XVIII ENCONTRO NACIONAL DE CONFORTO NO AMBIENTE CONSTRUÍDO
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AMBIENTE CONSTRUÍDO E USUÁRIO: PERSPECTIVAS LATINO-AMERICANAS

Prazer e conforto térmico em residências naturalmente ventiladas: perspectivas de um estudo de campo em clima quente e úmido

Placer y confort térmico en viviendas naturalmente ventiladas: perspectivas de un estudio de campo en clima cálido y húmedo

Thermal pleasure and comfort in naturally ventilated homes: insights from a field study on hot and humid climate

Conforto térmico / *Confort térmico / Thermal Comfort*

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Resumo

Este estudo investiga a percepção subjetiva do prazer térmico em residências localizadas em clima quente e úmido no Brasil. A pesquisa baseou-se em um estudo de campo de longo prazo na cidade de São Luís (MA) com monitoramento constante da temperatura do ar, umidade relativa e velocidade do ar, enquanto os moradores relataram suas percepções e o prazer térmico. Os resultados indicam que o aumento da velocidade do ar pela ventilação natural é fundamental na promoção do conforto térmico. Observou-se uma forte associação entre neutralidade térmica e prazer térmico em ambientes ventilados naturalmente, sugerindo que a aceitação térmica pode ser alcançada ao se priorizar a ventilação natural como estratégia de climatização. Essas descobertas reforçam a importância de considerar o prazer térmico, contribuindo para compreensão do conforto térmico adaptativo residencial nestas condições climáticas.

Palavras-chave: Prazer térmico. Ventilação natural. Movimento do ar. Clima quente e úmido.

Resumen

Este estudio investiga la percepción subjetiva del placer térmico en viviendas ubicadas en un clima cálido y húmedo en Brasil. La investigación se basó en un estudio de campo en São Luís con monitoreo constante de la temperatura del aire, humedad relativa y velocidad del aire, mientras los residentes informaban sus percepciones térmicas. Los resultados indican que el aumento de la velocidad del aire a través de la ventilación natural és fundamental en la promoción del confort. Se observó una fuerte asociación entre la neutralidad térmica y el placer térmico en entornos con ventilación natural, lo que sugiere que la aceptación térmica puede lograrse dando prioridad a la ventilación natural como estrategia de control climático. Estos hallazgos refuerzan la importancia de considerar el placer térmico, contribuyendo a la comprensión del confort térmico adaptativo residencial en estas condiciones climáticas.

Palabras clave: Placer térmico. Ventilación natural. Movimiento del aire. Clima cálido y húmedo.

Abstract

This study investigates the subjective perception of thermal pleasure in homes in a hot and humid climate in Brazil. The research was based on a long-term field study in São Luís with constant monitoring of air temperature, relative humidity and air speed while residents reported their thermal perceptions. The results indicate that increased air velocity through natural ventilation is crucial in promoting comfort. A strong association between thermal neutrality and pleasure was observed in naturally ventilated environments, suggesting that thermal acceptance can be achieved by prioritizing natural ventilation as a conditioning strategy. These findings reinforce the importance of considering thermal pleasure, contributing to a broader understanding of residential adaptive thermal comfort in the climate conditions which prevail in Brazil.

Keywords: Thermal pleasure. Natural ventilation. Air movement. Hot and humid climate.

Introduction

Field studies for thermal comfort assessments typically integrate objective variables, obtained through environmental measurements (e.g., air temperature, relative humidity, and air velocity), with subjective variables, derived from occupant surveys. Regarding subjective assessments, both ASHRAE Standard 55 (ASHRAE, 2023) and the proposed Brazilian National Standard NBR 16401-2 (ABNT, 2021) recommend the inclusion of *thermal acceptability*, *thermal sensation* (whose average scores for the population correspond directly to PMV), *temperature* and *air movement preferences*, besides local thermal discomfort for short-term analyses.

Subjective assessments collectively interpret occupants' votes of the thermal environment, providing insights into comfort conditions. For instance, an occupant may report feeling "hot" while still considering the environment "acceptable" and preferring "no change" to current conditions. In this way, thermal comfort is inferred from combining these responses rather than being directly asked. For long-term evaluations, standards recommend satisfaction surveys, as they help identify sources of dissatisfaction and optimize building operations based on occupant feedback. The underlying assumption is that individuals can provide an "overall" comfort assessment of their environment, with *thermal satisfaction* generally being the preferred measure.

The relationship between thermal comfort and occupant satisfaction has been widely explored in the context of energy efficiency in residential buildings. Previous research suggests that residents in hot climates often develop adaptive strategies, such as using natural ventilation and fans, to balance comfort and energy consumption (JEONG; KIM; DE DEAR, 2024; RAMOS *et al.*, 2020; SOEBARTO; BENNETTS, 2014). Moreover, previous studies indicate that thermal comfort depends not only on air temperature but also on its interaction with relative humidity and air velocity (VELLEI *et al.*, 2017; YAN *et al.*, 2020). Since air movement from natural ventilation affects the surrounding thermal conditions, monitoring approaches involving both objective and subjective measures are demanded to understand the impact of this adaptation on occupants' thermal comfort indoors.

A less frequently explored yet significant measure in subjective assessment is *thermal pleasantness,* also known as *thermal pleasure* or *delight*. Rooted in the psychophysiological concept of 'alliesthesia' (CABANAC, 1979), this measure suggests that localized changes in skin temperature that contrast with the body's overall thermal state elicit positive sensory responses. The primary driver of thermal pleasure is pre-existing thermal discomfort (PARKINSON; DE DEAR, 2015), a principle that also applies to air movement (PARKINSON; DE DEAR, 2017). Assessments of thermal pleasure are often conducted alongside thermal sensation votes to understand the affective dimension of thermal experiences better.

Many past studies have shown the positive influence of increased air movement intensity on thermal evaluation, particularly thermal sensation, acceptability and comfort votes (HUANG *et al.*, 2013; MIHARA *et al.*, 2019; YAN *et al.*, 2020). Moreover, previous chamber studies focused on the impact of dynamic airflow patterns - resembling natural wind characteristics - on thermal sensation and comfort assessment (HUA *et al.*, 2012; LUO *et al.*, 2018; ZHOU *et al.*, 2006). However, only a few have addressed thermal pleasure from air movement (PARKINSON; DE DEAR, 2017; PARKINSON; DE DEAR; CANDIDO, 2016). Moreover, those chamber studies were conducted under the alliesthesia framework, focusing on localized, short-in-time airflow stimuli with physiological implications for the human body.
This study aims to add evidence to the subjective evaluation (affective dimension) of thermal pleasure from a residential field study in a Brazilian hot and humid climate, whose built stock strongly relies on natural ventilation and increased air movement to ensure occupants' thermal comfort indoors. By depicting thermal pleasure in terms of correlated evaluation criteria and environmental conditions, this research intends to shed light on comprehension as close as to occupants' thermal satisfaction in the national residential building sector.

Objective Statement
This paper aims to depict thermal pleasure at home in a hot and humid climate in Brazil, based on the surrounding environmental conditions (indoor air temperature, relative humidity, and air velocity) and occupants' correlated thermal sensations and preferences.

Method

A residential thermal comfort field survey was conducted in São Luís, Brazil's Northeast, in Zone 0A of the ASHRAE 169 climate classification (ASHRAE, 2020). This zone represents the hottest and most humid areas in Brazil, with a high tendency for thermal discomfort due to heat throughout the year. In São Luís, the monthly mean outdoor air temperature ranges from 23 to 32 °C, while the monthly mean outdoor relative humidity varies between 76% and 88% annually.
The field study comprised a point-in-time and a long-term (longitudinal) survey. Nonetheless, this paper's scope is restricted to the long-term survey for fit purposes. The long-term environmental monitoring of each home was planned based on in-person interviews conducted at the surveyed homes. The interview collected participants' perceptions of the thermal environment, particularly regarding natural ventilation in their homes, and residents' habits of room occupancy. During in-person interviews, air velocity (Va) was monitored for over 30 minutes in empty, naturally ventilated rooms with a SENSU microclimatic station. The criteria for defining rooms for Va monitoring were the most frequently occupied and the most naturally ventilated ones, following the occupants' advice. After conducting the interviews, indoor air temperature (Ta) and relative

humidity (RH) were continuously and remotely monitored with HOBO sensors for approximately 30 days. These two variables were recorded in a timestamp of 10 minutes. The room placement of HOBO sensors followed the most frequently occupied rooms as depicted by the participants. After long-term monitoring, HOBO sensors were moved from one residence to another, restarting the survey protocol.

During the monitoring period, participants received at least six survey forms (longitudinal questionnaires, QL) through their smartphones. The QL sending schedule followed the outdoor wind conditions as indicated on the national weather forecast (moderate wind intensity) and residents' occupancy routine at the most frequently occupied rooms. QL was designed to capture the instantaneous thermal perception (Frame 1) in the rooms, the occupants' location in the residence, their current activity and clothing level. No personal data (e.g., age, gender) was collected in the QL. The goal was to gather over 500 valid responses to QL from all participants, which was successfully achieved with 597 responses from July to November 2022. Fifty-six residences were visited, and 111 individuals participated in the longitudinal monitoring phase.

Frame 1: Thermal perception survey in the longitudinal questionnaire (QL).

Thermal perception criteria	Scale	Extreme 1	Middle (0)	Extreme 2
Thermal Pleasure Vote (delight)	7-point	Very unpleasant	Neither pleasant nor unpleasant	Very pleasant
Thermal Sensation Vote	7-point	Hot	Neutral	Cold
Thermal Preference Vote	3-point	To be cooler	To stay as I am	To be warmer

Source: The authors (2025).

For data treatment, QL responses were manually assigned to indoor environmental data (air temperature, relative humidity and air velocity) and outdoor conditions (air temperature, relative humidity, and wind speed from INMET[1]) using the QL timestamp as a reference. For naturally ventilated spaces, indoor air velocity values were assigned and assumed based on the point-in-time measurements with the SENSU microclimatic station during the in-person interviews. Therefore, Va measurements were linked to complete questionnaires under the following conditions: if Va was measured in the same room from which the participants responded (1) and under the same operation mode running when participants responded (2). In contrast, Ta and RH measurements had spatial and temporal coincidences in the long-term monitoring (same room and same or nearly times). Consequently, the assignment rate for Ta and RH was 507

[1] Outdoor measurements were obtained from the INMET (National Weather System) by selecting data from the SAO LUIS A203 automatic station from June to November 2022. Available at: https://tempo.inmet.gov.br/.

measurements out of 597 completed questionnaires (85%), while the assignment rate for Va was only 295 out of 597 (50%).
The study received ethical clearance from the Ethics Committee on Research with Human Beings (CEPSH-UFSC) under registration number CAAE 58653622.8.0000.0121. The detailed field study's methodology, including sampling, indoor measurement sensors, complete survey questionnaires, and data treatment, can be found in BUONOCORE (2023).

Results

Sample characterization

The sample's environmental characteristics such as air-conditioning (AC) availability and AC running, and the participants' descriptors of metabolic rate and clothing insulation at the response moment are depicted in Table 1.

Table 1: Summary of the sample characteristics.

Criteria	Levels	N	%
AC Availability at home	No	224	38
	Yes	365	62
AC Running at the response moment	Yes (AC)	43	7.2
	No (N-AC)	554	92.8
Metabolic Rate (met)	< 1 met	434	72.7
	~1.1 met	104	17.4
	>1.6 met	57	9.5
	>2 met	2	0.3
Clothing Insulation (clo)	~0.25 clo	441	73.9
	~0.36 clo	114	19.1
	~0.57 clo	32	5.4
	~0.74 clo	10	1.7
Total sample	-	597	100%

Source: The authors (2025).

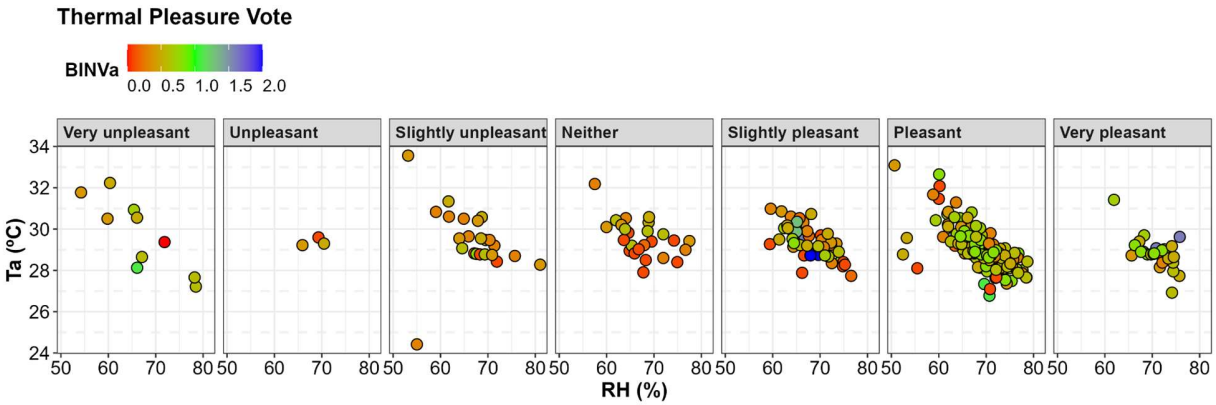
Most residences visited had air-conditioners installed, resulting in a frequency of 62% of the survey sample with AC availability. Nonetheless, the frequency of AC running – captured from the moment of responding to questionnaires at home – was significantly lower, 7.2%. In other words, residents mainly resorted to operation modes other than AC (N-AC), including natural ventilation alone (windows opened), natural ventilation supported by fans, fans only and free-running mode

(windows closed and no systems operating). Completing the sample characterization, light clothing patterns (~0.25 clo) and sedentary activities (<1 met) prevailed at the response moment.

Thermal pleasure and the environmental conditions

Figure 1 illustrates the relationship between indoor air temperature, indoor relative humidity, and thermal pleasure votes, with binned air velocity values (m/s) represented by a color gradient ranging from red (lower values) to blue (higher values). The observations with no Va assigned were excluded from this analysis, which means thermal pleasantness evaluation in naturally ventilated rooms. Indoor air temperatures ranged from 24 to 34 °C, with the most frequent occurrences between the 28-32 °C interval. Indoor relative humidity values varied between 50% and 80%, with the predominance of RH > 60%. Indoor air velocity bins ranged from nearly 0 to 2 m/s.

Figure 1: Thermal Pleasure Vote depicted by indoor air temperature, relative humidity and air velocity.



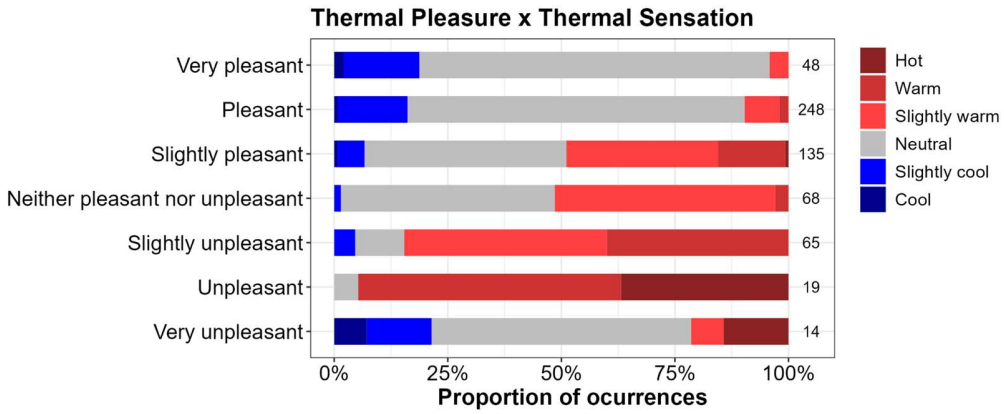
Source: The authors (2025).

Generally, the path from “Very unpleasant” to “Very pleasant” votes comprised decreasing air temperatures and increasing air velocities, particularly from “Slightly unpleasant” to “Very pleasant”. An unspecific trend regarding the environmental variables characterized the “Very unpleasant” and “unpleasant” votes, particularly because there were very few complete observations within those two voting categories. Nonetheless, the occurrence probability of air velocities between 0.5 to 1 m/s (green dots in Figure 1) associated with the pleasantness votes was noticeable in this survey, suggesting the thermal pleasure sensation from increased wind intensity in naturally ventilated residential rooms.

Thermal pleasure and thermal sensation

The bar plot illustrates the relationship between thermal pleasure and thermal sensation votes based on the proportion of occurrences within each thermal pleasure category (Figure 2). The overall distribution of thermal pleasure (delight) shows the predominance of "Pleasant" (n = 248) and "Slightly pleasant" (n = 135) occurrences. Neutral thermal sensation predominates across most categories, particularly in "Pleasant" and "Very pleasant". Warm and slightly warm thermal sensations prevailed in the "Slightly unpleasant" and "Unpleasant" categories, with their proportion increasing as thermal pleasure decreased. Conversely, slightly cool thermal sensations were more concentrated in the "Very pleasant" and "Pleasant" categories. Noticeably, the depicted "Very unpleasant" category (14 occurrences) broke the thermal sensation distribution trend observed across the "Very pleasant" and "Unpleasant" categories, including a great proportion of neutral votes. Overall, the results highlight the nuanced interplay between subjective thermal pleasure and thermal sensation responses, with neutral votes generally associated with more positive pleasure ratings and the warmer side of the thermal sensation scale relating to negative pleasure ratings.

Figure 2: Depicting thermal pleasure based on thermal sensation.



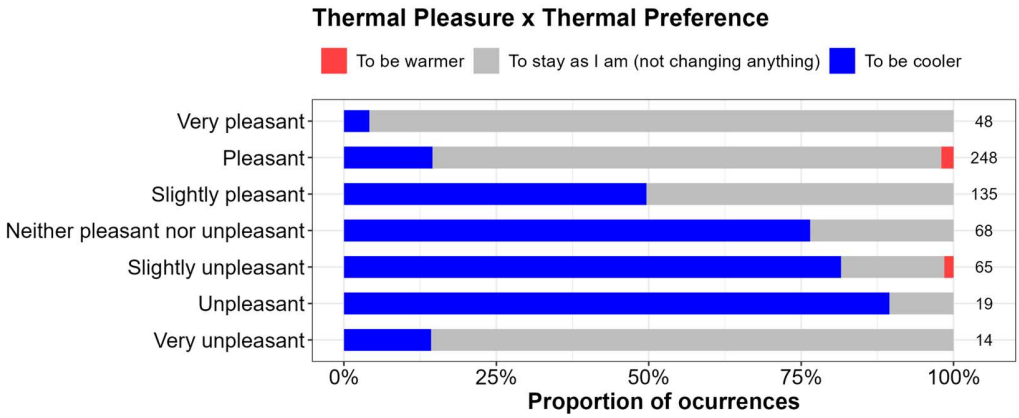
Source: The authors (2025).

Thermal pleasure and thermal preference

The bar plot depicts the relationship between thermal pleasure and thermal preference, categorized by the proportion of responses within each thermal pleasure level (Figure 3). Overall, most participants preferred "To stay as I am (not changing anything)" in the survey. Proportionally, this preference prevailed in the "Pleasant" and "Very pleasant" categories. Nonetheless, a significant increase in the vote "To be cooler" was observed from "Slightly

pleasant” towards the negative pleasure rating categories. Conversely, the preference "To be warmer" was notably minimal and primarily observed in the "Slightly unpleasant" and “Pleasant” categories without a trend. These findings indicate that higher thermal pleasure levels are associated with a stronger tendency to maintain current thermal conditions. Moreover, the desire to be cool increased drastically towards the unpleasant votes (above 75%), confirming occupants’ dissatisfaction with the idea of feeling warm or hot at home in the studied context. Responses of “Very unpleasant” regarding preference also disagreed with the distribution trend observed across the "Very pleasant" and “Unpleasant” categories, which may indicate a lack of attention when filling out the questionnaire.

Figure 3: Depicting thermal pleasure based on thermal preference.



Source: The authors (2025).

Discussion

From the study’s outcomes, air movement from natural ventilation (resembling air velocities above 0.5 m/s) increased occupants’ thermal pleasure ratings. This was true considering the context in which the survey was conducted, which included hot and humid environmental conditions throughout the year (up to 32 °C and 85%) and free adaptations for metabolic rate and clothing garments in the residential sector. Previous studies indicated the role of increased air movement on thermal delight (PARKINSON; DE DEAR; CANDIDO, 2016), leading to occupants’ thermal acceptability in controlled environmental and personal variables (DE DEAR, 2011). Experiencing such air movement conditions from natural ventilation in residences – in which occupants adapt more flexibly – might have contributed to the positive evaluation of thermal pleasantness, potentially leading to occupants’ thermal satisfaction. Moreover, experiencing high

air velocities under non-extreme air temperatures (below 30 °C) favored the feeling of being “very pleasant”.

Furthermore, this study intended to detail what was behind the thermal delight evaluation by cross-relating thermal pleasure, sensation and preference votes. The cross-analysis indicated the association between thermal delight, thermal neutrality and the preference to make no changes in the thermal environment. However, there was an inherent trend of preferring to be cooler than neutral as unpleasantness increased, indicating that residents could be more thermally satisfied if indoor air temperatures were lower. A previous study conducted in undergraduate classrooms in the same city depicted the association between thermal acceptability, comfort and sensation votes, showing that warmer thermal sensations evoked proportionally more unacceptable and uncomfortable evaluations than cooler ones (BUONOCORE *et al.*, 2020).

In this line of reason, there is strong evidence of a dissociation between comfortable and neutral thermal conditions in the literature from non-residential buildings in hot and humid climates, particularly if the neutral temperature is greater than 26 °C, evoking subjects’ preference for being in a cooler environment (SHAHZAD; RIJAL, 2019; TAIB *et al.*, 2022; WU *et al.*, 2019). Nonetheless, the more positive pleasantness ratings in this study were predominantly associated with the neutral thermal sensation and the wish to stay under such a perception of neutrality. From the perspective of the thermal environment, increased air velocity was crucial to improve thermal delight, thus favoring the achievement of thermal neutrality. The fact that the present study was conducted in residential settings with adaptive possibilities might explain why most residents expressed a positive evaluation of the thermal environment.

The absolute and prevalent number of positive ratings (n=431 from “very pleasant”, “pleasant”, and “slightly pleasant” votes) even under warm environmental conditions and the overall AC availability in this sample corroborate the idea of residents’ acceptance of thermal neutrality in this survey. As learned from the sample’s characterization, most residents had access to AC equipment at home but did not operate them frequently, so natural ventilation operation prevailed throughout the monitoring. Comparable usage patterns were identified in previous studies in Brazilian residences with similar sampling methods (BUONOCORE *et al.*, 2024; RAMOS *et al.*, 2020). Nonetheless, it must be emphasized that those samples do not reflect the reality of the whole Brazilian residential sector, in which AC ownership is only 17%, according to the latest National Survey (MITSIDI, 2024). Such acknowledgement points to the relevance of this study’s findings regarding thermal neutrality and the importance of natural ventilation in Brazilian homes.

Overall, the results presented so far are aligned with the outcomes from Parkinson and de Dear’s study (2017), in which the mean pleasantness vote between “indifferent” and “slightly unpleasant” corresponded to the mean thermal sensation of “slightly warm” (precondition scenario; Ta = 27.5 °C; no airflow stimuli). The insertion of local airflow stimuli of various dynamic

patterns with an average air velocity of 0.65 m/s on the subjects' necks improved their thermal sensation and pleasantness to closer to "neutral" and "slightly pleasant", respectively. Participants from the present study expressed better pleasantness evaluations under similar air velocity magnitudes, which can be attributed to the differences in experimental arrangements (tight versus flexible) and airflow sources (artificial versus natural).

Conclusion

The findings of this study reinforce the association between thermal pleasure and neutrality in naturally ventilated residential buildings, potentially leading to residents' thermal satisfaction. The results indicate that pleasantness was closely linked to neutrality, yet slightly cooler conditions tended to be preferred as unpleasantness increased. Additionally, the study suggests that increased air velocity positively influences thermal delight, reinforcing previous findings on airflow and comfort perceptions. Additionally, the limited number of "very unpleasant" votes during the monitoring may have been inaccurately recorded in the online questionnaire, as they were predominantly linked to a neutral thermal sensation and a preference for maintaining the existing thermal condition.

The high prevalence of positive pleasantness votes, even in warmer conditions, and the observed preference for maintaining the current state suggest that residents effectively adapt to their environment, often choosing natural ventilation over mechanical cooling. These outcomes further support that natural ventilation strategies enhancing air movement are essential for achieving residential thermal comfort in Brazilian hot and humid climates. Ultimately, this study underscores the importance of considering thermal pleasantness as a key factor in residential thermal comfort assessments. By integrating air movement strategies into building design and operation, occupants can achieve comfortable indoor environments while reducing reliance on mechanical cooling systems. These insights contribute to the broader understanding of adaptive thermal comfort in hot and humid climates.

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