VOL. 08 NO. 4,
MAY, 2025
E-ISSN 3026-9210
P-ISSN 3026-815X

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Built Env. & Geological Research (JBEGR)

Evaluating Thermal Comfort Standards of Residential Housing in Tropical Climates: A Systematic Review

Adetoye M. Aderinsola; Oladipo Dare-Abel; Olatunde Arayela; & Oluwatoyin O. Ajayi

Department of Architecture, College of Environmental Science and Management, Caleb University, Imota, Ikorodu, Lagos, Nigeria

DOI: https://doi.org/10.70382/ajbegr.v8i4.045

Abstract

Thermal comfort is a fundamental determinant of health, productivity, and well-being within residential buildings. However, prevailing international thermal comfort standards (such as ASHRAE 55 and ISO 7730) are largely derived from temperate climate research and office-based contexts, limiting their relevance to tropical residential environments. This systematic review critically evaluates the applicability and effectiveness of these standards in residential buildings located in tropical climates. Guided by PRISMA protocols, the study analyzed 13 peer-reviewed field studies published between 2020 and 2025, selected through a comprehensive Google Scholar search. Included studies involved in-situ measurements and subjective occupant assessments in naturally ventilated and mixed-mode tropical dwellings. Findings reveal a consistent mismatch between predicted comfort conditions based on standard PMV/PPD models and actual occupant thermal sensation and preference, particularly in warm and humid settings. Occupants in tropical climates often express comfort at higher indoor temperatures (27–30°C) than standard upper limits, with air movement and adaptive behaviors playing a critical role in achieving satisfaction. The review identifies significant gaps in standard frameworks, including their inadequate consideration of adaptive opportunities, socio-cultural context, and non-steady-state environmental conditions common in residential settings. It concludes that a one-size-fits-all application of current standards may inadvertently drive unsustainable cooling demand and misrepresent user comfort. The study recommends the development of

context-specific guidelines grounded in empirical data and adaptive comfort models tailored to tropical climates.

Keywords: Adaptive comfort, ASHRAE 55, Indoor environment, ISO 7730, Residential buildings, Thermal comfort, Tropical climate

Introduction

Thermal comfort, defined as the state of mind expressing satisfaction with the thermal environment (ASHRAE Standard 55), is a fundamental determinant of occupant health, well-being, productivity, and overall quality of life within the built environment (Fan, Chen & Deng, 2023). Achieving this comfort efficiently is paramount for sustainable development. In tropical climates, characterized by high and relatively constant temperatures, elevated humidity levels, and intense solar radiation year-round, the challenge of providing thermal comfort in residential buildings is particularly acute and distinct from temperate regions (Amin, 2021). The residential sector in these regions faces a confluence of pressures: rapidly expanding urbanization, escalating demand for cooling driven by rising incomes and climate change, and the critical need to mitigate associated energy consumption and greenhouse gas emissions. Traditional reliance on mechanical air-conditioning (AC) presents significant sustainability challenges, including strain on energy grids, high operational costs (especially for low-income households), and exacerbation of the urban heat island effect (Joshi, Khan, Anand & Sen, 2024). Consequently, there is an urgent imperative to develop and implement residential thermal comfort strategies that are both genuinely effective in the unique tropical context and inherently energy-efficient.

Despite decades of research on thermal comfort, a critical problem persists: prevailing international thermal comfort standards (e.g., ASHRAE Standard 55, ISO 7730) are predominantly based on research and models developed for temperate climates and controlled, often air-conditioned, office environments. This creates a fundamental mismatch when applied uncritically to residential buildings in tropical climates. These standards often underestimate the significant adaptive capacity of occupants in naturally ventilated dwellings, overlook culturally specific comfort expectations and behaviours, and fail to adequately account for the dynamic interplay of high humidity and temperature prevalent in the tropics. Furthermore, the residential sector exhibits unique patterns of occupancy, activity levels, clothing choices, and control over the environment compared to commercial buildings, factors inadequately addressed by existing frameworks (Ouldboukhitine, Belazi, Bakkour & Bouchair, 2025). This misalignment risks promoting over-reliance on energy-intensive mechanical

cooling in residences where passive and adaptive strategies could be sufficient for significant portions of the year, leading to unnecessary energy consumption, increased carbon footprints, economic burdens on households, and potentially even sub-optimal comfort conditions when standards are rigidly applied. There is a substantial and growing body of research specifically investigating thermal comfort in tropical residential settings; however, this knowledge remains fragmented, and its implications for refining or developing climate-specific standards and design guidelines have not been comprehensively synthesized and evaluated through a rigorous, systematic review.

This systematic review therefore aims to critically evaluate the applicability, effectiveness, and underlying assumptions of existing thermal comfort standards for residential housing in tropical climates by synthesizing the global body of empirical evidence. The objectives of the study to achieve the aim are to;

1. To systematically identify, critically appraise, and synthesize the existing empirical evidence; and
2. To evaluate the alignment (or misalignment) between the collected empirical findings from tropical residences and the predictive models, comfort boundaries, and methodological approaches stipulated by major international thermal comfort standards (principally ASHRAE 55 and ISO 7730)

This review focuses explicitly on *residential* buildings (detached houses, apartments, low-rise/high-rise housing) within defined tropical climatic zones (Köppen climate classifications A- Tropical/Megathermal). The microclimates under the Tropical climate are; f=Wet (from German "feucht" for moist), m=Monsoonal, W=Winter dry season (see figure 1). It excludes commercial, institutional, or industrial buildings. The review encompasses studies involving field measurements and occupant surveys.

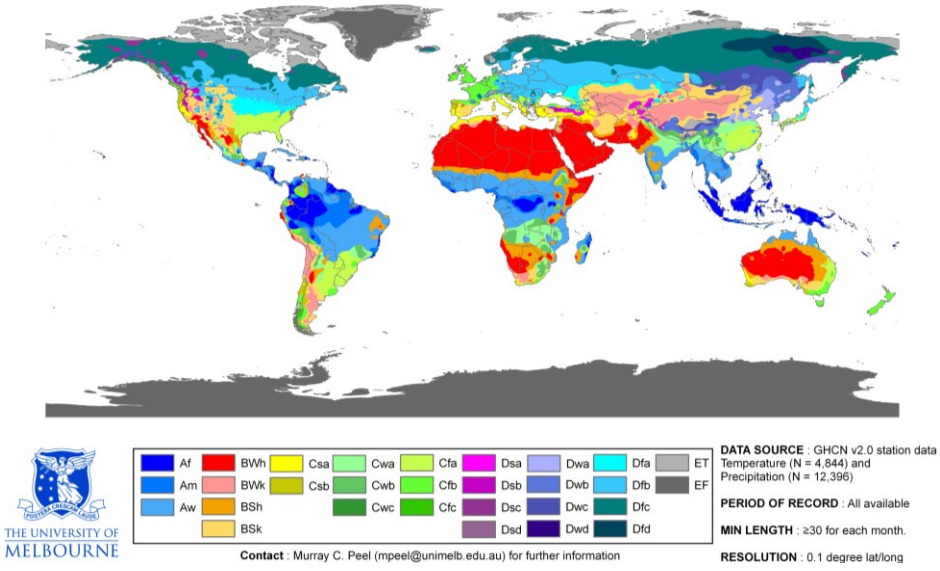


Figure 1: World map of Köppen climate classification

Source: Means (2025)

LITERATURE REVIEW

Empirical Review

Field studies conducted in naturally ventilated (NV) and mixed-mode (MM) residential buildings across diverse tropical regions (Southeast Asia, South Asia, Africa, Latin America, Oceania) consistently reveal a significant departure from comfort conditions predicted by international standards like ASHRAE Standard 55 and ISO 7730. Kajjoba, Wesonga, Lwanyaga, Kasedde, Olupot & Kirabira (2025) and Pourabrishami (2024) demonstrates that residents in the tropics express thermal comfort at substantially higher indoor operative temperatures than the upper limits typically prescribed (e.g., 26-28°C in ASHRAE 55 for summer). Neutral temperatures often range between 27°C and 30°C, with acceptable temperatures extending even higher, particularly in NV dwellings. Crucially, these studies highlight the paramount importance of air movement, often achieved through natural ventilation or ceiling fans, in achieving comfort at elevated temperatures. Humidity, while universally high, appears to be tolerated more readily than PMV-based models predict, provided sufficient air movement exists (Liu, Li & Xi, 2023). Occupant adaptation emerges as a central theme, with frequent behavioral adjustments such as opening windows, using fans, modifying clothing (often to very light levels), adjusting activity schedules, and consuming cool drinks being widely documented as effective strategies. This body of evidence strongly suggests that the static comfort zones of mainstream standards are inadequate for capturing the dynamic and adaptive reality of thermal comfort perception in tropical homes.

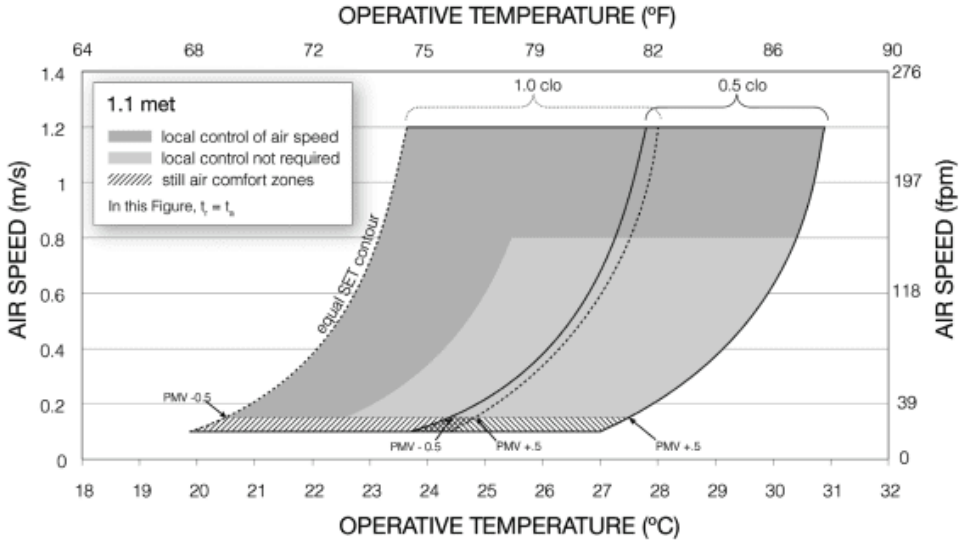


Figure 2: Extended thermal comfort zones based on the adaptive comfort model from ASHRAE 55

Source: Jenkins (2025)

Theoretical Review (Fanger's Heat Balance Model- PMV/PPD)

Proposed by Povl Ole Fanger in the 1970s, this model (formalized in ISO 7730 and ASHRAE 55) posits thermal comfort as a deterministic outcome of achieving thermal equilibrium between the human body and its immediate environment (Fabbri, 2024). It quantifies comfort through the Predicted Mean Vote (PMV), derived from six primary factors: air temperature, mean radiant temperature, air velocity, humidity, metabolic rate, and clothing insulation (Freudenberg, 2024). The Predicted Percentage Dissatisfied (PPD) indicates the expected discomfort level. Proponents argue its rigor and laboratory validation under steady-state, controlled conditions (Fanger, 1970; ISO, 2005; ASHRAE, 2020). The objective of the theory is to provide a universal, physics-based prediction of thermal sensation. PMV/PPD forms the core of major international standards under evaluation. However, studies against its applicability in tropical NV residences are extensive and compelling. Field research consistently shows PMV overestimates actual thermal sensation (TSV) in warm conditions (Shin, Kang, Mun, Kwak & Huh, 2021; Laouadi, 2022; Wu, Zhang, Liu & Cheng, 2023), primarily because it inadequately accounts for the profound impact of behavioral adaptation, psychological acclimatization, and contextual expectations prevalent in real-life residential settings in the tropics. Its reliance on steady-state conditions also conflicts with the dynamic nature of NV environments.

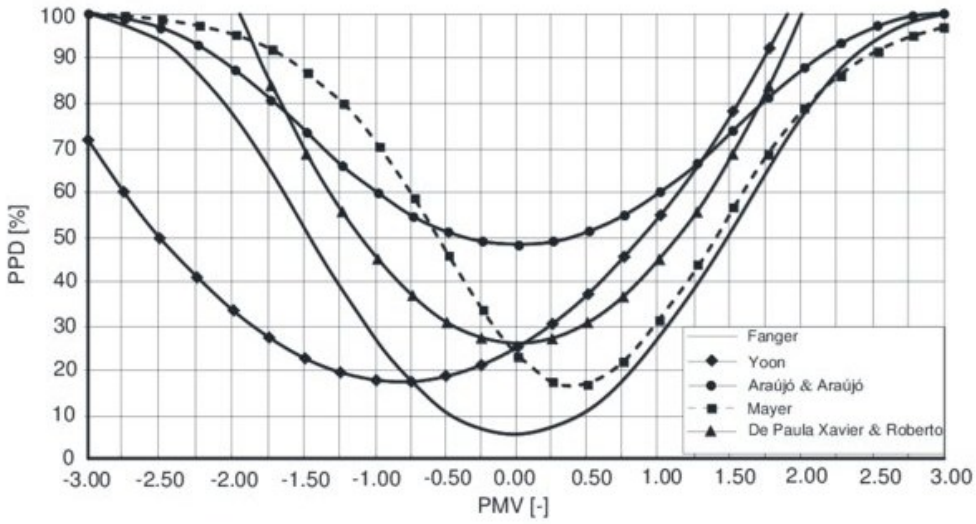


Figure 3: The relation between PMV and PPD

Source: Kajtar, Nyers, Szabo, Ketskemety, Herczeg, Leitner & Bokor (2017)

Conceptual Review

The concept of thermal comfort in tropical residential housing is a 3-dimensional construct resulting from the inter-relationship of factors namely; core environmental variables,

personal factors and contextual and adaptive factors. Core Environmental Variables include air temperature (Ta), mean radiant temperature (Tmr), air velocity (Va), and relative humidity (RH). In the tropics, Va and Tmr (influenced by solar gain and surface temperatures) often play more critical roles than in temperate zones. Personal Factors encompass metabolic rate (Met) and clothing insulation (Clo); tropical contexts typically feature lower Clo values (Yang, 2024). Critically, Contextual and Adaptive Factors significantly modulate the relationship between the environment and subjective comfort (Mohammad, 2024). They include: adaptive opportunities, building design & operation, climatic context, occupant characteristics, time/season. The core relationship posits that subjective thermal perception (Sensation/TSV, Preference/TPV, Acceptance/TAV, Comfort/TCV) is the outcome of the interaction between Environmental Variables and Personal Factors, heavily moderated by Contextual and Adaptive Factors. This holistic conceptualization moves beyond simplistic cause-and-effect models and underscores the necessity of context-sensitive assessment for tropical residences.

Research Gaps

There is a lack of standardized methodologies for measuring and reporting key contextual variables (especially detailed adaptive behaviors, precise microclimatic conditions, and socio-cultural expectations), making cross-study comparison and meta-analysis challenging. The existence of adaptation is well-documented, but, the quantitative contribution of specific behavioral adjustments (e.g., fan speed vs. window opening vs. clothing change) and psychological factors (e.g., cultural tolerance, expectations) to overall comfort perception in diverse tropical residential settings remains inadequately quantified and integrated into predictive models. There is a significant geographical and demographic imbalance in the literature as research heavily concentrates on specific regions (e.g., Southeast Asia, India), while other populous tropical areas (e.g., parts of Africa, Latin America, Pacific Islands) are underrepresented. This systematic review directly addresses these gaps by synthesizing global evidence, rigorously evaluating standard applicability, and proposing targeted recommendations for context-specific standards and design practices.

METHODOLOGY

This systematic review employed a rigorous, transparent, and reproducible protocol aligned with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to critically evaluate the applicability of thermal comfort standards in tropical residential housing. The methodology encompassed distinct stages: search strategy development, study screening and selection based on predefined criteria, quality assessment, data extraction, and synthesis.

Search Strategy: A comprehensive and systematic literature search was conducted to identify all relevant peer-reviewed studies published between January 2020, and December 2025. The search was done on google scholar. The search strategy employed a combination of keywords and controlled vocabulary terms related to the core concepts. Supplementary searches included scanning the reference lists of included studies and relevant recent articles identified during the search. The exclusive reliance on Google Scholar may have limited the comprehensiveness of the literature search, as specialized databases like Scopus or Web of Science were not utilized due to institutional access constraints.

Study Selection: Inclusion and Exclusion Criteria: Studies identified through the search strategy underwent a two-stage screening process (title/abstract, full-text). Discrepancies were resolved through discussion or consultation with a third reviewer. Selection was based on a predefined criteria (inclusion and exclusion criteria): Inclusion criteria includes; Studies conducted in occupied residential buildings, Buildings located within defined tropical climates, Studies involving field measurements of IEQ parameters and concurrent administration of subjective occupant surveys and Studies explicitly comparing measured conditions and/or occupant responses to established thermal comfort standards Exclusion criteria includes; Studies conducted in non-residential buildings, Studies located outside defined tropical climate zones, Studies based solely on simulations, laboratory experiments, or questionnaires without concurrent environmental measurements, Studies lacking explicit subjective comfort assessment data linked to measurements and Studies not providing data allowing comparison to standards or not analyzing results in the context of standards.

Screening Process & Flow of Studies The study selection process followed the PRISMA flow diagram. The initial search on google scholar yielded 67 records. The 67 records were screened against inclusion/exclusion criteria and 42 records were excluded. Full texts of 25 articles were assessed for eligibility against all criteria. 10 articles were excluded for not having insufficient data for standard comparison. At the end, 13 studies met all inclusion criteria and were included in the final review and synthesis.

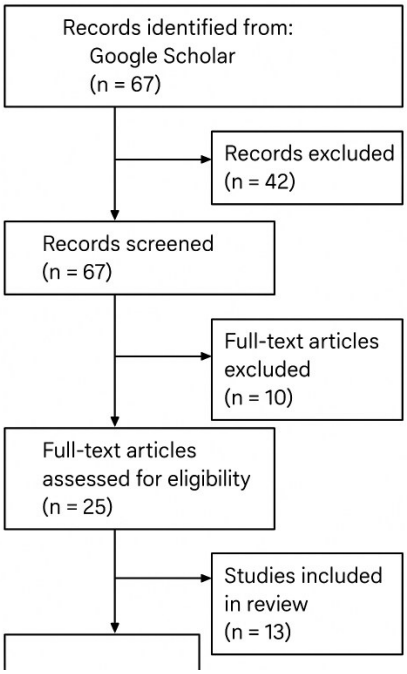


Figure 4: PRISMA Flow Diagram
Source: Authors (2025)

Key data extracted from the included 13 studies are:

i. Study Characteristics: Study location (country, city, Köppen climate zone), study period/duration.
ii. Building/Sample Characteristics: Building type (detached, apartment etc.), construction type/materials, ventilation strategy (NV, MM, AC), number of buildings/dwellings, number of occupants surveyed, occupant demographics (if available).
iii. Methodology: Environmental parameter measurement details (instruments, locations, frequency, duration, metrics reported - e.g., Ta, RH, Va, Tmr, TOP), subjective survey details (scale used, frequency, timing, key metrics reported - e.g., TSV, TPV, TAV, neutral temp, acceptable range), recording of adaptive behaviors (types, frequency).
iv. Key Findings Related to Standards: Reported neutral temperature (Tn) and/or comfort temperature (Tc), Reported acceptable temperature range/upper limit, Comparison of measured TOP/RH to ASHRAE 55/ISO 7730 comfort zones, Calculated PMV/PPD vs. actual TSV/PD (including correlation coefficients or regression results if reported), Applicability of adaptive models (e.g., relationship between Tc/Tn and outdoor temperature (Tout)), Identified factors causing deviation from standards (e.g., high air velocity, adaptation) and Author conclusions regarding standard applicability.

Given the anticipated heterogeneity in methodologies, building types, specific climates, and outcome reporting across the included studies, a meta-analysis was deemed inappropriate. Instead, a narrative synthesis approach was employed, structured according to the review objectives.

RESULTS AND DISCUSSION

Objective 1

Table 1 provides a synthesized summary of all the reviewed papers.

Table 1: Synthesis of Reviewed Papers

S/N	Citation	Study Location & Climate	Duration	Building Type & Construction	Ventilation & Sample	Measurements & Surveys	Neutral/Comfort Temp & Range	Standards Comparison & Conclusions
1	Yadeta et al., 2022	Jimma, Ethiopia – Cwb	~3 mo field	Detached homes; brick/concrete	NV; occupants surveyed (~N not specified)	Ta, RH, Va, OP; ASHRAE TSV surveys	Neutral ~25-26 °C; wide acceptance	PV model less fitting; adaptive model recommended
2	Yadeta et al., 2023	Jimma, Ethiopia – Cwb	~3 mo	Same building types (NV)	NV; sample size unspecified	Ta, RH, Va indoor/outdoor; ASHRAE surveys	Tn linked to outdoor running mean	PMV inaccurate; occupant behavior crucial; supports adaptive model
3	Taing et al., 2023	Phnom Penh, Cambodia – Am	Dry & wet 2021	Townhouse, detached, apartment; masonry	NV; ~207 occupants	Ta, RH, Va loggers; ASHRAE surveys	Range 29-30 °C; acceptable to 32.5 °C w/ fans	PMV undervalues comfort with higher Va; adapt ASHRAE for high RH & velocity
4	Faheem et al., 2023	Tiruchirappalli, India – humid tropic	1 year (Sep 2019–Aug 2020)	Hostels; masonry, NV, ceiling fans	27 hostels, ~2,028 student responses	Ta (20-34 °C), RH; ASHRAE TSV; recorded fan use, clothing changes	Neutral ~29.5 °C; range 26.1–32.8 °C	Much broader than ASHRAE; PMV underpredicts; behaviors critical
5	Therán-Nieto et al., 2023	Dry tropical climate	Not specified	Low-rise residential	NV; occupant surveys unspecified	Ta, RH, surveys	Comfort neutral not given	Conditions often outside ASHRAE comfort band; adaptation observed
6	Aqilah et al., 2025	Malaysian tropics	Field year	NV dwellings	53 dwellings, 209 respondents	Ta, Tg, Va; fan usage effect; ASHRAE surveys	Comfort mean ~30.5 °C; range 26–33 °C	Fan increases 1 °C; standards don't account air movement
7	Safarova et al., 2022	Darwin, Australia – Aw	Not specified	38 houses (NV, NatHERS rated)	NV; occupant surveys	Ta, RH; ASHRAE surveys	Neutral unspecified	Codes should better reflect local comfort expectations
8	Allah et al., 2023	Malaysian tropics	Not given	Courtyard, semi-outdoor, air-conditioned	NV and AC zones; sample size unspecified	Ta; surveys	Semi-outdoor comfort high but ASHRAE compliant	Semi-outdoor viable; standards need adaptation
9	Islam & Ahmed, 2021	Bangladesh tropics	Not given	Traditional timber houses	NV; occupant observation surveys	Ta, RH; activity & space use surveys	Neutral/comfort not specified	Occupants adapt using semi-open spaces and fans
10	Handayani et al., 2024	Surakarta, Indonesia – tropic	Not stated	Low-cost HBE homes	NV; occupant interviews	Ta, RH; surveys	Not detailed	Heat is barrier; local behaviors important; standards lack alignment
11	Misni & Nik Hassin, 2024	Melaka, Malaysia – tropic	Simulation & survey	Traditional Malay house	NV; 48 occupant responses	Ta, Va; ASHRAE surveys	Neutral up to 30.35 °C	Adaptive comfort met; wall/window design key
12	Iqbal et al., 2022	Indonesia tropic	Not clear	NV houses	Two types; ~240 occupants	Ta; window opening ratios; surveys	Not provided	PMV overestimates discomfort; larger opening improves comfort
13	Maddumaarachchi et al., 2022	Singapore tropic	Not specified	Non-AC residential	NV; occupant surveys	Ta; surveys	Not specified	Predicted PMV differs from actual; adaptive adjustment needed

Objective 2

Mismatch Between Measured Comfort and Standard Comfort Zones

A recurrent theme across the reviewed studies is the inadequacy of static comfort models, particularly the Fanger's PMV/PPD framework, in capturing the thermal experiences of residents in NV tropical dwellings. In multiple studies, including those by Yadeta et al. (2022, 2023), Faheem et al. (2023), Taing et al. (2023), and Aqilah et al. (2025), neutral or preferred temperatures reported by occupants consistently exceeded the upper comfort limits specified by ASHRAE 55, which typically sets the upper boundary of comfort at approximately 26–27 °C for sedentary activity in NV spaces. In Jimma, Ethiopia, residents reported comfort at temperatures above 29 °C, significantly exceeding the predictive boundaries of ASHRAE 55 (Yadeta et al., 2022, 2023). In Tiruchirappalli, India, neutral temperatures reached 29.5 °C with an acceptable range extending up to 32.8 °C (Faheem et al., 2023). Similar findings were observed in Phnom Penh, Cambodia, where comfort persisted up to 32.5 °C with adequate air movement (Taing et al., 2023). In Malaysia, Aqilah et al. (2025) reported a comfort temperature of 30.5 °C, with fan use shifting perceived comfort boundaries. These discrepancies highlight a fundamental misalignment between empirical findings and PMV-based predictions, particularly in high-humidity and low-airflow tropical environments, where occupants exhibit different physiological and psychological adaptations than those assumed in standard models.

Applicability and Limitations of Adaptive Comfort Models

Although adaptive comfort models, such as those incorporated into ASHRAE 55 for NV buildings, perform better than static models in tropical contexts, they still show partial misalignment due to regional climatic, cultural, and behavioral variations. The adaptive model's reliance on outdoor running mean temperature as a predictor of indoor comfort has been validated in several studies (Yadeta et al., 2023; Safarova et al., 2022), but it fails to account for specific adaptive strategies employed by tropical occupants, such as: Frequent use of ceiling or table fans (Faheem et al., 2023; Aqilah et al., 2025), Window and door opening patterns (Iqbal et al., 2022; Islam & Ahmed, 2021), Use of shaded or semi-outdoor living spaces (Allah et al., 2023; Handayani et al., 2024), Daily activity scheduling to avoid indoor overheating (Islam & Ahmed, 2021). This suggests that while the adaptive model offers a closer approximation of comfort in NV buildings, it still requires regional calibration and integration of behavioral adaptation data to enhance its predictive accuracy.

Differences in Acceptable Ranges and Upper Limits

Several studies reported wider comfort bands than those recommended by standards. Faheem et al. (2023) and Misni & Nik Hassin (2024) observed acceptable ranges that

extended from 26 °C to over 32 °C, indicating a higher thermal tolerance among tropical occupants. Additionally, Taing et al. (2023) and Aqilah et al. (2025) demonstrated that air velocity significantly shifts the upper limit of acceptability. Safarova et al. (2022) in Darwin, Australia, and Therán-Nieto et al. (2023) in a dry tropical setting reported thermal acceptability at temperatures exceeding the ASHRAE-defined thresholds, especially in homes with no mechanical cooling. This evidence strongly supports the argument that comfort thresholds used in global standards do not accurately reflect local expectations or tolerances, particularly where occupants have adapted physiologically and behaviorally to warmer conditions over time.

Inadequacies in Standard Methodologies and Metrics

The reviewed studies further expose methodological gaps in international standards that limit their application in real-world tropical settings. ISO 7730 and ASHRAE 55 rely heavily on steady-state assumptions, fixed metabolic rates, and clothing insulation levels, which often fail to reflect the variability observed in tropical residences. Residents dynamically adjust clothing, change spaces within dwellings (e.g., move to shaded areas), and modulate activity levels (Handayani et al., 2024; Islam & Ahmed, 2021). Maddumaarachchi et al. (2022) explicitly compare predicted PMV with actual Thermal Sensation Votes (TSVs) and find significant divergence, especially under naturally ventilated, high-humidity conditions. These results underscore the need for comfort standards to incorporate dynamic and contextual variables, including real-time adaptive behavior, diurnal climate variation, and non-uniform environmental exposure within the home.

Cultural and Architectural Mediators of Comfort

The architectural characteristics of tropical homes and local cultural practices influence comfort in ways not captured by standard frameworks. Traditional Malay houses (Misni & Nik Hassin, 2024) and timber homes in Bangladesh (Islam & Ahmed, 2021) provide natural ventilation, high ceilings, and shading, which reduce thermal discomfort. Occupants in Indonesia and Cambodia (Iqbal et al., 2022; Taing et al., 2023) reported greater comfort in spaces with larger openings and cross-ventilation, even at temperatures above 30 °C. These findings suggest that thermal standards should not only adapt to physiological responses but also integrate architectural typologies and cultural living patterns to be relevant and actionable in tropical contexts.

CONCLUSION AND RECOMMENDATIONS

This study critically examined the alignment between empirical thermal comfort findings from tropical residential environments and the predictive frameworks established by major international standards such as ASHRAE 55 and ISO 7730. In synthesizing data

from 13 peer-reviewed studies conducted across various tropical contexts, including Ethiopia, India, Malaysia, Indonesia, Bangladesh, Cambodia, and Australia, the study highlights fundamental gaps in both the applicability and adequacy of existing comfort models when applied to naturally ventilated (NV) tropical dwellings. The findings reveal a consistent misalignment between standard comfort thresholds and actual occupant comfort experiences. Neutral and acceptable temperatures reported in tropical settings frequently exceed the upper boundaries defined by ASHRAE and ISO, with comfort bands often extending beyond 30 °C, particularly in the presence of adaptive behaviors such as the use of ceiling fans, clothing adjustments, and space-switching strategies. These elevated comfort tolerances reflect long-term physiological and psychological adaptation to warm and humid climates, factors that static models like PMV/PPD inadequately address. Even though adaptive comfort models offer a better fit than steady-state models, their reliance on outdoor temperature alone fails to capture the nuanced role of behavioral, cultural, and architectural adaptations that significantly shape comfort in tropical homes. Moreover, international standards often assume uniform building typologies and HVAC presence, which contrasts starkly with the reality of low-energy, passive dwellings in many tropical regions. Based on these findings, the study recommends the following:

i. Regional Calibration of Adaptive Comfort Models: Existing adaptive comfort equations should be modified using empirical datasets from different tropical zones to reflect locally appropriate comfort temperatures and acceptable ranges.
ii. Integration of Behavioral Adaptation in Standards: Comfort models and guidelines should explicitly account for common occupant adaptations (such as fan use, window operation, and temporal activity changes) that influence thermal perception.
iii. Reformulation of Comfort Thresholds for NV Tropical Buildings: International standards should reassess fixed comfort boundaries and expand the acceptable temperature range for NV buildings in tropical climates, particularly where air movement is present.
iv. Contextual Thermal Comfort Frameworks: New or modified standards should integrate building design parameters (e.g., wall materials, roof types, ventilation strategies) and cultural practices that mediate comfort, especially in traditional or low-cost housing contexts.
v. Occupant-Centric Monitoring in Future Research: Future studies should prioritize continuous, high-resolution environmental monitoring alongside subjective thermal assessments and behavior tracking to strengthen empirical grounding for regional model development.

In conclusion, the current one-size-fits-all approach embedded in global thermal comfort standards does not sufficiently address the climatic diversity and lived realities of occupants in tropical residential environments. This synthesis of empirical evidence

provides a critical foundation for revising ASHRAE 55 and ISO 7730 to incorporate adaptive principles for tropical residential contexts, and informs the development of region-specific standards that prioritize passive design, cultural practices, and quantified behavioral adaptations, ultimately advancing equitable, energy-efficient thermal comfort frameworks globally.

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