14.5°C, and in the bedroom/House B it was 12.5°C. The temperature range in the living room/House C was 11.7°C, and in the bedroom/House C it was 12.1°C. These results demonstrate that House A has higher internal temperatures compared to the other buildings analyzed.

When comparing the living rooms of Houses A, B, and C, the results show that the living room/House A (located on the corner) has a greater thermal amplitude than the living rooms of Houses B and C (both located in the middle of the row), as shown in Figure 9.

Figure 9 – Thermal monitoring of the rooms of Houses A, B, C, compared with the comfort zone and neutral temperature.



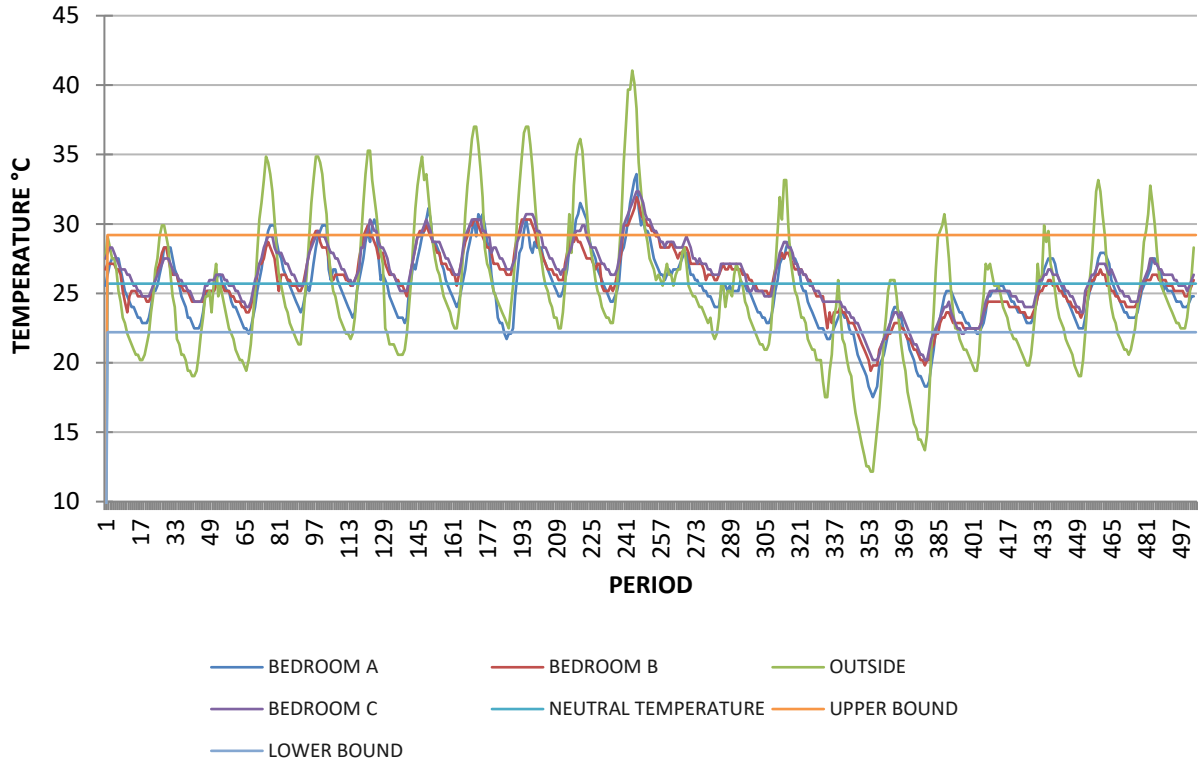
Source: Authors, 2024.

As shown in Figure 9, this difference in thermal amplitude between the analyzed living rooms probably occurs because House A is located on the corner, having a larger external sealing area in contact with the external environment, which leads to greater exchange of heat with the outside air. Furthermore, reinforced concrete has a high thermal transmittance index, which provides low thermal insulation to the enclosure.

Houses located in the middle of rows (Houses B and C), due to the semi-detached configuration, have a smaller heat exchange area with the external environment and greater capacitive thermal insulation, since the duplication of dividing walls between houses increases the thermal mass of the internal walls.

When comparing the bedrooms, it is observed that the bedroom/House A, which has air conditioning, has a greater thermal amplitude compared to the bedrooms in Houses B and C, which only have natural ventilation (Figure 10).

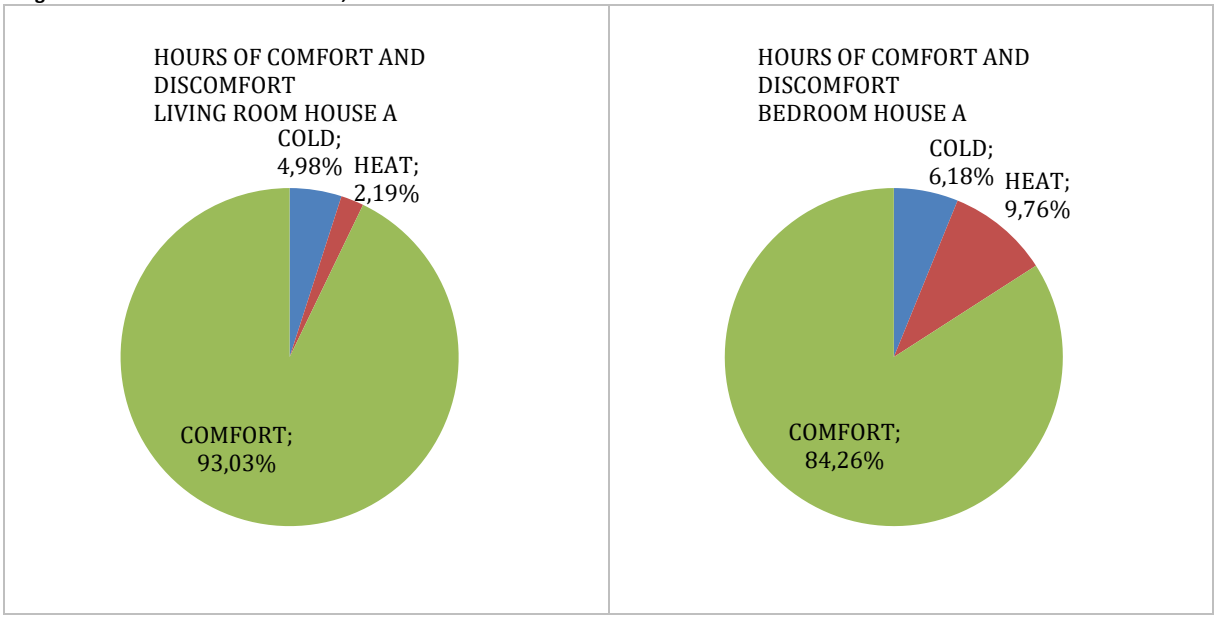
Figure 10 – Thermal monitoring of the bedrooms of Houses A, B, C, compared with the comfort zone and neutral temperature.



Source: Authors, 2024.

The assessment of the level of thermal comfort according to ASHRAE Standard 55 (ASHRAE, 2020) also allows us to obtain the number of hours in thermal comfort, the number of hours in discomfort due to cold and discomfort due to the heat of the environment, as shown in Figure 11 (House A), Figure 12 (House B) and Figure 13 (House C).

Figure 11 – Comfort level in House A, from ASHRAE Standard 55.

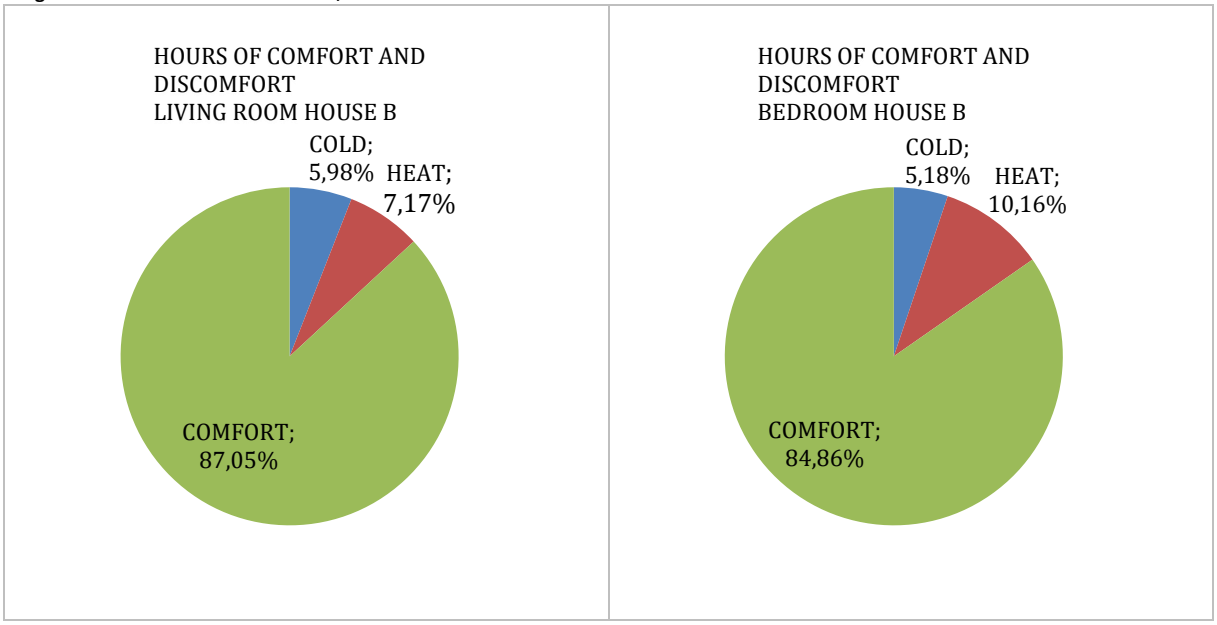


Source: Authors, 2024.

According to Figure 11, in relation to House A (corner), it is observed that the bedroom presents a significant increase in the percentage of hours of discomfort due to heat compared to the living room. As already explained, this probably occurs because the bedroom, unlike the living room, has an

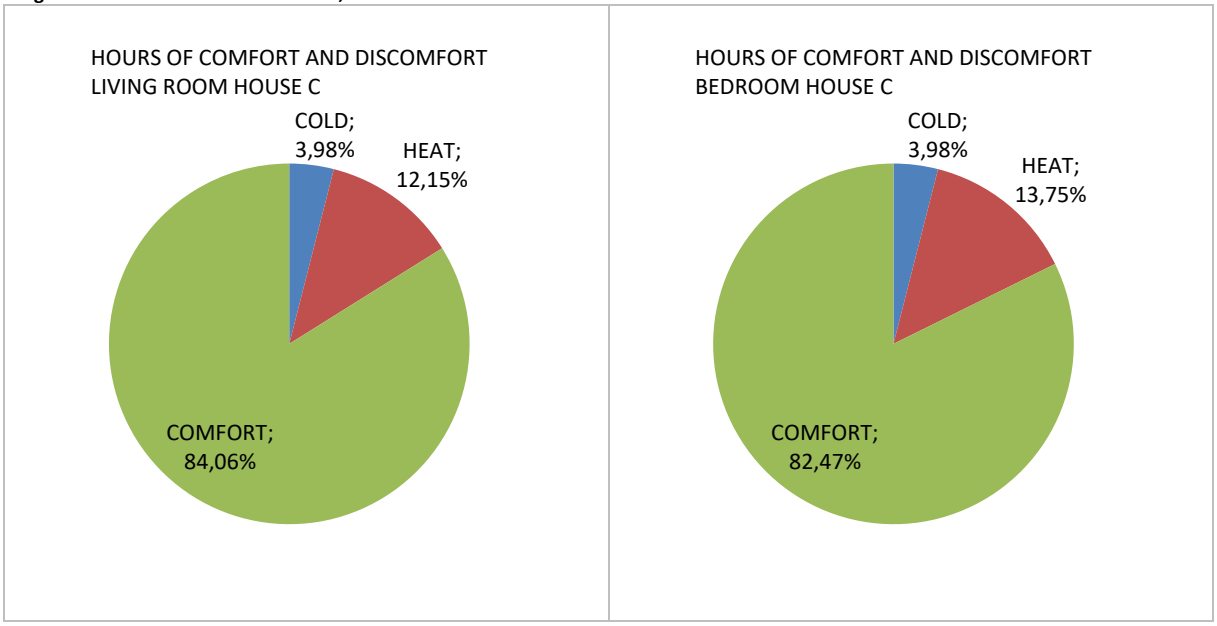
external wall facing the outside, which causes exposure to direct sunlight from the Northwest orientation.

Figure 12 - Comfort level in House B, from ASHRAE Standard 55.



Source: Authors, 2024.

Figure 13 – Comfort level in House C, from ASHRAE Standard 55.



Source: Authors, 2024.

As illustrated in Figures 12 and 13, when comparing the two mid-row houses, with the same solar orientation, House C with natural ventilation and House B with a hybrid system, an increase of 5% in the percentage of hours of discomfort due to heat is noted in the room of House C, since the ventilation of the environment occurs naturally.

4.3. Results of qualitative assessment matrices

As mentioned in the Method section, the qualitative assessment matrices formulated within the scope of this research were constructed based on three parameters:

a) the level of thermal comfort of the environment based on ASHRAE Standard 55 (ASHRAE, 2020);

b) the user's thermal perception covers the categorization "comfort" or "thermal discomfort";

c) the artificial acclimatization strategies used by the user: defined as "yes" or "no", that is, whether the resident uses or does not use any acclimatization strategy.

In relation to the first parameter, the level of thermal comfort of the environment calculated according to ASHRAE Standard 55 (ASHRAE, 2020) for more than 80% of the hours showed that the buildings analyzed were within the thermal comfort zone; therefore, the environment is thermally comfort.

Using the eight matrices listed in Table 4, the three parameters were crossed for each user, and the classification of each respondent was obtained, in the bedroom and in the living room. Table 8 presents the percentage classification of user types regarding thermal resilience.

Table 8 – Percentage values related to types of users regarding thermal resilience.

Environment	Classification	Percentage
Bedroom	Non-resilient	57%
	Resilient	23%
	Typical	20%
Living room	Non-resilient	70%
	Resilient	13%
	Typical	17%

Source: Brandelli, 2024, p. 81.

According to the method proposed in this study, the resulting classifications indicate that the vast majority of users participating in the research present Non-Resilient behavior, with the percentage being significantly higher in relation to the room (70%). This characteristic is probably related to the shift that the user predominantly occupies in each of the environments, as well as their mode of occupation. For example, the living room, as it is integrated with the kitchen, is probably the room used for more hours during the day, compared to the bedroom, which is used predominantly at night. Furthermore, in the living room/kitchen, the user must perform more activities in movement, and in the bedroom, resting activities prevail.

The results obtained in this study are consistent with, and extend upon, previous research on thermal resilience, while introducing an innovative perspective centered on occupant behavior. Studies such as D'Agostino et al. (2023) and Ji et al. (2023) have evaluated thermal resilience through quantitative indicators related to overheating risk, passive survivability, and retrofit performance, emphasizing the role of the building envelope and energy systems. In contrast, Schweiker (2020) and Tavakoli et al. (2022) highlight the scarcity of approaches that explicitly incorporate the human adaptive dimension of resilience, an aspect that the present research directly addresses.

The discrepancy identified between comfort levels calculated according to ASHRAE Standard 55 (ASHRAE, 2020) and users' subjective perception aligns with observations by Nicol et al. (2020), who emphasize that cultural and contextual factors often shape thermal expectations more strongly than physical parameters alone. This finding reinforces the need for regionally calibrated adaptive models for the Brazilian climate.

Moreover, the classification matrices proposed in this study represent an advancement over previous Post-Occupancy Evaluation (POE) methods applied to Social Housing in Brazil. By integrating users' perceptions, objective comfort levels, and acclimatization behavior, the proposed method introduces a qualitative tool capable of identifying degrees of user thermal resilience, thereby bridging the gap between thermal performance analysis and environmental psychology in the built environment.

5. Conclusions

Most research on thermal resilience has focused on the risks of overheating in built environments, aiming to quantify the capacity of buildings and cities to cope with extreme weather conditions. (Borghero et al., 2023; D'Agostino et al., 2023; Ji et al., 2023; Siu et al., 2023; Cox, 2023; Diz-Mellado

et al., 2023; Lim et al., 2022; Xiang et al., 2022; Tavakoli et al., 2022; Ozkan; Good, 2022; López-García et al., 2022; Homaei; Hamdy, 2021; Croce; Vettorato, 2021; Miller et al., 2021; Ahmed; Kumar; Mottet, 2021; Sun; Specian; Hong, 2020; Samuelson; Baniassadi; Gonzalez, 2020; Kesik; O'Brien; Ozkan, 2020; Baniassadi; Heusinger; Sailor, 2018; Fosas et al., 2018).

However, as emphasized by both Schweiker (2020) and Peri et al. (2025), there remains a considerable gap in the literature concerning the thermal resilience of building occupants. In this context, the present study is understood to contribute to addressing this gap by developing and testing a concrete method for analyzing user thermal resilience—namely, the formulation of qualitative user assessment matrices. This methodological approach was based on the integration of the thermal comfort level of the indoor environment, calculated according to ASHRAE Standard 55 (ASHRAE, 2020), the user's thermal perception of the indoor space, and the acclimatization strategies adopted by the user. In other words, the method was developed by cross-referencing qualitative data derived from user responses with quantitative data obtained from sensor monitoring and comfort level calculations.

The pilot study was conducted in social housing units located in Bioclimatic Zone 2 of Rio Grande do Sul, Brazil, over a 22-day period during the summer of 2023. The results revealed limitations in the direct application of ASHRAE Standard 55 (ASHRAE, 2020) to the southern Brazilian context. Although the standard indicated that more than 82% of the hours were within thermal comfort limits, 79% of respondents reported thermal discomfort in the living room and 83% in the bedroom during the afternoon period, suggesting a possible overestimation of comfort conditions when assessed solely by the standard.

The in-person application of questionnaires proved essential not only for clarifying doubts but also for uncovering relevant user practices, such as the indirect use of air conditioning in non-conditioned spaces. This finding underscores the influence of cultural, economic, and subjective factors on thermal comfort strategies, which may not be fully captured by standardized or remotely applied questionnaires.

Additionally, the importance of mapping user behavior regarding natural ventilation—particularly the opening of windows and doors—was noted, although this variable was not integrated into the comfort analysis at this stage. This study was limited to reporting only the artificial strategies adopted. Regarding thermal monitoring, it is recommended that indoor and outdoor air temperature measurements be carried out continuously over a full year, with regular visits for data collection and sensor maintenance.

In conclusion, the proposed method shows potential for capturing the complexity of user behavior in response to thermal discomfort, particularly in the context of social housing. Preliminary results suggest that cultural factors significantly influence users' adaptive strategies, highlighting the need for more comprehensive future analyses.

This research, therefore, contributes to broadening the scope of thermal resilience studies by shifting the analytical focus from building-centered metrics to a user-centered resilience framework, essential for understanding the dynamics of thermal comfort in low-income housing contexts and for informing socially sensitive housing policies.

Declaration

The authors declare the use of generative artificial intelligence to enhance the English grammar and vocabulary throughout the text. After using this tool/service, the authors have reviewed and edited the content as necessary and take full responsibility for the content of the publication.

References

AHMED, T.; KUMAR, P.; MOTTET, L. Natural ventilation in warm climates: The challenges of thermal comfort, heatwave resilience and indoor air quality. **Renewable and Sustainable Energy Reviews**, v. 138, p. 110669, Mar. 2021. DOI: https://doi.org/10.1016/j.rser.2020.110669.

AL-HUMAIQANI, M. M.; AL-GHAMDI, S. G. The built environment resilience qualities to climate change impact: Concepts, frameworks, and directions for future research. **Sustainable Cities and Society**, v. 80, p. 103797, May 2022. DOI: https://doi.org/10.1016/j.scs.2022.103797.

AMORE, C. S.; SHIMBO, L. Z.; RUFINO, M. B. (org.). **Minha casa... e a cidade? Avaliação do Programa Minha Casa Minha Vida em seis estados brasileiros**. 1 ed. Rio de Janeiro: Letra Capital, 2015.

ARAUJO, G. M. **Bem-estar e resiliência em habitação social: uma relação necessária. Estratégias orientadas aos usuários**. 2020. 316f. Dissertação (Mestrado em Arquitetura e Urbanismo) – Programa de pós-graduação em Arquitetura e Urbanismo. Faculdade de Arquitetura e Urbanismo e Design. Universidade Federal de Uberlândia, Uberlândia, 2020. DOI: http://doi.org/10.14393/ufu.di.2020.833.

ASHRAE - AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS. **Standard 55-2020: Thermal Environmental Conditions for Human Occupancy**. Atlanta, USA, 2020.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 15220-3:2024:** Desempenho térmico de edificações — Parte 3: Zoneamento bioclimático por desempenho. Rio de Janeiro: ABNT, 2005.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 15575:** Edificações habitacionais — Desempenho. Rio de Janeiro: ABNT, 2021.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 16055:** Paredes de concreto moldadas no local para a construção de edificações. Rio de Janeiro: ABNT, 2022.

ATTIA, S.; LEVINSON, R.; NDONGO, E; HOLZER, P.; KAZANCI, O. B.; HOMAEI, S.; ZHANG, C.; OLESEN, B. W.; QI, D.; HAMDY, M.; HEISELBERG, P. Resilient cooling of buildings to protect against heat waves and power outages: Key concepts and definition. **Energy and Buildings**, v. 239, p. 110869, May 2021. ISSN 0378-7788. DOI: https://doi.org/10.1016/j.enbuild.2021.110869.

BANIASSADI, A.; HEUSINGER, J.; SAILOR, D. J. Energy efficiency vs resiliency to extreme heat and power outages: The role of evolving building energy codes. **Building and Environment**, v. 139, p. 86-94, July 2018. DOI: https://doi:10.1016/j.buildenv.2018.05.024.

BAVARESCO, M. V.; CUCHIVAGUE, H. Y. O.; SCHINAZI, A.; GHISI, E. Aspectos impactantes no desempenho energético de habitações de interesse social brasileiras: revisão de literatura. **Ambiente Construído**, v. 21, n. 1, p. 263-292, Jan./Mar. 2021. DOI: https://doi.org/10.1590/s1678-86212021000100505.

BORGHERO, L.; CLÈRIES, E.; PÉAN, T.; ORTIZ, J.; SALOM, J. Comparing cooling strategies to assess thermal comfort resilience of residential buildings in Barcelona for present and future heatwaves. **Building and Environment**, v. 231, p. 110043, Mar. 2023. ISSN 0360-1323. DOI: https://doi.org/10.1016/j.buildenv.2023.110043.

BORTOLI, K. C. R. **Avaliando a resiliência no ambiente construído: adequação climática e ambiental em habitações de interesse social no Residencial Sucesso Brasil** (Uberlândia/MG). 2018. 282f. Dissertação (Mestrado em Arquitetura e Urbanismo) – Programa de Pós-graduação em Arquitetura e Urbanismo. Faculdade de Arquitetura e Urbanismo e Design, Universidade Federal de Uberlândia, Uberlândia. 2018. DOI: http://dx.doi.org/10.14393/ufu.di.2018.1370.

BORTOLI, K. C. R.; VILLA, S. B. Adequação ambiental como atributo facilitador da resiliência no ambiente construído em Habitações de Interesse Social. **Ambiente Construído**, v. 20, n. 1, p. 391–422, Jan./Mar. 2020. DOI: https://doi.org/10.1590/s1678-86212020000100381.

BRANDELLI, Talita Marini. **Método de avaliação da resiliência térmica do usuário em edifícios: estudo de caso em HIS no sul do Brasil**. 2024. 156f. Dissertação (Mestrado em Arquitetura e Urbanismo) – Programa Pós-Graduação em Arquitetura e Urbanismo, Pelotas, 2024. Disponível em: http://guaiaca.ufpel.edu.br/xmlui/handle/prefix/14357. Acesso em: 20 maio 2025.

COX, M. "I hope they shouldn't happen": Social vulnerability and resilience to urban energy disruptions in a digital society in Scotland. **Energy Research & Social Science**, v. 95, p. 102901, Jan. 2023. ISSN 2214-6296. DOI: https://doi.org/10.1016/j.erss.2022.102901.

CROCE, S.; VETTORATO, D. Urban surface uses for climate resilient and sustainable cities: A catalogue of solutions. **Sustainable Cities and Society**, v. 75, p. 103313, Dec. 2021. ISSN 2210-6707. DOI: https://doi.org/10.1016/j.scs.2021.103313.

CURCIO, D. da R. **Desempenho termo-energético de habitações de interesse social produzidas pelo programa de arrendamento residência-Par, na cidade de Pelotas/RS**. 2011. 180f. Dissertação (Mestrado em Arquitetura) – Faculdade de Arquitetura e Urbanismo. Programa de Pós-Graduação em Arquitetura e Urbanismo. Universidade Federal de Pelotas. Pelotas, 2011. Disponível em: http://guaiaca.ufpel.edu.br/handle/prefix/8669. Acesso em: Acesso em: 20 maio 2025.

D'AGOSTINO, D.; BECCHIO, C.; CRESPI, G.; CORGNATI, S. P. Assessment of passive and active buildings resilience to gas supply disruption in winter across European climates. **Sustainable Cities and Society**, v. 92, p. 104461, May 2023. ISSN 2210-6707. DOI: https://doi.org/10.1016/j.scs.2023.104461.

DIZ-MELLADO, E.; LÓPEZ-CABEZA, V. P.; ROA-FERNÁNDEZ, J.; RIVERA-GÓMEZ, C.; GALÁN-MARÍN, C. Energy-saving and thermal comfort potential of vernacular urban block porosity shading. **Sustainable Cities and Society**, v. 89, p. 104325, Feb. 2023. ISSN 2210-6707. DOI: https://doi.org/10.1016/j.scs.2022.104325.

FANGER, P. O. **Thermal comfort. Analysis and applications in environmental engineering**. Copenhagen: Darlish Technical Press, 1970.

FOSAS, D.; COLEY, D. A.; NATARAJAN, S.; HERRERA, M.; FOSAS DE PANDO, M.; RAMALLO-GONZALEZ, A. Mitigation versus adaptation: Does insulating dwellings increase overheating risk? **Building and Environment**, v. 143, p. 740-759, Oct. 2018. ISSN 0360-1323. DOI: https://doi.org/10.1016/j.buildenv.2018.07.033.

GARCIA, E. J.; VALE, B. **Unravelling Sustainability and Resilience in the Environment**. 1. ed. London and New York: Routledge, 2017.

GRIMM, A. M. Clima da Região Sul do Brasil. *In*: CAVALCANTI, I. F. A.; FERREIRA, N. J.; SILVA, M. G. A. J.; DIAS, M. A. F. S. (org.) **Tempo e clima no Brasil**. São Paulo: Oficina de Textos, 2009. p. 320-341.

HASSLER, U.; KOHLER, N. Resilience in the built environment. **Building Research & Information**, v. 42, n. 2, p. 119-129, Jan. 2014. DOI: https://doi.org/10.1080/09613218.2014.873593.

HOMAEI, S.; HAMDY, M. Thermal resilient buildings: How to be quantified? A novel benchmarking framework and labelling metric. **Building and Environment**, v. 201, p. 108022, Aug. 2021. DOI: https://doi.org/10.1016/j.buildenv.2021.108022.

HONG, T.; MALIK, J.; KRELLING, A.; O'BRIEN, W.; SUN, K.; LAMBERTS, R.; WEI, M. Ten questions concerning thermal resilience of buildings and occupants for climate adaptation. **Building and Environment**, v. 244, p. 110806, 2023. ISSN 0360-1323. Doi: https://doi.org/10.1016/j.buildenv.2023.110806.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). Pelotas (RS). 2022. Disponível em: https://www.ibge.gov.br/cidades-e-estados/rs/pelotas.html. Acesso em: 26 abr. 2024.

INSTITUTO NACIONAL DE METEOROLOGIA (INMET). **Dados Históricos Anuais**. Disponível em: https://portal.inmet.gov.br/dadoshistoricos. Acesso em: 25 abr. 2024.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. **ISO 10551:2019.** Ergonomics of the physical environment – Subjective judgment scales for assessing physical environment. Genève: ISO, 2019.

JHA, K. A.; MINER, T. W.; STANTON-GEDDES, Z. (ed.). **Building Urban Resilience**: Principles, Tools, and Practice. Washington, DC: World Bank, 2013. ISBN 978-0-8213-8865-5. DOI: https://doi.org/10.1596/978-0-8213-8865-5.

JI, L.; SHU, C.; LAOUADI, A.; LACASSE, M.; WANG, L. Quantifying improvement of building and zone level thermal resilience by cooling retrofits against summertime heat events. **Building and Environment**, v. 229, p. 109914, Feb. 2023. ISSN 0360-1323. DOI: https://doi.org/10.1016/j.buildenv.2022.109914.

KESIK, T.; O'BRIEN, W.; OZKAN, A. Towards a Standardized Framework for Thermal Resilience Modeling and Analysis. *In*: 2020 Building Performance Analysis Conference and Sim Build coorganized by ASHRAE and IBPSA-USA. 2020. **Proceedings** […]. Virtual September 29 - October 1, 2020. p. 61-68. Disponível em: https://publications.ibpsa.org/conference/?id=simbuild2020. Acesso em: 25 maio 2026.

LABOY, M.; FANNON, D. Resilience Theory and Praxis: A Critical Framework for Architecture. **Enquiry The ARCC Journal for Architectural Research**, v. 13, n. 1, p. 39-52, Dec. 2016. DOI: https://doi.org/10.17831/enq:arcc.v13i2.405.

LIM, T. C.; WILSON, B.; GROHS, J. R.; PINGEL, T. J. Community-engaged heat resilience planning: Lessons from a youth smart city STEM program. **Landscape and Urban Planning**, v. 226, p. 104497, Oct. 2022. ISSN 0169-2046. DOI: https://doi.org/10.1016/j.landurbplan.2022.104497.

LOMAS, K. J.; GIRIDHARAN, R. Thermal comfort standards, measured internal temperatures and thermal resilience to climate change of free-running buildings: A case-study of hospital wards. **Building and Environment**, v. 55, p. 57-72, Sept. 2012. ISSN 0360-1323. DOI: https://doi.org/10.1016/j.buildenv.2011.12.006.

LÓPEZ-GARCÍA, E.; LIZANA, J.; SERRANO-JIMÉNEZ, A.; DÍAZ-LÓPEZ, C.; BARRIOS-PADURA, A. Monitoring and analytics to measure heat resilience of buildings and support retrofitting by passive cooling. **Journal of Building Engineering**, v. 57, p. 104985, Oct. 2022. ISSN 2352-7102. DOI: https://doi.org/10.1016/j.jobe.2022.104985.

MARTIN, R.; SUNLEY, P. On the notion of regional economic resilience: Conceptualization and explanation. **Journal of Economic Geography**, v. 15, n. 1, p. 1-42, Jan. 2015. DOI: https://doi.org/10.1093/jeg/lbu015.

MILLER, W.; MACHARD, A.; BOZONNET, E.; YOON, N.; QI, D.; ZHANG, C.; LIU, A.; SENGUPTA, A.; AKANDER, J.; HAYATI, A.; CEHLIN, M.; KAZANCI, O. B.; LEVINSON, R. Conceptualising a resilient cooling system: A socio-technical approach. **City and Environment Interactions**, v. 11, p. 100065, Aug. 2021. ISSN 2590-2520. DOI: https://doi.org/10.1016/j.cacint.2021.100065.

NEX GROUP INCORPORADORA. **Manual do proprietário**: Moradas Pelotas 2. Pelotas, [s.d.]. 133 p.

NICOL, F.; BAHADUR RIJAL, H.; IMAGAWA, H.; THAPA, R. The range and shape of thermal comfort and resilience. **Energy and Buildings**, v. 224, p. 110277, Oct. 2020. ISSN 0378-7788. DOI: https://doi.org/10.1016/j.enbuild.2020.110277.

NIMER, E. **Climatologia do Brasil**. 2. ed. Rio de Janeiro: IBGE, Departamento de Recursos Naturais e Estudos Ambientais, 1989. 421 p., il., mapas. ISBN 8524002824. Disponível em: https://biblioteca.ibge.gov.br/biblioteca-catalogo?id=281099&view=detalhes. Acesso em: 25 abr. 2024.

NUNES, G.; GIGLIO, T. Effects of climate change in the thermal and energy performance of low-income housing in Brazil—assessing design variable sensitivity over the 21st century. **Renewable and Sustainable Energy Reviews**, v. 168, p. 112885, Oct. 2022. ISSN 1364-0321. DOI: https://doi.org/10.1016/j.rser.2022.112885.

OZKAN, A.; GOOD, J. Evaluation of the Thermal Resilience of a Community Hub. *In*: **Building Performance Analysis Conference and Sim Build coorganized by ASHRAE and IBPSA-USA**. Chicago, IL, 14-16 Sept. 2022.

PERI, G.; LICCIARDI, G.R.; CIRRINCIONE, L.; SCACCIANOCE, G. On the Active Involvement of Occupants for Improving the Thermal Resilience of Buildings: An Opportunity Still Overlooked. **Energies,** v. 18, n. 19, p. 5201, 2025. DOI: https://doi.org/10.3390/en18195201.

PICKETT, S. T. A.; MCGRATH, B.; CADENASSO, M. L.; FELSON, A. J. Ecological resilience and resilient cities. **Building Research & Information**, v. 42, n. 2, p. 143-157, 2014. DOI: https://doi.org/10.1080/09613218.2014.850600.

PINTO, J. V. **Contribuições para estudo do "Programa Minha Casa, Minha Vida" para uma cidade de porte médio, Pelotas-RS: caracterização das empresas construtoras e incorporadoras privadas e inserção urbana**. 2016. 291 p. Dissertação (Mestrado em Arquitetura) – Faculdade de Arquitetura e Urbanismo. Programa de Pós-Graduação em Arquitetura e Urbanismo. Universidade Federal de Pelotas. Pelotas, 2016. Disponível em: http://guaiaca.ufpel.edu.br/handle/prefix/5224. Acesso em: 20 maio 2025.

SAMUELSON, H. W.; BANIASSADI, A.; GONZALEZ, P. I. Beyond energy savings: Investigating the co-benefits of heat resilient architecture. **Energy**, v. 204, p. 117886, Aug. 2020. DOI: https://doi.org/10.1016/j.energy.2020.117886.

SANTO, A. D.; ALVAREZ, C. E.; NICO-RODRIGUES, E. A. Conforto e desempenho térmico em contradição na NBR 15575. **Cadernos PROARQ**, v. 20, n. 20, p. 116-136, 2013. Disponível em: https://cadernos.proarq.fau.ufrj.br/public/docs/Proarq_20-114.pdf. Acesso em: 20 maio 2025.

SCHWEIKER, M. Rethinking resilient comfort – definitions of resilience and comfort and their consequences for design, operation, and energy use. *In*: WINDSOR CONFERENCE: RESILIENT COMFORT, 11., 2020. **Proceedings** […] Windsor: Ecohouse Initiative Ltd., 2020. p. 34–46. Disponível em: https://windsorconference.com/wp-content/uploads/2020/05/WC2020_Proceedings_final_compressed.pdf. Acesso em: 25 jun. 2025.

SILVA, M. E. **Impacto do novo uso no microclima e no estado de conservação de edificações históricas recicladas**. 208 f. Dissertação (Mestrado em Arquitetura e Urbanismo) – Programa de Pós-Graduação em Arquitetura e Urbanismo, Faculdade de Arquitetura e Urbanismo, Universidade Federal de Pelotas, Pelotas, 2017. Disponível em: http://guaiaca.ufpel.edu.br/handle/prefix/5248. Acesso em: 25 jun. 2025.

SIU, C. Y.; O'BRIEN, W.; TOUCHIE, M.; ARMSTRONG, M.; LAOUADI, A.; GAUR, A.; JANDAGHIAN, Z.; MACDONALD, I. Evaluating thermal resilience of building designs using building performance simulation – A review of existing practices. **Building and Environment**, v. 234, p. 110124, Apr. 2023. ISSN 0360-1323. DOI: https://doi.org/10.1016/j.buildenv.2023.110124.

SUN, K.; SPECIAN, M.; HONG, T. Nexus of thermal resilience and energy efficiency in buildings: a case study of a nursing home. **Building and Environment**, v. 177, p. 106842, June 2020. DOI: https://doi.org/10.1016/j.buildenv.2020.106842.

TAVAKOLI, E.; O'DONOVAN, A.; KOLOKOTRONI, M.; O'SULLIVAN, P. D. Evaluating the indoor thermal resilience of ventilative cooling in non-residential low energy buildings: A review. **Building and Environment**, v. 222, p. 109376, Aug. 2022. ISSN 0360-1323. DOI: https://doi.org/10.1016/j.buildenv.2022.109376.

UN-HABITAT. **Envisaging the Future of Cities**. [S.l.]: [s.n.], 2022. *E-book*. Disponível em: https://unhabitat.org/sites/default/files/2022/06/wcr_2022.pdf. Acesso em: 25 abr. 2025.

VILLA, S. B.; BORTOLI, K. C. R.; OLIVEIRA, N. F. G. Resiliência no ambiente construído em habitação social: métodos digitais de avaliação pós-ocupação. *In*: VI ENANPARQ – VI ENCONTRO DA ASSOCIAÇÃO NACIONAL DE PESQUISA E PÓS-GRADUAÇÃO EM ARQUITETURA E URBANISMO. **Anais** [...] Brasília: Associação Nacional de Pesquisa e Pós-Graduação em Arquitetura e Urbanismo, 2021. v. 1, p. 2563-2583.

VILLA, S. B.; OLIVEIRA, N. F. G. Métodos de avaliação da resiliência no ambiente construído em habitação de interesse social: uma abordagem teórica no contexto da cidade de Uberlândia-MG. *In:* CONGRESSO LUSO-BRASILEIRO PARA O PLANEJAMENTO URBANO, REGIONAL, INTEGRADO E SUSTENTÁVEL, 9., 2021, Bauru. **Anais** [...] Bauru: PLURIS, 2021.

WANG, C.; DENG, S.; NIU, J.; LONG, E. A numerical study on optimizing the designs of applying PCMs to a disaster-relief prefabricated temporary-house (PTH) to improve its summer daytime indoor thermal environment. **Energy**, v. 181, p. 239-249, Aug. 2019. ISSN 0360-5442. DOI: https://doi.org/10.1016/j.energy.2019.05.165.

XIANG, Z.; QIN, H.; HE, B.-J.; HAN, G.; CHEN, M. Heat vulnerability caused by physical and social conditions in a mountainous megacity of Chongqing, China. **Sustainable Cities and Society**, v. 80, p. 103792, May 2022. ISSN 2210-6707. DOI: https://doi.org/10.1016/j.scs.2022.103792.

ZHAO, Q.; LIAN, Z.; LAI, D. Thermal comfort models and their developments: A review. **Energy and Built Environment**, v. 2, n. 1, p. 21-33, Jan. 2021. ISSN 2666-1233. DOI: https://doi.org/10.1016/j.enbenv.2020.05.007.

1 **Talita Marini Brandelli:** conceptualization, data curation, formal analysis, investigation, methodology, visualization, writing–original draft, writing–review and editing. E-mail: talitabrandelli@hotmail.com

2 **Nébora Lazzarotto Modler:** formal analysis, methodology, supervision, writing–review and editing. E-mail: lazznebora@gmail.com

3 **Luiz Antonio dos Santos Franz:** conceptualization, methodology, supervision, writing–review and editing. E-mail: luisfranz@gmail.com

4 **Thaísa Leal da Silva:** conceptualization, methodology, writing–review and editing. E-mail: thaisa.silva@atitus.edu.br

5 **Júlia da Cruz Lopes:** data curation, investigation, visualization. E-mail: ju-0-9@hotmail.com

6 **Eduardo Grala da Cunha:** conceptualization, methodology, supervision, writing–review and editing. Address: Universidade Federal de Pelotas. Rua Benjamin Constant, nº 1359, Bairro Centro, Pelotas–RS. ZIP Code: 96010-020. E-mail: eduardogralacunha@yahoo.com.br

7 **Nirce Saffer Medvedovski:** conceptualization, supervision, writing–review and editing. E-mail: nirce.sul@gmail.com