Development of a Comfort Rating Method for Australia's Nationwide House Energy Rating Scheme (NatHERS) – Darwin Houses Case Study

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Abstract

In the face of escalating global temperatures and extreme climate challenges, this study addresses the pressing concern of overheating within homes by introducing a new Comfort Rating Method. Our approach presents a departure from conventional norms in the domain of thermal comfort modelling by incorporating the Effective Temperature index (ET*), which considers not only air and mean radiant temperature but also humidity, essential for holistic comfort assessment. Moreover, we extend our model to account for indoor air movement, a significant contributor to comfort in tropical environments. This method has been embedded in AccuRate, the benchmark software for Australia's Nationwide House Energy Rating Scheme (NatHERS) and validated against real-world data from an extensive Darwin thermal comfort field study.

The new comfort calculation method was applied to examine 1,043 dwellings from Commonwealth Scientific Industrial Research Organisation (CSIRO)'s Australian House Data (AHD) sets. We proposed 10 comfort bands, providing a framework for evaluating comfort in residential settings. This research not only advances thermal comfort knowledge but also offers architects, designers, and stakeholders a tool to create climate-sensitive, resilient residential buildings. While this study focuses on Darwin only, future research can adapt this method to various extreme climates, refining its model based on regional nuances.

Keywords - Thermal Comfort, Effective Temperature, Extreme Climates, Climate-Sensitive Design, Residential Buildings.

1. Introduction

In the realm of human comfort, few challenges are as pertinent and pressing as ensuring comfort amidst extreme climatic conditions. The Northern Territory of Australia, specifically the tropical climate of Darwin, is characterised by its unique climatic challenges, where high temperatures and humidity levels intersect to create a distinctive atmosphere of persistent discomfort. At the heart of these challenges lies the pressing concern of overheating within residential homes [1]. As the mercury rises, homes become potential hotspots for discomfort, posing serious risks to the inhabitants' well-being (e.g., Refs. [2-4]). Overheating not only disrupts sleep patterns but also heightens the susceptibility to heat-related illnesses, thereby warranting a comprehensive exploration of this critical topic (e.g., Refs. [5-6]).

In the pursuit of human health and well-being, the implications of overheating extend beyond mere comfort [7]. Prolonged exposure to elevated indoor temperatures has been linked to a range of health issues, encompassing heat stress, dehydration, and compromised cognitive functioning [8]. Vulnerable segments of the population, such as the elderly and children, are particularly susceptible to the adverse effects of overheating. Furthermore, the compounding influence of climate change and global warming elevates the urgency of addressing this concern [9]. As these phenomena escalate, the potential for frequent and intense heat waves amplifies, casting a shadow of concern over the safety and comfort of inhabitants in extreme climates like tropical climate context [10].

The prevailing thermal comfort standards, exemplified by international standards such as the ASHRAE Standard 55 (2020) adaptive model, EN 15251 (2007), CIBCE Gide A (2015), and CIBSE TM52 [11-14], have predominantly centred around the utilization of operative temperature, a metric that regrettably disregards influential factors such as humidity and indoor air movement [15], though these models allow the correction using air movement. This notable deficiency becomes especially evident when grappling with extreme climates, such as tropical environments, where these unaccounted parameters play pivotal roles. Recognising this oversight, our research endeavours to bridge this gap by using the Effective Temperature (ET*) as the index for our thermal comfort calculation [16]. Unlike the conventional approach, ET* encompasses not only air temperature and mean radiant temperature but also crucially integrates humidity, rendering it an encompassing metric for a holistic comfort evaluation within tropical climates [17].

Additionally, the conventional comfort models have heretofore bypassed the intricate interplay between indoor air movement and comfort, an omission that becomes glaringly significant in tropical climates [18]. As a response to this oversight, we have extended the equation for ET*, encapsulating the tangible impact of indoor air movement. By doing so, we strive to deliver a more realistic representation of the comfort experience in such environments, where air movement can distinctly influence thermal perceptions.

The culmination of our efforts finds expression through integration into Commonwealth Scientific Industrial Research Organisation (CSIRO)'s AccuRate software [19], the benchmark software for the Nationwide House Energy Rating Scheme (NatHERS) [20]. The proposed method was examined against field-measurement data gleaned from an extensive field study conducted on residential buildings in Darwin. Through AccuRate's simulation platform, we examined 1,043 dwellings (from CSIRO's Australian House Data (AHD) sets) and 96 dwelling simulations (for 8 typical houses in 12 variations) and proposed a Comfort Rating scale ranging from 0 to 10 for assumed occupied hours for living room and bedroom zones [21].

This paper sets out with a dual purpose; first and foremost, it aims to extend the horizons of comfort modelling by developing a new rating methodology that accounts for the unique dynamics of extreme climates, specifically tailored for tropical contexts. Secondly, it seeks to integrate the role of ventilation, a vital component in the pursuit of human comfort, into the thermal comfort equation. By delving into the unexplored realm of how ventilation impacts the thermal comfort model, this study aims to address a pivotal gap in existing research. Such a method could be used to, (a) educate architects, designers, and other stakeholders to learn about an applied climate sensitive design for hot humid tropics, including methods to optimise comfort when air conditioning is not used; (b) improve passive comfort outcomes in residential building design; and (c) increase stakeholder awareness of the need to design and build climate change resilient residential buildings, to the extent possible, to reduce health risks when air conditioning is not available.

2. Methods

This section describes the steps that have been applied to develop a new comfort rating method for Darwin Dwellings.

2.1. Proposed thermal comfort calculation method

In order to develop the thermal comfort rating method, we propose using the same index, ET*, which has been used to define comfort neutrality at 29 oC at 50% relative humidity (RH) by Delsante [19]. ET* is an index that includes air temperature (°C), relative humidity (%), mean radiant temperature (°C), clothing value (clo), and metabolic rate (met). The proposed method is presented as followings (Figure 1):

a) To calculate ET* for the given air temperature and humidity (example A in illustrated in Figure 1).
b) Trace along the calculated ET* iso-line until it intersects with 50% RH, which was the relative humidity level for neutral temperature of 29 °C.

c) Degree of Discomfort (DD) will be estimated with a ΔET* (the difference between the nominated point's ET* and the nearest comfort zone boundary ET*, called Comfort ET* (CET).
d) To take account the enhanced Cooling Effect of Ventilation (CEV). CEV was subtracted from the ΔET*, as described in Equation 1. The equivalent temperature benefit of enhanced ventilation has been estimated in Williamson et al. [22] and described in equation 2.

$$DD = ET^* - CET - CEV \qquad (1)$$

Where,

DD = Degree of Discomfort (°C)

ET^* = Effective temperature for the given air temperature and humidity (°C)

CET = Comfort ET* (°C), the base acceptable adaptive comfort effective temperature at still air conditions

CEV = Cooling Effect of Ventilation (°C)

The equivalent temperature benefit of ventilation was calculated via equation 2 using Williamson et al. equation [22].

$$CEV = 1.67\ ln\ (v) + 3.97 - 0.02RH\% \qquad (2)$$

Where,

CEV = Temperature equivalent benefit of ventilation (°C)

v = Indoor air movement (m/s), limited to max of 4m/s

RH = Relative humidity (%)

The proposed comfort model is illustrated on a psychrometric chart in Figure 1.

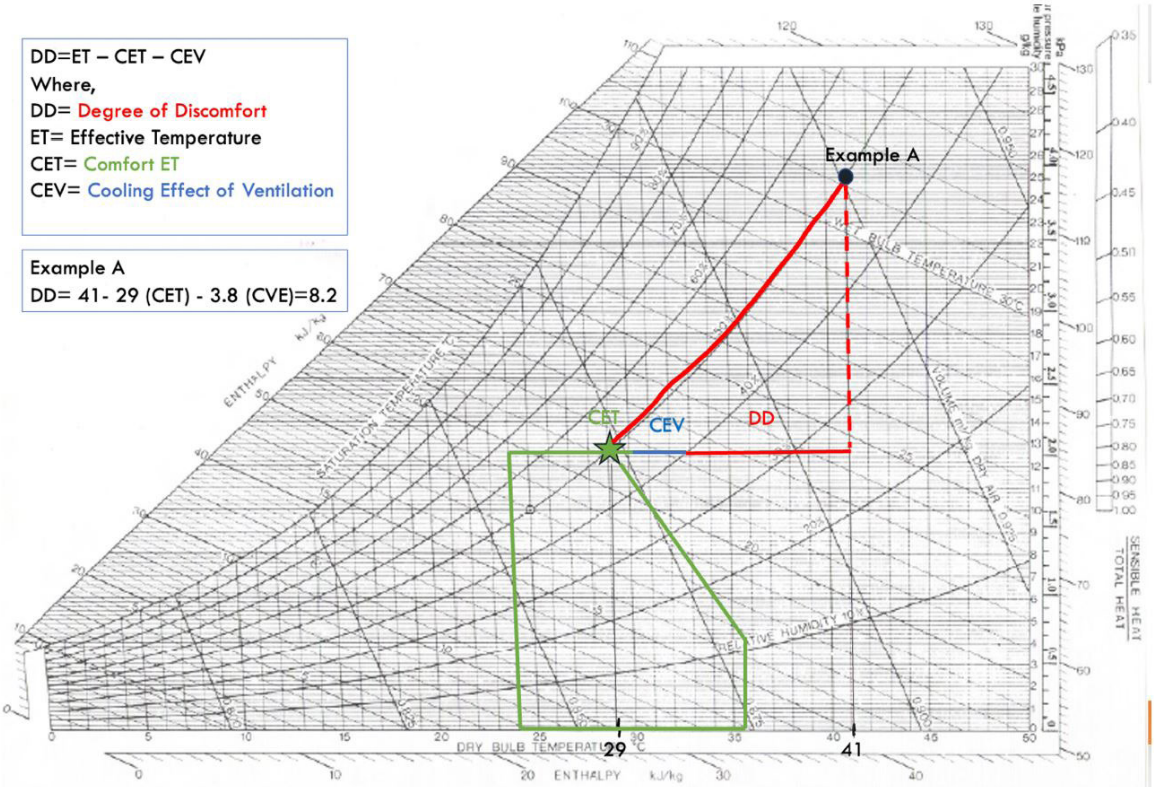

Figure 1: Proposed thermal comfort calculation model.

The maximum acceptable conditions at this study was CET+ 80% acceptability + CEV. The metric that we used in this study was Degree hours of Discomfort (DhD). To calculate DhD, firstly, DD was calculated at each hour for each room/zone. Secondly, all hours of DD readings were accumulated to represent the overall comfort performance of each zone in the house in Degree hours of Discomfort (DhD).

2.2 Field study measurements

Thermal comfort votes and percentage of acceptability were driven from field study, where 58 dwellings in Darwin were monitored [23-24]. Households were invited to participate in 20 houses which were naturally ventilated (NV), and 38 houses were operated under mixed mode. 2415 comfort vote assessments were collected. Environmental parameters including air temperature, humidity and air movement were recorded hourly in the living room and bedrooms. During 12 months period of the study the residents 18 years old and above were invited to complete daily a thermal comfort survey that consisted of three widely used subjective measures of thermal comfort that included; sensation 1=Cold to 7=Hot [11]; preference 1=Cooler, 2=No change, 3=Warmer and; comfort 1=Very uncomfortable to 6=Very comfortable [25]. The survey also asked the respondents to report their clothing level, activity, and window, fan and artificial heating/cooling operation.

During the field study, weather data were obtained from Australia's Brue of Meteorology (BOM) from the station closest to the house to describe the weather conditions during the monitoring periods. The mean monthly outdoor temperature was calculated from this data.

2.3 Comfort rating method

The comfort calculation method was incorporated into a new version of AcuRate (AccuRate Homes V1.0.3.22) , that was modified for this project, and was applied to two sets of dwellings, (a) 1,043 dwellings from CSIRO's Australian Housing Data (AHD), Darwin dwellings that had a Universal Certificate issued for the years 2020 and 2021 (named AHD dwelling sets); and (b) 8 typical dwellings in Darwin (4 detached houses , 2 duplexes and 2 apartments) named typical dwelling sets. All 8 types of dwellings were simulated for the four cardinal orientations and 3 design variations (12 variations for each type of dwelling). Each variant was modelled using 2016 and 2050 Reference Meteorological Year (RMY) weather files [26]. To calculate ET* metabolic rate and clothing value were considered as follows: Living room activity rate (Met) = 1.53; living room clothing level (clo) = 0.38; bedroom activity rate (Met) = 1.25; bedroom clothing level (clo) = 0.33.

We calculate DhD for two sets of dwellings, in two zones, kit/living zone and bedroom during the occupied hours. The maximum DD for all dwellings and zones were also calculated. Based on the results of DhD for each zone, Comfort Rating scale ranging from 0 to 10 has been determined for assumed occupied hours in the kit/living area and the worst bedroom.

3. Results

This section reports the detailed results of one of the 8 typical dwelling sets and comfort rating analysis for the AHD dwelling sets and Typical dwelling sets.

3.1 Typical dwelling sets – DhD analysis

The typical dwelling selected to be reported in this study was a flat roof home (Figure 2), with a large proportion of the understorey. The upper storey consists of a kitchen/living zone and 3 bedrooms. The simulation has been conducted for three different designs of the house (with different energy efficiency features to compare the comfort performance of the house under each design). The simulations for each design have been conducted in four orientations, north, east, west, and south, in total 12 series of simulations were generated.

Annual Degree hours of Discomfort for occupied hours and maximum Degree of Discomfort (DD) for two variations (north facing and east facing) of the most energy efficient design for the house is demonstrated in Figure 3. The figure shows the results for the living/kitchen zone and the worst bedroom during the occupied hours.

The DhD performance (Figure 3a) shows that the eastern orientation provides for a better kitchen/living zone, but only a slightly better worst bedroom. The max DD (Figure 3b) however, shows that the kitchen/living zone in the eastern orientation has a higher 'worst hour', compared to the northern orientation. These charts demonstrate the impact of orientation on comfort, and the challenge of deciding on comfort parameters. Both total DhD and max DD will impact occupants.

Figure 2. A typical dwelling in Darwin, Australia.

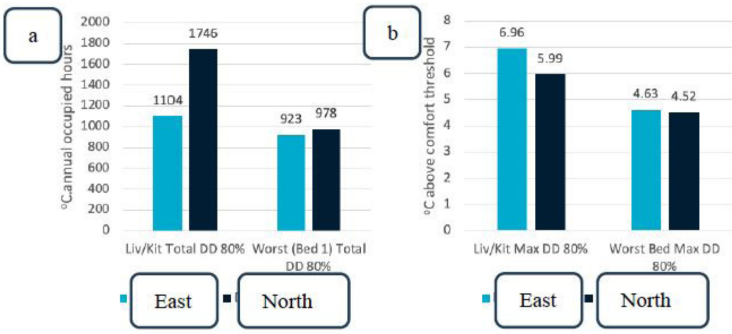

Figure 3: a) Annual Degree hours of Discomfort (DhD) during the occupied hours in living/kitchen and bedroom zones; b) Max Degree of Discomfort (DD) in Living/kitchen and bedroom zones for east and north facing dwellings.

3.2. Comfort rating analysis

Applying the methodology for DhD and maximum DD calculation, we examined 1043 dwellings from AHD data set (AHD dwelling sets) and all the 8 typical dwelling sets (each dwelling under 12 variants) to identify the minimum and maximum annual DhD and DD. A summary of the highest and lowest DD values is provided in Table 1, differentiating AHD dwelling sets and typical dwelling sets (all simulations). The highlighted figures are the highest/lowest figures from the complete set of data and could be used to provide the outer boundaries of the comfort rating.

Table 1: Summary of Maximum (Max) and minimum (Min) annual Degree hour of Discomfort (DhD), and maximum Degree of Discomfort (DD) for kitchen/living room (kit/liv) and bedroom (bed) for AHD dwelling sets and typical dwelling sets.

Criteria	AHD Dwelling Sets	Typical Dwelling Sets
Min DhD kit/liv	233	699
Max DhD kit/liv	17,611	4,230
Min DhD bed	5	66
Max DhD bed	3,185	3,678
Max DD kit/liv –lowest rate	2.58	4.07
Max DD kit/liv –highest rate	13.73	8.79
Max DD bed – lowest rate	0.60	1.61
Max DD bed Max DD bed Highest rate	5.44	7.33

Based on the highest and lowest values of all data sets (AHD and typical dwelling sets), the boundaries for the comfort ratings for the two zones (Living room and bedroom) were proposed (Table 2). The values for comfort ratings 1 and 10 are loosely based on a rounding down of the highest and lowest values from the combined data set. A constant multiplier of 0.6 for comfort bandwidths was found to provide the best fit for DD in both the living zone and bedroom. The proposed comfort bands are illustrated in Figure 4.

Table 2: Proposed comfort rating bands in kitchen/living room (kit/liv) and bedrooms (bed).

Comfort rating	Kit/liv DhD (°Ch)	Bed DhD (°Ch)
1	15000	3600
2	9000	2160
3	5400	1296
4	3240	778
5	1944	467
6	1166	280
7	700	168
8	420	101
9	252	60
10	151	36

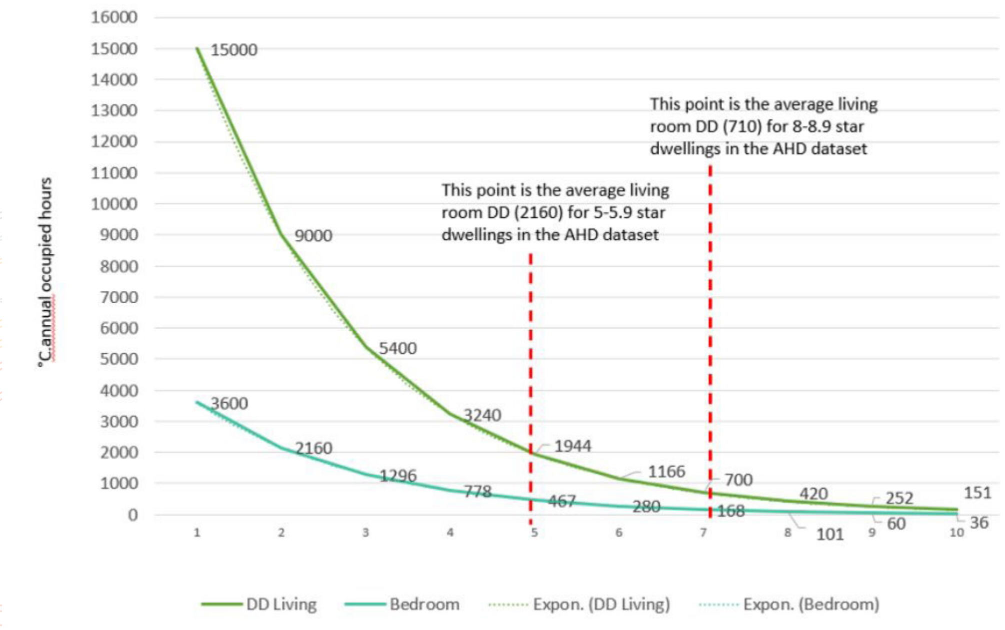

Figure 4: Proposed comfort bands with annual Degree hours of Discomfort (DhD).

3.3. Sensitivity analysis

For further sensitivity analysis, the kitchen/living zone data from AHD data set was used to investigate whether the ranking of total DhD changed with the different climate files (2016 and 2050 RMY files).

Figure 5 shows the rank order comparison of DhD results between the 2016 and 2050 RMY climate files. While DhD was always worse in 2050, the relative ranking between designs doesn't change enough to significantly change the comfort ranking. This was indicated by a high Spearman rank correlation coefficient ρ=0.958.

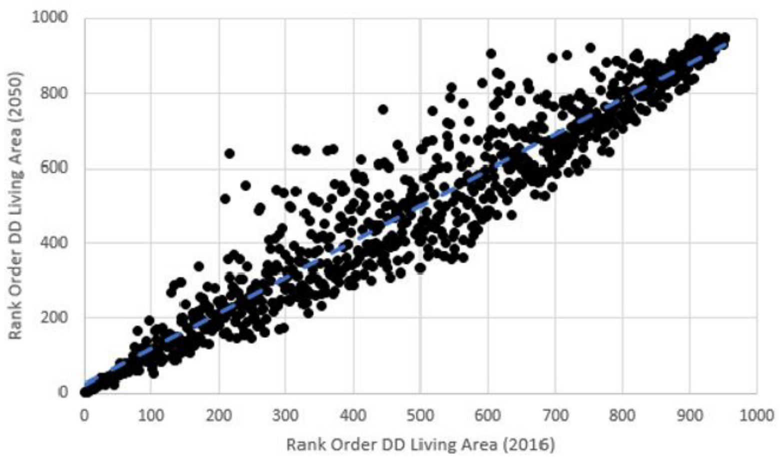

Figure 5: Rank order of houses (kitchen/living zone) for 2016 and 2050 RMT climate data files for ADH dwelling sets.

The comfort rating bands were then applied to the kitchen/living zone of all houses, for both the 2016 and 2050 data results. The 2016 results, shown in light blue in Figure6, have a fairly standard Bell curve distribution. The 2050 results, shown in dark blue, reveal that no dwellings will rate above the comfort rating of 4, with the majority achieving a rating of 2 or 3. Note that there are some dwellings that fail to achieve a comfort rating (shown as band 0). The sensitivity analysis confirms that the proposed comfort rating bands (Table 2 and Figure 4) can be applied to Darwin dwellings to provide more insight into the performance of the dwellings.

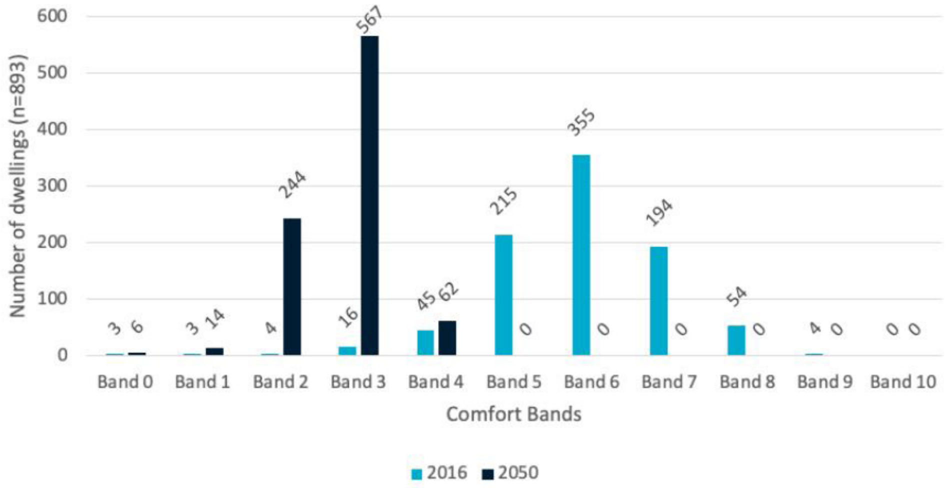

Figure 6: Comparison of comfort rating under 2016 and 2050 RMY data files for AHD dwelling sets for kitchen/living zone.

4. Discussion

In interpreting our findings, it becomes evident that our proposed thermal comfort rating method, incorporating the Effective Temperature (ET*) and indoor air movement, contributes significantly to the understanding of thermal comfort in extreme climates. By addressing the limitations of previous models, our methodology allows for a more realistic assessment of comfort in tropical and sub-tropical climate contexts. The implementation of ET* acknowledges the influence of humidity, which can substantially impact thermal perceptions. Furthermore, our inclusion of indoor air movement recognises its vital role, especially in tropical environments where natural ventilation plays a significant role in maintaining comfort.

Considering the broader perspective, our research offers a departure from conventional norms in thermal comfort modelling. It bridges the gap between theoretical understanding and practical application, enabling architects, designers, and stakeholders to create climate-sensitive and resilient residential buildings. This approach is of utmost importance in light of climate change and global warming, which are projected to intensify extreme climatic conditions, including heatwaves. By addressing these challenges proactively, we contribute to the promotion of human health and well-being in extreme climates, even in the absence of air conditioning.

However, it's important to acknowledge the limitations of our study. Our methodology, while comprehensive, was specific to the context of Darwin and may require adaptation for different extreme climates. Additionally, while our field study provided empirical data, in some cases it was limited to 11 months (in 20 houses) and mixed-mode homes – not only naturally ventilated homes (in 38 cases). Future research should focus on expanding the applicability of our Comfort Rating Method to various extreme climates and further refining the model based on regional nuances.

In addition, neither the 2016 nor the 2050 weather files utilised in this project took into account heat wave conditions (i.e., both files are based on a Reference Meteorological Year (RMY) that uses average weather conditions). As such, the building performances simulated do not reflect the full extent of 'discomfort' that might be experienced during sequential or extreme hot days that exceed the average maximum temperature and humidity for each month.

5. Conclusion

In the face of extreme climatic challenges, as exemplified by the tropical climate of Darwin, Australia, this study aimed to develop a new Comfort Rating Method tailored to Australia's Nationwide Energy Rating Scheme (NatHERS). The pressing concern of overheating within residential homes in such climates necessitated a comprehensive exploration of thermal comfort factors, particularly relevant for vulnerable populations like the elderly and children. Our research has unveiled the limitations of conventional thermal comfort models, i.e., the ASHRAE Standard 55 (2020) adaptive model, EN 15251 (2007), CIBCE Gide A (2015), and CIBSE TM52 [1114], in addressing the specific dynamics of extreme climates. These models often rely on operative temperature, a metric that overlooks crucial factors like humidity and indoor air movement, which are significant contributors to comfort in tropical environments.

In response to these limitations, our study implemented the Effective Temperature (ET*) index in our thermal comfort calculation. ET* not only considers air temperature and mean radiant temperature but also incorporates humidity, providing a more holistic assessment of comfort within extreme climates. Furthermore, we have extended our model to account for the impact of indoor air movement, a factor often neglected in existing models. By doing so, we aim to provide a more realistic representation of the comfort experience in tropical climates. Our efforts culminate in AccuRate, a specialised software integrated into the NatHERS [19] framework and was examined for Darwin climate context. The results were validated against real-world data from an extensive field study conducted on residential buildings in Darwin.

We calculated Degree hours of Discomfort (DhD) and maximum Degree of Discomforts for two zones, living and bedroom zones during the occupied hours. By applying this method into CSIRO'S AHD dataset, we introduced 10 comfort bands from 0-10 corresponding to the comfort threshold of DhD for each band. Through the validation of AccuRate, both theoretically and practically, our approach paves the way for a paradigm shift in the assessment and design of comfortable living spaces in extreme climates. This research not only contributes to the knowledge base in the field of thermal comfort but also holds significant implications for architects, designers, and stakeholders aiming to create climate-sensitive, resilient residential buildings, thus promoting human health and well-being when air conditioning may not be available.

6. Acknowledgements

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