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Review

Bibliometric Review of Passive Cooling Design Strategies and Global Thermal Comfort Assessment: Theories, Methods and Tools

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Abstract: Globally, a variety of factors, ranging from ethnicity and occupants' lifestyles to the local climate characteristics of any studied location, as well as people's age, can affect thermal comfort assessments. This review paper investigates the energy effectiveness of state-of-the-art passive systems in providing neutral adaptive thermal comfort for elderly people by exploring passive design strategies in four distinct climates, namely Canada, India, Abu Dhabi and the Eastern Mediterranean basin. The aim of the study is to analyse the available data provided by the American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE) Global Thermal Comfort Database II, version 2.1. The main objective of the study is to develop an effective methodological framework for the on-going development of adaptive thermal comfort theory. To this extent, this study presents a comprehensive review of the assessment of energy effectiveness of passive design systems. To accomplish this, the impact of climate change factors in passive design systems was investigated. A meta-analysis method was adopted to determine the input variables for the statistical analysis. *Cramer's V* and *Fisher's Exact* tests were used to assess occupants' thermal sensation votes (TSVs). The findings revealed that there are discrepancies detected between the in situ field experiments and the data recorded in the ASHRAE Global Thermal Comfort Database II. The study findings contribute to the development of adaptive thermal comfort theory by reviewing the existing methodologies globally. Furthermore, a critical review of the significance of occupants' age differences should be conducted in the identification of neutral adaptive thermal comfort.

Keywords: ASHRAE; climate change; passive cooling; thermal comfort; thermal sensation

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1. Introduction

The provision of thermal comfort in buildings to improve the health and overall well-being of elderly people has led to the development of advanced and economically viable building design systems through energy savings targets [1]. Vulnerable elderly people contribute to the balance of technical assessments in the development of adaptive thermal comfort worldwide. Improving the energy efficiency of building stock provides knowledge and learning experiences to any affluent society; therefore, it is important to consider vulnerable elderly people's health needs [2]. Recent data indicate that the total population of the elderly in India increased by 2.7% from 2001 to 2021, and this figure is expected to further increase by 3.0% by 2031 due to the necessity for better living conditions and better medical care [3]. As a result, this steady increase has led to a rising demand for allocating vulnerable elderly populations in nursery homes [4]. Awareness of climate change and future energy projections represents a foundation for the evolution of better heating and cooling designs in buildings [5]. Hence, climate analysis and classification tools have been developed and are gradually modified to identify human thermal comfort ranges of people at different ages [6].

Haldi and Robinson (2010) investigated the thermal experience and adaptive thermal preference behaviours of elderly people in Crete and Greece through a questionnaire survey [7]. It was observed that the heating energy demand was higher than the cooling demand, indicating the preference of heat for elderly people. On the contrary, D'Souza (2014) highlighted that experimental analysis was of the utmost importance in identifying differences in the thermal comfort perceptions for elderly people in different climates in five nursing homes in Spain [8]. Although, there was no difference in the neutral adaptive temperature of the elderly in different climates. Notably, it was found that thermal comfort ranges have shown differences. An in-depth study conducted by Kalmár (2016) found that three different age groups have shown the possibility to reduce energy consumption, while indoor air parameters were selected by considering different age groups in the population sample [9]. In this regard, the development of an adaptive model with a criterion for identifying thermal comfort parameters with different age groups is fundamental in thermal comfort studies. Furthermore, Hong et al. (2023) raised concerns about the connection between building thermal resilience and occupant age group, indicating variations in the thermal comfort levels of the elderly and younger people. A thermally resistant building maintains comfort during extreme weather, and Hong et al. (2023) suggested the inclusion of passive measures to minimize the effects of extreme weather effects on occupants' health [10].

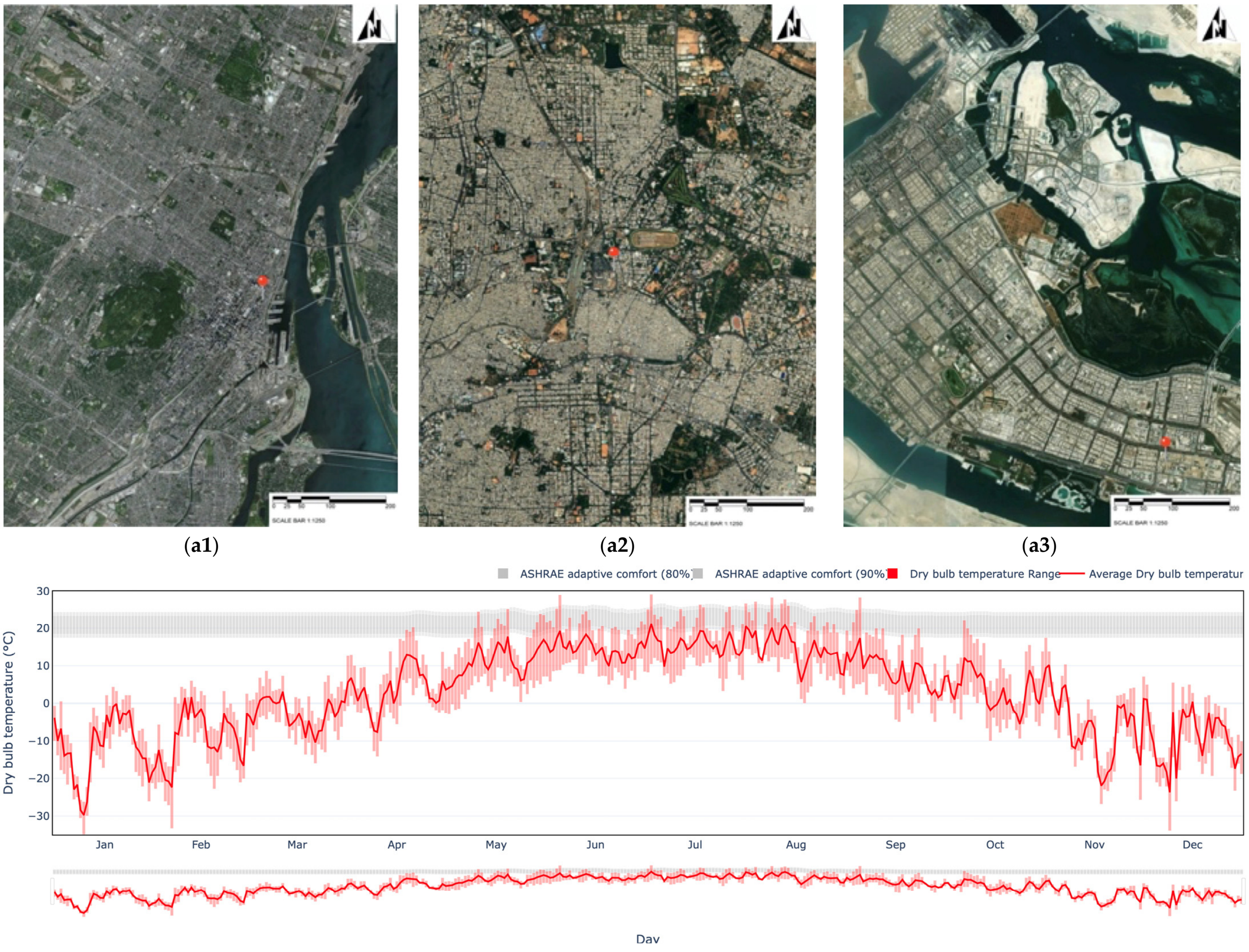
Patiño et al. (2018) highlighted the importance of thermal comfort in 70 social housing units in Toronto by monitoring indoor thermal parameters, including relative humidity, temperature and CO_2 concentration, to understand the effects of seasons on thermal comfort [11]. The results of the field study conclusively demonstrated severe discomfort in social housing due to insufficient cooling during summer periods and the winter season. It was found that overheating, with temperatures exceeding 28 °C, was experienced in some units during the winter season. Ji et al. (2023) proposed a structure to measure and assess building thermal resilience against summertime heatwaves. The resilience trapezoid method was used as the resilience profile while standard effective temperature (SET) was used to measure the thermal performance of buildings. The thermal resilience index (TRI) was utilized as the resilience metric to assess the improvement in resilience attained by implementing different passive cooling retrofit strategies, both for the whole building and thermal zone levels [12]. The findings recommended the combination of natural ventilation and exterior shading to improve thermal resilience by more than 50%, highlighting the effectiveness of coordinated passive cooling strategies in enhancing thermal comfort [12].

The International Energy Agency (IEA) addressed the challenges against the development of resilient cooling in buildings by evaluating performance indicators of resilient cooling strategies. Certain KPIs were developed to enable systematic comparisons of different cooling technologies. Four thermal comfort KPIs, including hours of exceedance (HE), indoor overheating degree (IOD), ambient warmness degree (AWD) and overheating escalation factor (OEF) were identified, with values set at 1245 h/year, 0.393 °C, 3.57 °C and 0.11, respectively [13].

Three key study locations were selected to represent three different climate characteristics. Many pilot studies were conducted to identify neutral adaptive thermal comfort, but none of studies focused on investigating both the available literature and the data gathered from the ASHRAE Global Comfort Database II, version 2.1, as shown Figure 1(a1–a3).

According to the Center of the Built Environment (CBE) climate tool, in 2022, Canada's climate was identified by the Köppen–Geiger climate classification type as humid continental, with no dry season and a warm summer [14]. The hottest yearly temperature is approximately 26.4 °C, while the coldest yearly temperature is estimated at −27.6 °C, as shown in Figure 1(a1–a3,b1–b3). The need for heating energy in Canada is therefore high, especially when considering people of ages 65 years or above. The application of passive systems in building design for insulation is necessary; however, the performance of the system is crucial for meeting the thermal comfort range expectations for the elderly. The tropical wet and dry/savanna climate of India, with the hottest yearly temperature estimated at 37.0 °C and a coldest yearly temperature of approximately 20.5 °C on average, is different from the subtropical desert climate of Abu Dhabi, as shown in Figure 1(b2) [15]. It should be noted that Abu Dhabi experiences hot summers, with the hottest temperatures reaching 43.0 °C on average, while the lowest average temperature is approximately 12.0 °C, as shown in Figure 1(b1–b3). Figure 1(b1–b3) demonstrate the temperature fluctuations of each case study location. The red lines represent the recorded outdoor air temperature, and the grey coloured parts represent the thermally acceptable annual temperature levels. The lower temperature fluctuations demonstrate 10 min intervals for recording the temperatures.

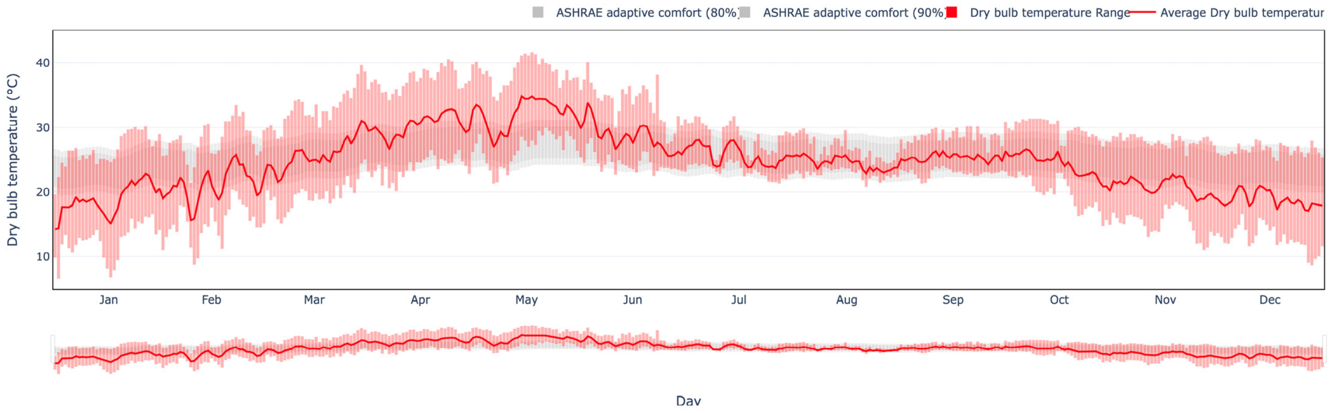
This paper set out to execute a state-of-the-art methodological framework to identify a knowledge gap using four lay terms, namely thermal comfort, indoor air quality assessment, passive heating and cooling and energy saving, as presented in Section 2. To this extent, a methodological framework was adopted to determine the data extracted from the American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE) Global Thermal Comfort Database, version 2.1, presented in Section 3. Parametric data analysis was presented in conjunction with field measurements in the Eastern Mediterranean basin in Section 4. Discussion was delineated to provide an evidence-based roadmap to the on-going adaptive thermal comfort assessment in Section 4. Conclusions were drawn to demonstrate the significance of research outputs in Section 5.



(**a1**) (**a2**) (**a3**)

(**b1**)

Figure 1. *Cont.*



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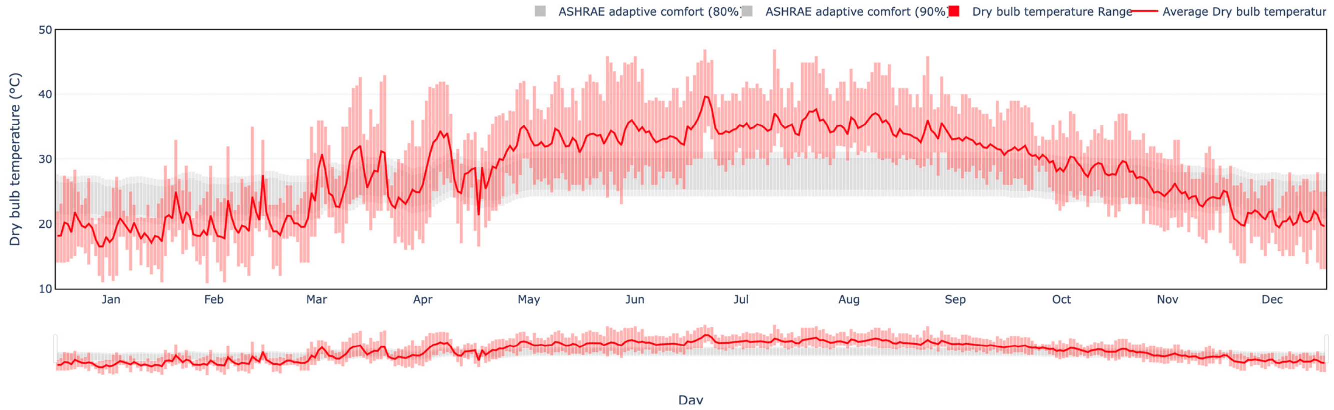


(**b3**)

Figure 1. (**a1**) Territorial map of Canada; (**a2**) Territorial map of India; (**a3**) Territorial of Abu Dhabi. (**b1**) Average monthly temperature of Canada; (**b2**) average monthly temperature of India; (**b3**) average monthly temperature of Abu Dhabi. Sources: https://clima.cbe.berkeley.edu (accessed on 20 January 2023); maps were extracted from the ArcGIS Pro Version 2021.01 software suite, which was developed by Esri (Aylesbury, UK).

2. Methodology

2.1. Conceptual Framework

This section reviews the different adaptive thermal comfort models which were used by previous scholars. The objective of this study is to explore climate variations on occupants' TSVs by considering the necessity of passive cooling design strategies during the decision-making process. A mixed method design approach was adopted. First, a systematic literature review was conducted using four key terms to identify the knowledge gap. Second, the ASHRAE Global Thermal Comfort Database, version 2.1, was chosen. This data provide a global overview to identify baseline thresholds in selected case study locations, namely Canada, India, Abu Dhabi and the Eastern Mediterranean basin. Third, secondary data were gathered from the field measurements in Cyprus to validate the study findings and interpret the statistical findings with the literature review. In this study, the data collection methods were investigated to outline an effective adaptive thermal comfort assessment. Additionally, the impact of disregarded data and non-inclusion of other factors are also presented.

This paper also reviews the methods used in the selection of passive cooling techniques according to the climatic characteristics of three different countries: the sub-tropical dessert climate of Abu Dhabi, tropical wet and dry/savanna climate of India and the humid continental climate of Canada. To this extent, thermal comfort models were classified based on the qualities, application and limitation of thermoregulatory models and adaptive thermal comfort models included in the ASHRAE Global Thermal Comfort Database, version 2.1.

Figure 2 demonstrates the step-by-step development of methodological workflow for the present study.

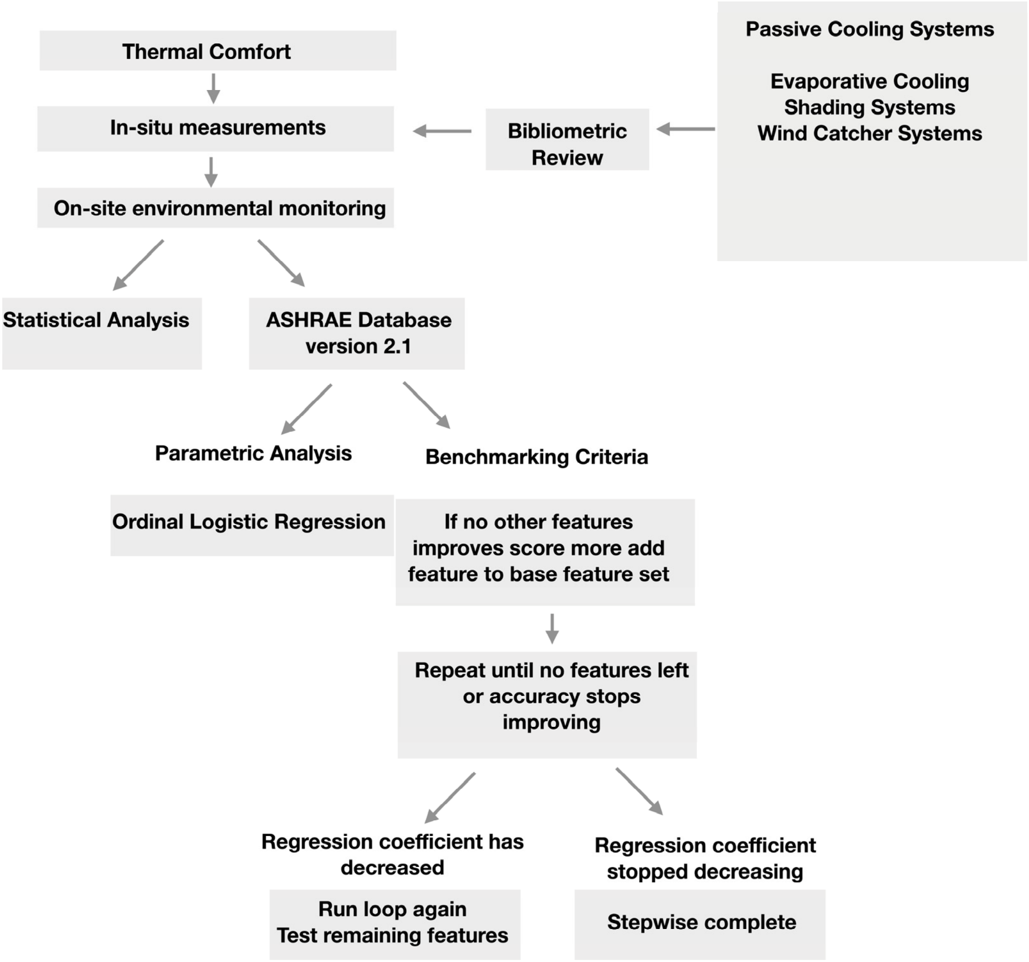
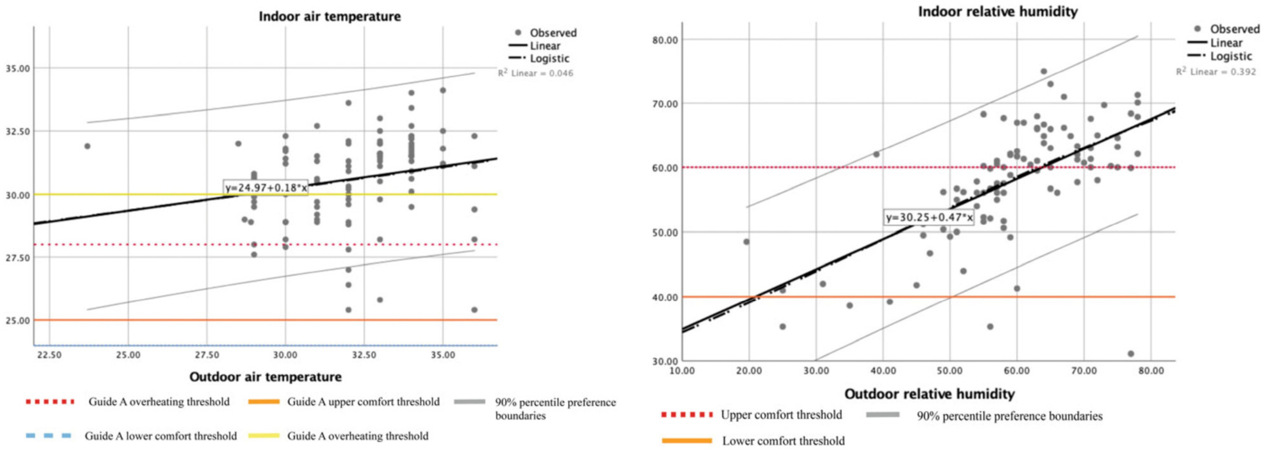


Figure 2. Methodological workflow for the present study. Image Credit: Drawn by author. Image Credit: Diagram was conceptualized by Ozarisoy (2024).

2.2. *Adaptive Thermal Comfort Models*

The availability of different thermal comfort models could determine thermally acceptable thresholds. However, the technical specifications of each tool have shown variations, such that this could lead to discrepancies in identifying accuracy in the dataset. It must be stressed that there is an urgent need to identify the most accurate adaptive thermal comfort model while assessing subject respondents' TSVs [16]. Figure 3a,b highlight the differences between the American standard, ASHRAE-55-2020, and European standard, EN-16798. In these graphs, the input variables selected were the mean outdoor temperature of 25 °C, operative temperature of 25 °C and air velocity of 0.3m/s. It can be seen that in Figure 3a the 80% acceptability operative temperature of the American standard ranges from 25 to 34.8 °C. Figure 3b demonstrates the relative humidity level ranges from 30% to 80% within the thermally acceptable threshold range. The differences of certain thermal comfort models, scales and indexes can be attributed to the differences in climate, lifestyle and human body activities. One of the main reasons is that these two models were predicting individual thermal preferences. Hence, the European norm EN-16798 has been set to classify thermal satisfaction in three categories, as shown in Table 1.



(**a**) (**b**)

Figure 3. Adaptive thermal comfort assessment using the criteria (**a**) ASHRAE-55-2020—operative air temperature; (**b**) European norm (EN-16798)—relative humidity. Image Credits: Ozarisoy & Altan (2023) [17]. Note: * represents the significance of environmental monitoring data.

Table 1. Both (ASHRAE-55-2020) and (EN-16798) thermal acceptability results obtained from the CBE thermal comfort tool.

Input Variables		**Adaptive Thermal Comfort Assessment Criteria**			
		ASHRAE-55-2020 80% Acceptable Limits		**EN-16798 Acceptable Comfort Limits**	
Mean outdoor air temperature	25 °C	Comfortable operative air temperature:	22.1 to 29.1 °C	Class III	22.1 to 31.1 °C
Operative air temperature	25 °C	90% acceptable limits		Class II	23.1 to 30.1 °C
Air velocity	3 m/s	Comfortable operative air temperature:	23.1 to 28.1 °C	Class I	24.1 to 29.1 °C

Source: Adapted from https://comfort.cbe.berkeley.edu (accessed on 20 January 2023).

Toe and Kubota (2015) indicated that a clear definition of adaptive thermal comfort theory and the simplification of assessment methods are fundamental while assessing subject respondents' TSVs [18]. To avoid any research bias, many researchers adhered to the traditional convention identified by the ASHRAE and European standards in thermal comfort studies. According to ASHRAE-55-2020 and EN-16798, Fanger's adaptive thermal comfort model has been accepted for statistical analysis. It should be noted that the application of zone conditioning in thermal comfort analysis is not applicable for ASHRAE-55-2020. Hence, thermal comfort analysis has been accepted only for naturally ventilated buildings in the ASHRAE-55-2020 assessment criteria. Notably, Adaptive (K) is the nearest neighbours (KNN)-based thermal comfort model. It is a personalized adaptive thermal comfort model that can adjust to environmental changes and the preferences of occupants. Table 2 delineates a description of thermal comfort categories.

Table 2. Theoretical framework of thermal comfort categories according to ASHRAE 55-2020.

ASHRAE 55 (%)	**Suitability**	**PPD (%)**	**Fanger (PMV)**	**Adaptive (K)**
90	Suitable for high standard thermal comfort	<10	−0.5 < PMV < +0.5	+2.5
80	Suitable for typical applications when certain parameters are unavailable	<20	0.85 < PMV < 0.85	+3.5

Source: Adapted from Nicol et al. (2020) [19].

Many researchers developed different thermoregulatory models to assess subject respondents' TSVs by considering only physiological parameters, such as metabolic rate activity (met) level, subject respondents' body mass index factor, gender and their skin thicknesses [20–22]. Thermoregulatory models are predominantly reliant on heat transfer of human body and skin thickness in order to tolerate extreme environmental conditions. Kim et al. (2019) identified the determinant parameters for personal comfort models. In this study, commonly used adaptive models developed from the data gathered during field measurements and inclusion of on-site recorded environmental conditions were used in order to identify adaptive thermal comfort [22]. Additionally, other external variables were also included in the data set, such as subject respondents' heart rate, metabolic rate activity (met) and clothing insulation level (*clo*) values to develop stochastic adaptive thermal comfort models.

Table 3 summarizes some of the adaptive thermal comfort models which were gathered from field studies. The study conducted by Yang et al. [23] revealed that although elderly people are sensitive to outdoor temperature changes, they vary their clothing according to seasonal changes. Clothing insulation values were determined as 0.39 ± 0.08, 0.72 ± 0.16 and 0.77 ± 0.10 for the cooling, mid and heating season, respectively. The adaptive model used resulted in a comfortable temperature range between 25 °C and 27 °C for elderly people. However, Wang et al. [24] discourage the use of traditional thermal comfort models such as PMV to analyse individual thermal comfort and support models which cater to individual physiological and psychological responses. Yuan et al. [25] discuss the importance of differentiated thermal comfort evaluation indices, considering that most standards exclude elderly populations whose thermoregulation differs from younger ones. Thermal comfort models must explore beyond environmental factors and include factors such as cultural practices and human adaptation. The thermal sensation vote (TSV) and predicted mean vote (PMV) results from Zhang et al. [26] showed that Europeans have the highest neutral temperature in contrast to Chinese people, indicating that Chinese people have a high tolerance for temperature variations. According to Zhao et al. [27] traditional models, including PMV, perform poorly in non-uniform environments. However, despite significant gaps remaining in addressing non-uniform environments, the development and advancement of thermal comfort models is evolving, encouraging researchers to seek more comprehensive physiological, psychological and cultural integrations.

Table 3. Adaptive thermal comfort models developed by other researchers.

Model	Region	Age	Outdoor Parameter(s)	Thermal Response
Yang et al. (2016) [23]	Korea	>65	4-day weighted running mean of outdoor air temperature	Clothing insulation
Wang et al. (2018) [24]	Shanghai	>65	7-day weighted running mean of outdoor air temperature	Neutral temperature
Yuan et al. (2022) [25]	China	>70	Prevailing mean outdoor temperature air	Neutral temperature
Zhang et al. (2017) [26]	China	>70	Outdoor air temperature	Clothing insulation, thermal sensation vote, proportion of air-conditioned
Zhao et al. (2021) [27]	Chongqing, China	>60	Outdoor air temperature	Proportion of windows opened; proportion of fans used

Source: Adapted from Cheung et al. (2019) [20].

Yi et al. (2022) studied three different thermal comfort models to assess elderly people's thermal dissatisfaction levels. In this study, the subject respondent's PMVs were examined, and the questionnaire survey data were validated with an infrared radiometer thermography (IRT) survey [28]. It should be noted that the IRT survey was conducted in communal areas in order to generalize the findings. In this field study, indoor air temperature, relative humidity and air speed were recorded. A weighted evaluation criteria was applied to measure the clothing insulation level (*clo*) factor. Notably, body temperature was measured using an adaptive-scan device [28].

Additionally, Yi et al. (2022) used a micro-bolometer detector (model A-600 series, FLIR, Täby, Sweden, image resolution 640 × 320 pixels) to perform the IRT survey [28]. It should be noted that priority was given to the subject participants; a resting period of 15-min intervals was provided in order to avoid body temperature fluctuations. The clothing insulation was estimated using Equation (1).

$$1clo = 0.00103W - 0.0253 \tag{1}$$

where (clo) represents the clothing insulation, while (W) is the weight of the garment. The effect of clothing insulation is complicated to assess because of the non-uniform structure of clothes, and because some body parts warm quickly compared to others due to blood flow and skin thickness; therefore, body parameters should be included when analysing clothing effect [29]. Halawa and Van Hoof (2012) indicated that thermal comfort evaluation was based on different adaptive models in order to assess and compare the results with the field measurements [30]. Table 4 delineates the factors affecting both the physical and environmental parameters during the longitudinal field surveys. Zhang et al. (2017) carried out a comparative study to develop an evidence-based adaptive thermal comfort model in different climate regions [26].

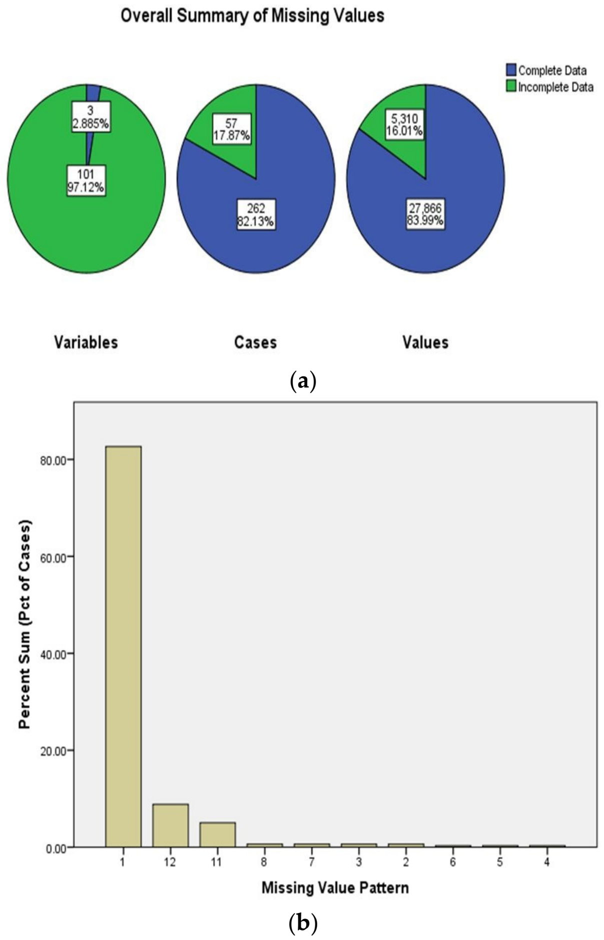
Table 4. Variation of thermal comfort index scales.

Scale	Thermal Sensation Vote (TSV)	Thermal Comfort Vote (TCV)	Thermal Acceptability (TA)	Thermal Preference (TP)
4	-	Unbearable	-	-
3	Hot	Very uncomfortable	-	-
2	Warm	Uncomfortable	Very unacceptable	-
1	Slightly warm	Slightly uncomfortable	Just acceptable	Warmer
0	Neutral	Uncomfortable	-	No change
−1	Slightly cool	-	Just acceptable	Cooler
−2	Cool	-	Very acceptable	-
−3	Cold	-	-	-

Source: Adapted from Zhang et al. (2017) [26].

The study highlighted that a Likert scale assessment is important to determine thermal sensitivity and acceptability by considering the climate classification type of each research context. The impact of the missing information can be further analysed, and the evaluation of the disregarded parameters should be conducted by using secondary data. Figure 4a,b present missing data in a field study conducted in the eastern Mediterranean region in Cyprus. Figure 4a highlights that most of the data were collected, and only 2.8% of the variables' data were incomplete. Some 17.8% of cases and 16% of values were missing. Missing cases and values are a matter of concern as the percentage of incomplete data is considerable. In such cases, secondary data can be used to conduct the validation of sample size, as shown in Figure 4b.

An extensive analysis of missing data was conducted for the present study. The results and recommendations are presented. In Figure 4a, the three pie charts summarize the frequency and percentage of missing data in the dataset by variable, case/observation and individual values. The third pie chart represents the full data matrix and was used to evaluate the 5% threshold of the proportion of missing values in the data matrix that was discussed above. It was found that the data were missing completely at random (MCAR). After preparing the data for analysis, it was observed that out of 100 recorded cases, 98 cases contained missing data (98.0%), and out of fifty-three variables, two variables contained missing data (2.8%), which amounted to a total of 0.04% missing information in the dataset. To assess whether the pattern of missing values was MCAR, Little's MCAR test was conducted. The null hypothesis of Little's MCAR test is that the pattern of the data is MCAR and follows a chi-square distribution.



(**a**)

(**b**)

Figure 4. (**a**) Percentage distribution of field study data in Cyprus; (**b**) the most frequently occurring patterns in the dataset selected for the present study. Sources: https://repository.uel.ac.uk/item/8q774 (accessed on 20 January 2023).

Using an expectation-maximization algorithm, the MCAR test estimates the univariate means and correlations for each of the variables. The results revealed that the pattern of missing values in the data was MCAR: χ^2 (104) = 121.645, p = 0.114. Even though the proportion of the total missing data is less than 5% and the data is MCAR, the final sample size may still be affected by listwise or pairwise deletion when the analysis is run.

2.3. Database Analysis

This paper reviews the extant literature on the state-of-the-art studies on adaptive thermal comfort. Hence, passive heating and cooling implementations have been a subject of interest to improve indoor air quality while optimizing occupants' thermal comfort; therefore, this study aims to highlight the importance of the revival applicability of passive design systems for the development of an adaptive thermal comfort approach globally. To this extent, the Vos viewer visualization tool was used to identify key terms for the present study. Figure 5 demonstrates the network visualization to demonstrate correlations between passive design systems and thermal comfort. First, the data were gathered from the Web of Science database. Original research papers and review articles were retrieved from the database. Some 122 published research papers were identified and exported in a 'plain text file'. To prepare these datasets, full record and cited references were selected from the content box before exporting the data into the Vos viewer software suite. Additionally, a visualization map was generated by selecting the 'create a map based on text data' option. This was followed by selecting the 'bibliographic database files', which aided in conducting the data mining process.

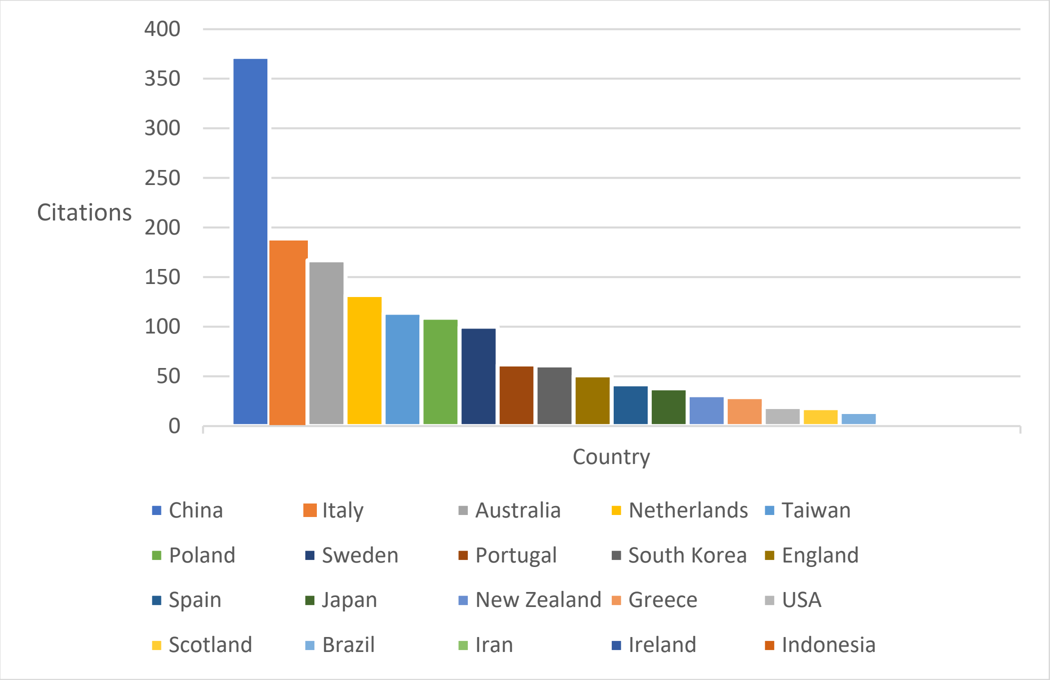


Figure 5. Published review and original research papers considering elderly people's thermal comfort globally. Image Credit: Drawn by author. Image Credit: Bema (2023).

With regards to the identification of neutral adaptive thermal comfort, worldwide investigation on thermal comfort assessment methods were carried out, as shown in Figure 5. In the key word analysis, 20 counties were identified from the ASHRAE Global Thermal Comfort Database, version 2.1. In this database, most of the datasets were gathered from Chinese cities due to the availability of large sample sizes. A total of 372 were included to assess occupant thermal comfort both in winter and summer seasons in China.

2.4. Bibliometric Review Criteria

The systematic review analysis was conducted by using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analysis) guidelines to identify and critically analyse the selected key terms for the study. To fulfil the knowledge gap, the systematic review analysis was carried on the assessment of passive cooling technologies to optimise occupants' thermal comfort globally. The data acquisition and inclusion processes are presented in Figure 6.

The research engines of Scopus and Web of Science (WoS) were used to analyse the literature review findings. In this study, the following keywords were used within the identified strategy of inquiry: climate AND thermal comfort AND indoor air quality assessment AND multi-family residential buildings. Passive cooling systems and thermal comfort have shown various meanings and connotations according to different disciplines and theoretical frameworks outlined for this study. Figure 6 demonstrates the search criteria from the Scopus database used to identify selected key terms. A database search was conducted using the systematic review method. The Vos viewer v.9 visualisation software suite was used to interpret the findings. The literature survey resulted in 94 documents, which included review articles, original research papers and conference proceedings that were collected between 1990 and July 2024. Abstracts of the documents were reviewed using the meta-analysis method. This was followed by an analysis of data range, technologies, approach, applicability to the market and main research outputs extracted from each research article.

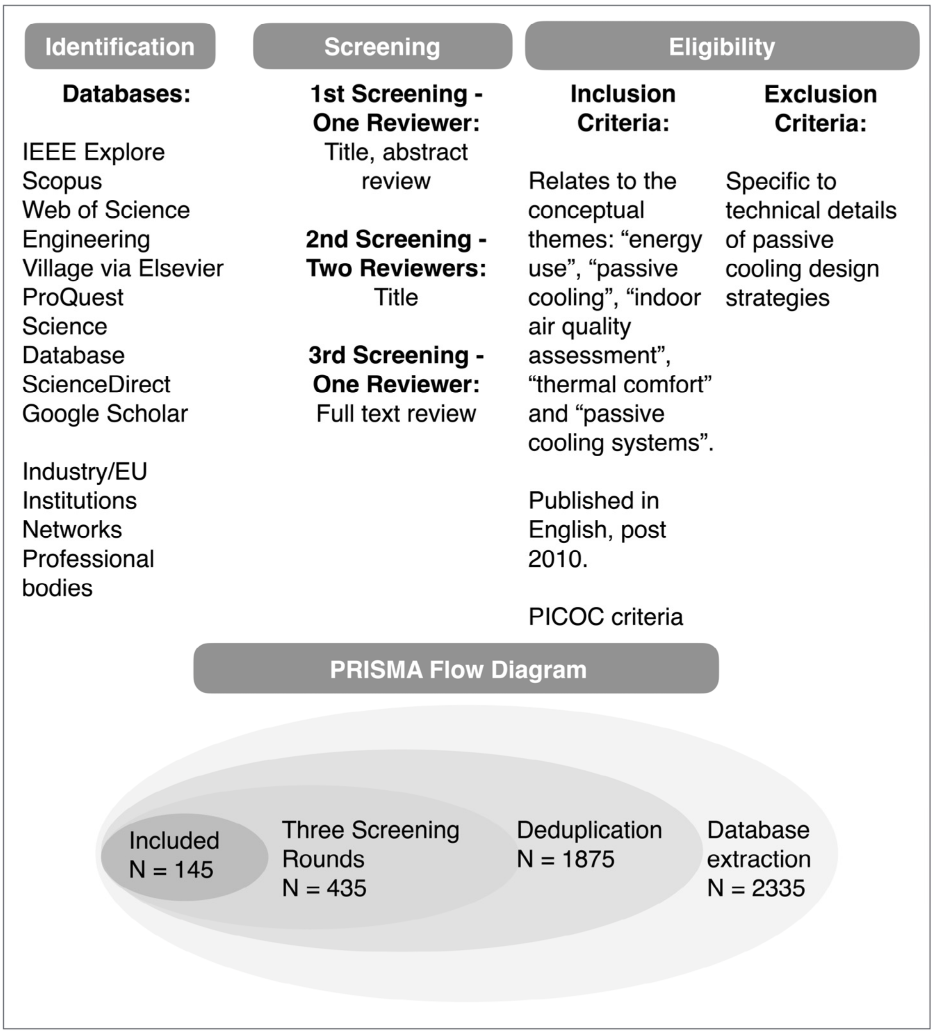


Figure 6. Selection criteria for the bibliometric review analysis. Image Credit: Drawn by author. Image Credit: Drawn by Ozarisoy (2024).

2.5. Data Acquisition

This section details the importance of basic assumption testing in inferential analyses, as well as how basic assumptions are assessed, the summary of the data preparation process, and options for coding data prior to conducting analysis, as shown in Table 5. Before any inferential analyses are conducted, basic assumptions must be met to avoid bias in a study’s findings. The validity of conclusions drawn from a statistical analysis depend on the validity of any assumptions made. Where data are lacking, assumption testing may have to be restricted to simply making a judgment about whether an assumption is reasonable. In addition, scholars may have to judge what effect the violation of an assumption might have on the findings. The effect of violating any of the assumptions is a change in the probability of making a Type I (input variables) or a Type II (output variables) error, and the researchers will not usually know whether the change has made it more or less likely to commit an inferential error. Basic assumptions are also accompanied by analysis-specific assumptions. Analysis-specific assumptions are tested during the analysis phase of the project. Table 5 includes variables used to analyse relationships and existing connections between occupant characteristics (such as ethnicity and income), housing characteristics (such as orientation), behaviour (such as reasons for thermal discomfort and closing windows), energy consumption and thermal comfort in the study. The encoding of the variables facilitates data analysis in understanding the factors influencing thermal comfort and energy use in homes.

Table 5. Coded variables during the data preparation stage.

Age band	Cooling energy consumption in August 2015	Floor level
Cooling consumption on weekdays	Cooling energy consumption in summer 2015	Health condition
Clothing insulation levels of participants	Heating energy consumption in winter 2015	Occupation
Type of cooling control in home	Cooling energy consumption in August 2016	Heating consumption on the weekend
Ethnicity	Cooling energy consumption in summer 2016	Household density
Thermal preference	Heating energy consumption in winter 2016	Income
Interviewed room condition	Metabolic rates of participants	Length of residency
Orientation	Reasons for thermal discomfort	Space conditioning
Overall thermal satisfaction in summer	Thermal sensation in bedrooms 1, 2, 3 and living room	Type of cooling system
Window closing reasons	Window opening patterns in winter	Type of heating system

Note: Additionally, all categorical variables were recorded in ordinal sequence where possible (e.g., metabolic rate). Variables related to occupants' thermal preferences were recoded from very cold to very hot. All variables were recoded from smallest value to largest value. All dichotomous variables were recoded as 1 = yes, 0 = no. Source: Ozarisoy (2022) [31].

As shown in Table 6, a general rule for sample sizes is that group sizes are approximately equal if *n* of the largest group is no more than about twice *n* of the smallest group. Another general rule for sample sizes is that at least 10% of the sample should be in each group. Categorical variables with very uneven splits between categories present problems for several multivariate analyses. The following variables were recoded to reflect the conceptualization of statistically representative findings in accordance with the research hypotheses.

Table 6. Input parameters included in the statistical analysis.

Contribution to Key Research Area(s)	**In Situ Measurements *(Measured)***	**On-site Environmental Monitoring *(Recorded)***	**Secondary Data *(Collected from the Authorities)***	**Primary Data I—Questionnaire Survey *(Gathered)***	**Primary Data II—Thermal Comfort Survey *(Gathered)***
Thermal Comfort + Overheating Risk	Indoor DEW (°C)	Outdoor heat stress index (°C)	Cooling energy consumption in summer of August 2015	Age	Location of subject respondent
Thermal Comfort + Overheating Risk	Indoor relative humidity (%)	Outdoor relative humidity (%)	Cooling energy consumption in summer of 2015	Age bands	Thermal preference [0 to 6]
Thermal Comfort + Energy Modelling	Operative air temperature (°C)	Outdoor air temperature (°C)	Cooling energy consumption in summer of August 2016	Energy efficiency awareness	Overall thermal satisfaction [−3, +3]
Overheating Risk + Energy Modelling	Solar radiation (°C)	Outdoor DEW (°C)	Cooling energy consumption in summer of 2016	Energy conservation	Thermal sensation in living room [−3, +3]
Thermal Comfort + Energy Modelling	Indoor WET (°C)	-	Heating energy consumption in winter of 2015	Door opening patterns in summer	Thermal sensation in kitchen [−3, +3]
Energy Modelling	Time-of-day	-	Heating energy consumption in winter of 2016	Door opening patterns in winter	Thermal sensation in bedroom 1 [−3, +3]
Thermal Comfort + Energy Modelling	Indoor temperature ground (°C)	-	Energy consumption in April of 2015	Type of heating control at home	Thermal sensation in bedroom 2 [−3, +3]
Thermal Comfort + Energy Modelling	-	-	Energy consumption in August of 2015	Type of cooling control at home	Thermal sensation in bedroom 3 [−3, +3]
Thermal Comfort + Energy Modelling	-	-	Energy consumption in December of 2015	Length of residency	Clothing insulation level of participants
Thermal Comfort	-	-	Energy consumption in February of 2015	Floor level	Reasons for thermal discomfort

3. Bibliometric Literature Review Analysis

3.1. Thermal Comfort

A field study conducted by Li et al. (2022) highlighted the importance of a universal design approach to outline a baseline for the design and construction principles of thermally comfortable nursery homes for elderly people in Mongolia [32]. According to Li et al. (2022), an adaptive thermal comfort model was identified in line with the Mongolian winter season for elderly people by considering the subject respondents' age differences factor. This pilot study also investigated vulnerable elderly people's thermal sensation votes (TSVs), thermal preference votes (TPVs) and their adaptive thermal comfort behaviour to the occupied spaces in both naturally and mechanically ventilated buildings. Indoor thermal conditions of existing nursery homes were investigated through long-term on-site environmental monitoring. In this study, the indoor thermal comfort satisfaction of 162 elderly people was questioned to determine the neutral adaptive thermal comfort in the Mongolian climate.

The results indicated that age and clothing insulation level (*clo*) affect the thermal sensitivity of the human body. This could result in changes to the physiological adaptive behaviour of subject respondents. It was also found that a subject respondent's clothing insulation level (*clo*) is the most determinant factor due to the tropical and subtropical steppe climate (BSk) characteristics of Mongolia. This pilot study also found that there is a direct correlation between the clothing value and the thermal sensation votes of elderly people in the survey. However, the results presented in this pilot study indicated that the 80% acceptable temperature range of the elderly was found to be between 15.4 and 25.5 °C, and the thermal expectation temperature was identified at 21.0 °C, which is much lower than the recommended winter thermal comfort ranges in the 2021 ASHRAE Handbook Fundamentals.

Most recently, the development of adaptive 'neutral' thermal comfort multi-family residential buildings in Eastern Mediterranean Europe has been accredited by the University of California, Berkeley, which is the research output of the entitled 'Assessing the Domestic Energy Use and Thermal Comfort of Occupants in a Post-war Social Housing Development Estate in Famagusta, Northern Cyprus' [31]. This approved research output of the ASHRAE Global Thermal Comfort Database II—records by country—in version 2.1 of the database has been released. It combines sets of objective indoor environmental measurements with accompanying 'right-here-right-now' subjective evaluations by occupants from buildings around the world. The database is intended to support diverse inquiries about thermal comfort in field settings. In this pilot study, it was found that the occupants' thermal sensation votes' findings were that the 'neutral' temperature was 28.5 °C, and the upper limit of the comfort range in warm indoor air temperature conditions was 31.5 °C. The field study in the Eastern Mediterranean climate of Cyprus is a unique context and a noteworthy addition to this public source. Anecdotally, the newly released ASHRAE dataset record provides a significant contribution to this review paper while investigating the available extant methodological framework on adaptive thermal comfort development. Hence, Table 7 demonstrates the global overview of thermal comfort studies.

The longitudinal field study conducted by Li et al. (2022) demonstrated that the neutral adaptive thermal comfort level was found to be 20.5 °C for vulnerable elderly people in Mongolia in the winter, where the weather is a tropical and subtropical steppe climate [32]. Additionally, Yuan et al. (2022) conducted a similar study in the rural areas of China and discovered the adaptive thermal comfort temperature was 16.7 °C in the cold climate of China [25]. The study highlighted that there are distinct temperature variations identified for the development of neutral adaptive thermal comfort between Mongolian and Chinese climates. This deterministic factor could be related to the subject respondents' cultural and lifestyle differences and their physiological body temperature adaptations to the local environmental conditions. To this extent, Yuan et al. (2022) suggested that the optimization of the building envelope could be achieved by increasing wall thickness and implementing appropriate fenestration designs on those opaque window surfaces. These strategies are aimed at reducing excessive heat gains on building envelopes, which are directly linked to reducing overheating risk in the summer [25].

The influence of seasonality on the thermal environment of elderly people in Korean care centres was assessed by Yang et al. A field study focusing on clothing insulation, metabolic rate, thermal comfort, thermal sensation and thermal satisfaction was conducted at 26 random care centres. The results demonstrated that regardless of minimum air conditioner use, the indoor environments were kept warmer and the operative and indoor temperatures were significantly high during the summer seasons. The results showed that thermal sensation votes (TSVs) for Korean elderly people are higher compared to the predicted mean vote (PMV) on the cold side. Furthermore, the thermal comfort range for the Korean elderly based on the PMV model was higher than expected [23].

Table 7. State-of-the-art field studies to investigate occupants' thermal sensations.

References	Study Location	Objective (s)	Methodology	Main findings
Li et al. (2022) [32]	Mongolia	To observe the thermal behavior of elderly people in terms of their thermal sensation, preference and their thermal adaptive behavior to winter climate conditions.	Using in situ environmental recording devices to measure the indoor air quality of the buildings. Longitudinal field survey was conducted to gather subject respondents' thermal sensation votes. Questionnaire survey was conducted. Field measurements were recorded.	Adaptive temperature range for elderly people was found to be between 15.4 and 25.5 °C. The neutral adaptive thermal comfort temperature was found to be 20.5 °C.
Yuan et al. (2022) [25]	China	To study the significant impact of thermal properties of buildings and thermal comfort preference of elderly people in naturally ventilated residential buildings.	Subject respondents' thermal sensation votes were gathered through a questionnaire survey. A total of 152 elderly people were recruited for the study.	The study found that the thermally acceptable level had reached 16.7 °C for elderly people in cold climates. Although, elderly people were more vulnerable to temperatures below 16.7 °C and less sensitive to temperatures above 15.6 °C.
Yang et al. (2016) [23]	Korea	To explore the impact of different seasonal variations on elderly people's thermal sensation in nursery homes and to assess the indoor air quality of occupied spaces in nursery homes.	Software simulation was used to optimize the building envelope by using different thermal parameters, including effective fenestration design principles applied.	According to the findings of a longitudinal survey, metabolism rates remained constant. At the same time, the clothing insulation level (lcl) factor had an impact on the adaptive thermal comfort assessment.
Vellei et al. (2017) [33]	Eastern Mediterranean basin	To identify the discrepancies in the thermal sensation votes and to assess subject respondents' thermal preference in conjunction with the in situ environmental measurements which were conducted at the time of undertaking the questionnaire survey in nursery homes in the winter.	In situ environmental monitoring was applied. A total of 25 representative nursery homes were selected for the study.	Therapists and caregivers indicated different thermal sensation votes. This deterministic factor proved that clothing insulation level is the major indictor for the adaptive thermal comfort assessment.
Forcada et al. (2021) [4]	Eastern Mediterranean basin	To identify the winter thermal preferences and perceptions of elderly people in nursing homes and compare them with non-residents (i.e., therapists, visitors and caregivers).	In situ environmental monitoring was applied to 25 representative nursery homes. Subjective comfort evaluations from building occupants were collected to assess occupants' thermal sensation votes, thermal preference and thermal acceptability.	Residents indicated different thermal sensation votes. A comfortable temperature for elderly residents with a 90% acceptability ranges from 21.6 °C to 22.9 °C.

Source: Conceptualised by author. Source: Bema (2022).

As shown in Figure 7, worldwide studies were targeted to highlight the significance of thermal comfort assessment. Although, different methods were also investigated to analyse the energy effectiveness of passive cooling systems in thermal comfort studies. The red colour represents the thermal comfort and its correlations with the adaptive thermal comfort model, thermal sensation, age difference and thermal condition of buildings. The graph demonstrates hybrid similarity between the blue-coloured parameters, such as neutral temperature, occupants, air conditioning, humidity and climate type AND the yellow-coloured parameters, such as seasons, indoor air quality and questionnaire survey. This proves that thermal comfort could be weighted equally with environmental parameters and indoor air quality of buildings.

Forcada et al. (2021) selected an 881 sample size to conduct the questionnaire survey [4]. In this pilot study, an experimental analysis was conducted studying the adaptive thermal comfort assessment of nursing homes in heated environments [4]. The study findings indicated that the neutral adaptive thermal comfort was found to be 21.6 °C for elderly people in the Mediterranean climate, where the weather is subtropical (*Cfa*) and partially semi-arid (*Bsh*). This finding could be related to thermal preference differences of subject respondents recruited during the survey. It should be noted that the subject respondents have different day-to-day activities and health conditions, which are linked with the identification of neutral adaptive thermal comfort. Notably, a greater energy demand was found for the heating of nursing homes during the winter season. The research findings highlighted the necessity for sustainable energy systems, such as the implementation of passive systems to reduce energy use and optimize occupants' thermal comfort in nursing homes. Furthermore, elderly people are adaptive to different seasons with the help of supplementary clothing, which provides insulation during the winter season. Although, this pilot study found that the clothing insulation level (*clo*) factor is not effective in extreme weather conditions, such that the further field measurements should be conducted to fill this research gap in thermal comfort studies.

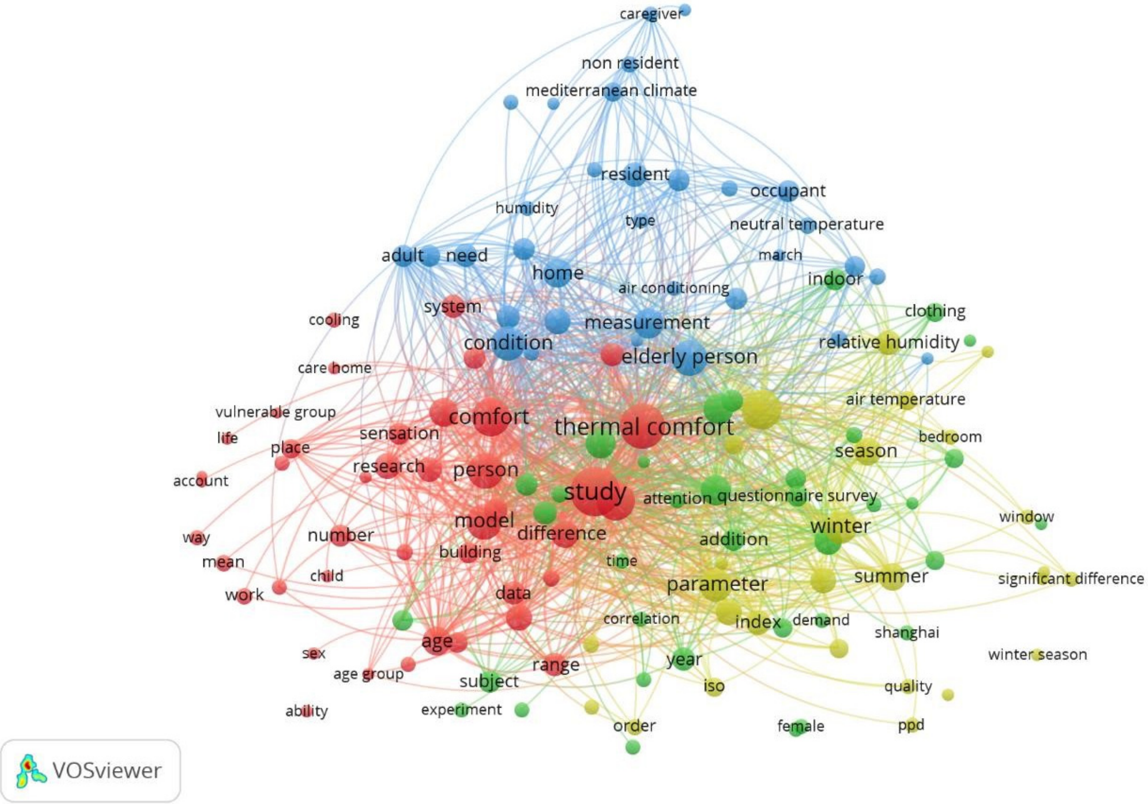


Figure 7. Network visualization was conducted to explore correlations between thermal comfort and field measurement methods globally. Source: https://www.vosviewer.com (accessed on 25 January 2023).

In India, the importance of climate is noticeable throughout thermal comfort studies, particularly in naturally ventilated buildings due to the low indoor quality conditions observed in existing buildings [34]. To support this argument, Song et al. (2018) suggested that India's tropical climate has shown variations throughout the country because of its large continental coverage [35]. Hence, there is not a single thermal model applicable to identify neutral adaptive thermal comfort models, and more field measurements are required.

3.2. Indoor Thermal Comfort Parameters

The Web of Science Core Collection was used to highlight the significance of adaptive thermal comfort in buildings. A total of 306 publications were gathered from the Web of Science database platform. To this extent, both original research papers and review articles were selected to explore correlations between indoor air quality and subject respondents' thermal comfort satisfaction globally. In the database analysis, the study only examined the last 10 years of publications, in line with the development of adaptive thermal comfort theory. The key word selection criteria were used, and three lay terms were identified, namely operative air temperature (T_o), relative humidity (RH) and wet bulb globe temperature (WBGT) factor, to fulfil the knowledge gap in thermal comfort studies. Notably, test reference year (TRY) meteorological data were collected from the nearest meteorological station to compute WBGT.

In thermal comfort studies, outdoor WBGT is calculated as the weighted sum of natural wet bulb temperature (T_{nwb}), globe temperature (T_g) and dry bulb/ambient temperature (T_a) (ISO 7243, Ergonomics of the Thermal Environment—Assessment of Heat Stress Using the WBGT Index by the International Standardization Organization [36–38]). The Vos viewer visualization tool was used to illustrate the findings. Figure 2 delineates the network visualization of determinant input variables. The air velocity is the most determinant factor in any type of thermal comfort research. The findings also demonstrate that the subject respondents' health condition is the most influential input parameter while assessing occupants' thermal sensation votes. Table 8 delineates the 10 most-cited papers in thermal comfort studies across the globe.

Table 8. Worldwide studies and their methodologies in thermal comfort.

Nicol et al. (2017) [39]	Asia, Middle East, Europe Australia	Compares indoor temperature ranges between mechanical controlled buildings and free running buildings.	Survey Adaptive approach	- Wide indoor temperature ranges in mechanically controlled buildings (active systems) and narrow ranges for free running buildings (passive system buildings). - Current indoor temperature guidelines require flexibility to cater for occupant' thermal preferences.
Vakalis et al. (2021) [40]	Canada	Quantification of retrofit strategies in relation to indoor environment, occupant perception and CO_2 emissions.	Survey	- Mechanical retrofits failed to meet thermal comfort needs of occupants in multi-residential buildings (MURBS).
De Dear & Brager (2001) [41]	Multi-regions, including Montreal and Ottawa	Evaluates ASHRAE thermal comfort standards relative to climatic conditions and assesses ASHRAE RP-884 project results.	Survey Adaptive approach	- A closer relationship between outdoor temperature and indoor temperature exists. - Passive cooling strategies in moderate climates can save energy.
Brager et al. (2004) [42]	San Francisco	Investigates the influence of personal control over operable office windows on thermal comfort and indoor thermal conditions.	Survey	- Various degree of personal control results in diverse thermal comfort responses.
de Dear & Brager (1998) [43]	Various locations, including but not limited to Montreal and Ottawa	Develops a thermal comfort and preference adaptive model.	Survey	- Climatic conditions and past thermal experiences significantly influence individual thermal comfort.
Nicol et al. (2020) [19]	Pakistan, Japan, Europe, Nepal	Explores acceptable indoor temperature ranges and shapes relative to outdoor temperatures.	Survey Adaptive approach	- Participants have a wide acceptable temperature range influenced by their experiences and circumstances.
Parkinson et al. (2020) [44]	Multinational, with mostly Western countries and Asia	Evaluates the ASHRAE 55 and EN15251 adaptive thermal comfort standards for naturally ventilated buildings.	Survey	Asian neutral temperatures are 1–2 higher than Western countries.
de Dear & Brager (2002) [45]	Multinational, including the USA	Evaluates thermal environmental conditions for occupants in naturally ventilated buildings under warmer climate regions.	Survey	It is impossible to create a neutral single optimum environment for all people. Promote individual control over their environments.
Schiavon & Melikov (2008) [46]	European and Mediterranean region	Explores potential energy savings from elevating air velocity.	Simulation (EnergyPlus) version 9.1	Increased air velocity improves comfort and minimises energy consumption.
Frontczak et al. (2012) [47]	United States	Examines office occupants' satisfaction by evaluating building features and indoor environmental parameters.	Web-based survey	Overall occupant satisfaction regardless of dissatisfaction with indoor environmental parameters, including air quality and temperature.

Source: Conceptualised by author. Source: Bema (2024).

The diverse thermal needs of occupants influence how they manage their indoor environments, because the human body has shown different physiological adaptions to changing weather conditions. However, the use of active cooling systems in buildings contributes to the optimisation of operative air temperature variation patterns to alleviate the impact of climate change in naturally ventilated free running buildings [39]. A study conducted by Nicol et al. (2017) showed that indoor temperatures in mechanically controlled buildings in Europe and Saudi Arabia indicated a minimal response to extreme outdoor temperatures. A 10 °C increase in outdoor temperature raises the indoor temperature by 1 °C. Nicol et al. (2017) mentioned the application of the PMV method in optimising thermal comfort in real life situations, since thermal comfort varies due to psychological and behavioural factors. However, the PMV method provides consistency and quantifying thermal comfort, which has led to the optimised indoor air quality of buildings [39].

Vakalis et al. (2021) explored discrepancies in energy retrofits in order to improve thermal comfort in multi-unit residential buildings by analysing the impacts of building upgrades (such as air handling units, boilers and radiators) on occupants' thermal comfort [40]. The field study findings indicated that buildings with initial low thermal comfort levels could improve the thermal adaptability of occupants.

Parkinson et al. (2020) analysed the ASHRAE 55 adaptive comfort standard using a relatively large sample size and evaluated the differences in adaptive comfort thresholds globally [44]. The results highlighted the importance of occupant control to optimise indoor air quality in air-conditioned buildings. However, the application of traditional adaptive models in air-conditioned buildings is affected by the control of HVAC systems. The study results indicated a similarity between the ASHRAE 55-2010 dataset and the updated model of ASHRAE 55-2022, with a regression gradient between 0.28 and 0.33, proving the effectiveness of the adaptive comfort model in naturally ventilated buildings. To validate the ASHRAE 55-2010 dataset, Parkinson et al. (2020) proposed adjustments of the Y intercept term in the adaptive comfort equation by adding a +2K and a +1K offset for Asian and Western regions, respectively [44]. The findings showed similar thermal comfort expectations between occupants in mixed mode buildings and those in naturally ventilated buildings. Although, De Dear and Brager (2001) highlighted the limitations of the ASHRAE 55-2010 dataset due to the lack of input for the free running buildings in the Mediterranean basin [41]. By contrast, Parkinson et al. (2020) suggested that the ASHRAE 55-210 is compatible with naturally ventilated buildings across various climatic zones [44].

Brager et al. (2004) evaluated the optimisation of indoor air quality in naturally ventilated buildings [42]. The study found that mean indoor temperatures ranged from 24.1 °C to 22.9 °C, respectively, during the warm season. Subject respondents' predicted mean vote results showed a variance between 72% and 78% in the acceptability range during the warm season. However, the adaptive thermal comfort model showed a variance between 86 and 90%. The study results validated the adaptive model in naturally ventilated buildings. Brager et al. (2004) emphasized that wider temperature ranges could also be accepted as thermally comfortable for occupants with air conditioning systems [42]. By contrast, De Dear and Brager (1998) argued that wider temperature ranges are inappropriate for occupants without direct thermal control of their indoor environment [43].

Nicol et al. (2020) employed a visual tool to analyse the environmental monitoring data from the field surveys in different climatic regions and cultures, including Nepal, Europe, Pakistan and Japan [19]. Nicol et al. (2020) suggested a robust data-driven approach compared to a one-size-fits-all in evaluating thermal comfort ranges [19]. The study addressed the concept of developing an evidence-based adaptive thermal comfort threshold globally. The findings revealed that 90% of thermal acceptability levels could be achieved during the autumn season. The study also highlighted the importance of psychological effects on thermal comfort in emergency shelters. It was found that subjective thermal comfort levels ranged between 2 and 6 °C. Furthermore, indoor air temperatures also ranged between 11 and 30 °C during the summer [19].

De Dear and Brager (2001) discussed the differences between PMVs and adaptive models in predicting indoor thermal comfort temperatures by analysing adaptive comforts [41]. The analysis indicated that the PMV model overestimates discomfort in comparison to the adaptive model, which shows that occupants could adapt their body to higher temperatures. Although some studies proposed a 10% reduction in metabolic rate estimations to maintain consistency with real world data, De Dear and Brager (2002) contradicted the suggestions because the discrepancies would still exist even with a 20% reduction in metabolic rate estimations [45]. De Dear and Brager (2002) suggested a further exploration of inter-individual differences in thermal comfort. Clothing choices influenced by the fashion industry affect dissatisfaction levels in thermal comfort [45]. Such individual differences have more significance in adaptive comfort levels than is often assumed in most studies. Therefore, the study suggested that more individualized and dynamic approaches to thermal comfort should be preferred to a uniform and neutral adaptive thermal comfort level.

Schiavon and Melikov (2008) studied the improvement of thermal comfort and potential energy savings from increased air speed at higher temperatures. The study focused on 54 observations from Berlin, Rome, Athens, Helsinki, Bordeaux and Jerusalem and included energy simulations using three different air velocity ranges (<0.2, 0.5 and 0.8 m/s). It was found that elevated airspeeds could result in cooling energy savings ranging from 17 to 48% and maximum cooling power reductions ranging from 10 to 28%. However, airspeed incrementation using fans contradicts the energy saving factor if the fan's power consumption exceeds 20 W. This trade-off is not usually addressed in most studies [46].

As shown in Figure 8, air velocity has shown a significant relationship with space conditions. Air velocity is represented in blue and space condition is indicated with red. These parameters are in close proximity to each other, and this proves the significance of these parameters for thermal comfort. Table 9 delineates the studies investigating correlations between occupants' thermal sensation votes and on-site monitored environmental parameters.

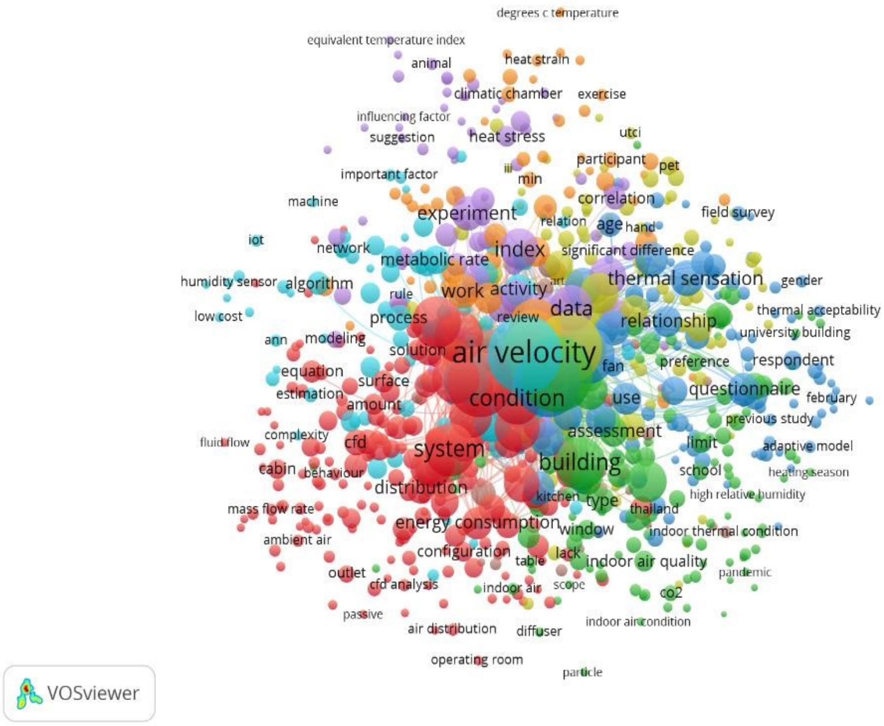


Figure 8. Correlations between air velocity and occupants' thermal sensation votes. Source: https://www.vosviewer.com (accessed on 25 January 2023).

Djamila (2017) indicated that adaptive thermal comfort models were scrutinized into two models, namely predicted mean votes (PMVs) and thermal sensation votes (TSVs) [48]. Although, the PMV model is not included in the identification of differences between physiological, psychological adaptive and behavioural factors in naturally ventilated buildings. One of the main reasons is that it is difficult to identify occupants' behaviour on window opening habits, so this could result in controlling the air infiltration rate for the experimental analyses. To avoid any research bias in thermal comfort studies, predicting thermal comfort has been validated by most scientists [49–51]. Implementation of adaptive thermal comfort models has highlighted the novel advancements in thermal comfort studies, such as innovative state-of-the-art climate chambers or laboratory environments in order to provide accurate statistical findings [52]. These conditions have shown variation with the location of any research context and climatic conditions of case study locations worldwide [53]. For example, the PMV models are commonly used in cold climate zones to provide constant thresholds, whereas adaptive models are mostly applied for warm climate conditions in order to generalize the research outputs effectively [54–56].

Table 9. Factors affecting occupants' thermal sensation in identifying neutral adaptive thermal comfort.

References	Operative Temp (°C)	Relative Humidity (%)	Air Velocity (m/s)	Clothing Insulation (lcl)	Outdoor Temp (°C)	Age (years)	Metabolic Rate (met)
Djamila (2017) [48]	22–24.1	<5%	0–1	0.02–2	-	18–75	0.8–1.3
		50	0.1	0.5–1			
Yi et al. (2022) [28]	25.6–32.1	5–95					
Rawal et al. (2022) [3]	25–35	30	0–1	-	-	-	-

Source: Conceptualised by author. Source: Bema (2024).

Rana et al. (2013) investigated the importance of humidity ratio for the expected air and operative air temperature for the optimisation of occupants' thermal comfort in different climate zones in Canada, India and Abu Dhabi [57]. In this pilot study, both the operative air temperature and relative humidity were integrated into the climate chamber to develop psychometric charts for each selected case study location. The humidity ratio was chosen as the control variable to measure the indoor air quality of the replicated local environment conditions in the climate chamber. The study also evaluated the impact of climate change on the temperature fluctuations annually. This has led to predicting the indoor thermal comfort by measuring its performance against the on-site monitored environmental conditions. However, Rana et al. (2013) indicated that the humidity ratio is commonly used to predict outdoor thermal comfort. One of the main reasons is that it provides more feasible calculation methods for the regression analysis in thermal comfort studies. In this regard, the ASHRAE RP-884 database and ASHARE Likert scale assessment were adopted to optimize thermally comfortable indoor environments globally [57].

Djamila (2017) emphasised that there is a lack of data to identify the accuracy of *on-site* environmental monitoring data in line with the adaptive thermal comfort theory, which was developed by Fanger in the 1970s [48]. Many researchers proposed a new criterion to determine thermal comfort ranges by considering the operative air temperature as a control input variable [44,58,59]. Additionally, different criteria and methods were used in analysing the ASHRAE RP-884 database. To accomplish this, operative air temperature and relative humidity were selected to conduct the statistical analysis (Ozarisoy & Altan, 2021) [60]. It should be noted that the effect of air movement should be considered to measure the infiltration rate of occupied spaces, but many thermal comfort studies have neglected to consider this aspect in their experimental analyses in the climate chamber [61,62]. It must be highlighted that air velocity is an important parameter because it helps to identify the discrepancies detected in different climate conditions.

Djamila (2017) also stated that occupants' TSVs have shown distinct differences between the local climate conditions and the physical parameters of buildings [48]. Many studies have highlighted that there is a direct link between air velocity and clothing insulation level (*clo*) in identifying neutral adaptive thermal comfort [63]. In these studies, it was observed that an average clothing insulation of 0.6 (*clo*) was required for an air velocity between 0.15 and 0.2 m/s. However, the clothing insulation level for indoor temperatures below 16.0 °C varied among subject participants, hence these results could require validation using a climate chamber. Djamila (2017) conducted a meta-analysis to develop a novel method for the identification of neutral adaptive thermal comfort. Hence, the meta-analysis results are based on the integration of different types of thermal assessment criteria, which have led to many discrepancies in research outputs [48]. Djamila (2017) stressed that the dataset should be adjusted in line with the power analysis method to calculate the sample size [48]. The study also highlighted that subject participants' age differences should also be taken into account because of the human body's adaption to different local climate conditions.

In a study conducted by Rawal et al. (2022), the India Model for Adaptive Comfort (IMAC) was proposed for residential buildings and the study findings were compared with the predicted mean vote (PMV). Furthermore, there are several discrepancies identified between the proposed model and the ASHRAE-55-2020 and EN 16798-1 thermal comfort assessment models [3]. Parameters included indoor air temperature and velocity, relative humidity and globe temperature by considering subject participants' age and gender.

Rawal et al. (2022) indicated that the thermal properties of buildings have had an impact on households' energy use, and this factor is not only limited with the physical condition of buildings, but it also has a direct correlation with local climate conditions in identifying neutral adaptive thermal comfort [3]. This study also highlighted that buildings with operational heating, ventilation and air conditioning (HVAC) systems offer optimum thermal comfort at a high energy cost. Although, naturally ventilated buildings may optimise occupants' thermal comfort while also considering energy conservation concurrently. It should be noted that the adaptation of the human body to extreme thermal conditions is important, but there is a lack of experimental analysis to provide guidance to future scholars on this matter.

Yi et al. (2022) concluded that Indian occupants are more tolerable to the warmer conditions than the predicted thermal adaptation thresholds recommended by ASHRAE-55-2020 and EN-16798 thermal comfort assessment models [28]. To this extent, Yi et al. (2022) proposed an adaptive model for mixed mode and naturally ventilated residential buildings in different Indian climate zones [28]. This pilot study predominantly assessed subject respondents' psychological parameters. In conjunction with the experimental analysis, air velocity, operative air temperature, global temperature and relative humidity were included for the development of neutral adaptive thermal comfort thresholds. Additionally, subject respondent's clothing insulation level (*clo*) and their metabolic rate (met) activity were determined by a longitudinal field survey and the weather data collected from the closest weather station.

Kaynakli and Kilic (2005) developed a mathematical model to analyse the effect of clothing insulation level (*clo*) and air velocity on human thermal comfort [64]. The mathematical model was used as an innovative approach for dividing the human body into 16 clothed segments in the statistical dataset. The study also analysed the subject respondents' TSVs and the recorded environmental parameters [64]. The study findings highlighted the steady increase on the air infiltration rate and the evaporative heat transfer coefficient ratio, which have led to increased heat losses. It should be noted that the human body's reaction to air velocity rates is one of the most-known deterministic factors. One of the main disadvantages of the mathematical model is the data mining and selection of exclusion criteria in the dataset. Both these factors could impact the occupants' TSVs. Yuan et al. (2022) indicated that the human body is complex in tolerating changing environmental conditions, such as extreme heat in the summer [25]. This has led to the development of Python 3.13.0/7 script or mathematical equations to reduce the bias for statistical analysis [25].

3.3. Adaptive Thermal Comfort Assessment

Taleghani et al. (2013) analysed the accuracy of the subject respondents' TSVs to develop an evidence-based adaptive thermal comfort assessment approach, and the study was validated with the IRT survey [65]. Although, the TSVs of elderly people with dementia were excluded from the dataset in order to avoid any research bias, but this could result in inaccuracies in the assessment criteria (ibid). Luo et al. (2018) indicated that the subject respondents' clothing insulation (*clo*) level and their metabolic rate (met) activity were two important determinant factors during field studies on thermal comfort assessment [66].

Gaetani et al. (2016) also highlighted the importance of passive design systems, which aid in penetrating fresh air into occupied spaces. The study recommended that effective fenestration design, window-to-wall ratio (WWR) and orientation of opaque glazed surfaces are required to provide optimum thermal conditions in summer [67]. Chen et al. (2021) proposed alternative models to assess elderly people's thermal comfort [68]. In this study, the main emphasis was given to exploring correlations between outdoor environmental parameters and subject respondents' TSVs. One of the limitations of this study was in assessing elderly people's behaviour on window opening habits and their record of metabolic activity level (met) indicators. Encinas and De Herde (2013) highlighted the importance of operative air temperature on elderly people's TSVs [69]. These two important debates demonstrated that there is a contradiction between the PMV and TSV approaches. To avoid any research bias, D'Souza (2013) proposed that using the thermoregulatory models could avoid discrepancies in the statistical dataset [70]. The study also highlighted that considering human body reactions to extreme weather conditions could require an evidence-based adaptive behavioural analysis and the development of feed-forward questionnaire surveys with subject respondents in order to gather accurate data and optimise occupants' thermal comfort thoroughly.

According to Singh and Chani (2018), the subject respondents' TSV results show that 80% of the Indian participants experienced the adaptive thermal comfort threshold level between temperature ranges of 20.5 and 29.5 °C [71]. However, these results may have been affected by using air conditioners and heaters during the field study. It should be noted that the difference between the PMV and TSV results was calculated by using the Center of the Built Environment's (CBEs) open-access Thermal Comfort tool to predict subject respondents' PMVs accurately. Furthermore, a difference of 5.2 °C was noticed between the predicted and observed neutral temperature. To conclude, Singh and Chani (2018) indicated that elderly people's thermal acceptability showed slightly different findings than the adaptive thermal comfort convention model which was proposed by Fanger in 1973 [71]. On the other hand, Indraganti et al. (2014) also indicated that the standard deviation is the determinant factor to avoid discrepancies in any type of statistical data gathered from field measurements in thermal comfort studies [72].

There has been very little research conducted to investigate Canadian households' thermal comfort. However, Zhang et al. (2017) conducted a comparative study considering North American households [26]. The study found that Canadian residents were more adaptable to extreme cold conditions than North American households while selecting outdoor daily mean temperature as control variable for the statistical analysis. Zhang et al. (2017) indicated that indoor air temperature is usually maintained within the range between 20 and 25 °C in Canada [26]. The study also explored the indoor temperature variations between Canadian and North American residents' occupied spaces in the winter. The findings highlighted that, in Canada, the indoor air temperature fluctuations were more stable due to high airtightness levels and good quality of insulation materials on external walls in newly built homes. According to Zhang et al. (2017), the thermally comfortable operative air temperature was found to be between 22 and 26 °C in North America. The study also found that multi-family residents' thermal acceptability was found between 22 and 26 °C in naturally ventilated residential buildings in Canada [26].

Furthermore, the effects of physiology, psychology and behaviour adaptation factors were analysed by using the households' TSVs [26]. In this study, it was found that thermal acceptability was the lowest amongst three regions in North America, which was found to be 4.6 °C. The results indicated that Canadian residents' energy consumption for space heating was significantly higher than in India and Abu Dhabi. This could result in an effect on the PMV model by considering occupants' TSVs in developing an evidence-based neutral adaptive thermal comfort model globally. The following section describes the purpose of using the ASHRAE Global Thermal Comfort database, version 2.1, in order to prove the necessity of passive design strategies while developing different adaptive thermal comfort thresholds worldwide.

3.4. Passive Cooling Strategies

The previous section introduced the main parameters that determine neutral adaptive thermal comfort, with a focus on the ASHRAE Global Thermal Comfort Database, version 2.1, and its role in shaping global adaptive thermal comfort theory. This section explores passive cooling design strategies and provides a definition for the optimisation of thermal comfort. It also examines traditional cooling systems in vernacular buildings, considering the different climatic characteristics of the built environment. Recent studies have indicated that passive cooling systems, particularly when applied to the building envelope, are gaining prominence [73,74]. Romero et al. (2013) proposed a comprehensive simulation-based framework for evaluating active and passive cooling strategies, comparing two air-based cooling strategies across six different climates [75]. This evaluation, based on three key indicators—ambient warmness degree (AWD), indoor overheating degree (IOD) and climate change overheating resistivity (CCOR)—allowed for the quantification of the indoor environment's resistance to climate change. The findings revealed that a variable air volume active cooling strategy in Toronto resulted in a significantly lower CCOR value of 9.32, while Brussels achieved the highest CCOR value of 37.46 using a combination variable refrigerant flow (VRF) and dedicated outdoor air system strategy. However, these studies largely focused on energy consumption reduction, neglecting the optimisation of thermal comfort for occupants. According to Porritt et al., implementing passive strategies in disadvantaged areas with extreme heat and humidity minimizes healthy effects caused by heat. Disadvantaged areas are often associated with heat-induced effects, contributing to increased medical consultations and expenses, whereas passive strategies such as proper shading, insulation and ventilation improve occupants' thermal comfort without relying on active cooling systems [76]. The effectiveness of cool roofs in hot climates like Saudi Arabia was analysed by Saber et al., and the use of reflective coating to minimize solar absorption resulted in significant energy savings and a reduced dependency on active cooling systems while satisfying occupants' thermal comfort. However, Saber et al. emphasize the integration of several passive cooling strategies and a consideration of the building envelope for better results [77]. Table 10 delineates some exemplar studies to optimise the indoor air quality of buildings.

Table 10. Passive cooling techniques applied in recent studies.

References	Strategy	Heating Load	Cooling Load	Energy Performance Improvement	Thermal Comfort Improvement	Location
Porritt et al. (2011) [76]	- Trombe wall - Green wall - Earth air heat exchanger	7.9 kWh/m^2	2.8 kWh/m^2	Achieved annual surplus energy of 180 kWh/m^2/annum	Achieved 88% of thermal comfort needs	Sweden
Saber et al. (2020) [77]	- Solar chimney - Earth air heat exchanger - Light colours in hotter climate zones -Darker colours in colder climate zones	20 kWh/m^2	99.2 kWh/m^2	Annual electrical energy savings of 42.9 kWh/m^2/year	Space temperature was 5 °C less than ambient temperature in summer; Space temperature was 10 °C higher than ambient temperature	Hot arid areas (Egypt)
Schweiker and Wagner (2015) [78]	- Micro-encapsulated phase change materials (PCMs) in concrete	-	-	A 13% energy savings	A 2 °C indoor temperature gain was achieved	Adana, Turkey
Hawighorst et al. (2016) [73]	- North-to-South orientation - Shape factor of 0.48 - Maximum exterior wall U-value (0.35 W m^{-2}K^{-1}) Window-to-Wall Ratio < 20%	70.11 kWh/m^2	18.43 kWh/m^2	Design was able to meet the Passivhaus Standard Building threshold	Not considered	Spain
Huang et al. (2020) [74]	Cylindrical PCM-assisted Earth Air Heat Exchanger (EAHE)	A 96% energy consumption reduction	An 8.7% energy consumption reduction; daily maximum cooling capacity of EAHE was increased by 28.5–39.7%	Electrical Energy consumption reduced by 78.9%; cooling output of the system increased by 20.0%	Not considered	China

Source: Conceptualised by author. Source: Bema (2022).

Ozarisoy (2022) identified the percentage people dissatisfaction (PPD) level among social housing residents in the Eastern Mediterranean basin [31]. The study found that elderly individuals were more vulnerable to extreme heat in the summer, which increased their reliance on cooling devices like domestic air conditioning (A/C) systems or portable fans to maintain thermal comfort at home. According to Ozarisoy (2022), passive cooling systems could contribute to as much as an 81% reduction in energy consumption in the hot and humid climate of Famagusta, Cyprus [31]. The study highlighted that the most effective passive design strategies for enhancing natural ventilation included adjusting the window-to-wall ratio (WWR), using operable pinewood external shutters, installing skylights and implementing windcatcher systems. These windcatcher systems, as shown by Ozarisoy (2022), help to prevent heat build-up in south-facing rooms and mitigate overheating risks in the summer [31]. While a wealth of experimental research has focused on assessing overheating risks in buildings, most studies have not prioritised optimising thermal comfort for occupants [79–81]. The overall conclusion was that passive cooling systems alone might not provide optimal thermal comfort without considering energy-efficient building materials [82].

De Dear et al. (2018) evaluated the effects of a state-of-the-art passive wall system on adaptive thermal comfort in a semi-arid Sudanese climate [83]. This wall system integrated both natural ventilation and evaporative cooling. The study compared indoor operative air temperatures to outdoor air temperatures after implementing a Trombe wall system, finding that indoor air temperature dropped from 30.3–44.8 °C to 18.9–26.5 °C.

Pastore and Andersen (2019) noted that air velocity and temperature were the primary variables incorporated into building simulation tools such as Integrated Environmental Solutions Virtual Environment (IES-VE), Design Builder and Environmental Design Solutions (EDSL-TAS) [84]. However, Gustin et al. (2019) emphasised that current methodologies often overlook the role of relative humidity when assessing occupants' thermal comfort in simulation engines [85]. The study found that standard deviation was the most influential factor in determining thermal comfort, as discrepancies were detected in the dataset, and the sample size was relatively small compared to Yao et al. (2009) [86]. The study also revealed that a 23.6% reduction in energy consumption was possible following the implementation of passive cooling design strategies.

Huang et al. (2020) emphasised that local climate conditions should be a top priority when implementing passive cooling systems in buildings. In India, four climatic zones were identified: hot-dry, hot-humid, temperate, cold and composite [74]. This climate variation was analysed to assess the passive cooling potential of the existing building stock [52]. The India Model for Adaptive Comfort (IMAC) was used to evaluate occupants' TSVs, aiding the development of evidence-based passive cooling design strategies. The findings highlighted that evaporative cooling was particularly effective for natural ventilation in India's composite climate. Night-time ventilation was also identified as a critical strategy for maintaining thermal comfort, particularly in the hot-dry climate. In conjunction with adaptive thermal comfort theory, many researchers have stressed the importance of night-time ventilation strategies in hot and humid climates globally [87].

3.4.1. Passive Evaporative Cooling Systems

Passive evaporative cooling systems are most commonly found in hot-dry and hot-humid climate regions [88]. These systems, which have been used for centuries across regions from India to Cyprus, are typically applied in residential buildings to optimise indoor thermal comfort during extreme summer heat [89]. The application of passive cooling systems is closely tied to regional architectural typology and urban characteristics, which have evolved in response to local climate conditions. For example, windcatcher systems, top-window openings and overhanging balconies with shading elements are highly efficient passive cooling strategies. These strategies are embedded in the local culture and adapted according to specific regional needs [90]. Frontier examples of these indigenous technologies often utilise locally sourced energy and construction materials that work harmoniously with the natural environment. However, these technologies have been marginalised, if not entirely suppressed, by the rapid expansion of industrialisation [91].

Table 11 delineates the widely used passive cooling technologies and their outputs. While passive strategies contribute to the improvement of indoor environments and thermal comfort, some studies recommend supplementary active systems in buildings [92–95]. Panchabikesan et al. suggest the introduction of new policies which support passive cooling strategies, and according to Santamouris et al., improving technical capabilities of passive systems should be preferred instead of adding various strategies [93,94]. Natural ventilation is a common cooling strategy applicable in regions with hot climates; hence, building designs which promote natural ventilation are important [96–98].

Table 11. Investigating effectiveness of passive cooling design strategies on thermal comfort.

References	Study Location	Methodology	Passive Cooling Technologies	Outcome
Normah et al. (2012) [92]	Malaysia	Simulation (EnergyPlus)	Shading, wall and roof insulation, high reflectance surface paint, nighttime ventilation.	Supplementary active air conditioning is required in the future.
Santamouris et al. (2007) [93]	Africa, Middle East, South America	Simulation (TRNSYS version 18)	Ground cooling, natural ventilation systems, cool reflective coatings.	Preference on improving technical capabilities of passive systems rather than providing occupants with various passive strategies.
Panchabikesan et al. (2017) [94]	India	Simulation	Nocturnal radiative cooling, phase change materials, evaporative cooling.	New policies are fundamental in supporting passive strategies in buildings.
Gilvaei et al. (2022) [95]	Not mentioned	Simulation (ANSYS version 6)	Windcatcher, direct evaporative cooling.	The proposed hybrid-passive cooling system with an air–earth heat exchanger provided thermal comfort conditions.
Imessad et al. (2014) [96]	Mediterranean region	Simulation (TRNSYS)	Night ventilation, insulation, thermal mass, window shading.	Combining natural ventilation and shading devices aid in improving thermal comfort.
Vitale et al. (2017) [97]	Rome	Simulation	Natural ventilation.	Comfortable indoor temperature ranges can be maintained by using natural ventilation and thermal mass.
Bravo & Gonzalez (2013) [98]	Venezuela	Survey	Natural ventilation, solar radiation roof control, wall heat gain reduction, indirect evaporative cooling.	Appropriate fenestration design provides thermal comfort for most occupants.
Calautit et al. (2017) [99]	UAE	Simulation	Windcatcher.	Integrating heat pipes to the windcatcher has a high cooling potential in buildings.

As previously mentioned, this investigation focused on passive-evaporative cooling systems. From this point, these systems will be adapted with the integration of porous ceramic materials intended for natural ventilation in residential retrofitting efforts. This low-tech passive-cooling solution facilitates the circulation of humid, hot air from the outdoors and must be placed adjacent to the perimeter walls or in contact with the roof [100]. Several pilot studies have explored the application of porous ceramics in inefficiently constructed residential buildings. However, in newly built residential buildings, only rooms with access to external walls can use this particular cooling technique. These studies have also highlighted mitigation techniques and effective low-tech passive cooling design solutions that should be adopted in service areas such as corridors, lobbies and general circulation spaces.

An industrial ideology has led to the development of new building styles, contributing to the energy crisis. However, Bencheikh et al. discuss the challenges of relying on active heating and cooling systems in meeting occupants' thermal comfort needs, and the study findings support the use of passive cooling strategies without any active systems in Algerian traditional buildings. According to Bencheikh et al., modern buildings require active cooling systems, escalating energy consumption, while traditional buildings can reduce space cooling demand by 100%. Furthermore, the bioclimatic strategies proposed for traditional buildings in this study resulted in a 39% heating energy demand reduction compared to modern buildings. Meanwhile, Bencheikh et al. suggest that adopting vernacular architecture and employing passive cooling strategies can pave the way for reaching the 2050 climate goals; the challenges of adopting traditional architectures in modern society (such as with space and materials) should be addressed [101]. Schiano-Phan et al. analysed the effectiveness of a passive evaporative cooling technique that cools a residential building in Spain by integrating porous ceramics into the building's walls. The proposed technique resulted in a radiant mean temperature of 27 °C, average indoor temperature of 26 °C and a 5% predicted percentage of dissatisfied, indicating high thermal comfort levels [102].

To investigate the integration of porous ceramic systems in residential retrofitting schemes, a 2008 study by Schiano-Phan tested the implementation of porous ceramic materials on building envelopes. This study examined the low-tech design solutions and their impact on optimising occupant thermal comfort at home. It supported the hypothesis of previous scholars, showing that in apartment blocks, the floor level influences the size of the porous ceramic system that is needed [103]. Ground-floor layouts affected by heat gains due to high-albedo asphalt surfaces may benefit from the installation of a porous ceramic façade on the outer skin [104].

Schiano-Phan (2009) also developed a novel approach for enhancing natural ventilation in social housing units [104]. This system allowed fresh air to enter through a wet-cavity wall system, which filtered particles and circulated water into occupied spaces. On intermediate and ground floors, reduced perimeter space was compensated by lower envelope gains and decreased indoor cooling demands. In top-floor apartments, where the roof can be used as an additional surface for the porous ceramic system, the system further enhanced indoor air acclimatisation [105]. Studies conducted by Schiano-Phan in 2010 [106] and Golzari in 2014 [107] concluded that mitigation techniques such as night-time ventilation, solar control and improvements to building envelopes significantly reduced cooling loads. These reductions were often achieved by using a wall-integrated porous ceramic system.

3.4.2. Windcatcher Systems

In hot-arid and hot-humid regions, wind towers are among the most commonly used passive design systems for providing natural circulation and cooling indoor spaces. One of the most well-known examples of passive-cooling systems is Iranian wind towers. These towers often have openings facing all directions or, in some cases, only the prevailing wind direction [108]. Scholarly articles have described the various types of wind towers, which differ in height, number of openings and cross-sections for airflow. The designs also vary based on airflow rate, heat transfer area, sensible heat storage and evaporative cooling surfaces.

A pilot study investigated the cross-section design of a wind tower system in the Dowlat Abad Garden in Yazd. This case-study building was extensively documented by Bahadori in 1979. This wind tower featured a small pool with a foundation at its base. The high wind velocity allowed air to be cooled as it descended, then further cooled evaporatively by the pool before circulating through indoor spaces [109]. Another pilot study investigated a wind tower system with access to an underground water stream. The cold underground water provided a more effective cooling rate than other wind towers. The natural ventilation cooled by the underground stream was drawn through the shaft, effectively cooling the indoor spaces.

As mentioned earlier, natural ventilation and passive cooling methods are based on traditional building systems that have proven efficient over time. However, applying these systems to concrete-built residential buildings poses challenges. There is often a gap between past and current systems in terms of efficiency, especially in retrofitting efforts. This study emphasizes the importance of effective natural ventilation, considering the local wind direction, as a key factor in modern high-rise residential buildings.

Experimental base-case ventilation strategies, tested by Giovanni et al. in 1991, showed that oblique winds at angles between 30° and 120° to the wall can provide effective cross-ventilation if there are openings in the windward and leeward sides. Determining a building's relationship to the prevailing wind direction is crucial when designing the placement of key rooms like living rooms and bedrooms during the early design stages. These findings can also help minimise or avoid overheating risks while assessing the energy performance of a residential building.

To conclude, this study underscores the importance of climate classification in developing passive cooling design strategies. It also highlights the use of existing thermal comfort models, such as those accredited by the ASHRAE Global Thermal Comfort Database, version 2.1, to propose a hybrid methodological framework for thermal comfort studies, which is discussed in Section 3.

3.5. Passive Design Strategies and Their Implications for Adaptive Thermal Comfort

In the systematic literature analysis, it was found that passive design systems are not highly effective in providing elderly occupants' thermal comfort in Canada. Few studies have been conducted on passive strategies [110–112] to consider the discrepancies of adaptive thermal comfort thresholds during extreme cold wintery conditions in Canada. It was found that active heating systems were considered to keep warmer indoor environment conditions; therefore, it was difficult to adjust the human body for changing indoor air temperatures. Furthermore, the study recommended that passive heating systems should be investigated to reduce energy costs and optimise thermal comfort in Canada. By contrast, a high airtightness of buildings could avoid air leakages in order to maintain the optimum indoor environmental conditions both in the summer and winter [113].

It was found that moisture content tends to be an issue in fully airtight mixed-mode buildings [113]. Although, energy efficient heat pump systems could allow fresh air to dissipate in order to improve air quality, but the high up-front costs of heat pumps were not found to be an economically viable option by investors during the decision-making process; therefore, their long-term viability was not considered [114]. The study recommended that effective humidity control systems should be implemented to optimise indoor thermal conditions because of the condensation issues related with building construction materials (ibid). Santangelo and Tondelli (2017) [114] indicated that window-to-wall-ratio (WWR) and orientation of opaque glazed surfaces have caused overheating risks in the summer. To this extent, Day and Gunderson (2015) [115] recommended that avoiding thermal bridges and the implementation of energy efficient insulation materials could provide thermally comfortable conditions in the winter, but these retrofitting principles could lead to making buildings warmer in the summer.

Cândido et al. (2010) [116] indicated that the installation of HVAC systems has caused a reduction in air movement acceptability thresholds. With regards to maintaining optimum thermal comfort, mixed-mode ventilation strategies are recommended to reduce the high energy costs of buildings [117]. Nicol (2004) indicated that occupants' thermal comfort adaptation is important, but when considering their psychological behaviour, it could bring a significant impact on the development of adaptive models globally.

Haldi and Robinson (2010). [7] stressed the importance of the humidity ratio in the tropical wet and dry/savanna climate of India. Although, none of the studies have explored the humidity ratio on the identification of elderly peoples' adaptive thermal comfort. To accomplish this, a total of 42 original research papers were reviewed by selecting three main keywords, namely thermal comfort, passive heating and cooling strategies. It was found that a considerable number of studies considered the energy effectiveness of passive cooling strategies in the composite climate of India, but there is very little research undertaken in tropical and dry/savannah climate regions. It was also found that there are many discrepancies in the ASHRAE Global Thermal Comfort Database II because of the uncertainty of field measurements.

In the present study, it was found that thermal comfort assessment was difficult in the hot and arid climate of Abu Dhabi. In this study, it is recommended that passive cooling strategies could optimise excessive solar radiation in the summer. This has been accepted as the most effective optimization strategy, which could help to reduce energy consumption up to 81% in naturally ventilated multi-family social housing estates. Bonte et al. (2014) [118]

also recommended that the implementation of windcatcher systems on the north–south orientation is the most appropriate decision to avoid direct sunlight exposure. Bonte et al. (2014) stressed that providing appropriate shading strategies is important in the south-facing social housing blocks in Spain because of the long duration of solar radiation in the summer [118]. The study recommended that a high thermal mass could help to optimise the indoor air thermal comfort of each occupied space at home. To sum up, passive cooling design strategies can be added by considering the local climate conditions, depending on further studies. This evidence-based framework can be used to inform future design guidelines and regulations for the development of adaptive thermal comfort theory to mitigate future extreme heat events.

4. Data Analysis to Identify Neutral Adaptive Thermal Comfort

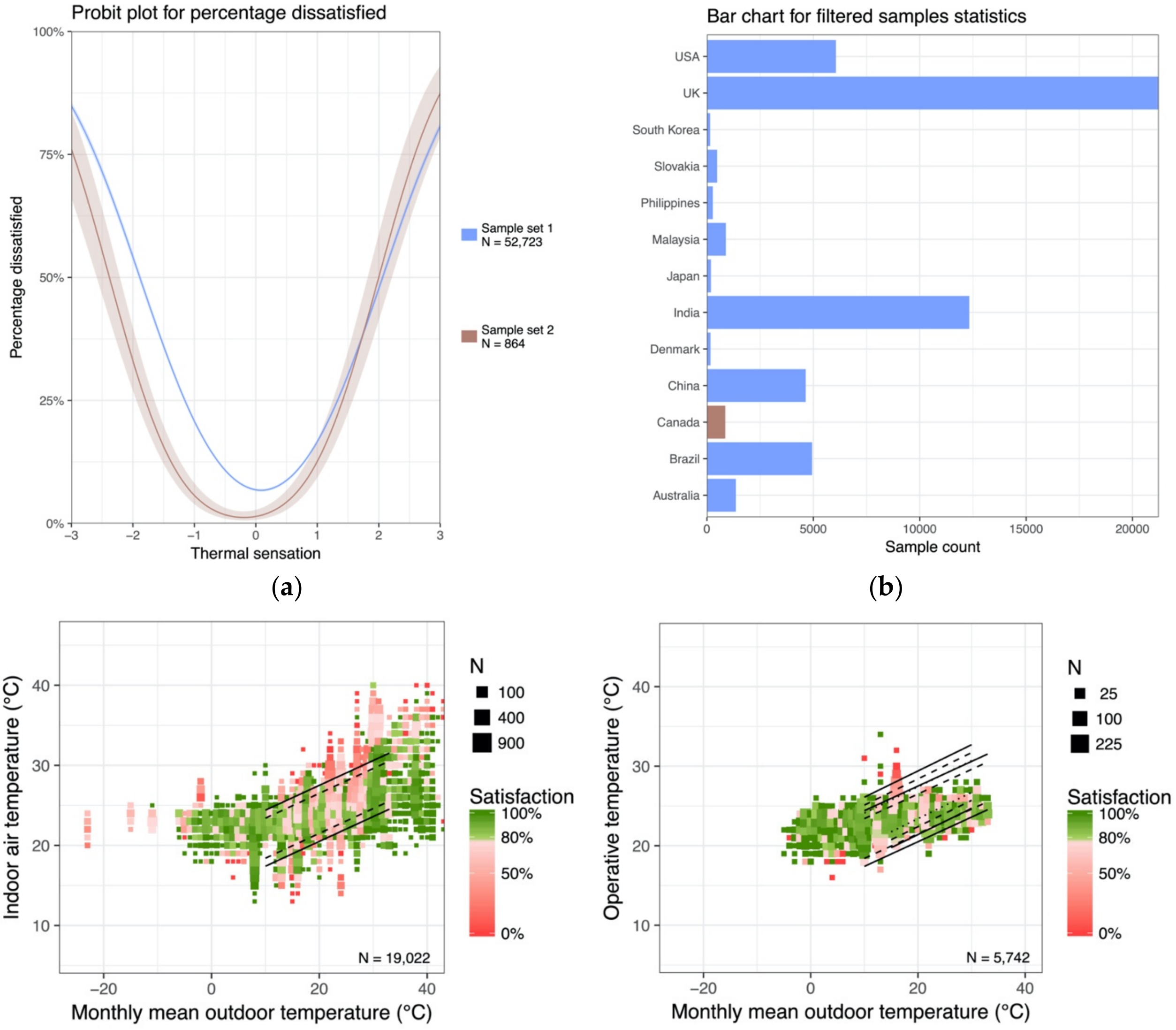
4.1. ASHRAE Global Thermal Comfort Database II

This section presents the data gathered from the ASHRAE Global Thermal Comfort Database, version 2.1. The aim was to explore correlations between environmental conditions and respondents' TSVs to develop an evidence-based adaptive thermal comfort approach. As shown in Figure 9a, Canadian residents' TSVs were included to illustrate the sample size used for the database analysis, with Canada contributing only 864 TSVs out of a global sample size of 52,723. In contrast, the United Kingdom, China and India contributed the highest sample sizes, as shown in Figure 9b.

As shown in Figure 9a,d, the occupants' TSVs were examined by considering indoor air, outdoor air and monthly mean outdoor temperatures to identify the 80% threshold of thermal acceptability. A total of 19,022 datapoints were used to determine adaptive thermal comfort levels between 21 °C and 28 °C, making it the largest sample size in the dataset and providing reliable research outputs. The study found that participants' overall thermal comfort levels indicated a higher dissatisfaction compared to Canadian occupants, likely due to the colder climate of Canada. Figure 9c shows correlations between indoor air temperature and monthly mean outdoor temperature, identifying neutral adaptive thermal comfort in cold climates, where occupants felt thermally comfortable between 23 °C and 29 °C. This dataset, which includes 19,002 samples, shows that thermal satisfaction ranged between 80% and 100%. Figure 9d highlights correlations between operative temperature and monthly mean outdoor temperature, demonstrating an upper thermal comfort threshold between 30 °C and 32 °C, with maximum tolerance reaching up to 34 °C. These findings suggest that occupants tolerate warmer indoor air conditions.

One limitation of the study was the lack of data on occupants' window-opening patterns and thermostat settings during the winter, which complicates efforts to validate the findings. This points to a need for future research using optimisation models to predict adaptive thermal comfort. Supporting this, Sánchez-García et al. (2018) conducted thermal comfort analysis in naturally ventilated multi-family buildings to assess the PPD using valid on-site field measurements [63].

There remains some uncertainty regarding the identification of an appropriate adaptive thermal comfort model for each field study. To mitigate research bias, the ASHRAE Global Thermal Comfort visualisation tool offers a parametric analysis approach to determine thermally acceptable thresholds. Figure 10a displays a scatter plot representing the thermal sensation scale of Canadian residents, with neutral adaptive thermal comfort identified between 20 °C and 30 °C, considering indoor air temperature. Figure 10b shows a scatter plot of the clothing insulation level (*clo*) against relative humidity. The findings suggest that moisture transfer could be reduced by using slightly higher clothing insulation levels. Further, the study confirms that clothing insulation is a significant factor in thermal comfort assessments. For example, very low relative humidity in Canada requires considerable clothing insulation, whereas regions like India and Abu Dhabi, with higher relative humidity, require less insulation. It should also be noted that the participants predominantly relied on HVAC systems for cooling in summer, making it difficult to maintain a constant relative humidity ratio, as recommended by ISO 13731:2001, Ergonomics of the thermal environment—Vocabulary and symbols.



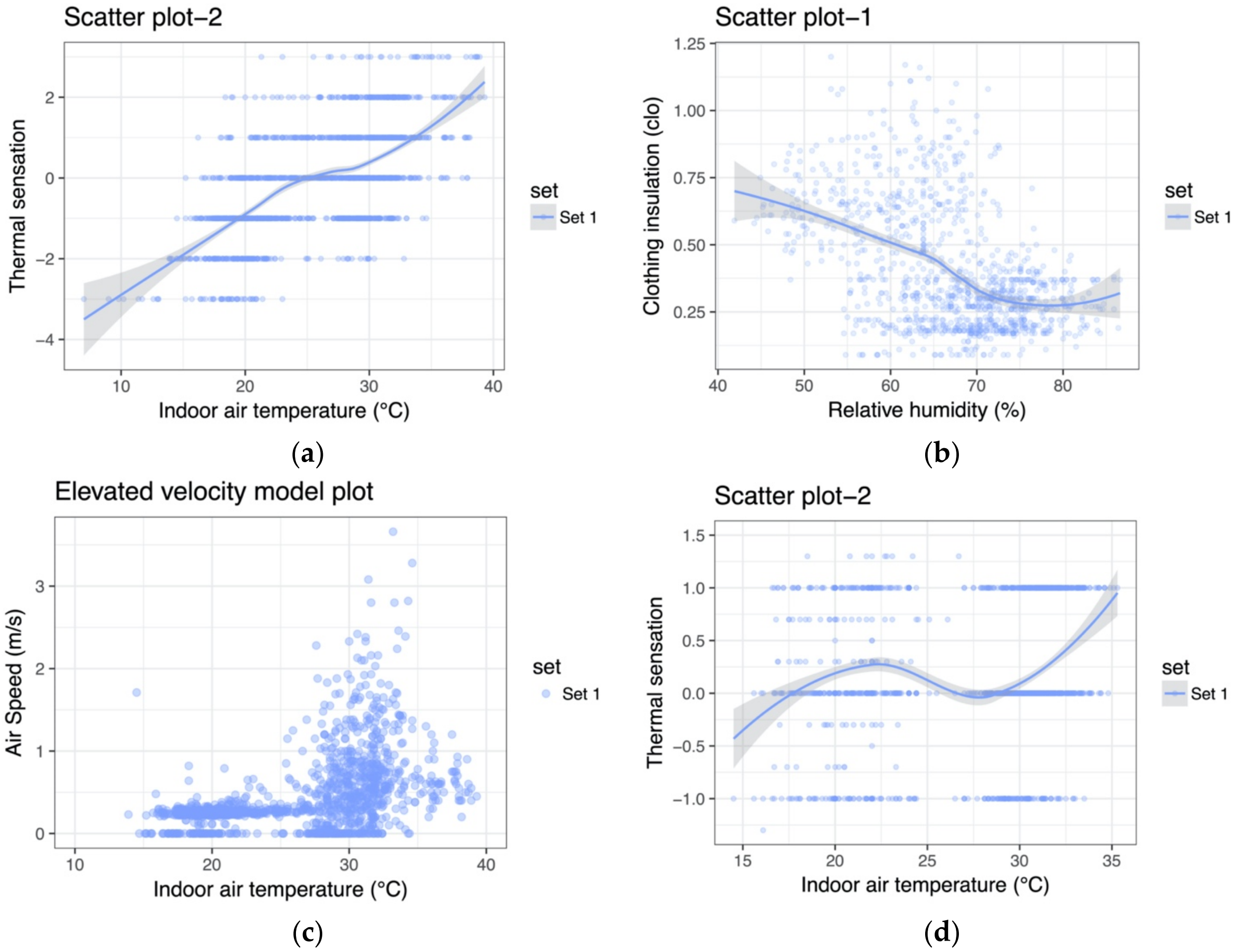
(**a**) (**b**)

(**c**) (**d**)

Figure 9. (**a**) Probit plot of dissatisfaction percentage; (**b**) bar chart distribution of filtered sample statistics; (**c**) overall thermal comfort for the Canadian climate considering indoor air temperature; (**d**) overall thermal comfort considering operative air temperature. Source: Thermal comfort data were extracted from https://cbe-berkeley.shinyapps.io/comfortdatabase/ (accessed on 15 January 2023).

Figure 10c shows the elevated velocity profile plot for India, highlighting a strong correlation between air speed and indoor air temperature in naturally ventilated buildings. The blue dots cluster between 28 °C and 32 °C, indicating that occupants felt thermally comfortable despite moderate air speed during the survey. Additionally, Figure 10d shows moderate correlations between indoor air temperature and occupants' TSVs in India. Occupants felt neutral or slightly warm, with TSVs ranging from 0.0 to 1.0, and the adaptive thermal comfort threshold ranged between 20 °C and 35 °C.

The study also found that air speed plays a fundamental role in adaptive thermal comfort assessments. However, this factor should not be limited to field measurements; climate chamber tests should also be conducted to validate occupants' TSVs. Regarding adaptive thermal comfort thresholds, further research is needed to investigate participants' psychological adaptation to local climate conditions, especially during prolonged heatwaves, which occur frequently in Canada. Notably, the newly released ASHRAE Global Thermal Comfort Database, version 2.1, lacks data on the impact of heatwaves on Canadian occupants' thermal comfort, representing a significant research gap that must be addressed.



(**a**) (**b**) (**c**) (**d**)

Figure 10. (**a**) Correlations between thermal sensation indicator and indoor air temperature; (**b**) overall thermal comfort for Canada considering respondents' clothing insulation level; (**c**) elevated velocity model plot for Indian climate zone; (**d**) thermal sensation for Indian climate zone. Source: Thermal comfort data were extracted from https://cbe-berkeley.shinyapps.io/comfortdatabase/ (accessed on 15 January 2023).

4.2. Thermal Comfort Assessment in the Eastern Mediterranean Basin

In this study, a dataset related to occupants' thermal sensation votes (TSVs) was designed in accordance with the thermal comfort assessment convention recommended by Wang et al. (2018) [24]. As presented in Section 4.1, in accordance with Wang et al. (2018), the thermal sensation scale was set out in two conceptual assessment criteria in order to undertake the statistical analysis accurately. First, Wang et al. (2018) recommend a seven-point discrete thermal sensation scale that can be applied to assess occupants' TSVs [24]. In this case, the TSV was set as an ordinal variable, thus enabling researchers to undertake *Cramér's V* test for the statistical analysis and apply the statistical findings whenever it is appropriate at the time of developing an evidence-based adaptive thermal comfort. In the questionnaire survey, questions related to households' thermal sensation were ranked on a seven-point Likert scale.

A Likert scale could be used as an ordinal measure. In this dataset, to provide consistency for the interpretation of households' TSVs [0 to 6], a coding range representation of a thermal sensation scale band at [−3, +3] was used, which was developed by Fanger in the 1970s and was commonly used by thermal comfort scholars between 1990 and 2000. Second, Ibraheem et al. (2012) recommend a seven-point continuous thermal sensation scale that can be applied to assess occupants' TSVs [105]. With the TSV set as a continuous variable, researchers can undertake Pearson's correlation analysis. This method of design is commonly applied by thermal comfort researchers to identify 'neutral' adaptive thermal comfort thresholds. Using occupants' TSVs as continuous variables is the most well-known method for reporting field survey findings concurrently with in situ measurements or on-site environmental monitoring findings. In this dataset, to provide consistency of the interpretation of households' TSVs, the [−3, +3] coding range represents the [Cold to Hot] thermal sensation scale, which was recommended by Fanger in the 1970s and further developed by de Dear in 1998 and 2001.

As shown in Table 12, weekday cooling consumption patterns were significantly and strongly related to weekend heating consumption patterns on weekends ($\chi^2 = 54.59$, $p < 0.001$, *Cramer's V* = 0.522). Specifically, a longer duration of heating consumption was related to a longer duration of cooling consumption. A similar result was also found between weekend cooling consumption patterns and weekend heating consumption patterns ($\chi^2 = 99.69$, $p < 0.001$, *Cramer's V* = 0.706), between weekday cooling consumption patterns and weekday heating consumption patterns ($\chi^2 = 74.57$, $p < 0.001$, *Cramer's V* = 0.611) and weekend cooling consumption patterns and weekday heating consumption patterns (*Fisher's exact* = 49.70, $p < 0.001$, *Cramer's V* = 0.504). For heating patterns, weekday consumption was moderately associated with weekend consumption ($\chi^2 = 27.89$, $p < 0.001$, *Cramer's V* = 0.373). For cooling patterns, weekday consumption was strongly associated with weekend consumption ($\chi^2 = 119.77$, $p < 0.001$, *Cramer's V* = 0.774). Occupation was only significantly and moderately related to weekly heating consumption (*Fisher's exact* = 12.49, $p = 0.042$, *Cramer's V* = 0.253), but it was not significantly related to any other cooling or heating consumption patterns. Notably, the relationships between household occupation and cooling and heating energy consumption patterns were examined using crosstabulations with chi-square tests or Fisher's Exact tests if over 25% of cells had less than five expected counts, as shown in Table 12.

Table 12. Relationships between household occupation and cooling and heating energy consumption patterns.

Research Questions	Occupation	Weekday Heating-Consumption Patterns	Weekend Heating-Consumption Patterns	Weekday Cooling-Consumption Patterns	Weekend Cooling-Consumption Patterns
Q 1: What is your occupation?	1	0.253 *	0.109	0.098	0.167
	—	0.042	0.896	0.955	0.579
Q 2: When do you turn on heating device(s) on weekdays?	0.253 *	1	0.373 *	0.611 *	0.504 *
	0.042	—	<0.001	<0.001	<0.001
Q 3: When do you turn on heating device(s) on the weekend?	0.109	0.373 *	1	0.522 *	0.706 *
	0.896	<0.001	—	<0.001	<0.001
Q 4: When do you turn on cooling device(s) on weekdays?	0.098	0.611 *	0.522 *	1	0.774 *
	0.955	<0.001	<0.001	—	<0.001
Q 5: When do you turn on cooling device(s) on the weekend?	0.167	0.504 *	0.706 *	0.774 *	—
	0.579	<0.001	<0.001	<0.001	1

Occupation − Weekend heating consumption, *Fisher's exact* = 2.41, $p = 0.896$, *Cramer's V* = 0.109
Occupation − Weekday heating consumption, *Fisher's exact* = 12.49, $p = 0.042$, *Cramer's V* = 0.253
Occupation − Weekend cooling consumption, *Fisher's exact* = 7.63, $p = 0.579$, *Cramer's V* = 0.167
Occupation − Weekday cooling consumption, *Fisher's exact* = 1.76, $p = 0.955$, *Cramer's V* = 0.098
Weekday cooling consumption − Weekend heating consumption, $\chi^2(4) = 54.59$, $p < 0.001$, *Cramer's V* = 0.522
Weekday cooling consumption − Weekday heating consumption, $\chi^2(4) = 74.57$, $p < 0.001$, *Cramer's V* = 0.611
Weekday cooling consumption − Weekend cooling consumption, $\chi^2(6) = 119.77$, $p < 0.001$, *Cramer's V* = 0.774
Weekend cooling consumption − Weekend heating consumption, $\chi^2(6) = 99.69$, $p < 0.001$, *Cramer's V* = 0.706
Weekend cooling consumption − Weekday heating consumption, *Fisher's exact* = 49.70, $p < 0.001$, *Cramer's V* = 0.504
Weekday heating consumption − Weekend heating consumption, $\chi^2(4) = 27.89$, $p < 0.001$, *Cramer's V* = 0.373

Note: * represents the statistically significance of input variable.

In this study, whilst correlations are indicative of association, there is some scope with the data to perform hypothesis testing of significant differences between variables that would add weight to the results to provide a clear representation of the study findings and report research outcomes in accordance with the research questions, which were set out to develop a novel methodological framework for adaptive thermal comfort assessment worldwide.

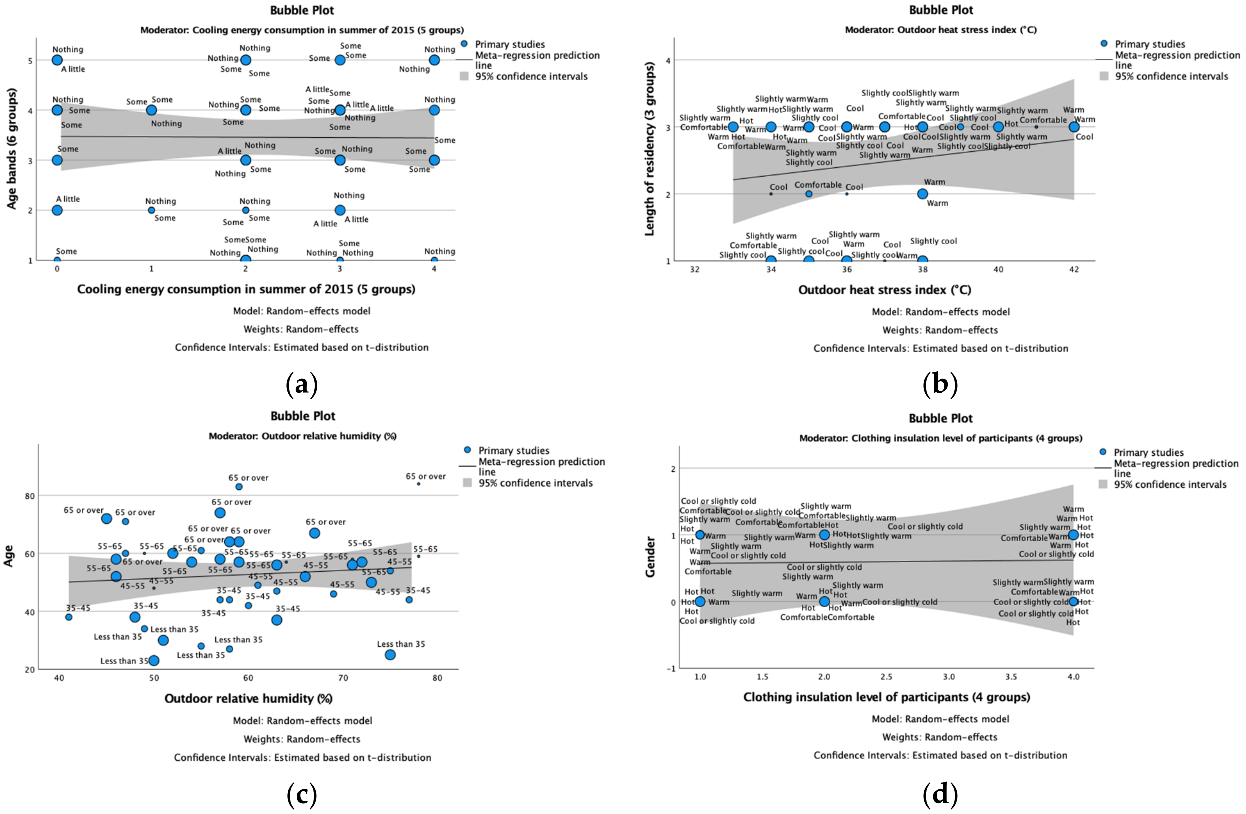
It must be stressed that the contingency tables were produced to understand households' socio-demographic characteristics and their habitual adaptive behaviour for thermal comfort assessments. The relevant *Cramer's V* tests are presented in Table 12. At the same time, the literature review recommended that reliable representativeness of sampling size within the variables identified to develop the concept of statistical convention plays an important role at the time of developing an evidence-based adaptive thermal comfort threshold. It can be seen that household thermal sensation is represented by the terminology of 'thermal feeling' indicators to provide a clear understanding to readers about household thermal sensation. It must be stressed that, in the dataset, the TSV code was set to [0 to 6] which represents the [−3, +3] thermal sensation band according to thermal comfort convention.

4.3. Global Thermal Comfort Assessment

It is evident that most of the field measurements were conducted to avoid discrepancies in the statistical datasets at the time of conducting liner regression analysis [119]. According to Zhao et al. (2021), the Indian Model of Adaptive Comfort (IMAC) approved by the Bureau of Indian Standards in 2016 [27] has been accepted the most commonly used adaptive thermal comfort model in India. However, many researchers have claimed that some assessment models overestimate the neutral adaptive thermal comfort thresholds, while the IMAC model also identifies discrepancies in the thermal comfort assessment criteria [112,120].

It should be noted that searching for a new method of design for the thermal comfort assessment is of the utmost importance [120]. Recent studies have indicated that using machine learning methods could help to reduce bias in the statistical dataset in thermal comfort studies [121,122]. To prove the statistical appropriateness of statistical findings, novel mathematical models have been developed and analysed. One of the main constraints of this mathematical model is the exclusion criteria of local parameters, such as the heat stress index factor, but further studies should be conducted to simplify the Python script language in thermal comfort studies.

It should be noted that the human body is complex, and there is a necessity for the development of evidence-based mathematical equations to perform parametric statistical analyses, such as *Cramer's V* test. Additionally, many different adaptive models are available in the ASHRAE Global Thermal Comfort database, version 2.1. This tool is a fundamental open-access platform providing background information for any type of field measurements related to thermal comfort assessment globally. Földváry Ličina et al. (2018) provided guidance on using occupants' TSV assessments by adopting both the ASHRAE-55-2020 and EN-16798 standards, which aid in simplifying the parametric statistical analyses [123]. Although, an in-depth investigation of the ASHRAE Global Database II highlighted important aspects for the identification of neutral adaptive thermal comfort thresholds by using Fanger's model. The present study found that a 34% optimization could be achievable when considering the PMV model based on the observed thermal satisfaction of occupants in field studies. Figure 11a–d demonstrate the output of a questionnaire survey to gather occupants in the Eastern Mediterranean basin's socio-demographic characteristics while assessing their thermal comfort.



(**a**) (**b**)

(**c**) (**d**)

Figure 11. Meta-analysis. (**a**) Age group factor with the participants' TSVs; (**b**) outdoor heat stress index factor with the participants' TSVs; (**c**) outdoor relative humidity factor with the participants' TSVs; (**d**) clothing insulation level factor with the participants' TSVs. Source: Thermal comfort data were extracted from https://repository.uel.ac.uk/item/8q774 (accessed on 20 January 2023).

Figure 11a demonstrates the subject respondents' energy saving awareness by considering their age group and cooling energy consumption in the summer. It can be seen that there is a very little or no energy saving awareness. In Figure 11b, the study investigates the impact of the outdoor heat stress factor on occupants' thermal comfort by considering length of residency. The data show that households who lived somewhere more than 10 years are more tolerable to warmer indoor air conditions. In Figure 11c, the study explores the correlations between age and outdoor relative humidity. The study found that the age groups between 45–55 and 55–65 are more tolerable to warmer indoor air conditions. In Figure 11d, the study examines the impact of gender and the influence of clothing insulation levels on occupants' thermal comfort level. The findings revealed that most of the subject respondents reported that they felt either slightly warm or hot within the threshold level.

Heidari and Sharples (2002) highlighted those occupants' lifestyle choices play a deterministic role on the TSV's assessment, amongst other factors, such as body mass index, age and their health condition [124]. Assessing subject respondents' habitual adaptive behaviours could provide more accurate TSV assessment criteria rather than solely focusing on field measurements [125]. A relationship between occupants' indoor thermal experience and occupants' thermal comfort perception was found by Luo et al. (2018) [66]. The study recommended that current thermal comfort standards may not comply with the reliable assessment criteria in providing effective guidance on the indoor air quality assessment. To conclude, this review paper recommends that longitudinal field studies should be conducted to include subject respondents' in vivo experiences in the TSV assessment. This could provide more reliability for the ASHRAE Global Thermal Comfort Database's open-access interface in the following years.

4.4. Limitations

This systematic review article comprehensively analysed different adaptive thermal comfort models and the revival applicability of passive cooling design strategies to provide an evidence-based adaptive thermal comfort model. In the meta-analysis, it was found that gender is the most determinant factor for elderly people's TSV assessments. This has been attributed to the identification of their health condition, which has a direct impact on the PMV model. In field measurements, it was found that a wide range of classification criteria caused difficulties in determining thermal acceptability levels.

The present study found that there is wealth of data on thermal comfort assessment, but most of the research outputs have shown contradictory results when considering the local climate conditions. Many scholars expressed that both participants' subjective and personal experiences should be considered when identifying neutral adaptive thermal comfort. This could help to reduce research bias and develop evidence-based deterministic models for TSV assessments. It also was found that there is a misinterpretation of the TSV findings because of language barriers of subject participants when responding to the questionnaire survey. Additionally, many studies have focused on evaluating the energy effectiveness of passive cooling design strategies, in line with considering different climate zones, but none of these studies investigated occupants' thermal comfort within the field measurements.

It was found that using the available open-access datasets required careful attention in determining the appropriateness of each datum for the adaptive thermal comfort assessment. In this review article, the study aimed to analyse four different climate zones, namely Canada, India, Abu Dhabi and the Eastern Mediterranean basin to provide a background for the development of passive cooling design strategies; hence, the identification of adaptive thermal comfort models requires more research based on field measurements. It should be noted that behavioural patterns were found to be the most difficult parameters to be directly linked with the TSV assessment. Studies recommended that households' lifestyles and their habitual adaptive behaviours should be considered with local parameters in the statistical analysis. To sum up, this review article demonstrates the significance of climate differences on adaptive thermal comfort development, and therefore the lack of users' experiences on window opening and closing patterns are among the limitations. Notably, the study also found that there has also been very little research conducted on the implementation of passive heating and cooling systems and its impact on adaptive thermal comfort in Canada, and this aspect should be addressed by future scholars.

5. Conclusions

This article reviewed the energy effectiveness of state-of-the-art passive systems in providing neutral adaptive thermal comfort for elderly people by exploring passive design strategies in four distinct climates, namely Canada, India, Abu Dhabi and the Eastern Mediterranean basin. In addition, available data provided by the ASHRAE Global Thermal Comfort Database II, version 2.1, were analysed in the present study. The development of an effective methodological framework for the on-going development of adaptive thermal comfort theory was accomplished first by analysing the impacts of climate change in passive system design strategies and adopting a meta-analysis method to determine the input variables for the statistical analysis. Occupants' thermal sensation votes (TSVs) were assessed by using *Cramer's V* and *Fisher's Exact* tests, and the results showed some discrepancies between the in situ field experiments and the data recorded in the ASHRAE Global Thermal Comfort Database II.

The meta-analysis findings revealed that age bands were significantly related to health condition, and this relationship was strong ($\chi^2 = 73.739$, $p < 0.001$, *Cramer's V* = 0.496). Younger ages appeared to report better health conditions (good or very good) than older ages. Household occupations were also significantly associated with age, with a moderate-strong relationship ($\chi^2 = 44.810$, $p < 0.001$, *Cramer's V* = 0.399). Of the surveyed flats, 73% had owner-occupiers whose ages ranged between 55 and 65 or were 65 and older; these age bands were in the high-income group, and the energy consumption of these households was higher than the national average, all of which demonstrates an association between age and level-of-income factors, which suggests that household socio-demographic characteristics should be evaluated before any type of adaptive thermal comfort model is developed.

The findings of this study not only add to the newly developed methodological framework for the assessment of available data from the ASHRAE Global Thermal Comfort Database in identifying neutral adaptive thermal comfort thresholds, but they also present a practical and robust adaptable regional methodology. One of the main limitations of this study is to analyse the large sample size gathered from the global thermal comfort database. Although a relatively large sample size was investigated in this study, more field study data could help in understanding the impact of climate change on occupants' thermal comfort. To sum up, these findings offer recommendations for future policies on thermal comfort studies. Passive cooling strategies should be assessed in future optimizations of indoor air quality conditions and the development of benchmarking criteria for each different climate zone. All neutral adaptive thermal comfort thresholds should be revised based on the impact of climate change. Climate resilience policies should not be developed without considering evidence-based data but fully integrated with environmental parameters, occupants' TSVs and the building fabric of buildings. Furthermore, considering global warming conditions and their impact on the built environment, further studies could be performed for more climate zones, since the importance of regional and local analysis was demonstrated.

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Abbreviations

°C	Celsius
p	Significance level
r	Number of elementary effects per parameter
R^2	R-squared (%)
Ta	Air temperature
Tg	Globe temperature of a non-conventional globe
A/C	Air-Conditioning
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
AWD	Ambient warmness degree
BS	British Standards
CBE	Center of the Built Environment
CCHT	Canadian Centre for Housing Technology
CCOR	Climate Change Overheating Resistivity
CIBSE	Chartered Institution of Building Services Engineers

CWEC	Canadian Weather for Energy Calculations
EAHE	Earth Air Heat Exchanger
EDSL	Environmental Design Solutions
EN	European Norm
FLIR	Forward-Looking Infrared Thermometer
GHG	Greenhouse Gasses
HE	Hours of exceedance
HVAC	Heating Ventilation and Air-Conditioning
IES	Integrated Environmental Solution
IMAC-R	India Model for Adaptive Comfort
IOD	Indoor Overheating Degree
IRT	Infrared Radiometer Thermography
KPI	Key Performance Indicator
MCAR	Missing Completely at Random
OEF	Overheating Escalation Factor
PPD	Predicted Percentage of Dissatisfied
PMD	Predicted Mean Vote
RH	Relative Humidity
SD	Standard Deviation
SET	Standard Effective Temperature
SPSS	Statistical Package for the Social Sciences
SCAT	European Survey Research Project Database
TRI	Thermal Resilience Index
TPV	Thermal Preference Vote
TSV	Thermal Sensation Vote
VRF	Variable Refrigerant Flow
WBGT	Wet Bulb Globe Temperature
WWR	Window-to-Wall Ratio

References

1. Földváry, V.; Bekö, G.; Langer, S.; Arrhenius, K.; Petráš, D. Effect of energy renovation on indoor air quality in multifamily residential buildings in Slovakia. *Build. Environ.* **2017**, *122*, 363–372. [CrossRef]
2. Altomonte, S.; Allen, J.; Bluyssen, P.M.; Brager, G.; Heschong, L.; Loder, A.; Schiavon, S.; Veitch, J.A.; Wang, L.; Wargocki, P. Ten questions concerning well-being in the built environment. *Build. Environ.* **2020**, *180*, 106949. [CrossRef]
3. Rawal, R.; Shukla, Y.; Vardhan, V.; Asrani, S.; Schweiker, M.; de Dear, R.; Garg, V.; Mathur, J.; Prakash, S.; Diddi, S.; et al. Adaptive thermal comfort model based on field studies in five climate zones across India. *Build. Environ.* **2022**, *219*, 109187. [CrossRef]
4. Forcada, N.; Gangolells, M.; Casals, M.; Tejedor, B.; Macarulla, M.; Gaspar, K. Field study on thermal comfort in nursing homes in heated environments. *Energy Build.* **2021**, *244*, 111032. [CrossRef]
5. Dabaieh, M.; Serageldin, A.A. Earth air heat exchanger, Trombe wall and green wall for passive heating and cooling in premium passive refugee house in Sweden. *Energy Convers. Manag.* **2020**, *209*, 112555. [CrossRef]
6. Geronazzo, A.; Brager, G.; Manu, S. Making sense of building data: New analysis methods for understanding indoor climate. *Build. Environ.* **2018**, *128*, 260–271. [CrossRef]
7. Haldi, F.; Robinson, D. On the unification of thermal perception and adaptive actions. *Build. Environ.* **2010**, *45*, 2440–2457. [CrossRef]
8. D'Souza, U. Measuring green roof performance, a solution to sustainable urban development in the UAE. *Int. J. Sustain. Dev. Plan.* **2014**, *9*, 376–388. [CrossRef]
9. Kalmár, F. Investigation of thermal perceptions of subjects with diverse thermal histories in warm indoor environment. *Build. Environ.* **2016**, *107*, 254–262. [CrossRef]
10. 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. *Build. Environ.* **2023**, *244*, 110806. [CrossRef]
11. Patiño, E.D.L.; Vakalis, D.; Touchie, M.; Tzekova, E.; Siegel, J. Thermal comfort in multi-unit social housing buildings. *Build. Environ.* **2018**, *144*, 230–237. [CrossRef]
12. 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. *Build. Environ.* **2023**, *229*, 109914. [CrossRef]
13. Qi, D.A.; Ji, L.; Shu, C.; Zhang, G.; Hu, Y.; Ai, Z.; Sengupta, A.; Leuven, K.; Breesch, H.; Chiesa, G.; et al. *Resilient Cooling of Buildings Field Studies Report (Annex 80) Energy in Buildings and Communities Technology Collaboration Programme*; Institute of Building Research & Innovation: Vienna, Austria, 2024.
14. Tartarini, F.; Schiavon, S.; Cheung, T.; Hoyt, T. CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. *SoftwareX* **2020**, *12*, 100563. [CrossRef]

15. Tartarini, F.; Schiavon, S. pythermalcomfort: A Python package for thermal comfort research. *SoftwareX* **2020**, *12*, 100578. [CrossRef]
16. Parkinson, T.; Schweiker, M. New Approaches to Modelling Occupant Comfort. *Buildings* **2022**, *12*, 985. [CrossRef]
17. Ozarisoy, B.; Altan, H. *Handbook of Retrofitting High Density Residential Buildings: Policy Design and Implications on Domestic Energy Use in the South-Eastern Mediterranean Climate of Cyprus*; Springer: Berlin/Heidelberg, Germany, 2023; ISBN 978-3-031-11853-1. Available online: https://link.springer.com/book/9783031118531 (accessed on 20 July 2024).
18. Toe, D.H.C.; Kubota, T. Comparative assessment of vernacular passive cooling techniques for improving indoor thermal comfort of modern terraced houses in hot–humid climate of Malaysia. *Sol. Energy* **2015**, *114*, 229–258. [CrossRef]
19. Nicol, F.; Rijal, H.B.; Imagawa, H.; Thapa, R. The range and shape of thermal comfort and resilience. *Energy Build.* **2020**, *224*, 110277. [CrossRef]
20. Cheung, T.; Schiavon, S.; Parkinson, T.; Li, P.; Brager, G. Analysis of the accuracy on PMV—PPD model using the ASHRAE Global Thermal Comfort Database II. *Build. Environ.* **2019**, *153*, 205–217. [CrossRef]
21. Kent, M.; Parkinson, T.; Kim, J.; Schiavon, S. A data-driven analysis of occupant workspace dissatisfaction. *Build. Environ.* **2021**, *205*, 108270. [CrossRef]
22. Kim, J.; Tartarini, F.; Parkinson, T.; Cooper, P.; de Dear, R. Thermal comfort in a mixed-mode building: Are occupants more adaptive? *Energy Build.* **2019**, *203*, 109436. [CrossRef]
23. Yang, J.; Nam, I.; Sohn, J.-R. The influence of seasonal characteristics in elderly thermal comfort in Korea. *Energy Build.* **2016**, *128*, 583–591. [CrossRef]
24. Wang, Z.; de Dear, R.; Luo, M.; Lin, B.; He, Y.; Ghahramani, A.; Zhu, Y. Individual difference in thermal comfort: A literature review. *Build. Environ.* **2018**, *138*, 181–193. [CrossRef]
25. Yuan, J.; Cong, Y.; Yao, S.; Dai, C.; Li, Y. Research on the thermal comfort of the elderly in rural areas of cold climate, China. *Adv. Build. Energy Res.* **2022**, *16*, 612–642. [CrossRef]
26. Zhang, N.; Cao, B.; Wang, Z.; Zhu, Y.; Lin, B. A comparison of winter indoor thermal environment and thermal comfort between regions in Europe, North America, and Asia. *Build. Environ.* **2017**, *117*, 208–217. [CrossRef]
27. Zhao, Q.; Lian, Z.; Lai, D. Thermal comfort models and their developments: A review. *Energy Built Environ.* **2021**, *2*, 21–33. [CrossRef]
28. Yi, C.Y.; Childs, C.; Peng, C.; Robinson, D. Thermal comfort modelling of older people living in care homes: An evaluation of heat balance, adaptive comfort, and thermographic methods. *Build. Environ.* **2022**, *207*, 108550. [CrossRef]
29. Ko, W.H.; Schiavon, S.; Zhang, H.; Graham, L.T.; Brager, G.; Mauss, I.; Lin, Y.-W. The impact of a view from a window on thermal comfort, emotion, and cognitive performance. *Build. Environ.* **2020**, *175*, 106779. [CrossRef]
30. Halawa, E.; van Hoof, J. The adaptive approach to thermal comfort: A critical overview. *Energy Build.* **2012**, *51*, 101–110. [CrossRef]
31. Ozarisoy, B. Assessing the Domestic Energy Use and Thermal Comfort of Occupants in a Post-War Social Housing Development Estate in Famagusta, Northern Cyprus. Ph.D. Thesis, University of East London, London, UK, 2022. [CrossRef]
32. Li, H.; Xu, G.; Chen, J.; Duan, J. Investigating the Adaptive Thermal Comfort of the Elderly in Rural Mutual Aid Homes in Central Inner Mongolia. *Sustainability* **2022**, *14*, 6802. [CrossRef]
33. Vellei, M.; Herrera, M.; Fosas, D.; Natarajan, S. The influence of relative humidity on adaptive thermal comfort. *Build. Environ.* **2017**, *124*, 171–185. [CrossRef]
34. Dhaka, S.; Mathur, J.; Brager, G.; Honnekeri, A. Assessment of thermal environmental conditions and quantification of thermal adaptation in naturally ventilated buildings in composite climate of India. *Build. Environ.* **2015**, *86*, 17–28. [CrossRef]
35. Song, Y.; Sun, Y.; Luo, S.; Tian, Z.; Hou, J.; Kim, J.; Parkinson, T.; de Dear, R. Residential adaptive comfort in a humid continental climate—Tianjin China. *Energy Build.* **2018**, *170*, 115–121. [CrossRef]
36. Ekici, C. Calibration of Heat Stress Monitor and its Measurement Uncertainty. *Int. J. Thermophys.* **2017**, *38*, 85. [CrossRef]
37. Vega, F.A.O.; Ríos, A.P.M.; Saraz, J.A.O.; Quiroz, L.G.V.; Damasceno, F.A. Assessment of black globe thermometers employing various sensors and alternative materials. *Agric. For. Meteorol.* **2020**, *284*, 107891. [CrossRef]
38. Alfano, F.R.D.; Dell'isola, M.; Ficco, G.; Palella, B.I.; Riccio, G. Small globes and pocket heat stress meters for WBGT and PHS evaluations. A critical analysis under controlled conditions. *Build. Environ.* **2022**, *226*, 109781. [CrossRef]
39. Nicol, F. Temperature and adaptive comfort in heated, cooled and free-running dwellings. *Build. Res. Inf.* **2017**, *45*, 730–744. [CrossRef]
40. Vakalis, D.; Patino, E.D.L.; Opher, T.; Touchie, M.F.; Burrows, K.; MacLean, H.L.; Siegel, J.A. Quantifying thermal comfort and carbon savings from energy-retrofits in social housing. *Energy Build.* **2021**, *241*, 110950. [CrossRef]
41. De Dear, R.; Brager, G.S. The adaptive model of thermal comfort and energy conservation in the built environment. *Int. J. Biometeorol.* **2001**, *45*, 100–108. [CrossRef]
42. Brager, G.; Paliaga, G.; De Dear, R. UC Berkeley Envelope Systems Title Operable Windows, Personal Control and Occupant Comfort. Available online: https://escholarship.org/uc/item/4x57v1pf (accessed on 20 July 2024).
43. De Dear, R.; Brager, G.S. Developing an Adaptive Model of Thermal Comfort and Preference. Ph.D. Thesis, University of California, Los Angeles, CA, USA, 1998.
44. Parkinson, T.; de Dear, R.; Brager, G. Nudging the adaptive thermal comfort model. *Energy Build.* **2020**, *206*, 109559. [CrossRef]
45. De Dear, R.J.; Brager, G.S. Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55. *Energy Build.* **2002**, *34*, 549–561. [CrossRef]

46. Schiavon, S.; Melikov, A.K. Energy saving and improved comfort by increased air movement. *Energy Build.* **2008**, *40*, 1954–1960. [CrossRef]
47. Frontczak, M.; Schiavon, S.; Goins, J.; Arens, E.; Zhang, H.; Wargocki, P. Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design. *Indoor Air* **2012**, *22*, 119–131. [CrossRef]
48. Djamila, H. Indoor thermal comfort predictions: Selected issues and trends. *Renew. Sustain. Energy Rev.* **2017**, *74*, 569–580. [CrossRef]
49. De Dear, R.J.; Akimoto, T.; Arens, E.A.; Brager, G.; Candido, C.; Cheong, K.W.D.; Li, B.; Nishihara, N.; Sekhar, S.C.; Tanabe, S.-I.; et al. Progress in thermal comfort research over the last twenty years. *Indoor Air* **2013**, *23*, 442–461. [CrossRef]
50. Roa, C.D.; Schiavon, S.; Parkinson, T. Targeted occupant surveys: A novel method to effectively relate occupant feedback with environmental conditions. *Build. Environ.* **2020**, *184*, 107129. [CrossRef]
51. He, Y.; Parkinson, T.; Arens, E.; Zhang, H.; Li, N.; Peng, J.; Elson, J.; Maranville, C. Creating alliesthesia in cool environments using personal comfort systems. *Build. Environ.* **2022**, *209*, 108642. [CrossRef]
52. Kim, J.; de Dear, R.; Parkinson, T.; Candido, C. Understanding patterns of adaptive comfort behaviour in the Sydney mixed-mode residential context. *Energy Build.* **2017**, *141*, 274–283. [CrossRef]
53. Li, P.; Froese, T.M.; Brager, G. Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review. *Build. Environ.* **2018**, *133*, 187–202. [CrossRef]
54. Mavrogianni, A.; Wilkinson, P.; Davies, M.; Biddulph, P.; Oikonomou, E. Building characteristics as determinants of propensity to high indoor summer temperatures in London dwellings. *Build. Environ.* **2012**, *55*, 117–130. [CrossRef]
55. Lomas, K.J.; Kane, T. Summertime temperatures and thermal comfort in UK homes. *Build. Res. Inf.* **2013**, *41*, 259–280. [CrossRef]
56. Schweiker, M.; Brasche, S.; Bischof, W.; Hawighorst, M.; Wagner, A. Explaining the individual processes leading to adaptive comfort: Exploring physiological, behavioural and psychological reactions to thermal stimuli. *J. Build. Phys.* **2013**, *36*, 438–463. [CrossRef]
57. Rana, R.; Kusy, B.; Jurdak, R.; Wall, J.; Hu, W. Feasibility analysis of using humidex as an indoor thermal comfort predictor. *Energy Build.* **2013**, *64*, 17–25. [CrossRef]
58. Ko, W.H.; Schiavon, S.; Brager, G.; Levitt, B. Ventilation, thermal and luminous autonomy metrics for an integrated design process. *Build. Environ.* **2018**, *145*, 153–165. [CrossRef]
59. Landsman, J.; Brager, G.; Doctor-Pingel, M. Performance, prediction, optimization, and user behavior of night ventilation. *Energy Build.* **2018**, *166*, 60–72. [CrossRef]
60. Ozarisoy, B.; Altan, H. Regression forecasting of 'neutral' adaptive thermal comfort: A field study investigation in the south-eastern Mediterranean climate of Cyprus. *Build. Environ.* **2021**, *202*, 108013. [CrossRef]
61. Parkinson, T.; Parkinson, A.; de Dear, R. Continuous IEQ monitoring system: Context and development. *Build. Environ.* **2019**, *149*, 15–25. [CrossRef]
62. Rupp, R.F.; Parkinson, T.; Kim, J.; Toftum, J.; de Dear, R. The impact of occupant's thermal sensitivity on adaptive thermal comfort model. *Build. Environ.* **2022**, *207*, 108517. [CrossRef]
63. Sánchez-García, D.; Rubio-Bellido, C.; Pulido-Arcas, J.A.; Guevara-García, F.J.; Canivell, J. Adaptive Comfort Models Applied to Existing Dwellings in Mediterranean Climate Considering Global Warming. *Sustainability* **2018**, *10*, 3507. [CrossRef]
64. Kaynakli, O.; Kilic, M. Investigation of indoor thermal comfort under transient conditions. *Build. Environ.* **2005**, *40*, 165–174. [CrossRef]
65. Taleghani, M.; Tenpierik, M.; Kurvers, S.; van den Dobbelsteen, A. A review into thermal comfort in buildings. *Renew. Sustain. Energy Rev.* **2013**, *26*, 201–215. [CrossRef]
66. Luo, M.; Wang, Z.; Brager, G.; Cao, B.; Zhu, Y. Indoor climate experience, migration, and thermal comfort expectation in buildings. *Build. Environ.* **2018**, *141*, 262–272. [CrossRef]
67. Gaetani, I.; Hoes, P.-J.; Hensen, J.L. Occupant behavior in building energy simulation: Towards a fit-for-purpose modeling strategy. *Energy Build.* **2016**, *121*, 188–204. [CrossRef]
68. Chen, S.; Liu, C.; Lin, G.; Hänninen, O.; Dong, H.; Xiong, K. The role of absolute humidity in respiratory mortality in Guangzhou, a hot and wet city of South China. *Environ. Health Prev. Med.* **2021**, *26*, 109. [CrossRef]
69. Encinas, F.; De Herde, A. Sensitivity analysis in building performance simulation for summer comfort assessment of apartments from the real estate market. *Energy Build.* **2013**, *65*, 55–65. [CrossRef]
70. D'Souza, U. The thermal performance of green roofs in a hot, humid microclimate. *Trans. Ecol. Environ.* **2013**, *173*, 1743–3541. [CrossRef]
71. Singh, S.; Chani, P.S. Thermal comfort analysis of Indian subjects in multi-storeyed apartments: An adaptive approach in composite climate. *Indoor Built Environ.* **2018**, *27*, 1216–1246. [CrossRef]
72. Indraganti, M.; Ooka, R.; Rijal, H.B.; Brager, G.S. Adaptive model of thermal comfort for offices in hot and humid climates of India. *Build. Environ.* **2014**, *74*, 39–53. [CrossRef]
73. Hawighorst, M.; Schweiker, M.; Wagner, A. Thermo-specific self-efficacy (specSE) in relation to perceived comfort and control. *Build. Environ.* **2016**, *102*, 193–206. [CrossRef]
74. Huang, H.; Nazi, W.I.B.W.M.; Yu, Y.; Wang, Y. Energy performance of a high-rise residential building retrofitted to passive building standard—A case study. *Appl. Therm. Eng.* **2020**, *181*, 115902. [CrossRef]

75. Romero, R.A.; Bojórquez, G.; Corral, M.; Gallegos, R. Energy and the occupant's thermal perception of low-income dwellings in hot-dry climate: Mexicali, México. *Renew. Energy* **2013**, *49*, 267–270. [CrossRef]
76. Porritt, S.; Shao, L.; Cropper, P.; Goodier, C. Adapting dwellings for heat waves. *Sustain. Cities Soc.* **2011**, *1*, 81–90. [CrossRef]
77. Saber, H.H.; Hajiah, A.E.; Maref, W. Impact of reflective roofs on the overall energy savings of whole buildings. *E3S Web Conf.* **2020**, *172*, 25008. [CrossRef]
78. Schweiker, M.; Wagner, A. A framework for an adaptive thermal heat balance model (ATHB). *Build. Environ.* **2015**, *94*, 252–262. [CrossRef]
79. De Vecchi, R.; Cândido, C.; Lamberts, R. Thermal history and its influence on occupants' thermal acceptability and cooling preferences in warm-humid climates: A new desire for comfort. In Proceedings of the 7th Windsor Conference: The Changing Context of Comfort in an Unpredictable World, Windsor, UK, 12–15 April 2012; Cumberland Lodge: Windsor, UK, 2012.
80. Mishra, A.K.; Ramgopal, M. An adaptive thermal comfort model for the tropical climatic regions of India (Koppen climate type A). *Build. Environ.* **2015**, *85*, 134–143. [CrossRef]
81. Tuck, N.W.; Zaki, S.A.; Hagishima, A.; Rijal, H.B.; Zakaria, M.A.; Yakub, F. Effectiveness of free running passive cooling strategies for indoor thermal environments: Example from a two-storey corner terrace house in Malaysia. *Build. Environ.* **2019**, *160*, 106214. [CrossRef]
82. Toe, D.H.C.; Kubota, T. Development of an adaptive thermal comfort equation for naturally ventilated buildings in hot–humid climates using ASHRAE RP-884 database. *Front. Arch. Res.* **2013**, *2*, 278–291. [CrossRef]
83. De Dear, R.; Kim, J.; Parkinson, T. Residential adaptive comfort in a humid subtropical climate—Sydney Australia. *Energy Build.* **2018**, *158*, 1296–1305. [CrossRef]
84. Pastore, L.; Andersen, M. Building energy certification versus user satisfaction with the indoor environment: Findings from a multi-site post-occupancy evaluation (POE) in Switzerland. *Build. Environ.* **2019**, *150*, 60–74. [CrossRef]
85. Gustin, M.; McLeod, R.S.; Lomas, K.J. Can semi-parametric additive models outperform linear models, when forecasting indoor temperatures in free-running buildings? *Energy Build.* **2019**, *193*, 250–266. [CrossRef]
86. Yao, R.; Li, B.; Liu, J. A theoretical adaptive model of thermal comfort—Adaptive Predicted Mean Vote (aPMV). *Build. Environ.* **2009**, *44*, 2089–2096. [CrossRef]
87. Olesen, B.W.; Brager, G.S. UC Berkeley Indoor Environmental Quality (IEQ). Ph.D. Thesis, University of California, Berkeley, CA, USA, 2004. Available online: https://escholarship.org/uc/item/2m34683k (accessed on 20 July 2024).
88. Givoni, B. *Passive and Low Energy Cooling of Buildings*; John Wiley & Sons: Hoboken, NJ, USA, 1994; p. 33.
89. Mirahmadi, F.; Altan, H. A solution for future designs using techniques from vernacular architecture in southern Iran. *Sustain. Build.* **2018**, *3*, 1. [CrossRef]
90. Case, C. Performance of Passive Design Architecture Application in Hot and Dry Performance of Passive Design Architecture Application in Hot and Dry Climate. Case study: Cairo, Egypt. In Proceedings of the PLEA 2017 Edinburgh—Design to Thrive, Edinburgh, UK, 2–5 July 2017.
91. Sahebzadeh, S.; Heidari, A.; Kamelnia, H.; Baghbani, A. Sustainability Features of Iran's Vernacular Architecture: A Comparative Study between the Architecture of Hot–Arid and Hot–Arid–Windy Regions. *Sustainability* **2017**, *9*, 749. [CrossRef]
92. Normah, M.G.; Lau, K.Y.; Yusoff, S.M. Thermal analysis of Malaysian double storey housing—Low/medium cost unit. *AIP Conf. Proc.* **2012**, *1440*, 513–520. [CrossRef]
93. Santamouris, M.; Pavlou, K.; Synnefa, A.; Niachou, K.; Kolokotsa, D. Recent progress on passive cooling techniques. Advanced technological developments to improve survivability levels in low-income households. *Energy Build.* **2007**, *39*, 859–866. [CrossRef]
94. Panchabikesan, K.; Vellaisamy, K.; Ramalingam, V. Passive cooling potential in buildings under various climatic conditions in India. *Renew. Sustain. Energy Rev.* **2017**, *78*, 1236–1252. [CrossRef]
95. Gilvaei, Z.M.; Poshtiri, A.H.; Akbarpoor, A.M. A novel passive system for providing natural ventilation and passive cooling: Evaluating thermal comfort and building energy. *Renew. Energy* **2022**, *198*, 463–483. [CrossRef]
96. Imessad, K.; Derradji, L.; Messaoudene, N.; Mokhtari, F.; Chenak, A.; Kharchi, R. Impact of passive cooling techniques on energy demand for residential buildings in a Mediterranean climate. *Renew. Energy* **2014**, *71*, 589–597. [CrossRef]
97. Vitale, V.; Salerno, G. A numerical prediction of the passive cooling effects on thermal comfort for a historical building in Rome. *Energy Build.* **2017**, *157*, 1–10. [CrossRef]
98. Bravo, G.; González, E. Thermal comfort in naturally ventilated spaces and under indirect evaporative passive cooling conditions in hot–humid climate. *Energy Build.* **2013**, *63*, 79–86. [CrossRef]
99. Calautit, J.K.; Hughes, B.R.; Nasir, D.S. Climatic analysis of a passive cooling technology for the built environment in hot countries. *Appl. Energy* **2017**, *186*, 321–335. [CrossRef]
100. Al Tawayha, F.; Braganca, L.; Mateus, R. Contribution of the Vernacular Architecture to the Sustainability: A Comparative Study between the Contemporary Areas and the Old Quarter of a Mediterranean City. *Sustainability* **2019**, *11*, 896. [CrossRef]
101. Bencheikh, D.; Bederina, M. Assessing the duality of thermal performance and energy efficiency of residential buildings in hot arid climate of Laghouat, Algeria. *Int. J. Energy Environ. Eng.* **2019**, *11*, 143–162. [CrossRef]
102. Schiano-Phan, R. The Development of Passive Downdraught Evaporative Cooling Systems Using Porous Ceramic Evaporators and Their Application in Residential Buildings. Ph.D. Thesis, British Library, London, UK, 2004.
103. Schianao-Phan, R. Post-occupancy evaluation of non-domestic buildings using passive downdraught evaporative cooling in south-west USA. *Archit. Sci. Rev.* **2012**, *55*, 1–21. [CrossRef]

104. Schiano-Phan, R. The Use of Porous Ceramic for Passive Evaporative Cooling in Buildings. 2009. Available online: http://www.phdc.eu/uploads/media/PHDC_Cooling_with_porous_ceramic_01-06-09.pdf (accessed on 20 July 2024).
105. Ibraheem, O.; Ford, B. The feasibility of passive down-draught evaporative cooling for high-rise office buildings in Cairo. *Archit. Sci. Rev.* **2012**, *55*, 315–327. [CrossRef]
106. Schiano-Phan, R. Environmental retrofit: Building integrated passive cooling in housing. *Arch. Res. Q.* **2010**, *14*, 139–151. [CrossRef]
107. Golzari, N. Re-Reading Affordable Technologies: The Role of Techno Cultural Elements and Invisible Technologies in Sustainable Design for the Middle East. Ph.D. Thesis, University of Westminster, London, UK, 2014.
108. Jomehzadeh, F.; Nejat, P.; Calautit, J.K.; Yusof, M.B.M.; Zaki, S.A.; Hughes, B.R.; Yazid, M.N.A.W.M. A review on windcatcher for passive cooling and natural ventilation in buildings, Part 1: Indoor air quality and thermal comfort assessment. *Renew. Sustain. Energy Rev.* **2017**, *70*, 736–756. [CrossRef]
109. Fernandes, J.; Mateus, R.; Gervásio, H.; Silva, S.M.; Bragança, L. Passive strategies used in Southern Portugal vernacular rammed earth buildings and their influence in thermal performance. *Renew. Energy* **2019**, *142*, 345–363. [CrossRef]
110. Teitelbaum, E.; Jayathissa, P.; Miller, C.; Meggers, F. Design with Comfort: Expanding the psychrometric chart with radiation and convection dimensions. *Energy Build.* **2020**, *209*, 109591. [CrossRef]
111. Ryu, J.; Kim, J.; Hong, W.; de Dear, R. Quantifying householder tolerance of thermal discomfort before turning on air-conditioner. *Energy Build.* **2020**, *211*, 109797. [CrossRef]
112. Sakiliba, S.K.; Wu, J.; Bolton, N.; Sooriyabandara, M. The Energy Performance and Techno-Economic Analysis of Zero Energy Bill Homes. *Energy Build.* **2020**, *228*, 110426. [CrossRef]
113. Jeong, B.; Jeong, J.-W.; Park, J. Occupant behavior regarding the manual control of windows in residential buildings. *Energy Build.* **2016**, *127*, 206–216. [CrossRef]
114. Santangelo, A.; Yan, D.; Feng, X.; Tondelli, S. Renovation strategies for the Italian public housing stock: Applying building energy simulation and occupant behaviour modelling to support decision-making process. *Energy Build.* **2018**, *167*, 269–280. [CrossRef]
115. Day, J.K.; Gunderson, D.E. Understanding high performance buildings: The link between occupant knowledge of passive design systems, corresponding behaviors, occupant comfort and environmental satisfaction. *Build. Environ.* **2015**, *84*, 114–124. [CrossRef]
116. Nicol, F. Adaptive thermal comfort standards in the hot–humid tropics. *Energy Build.* **2004**, *36*, 628–637. [CrossRef]
117. Cândido, C.; de Dear, R.; Lamberts, R.; Bittencourt, L. Air movement acceptability limits and thermal comfort in Brazil's hot humid climate zone. *Build. Environ.* **2010**, *45*, 222–229. [CrossRef]
118. Bonte, M.; Thellier, F.; Lartigue, B. Impact of occupant's actions on energy building performance and thermal sensation. *Energy Build.* **2014**, *76*, 219–227. [CrossRef]
119. Oropeza-Perez, I.; Petzold-Rodriguez, A.H.; Bonilla-Lopez, C. Adaptive thermal comfort in the main Mexican climat.e conditions with and without passive cooling. *Energy Build.* **2017**, *145*, 251–258. [CrossRef]
120. Dong, X.; Soebarto, V.; Griffith, M. Achieving thermal comfort in naturally ventilated rammed earth houses. *Build. Environ.* **2014**, *82*, 588–598. [CrossRef]
121. De Dear, R.; Xiong, J.; Kim, J.; Cao, B. A review of adaptive thermal comfort research since 1998. *Energy Build.* **2020**, *214*, 109893. [CrossRef]
122. Parker, J. The Leeds urban heat island and its implications for energy use and thermal comfort. *Energy Build.* **2020**, *235*, 110636. [CrossRef]
123. Ličina, V.F.; Cheung, T.; Zhang, H.; de Dear, R.; Parkinson, T.; Arens, E.; Chun, C.; Schiavon, S.; Luo, M.; Brager, G.; et al. Development of the ASHRAE Global Thermal Comfort Database II. *Build. Environ.* **2018**, *142*, 502–512. [CrossRef]
124. Heidari, S.; Sharples, S. A comparative analysis of short-term and long-term thermal comfort surveys in Iran. *Energy Build.* **2002**, *34*, 607–614. [CrossRef]
125. Bouden, C.; Ghrab, N. An adaptive thermal comfort model for the Tunisian context: A field study results. *Energy Build.* **2005**, *37*, 952–963. [CrossRef]