Geographical Variations in Thermal Comfort Preferences Based on ASHRAE Database II

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Abstract – Thermal comfort is a fundamental aspect of daily life, influencing our well-being in various environments. Understanding thermal comfort preferences across geographical locations is crucial for designing buildings and urban spaces that promote occupant satisfaction. This research investigates the factors contributing to thermal comfort, including air temperature, humidity, and air velocity. It further explores how individuals' origins and cultural backgrounds shape their perception of thermal comfort. The study examines the influence of geographic location on human thermal comfort within specific environments. We hypothesize that people in different regions develop varying thermal preferences due to climatic differences and acclimatization. This research utilizes a seven-point thermal sensation scale to assess comfort and analyzes acceptable ranges of ambient air temperature, relative humidity, and air velocity for diverse climate zones. We expect to find variations in thermal sensation patterns across geographical locations, along with differences in the preferred temperature and humidity ranges for occupants from various climates. The study will leverage the ASHRAE Database II to provide a summary of acceptable thermal conditions for different climate zones. This research aims to provide valuable insights into the factors affecting thermal comfort, ultimately contributing to the design of comfortable and healthy indoor environments for people globally.

Keywords: Thermal comfort, Thermal adaptation, Comfort zones, ASHRAE Database II, Composite climate, Group difference.

I. Introduction

Thermal comfort is an essential aspect of our daily lives, and it is necessary to ensure that we are comfortable in our surroundings. This is particularly important in areas where people spend long periods, such as homes, schools, and workplaces. In such areas, the temperature, humidity, and air quality can significantly affect the health, productivity, and comfort of people. Therefore, it is essential to understand the factors that contribute to thermal comfort, such as air temperature, humidity, air velocity, and radiant temperature, as well as individuals' origins and cultural backgrounds to ensure that the thermal environment is comfortable and safe for people(Parsons, n.d.).

Thermal comfort is a subjective sensation, but it is related to the physiological condition of thermal balance between the body and the surrounding environment. A narrow definition may define thermal comfort as the absence of heat or cold discomfort. However, a wider definition also includes specific factors related to the environment, personal characteristics, and other contextual factors that contribute to the thermal comfort of individuals(ANSI/ASHRAE Standard 55-2017, 2020).

Climate refers to the long-term weather pattern in a particular area, while the weather can change from hour to hour, day-to-day, month-to-month, or even year-to-year. Different parts of the world have different climates, and some parts of the world are hot and rainy nearly every day, while others are dry because moisture is rapidly evaporating from the air and there is very little precipitation (The Köppen Climate Classification, n.d.).

Geographic location can have a significant impact on how individuals perceive thermal comfort. Various factors, such as climate, altitude, and weather patterns, can affect how people feel in a particular environment (Liu et al., 2022; Yamtraipat et al., 2005). The human body can adapt to different thermal environments, but there are limits to this adaptation, which vary depending on the individual and the conditions they are exposed to (Lancaster & Humphreys, 2020). For example, people living in a hot and humid climate may have a higher heat tolerance than those in a cold climate. Similarly, people living at high altitudes may have a lower tolerance for cold temperatures due to the thin air and lack of humidity(Yu et al., 2013). A region's daily and seasonal weather patterns can also impact thermal comfort perception, as people tend to acclimate to their local climate over time.

(Song et al., 2017) has shown that people in different regions may have different thermal comfort preferences due to differences in climate and acclimatization. For example, a study in China found that people in the northern part of the country preferred a warmer indoor temperature than those in the south due to differences in climate and acclimatization. Similarly, research has shown that people in hot and humid climates may have different thermal comfort preferences than those in arid or temperate climates due to differences in the types of clothing people wear, activity levels, and metabolic rates (Binarti et al., 2020).

Another factor influencing thermal comfort perception is the building design and construction techniques used in a particular region. Different materials and building styles can affect how heat is distributed within a space, impacting how comfortable people feel in that environment (Alghamdi et al., 2022). Additionally, cultural norms and personal preferences can also affect how individuals perceive thermal comfort (Elnaklah et al., 2021).

Studying thermal comfort preferences in different geographical locations can help design buildings and urban spaces. By understanding how the thermal environment affects people in different regions, architects and urban planners can design buildings and urban spaces that are comfortable, safe, and energy efficient. This can significantly reduce energy consumption, as buildings can be designed to operate efficiently in their respective climatic conditions (Parsons, n.d.).

People in different regions have unique thermal preferences, influenced by weather patterns, climate, cultural norms, and personal factors such as metabolic rate and clothing level (Indraganti & Humphreys, 2021). The ability to control the thermal environment of indoor and outdoor spaces is essential in ensuring the comfort and well-being of individuals and designing spaces that consider these factors is important for creating comfortable and sustainable built environments (Kumar & Sharma, 2020).

This research paper investigates whether people's thermal comfort preferences vary across geographical locations. To achieve this, the paper will explore relevant factors in ASHRAE global thermal comfort database II, then introduce the Koppen Climate Classification System. The paper will present the research results, followed by a discussion of these results and any limitations encountered in geographical variations in the thermal sensation and acceptability section. Finally, the paper will conclude by summarizing the findings and their implications.

Table 1. Variable descriptions in ASHRAE Database II

Category	Variables	Unit	Range and Description	Number of samples	Number of missing samples
Comfort indices	Thermal sensation vote (TSV)		ASHRAE thermal sensation vote, 7-points, from −3 (cold) to +3 (hot)	104,454	3,129
	Thermal sensation acceptability		1-acceptable, 0-unacceptable	62,444	45,139
Indoor environment	T_{air}	ºC	0.5–65	99,911	7,672
	RH	%	0–100%	97,762	9,821
	V_{air}	m/s	0–56	89,892	17,691
Outdoor environment	Climate		Koppen climate classification	107,583	0
	Country		Country wher		

II. ASHRAE global thermal comfort database II

The ASHRAE Global Thermal Comfort Database II is an open-source research database that was launched in 2014 to advance the art and science of HVAC. The project was developed by the Center for the Built Environment at the University of California, Berkeley, and the Indoor Environmental Quality Laboratory at the University of Sydney (Földváry Ličina et al., 2018). The database contains approximately 107,584 complete sets of objective indoor climatic observations and subjective evaluations by building occupants exposed to them.

The ASHRAE Global Thermal Comfort Database II is a valuable resource for researchers and designers interested in exploring the relationship between building occupants and indoor environmental conditions. The database provides a large collection of objective indoor climatic observations with accompanying right-here-right-now subjective evaluations that can be used to develop models and improve the health, safety, and comfort of building occupants worldwide (ASHRAE Global Database).

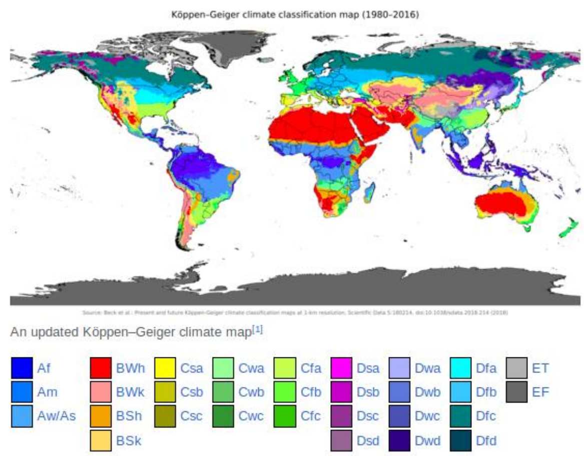

Fig 1. Koppen Climate Classification map (1980-2016)

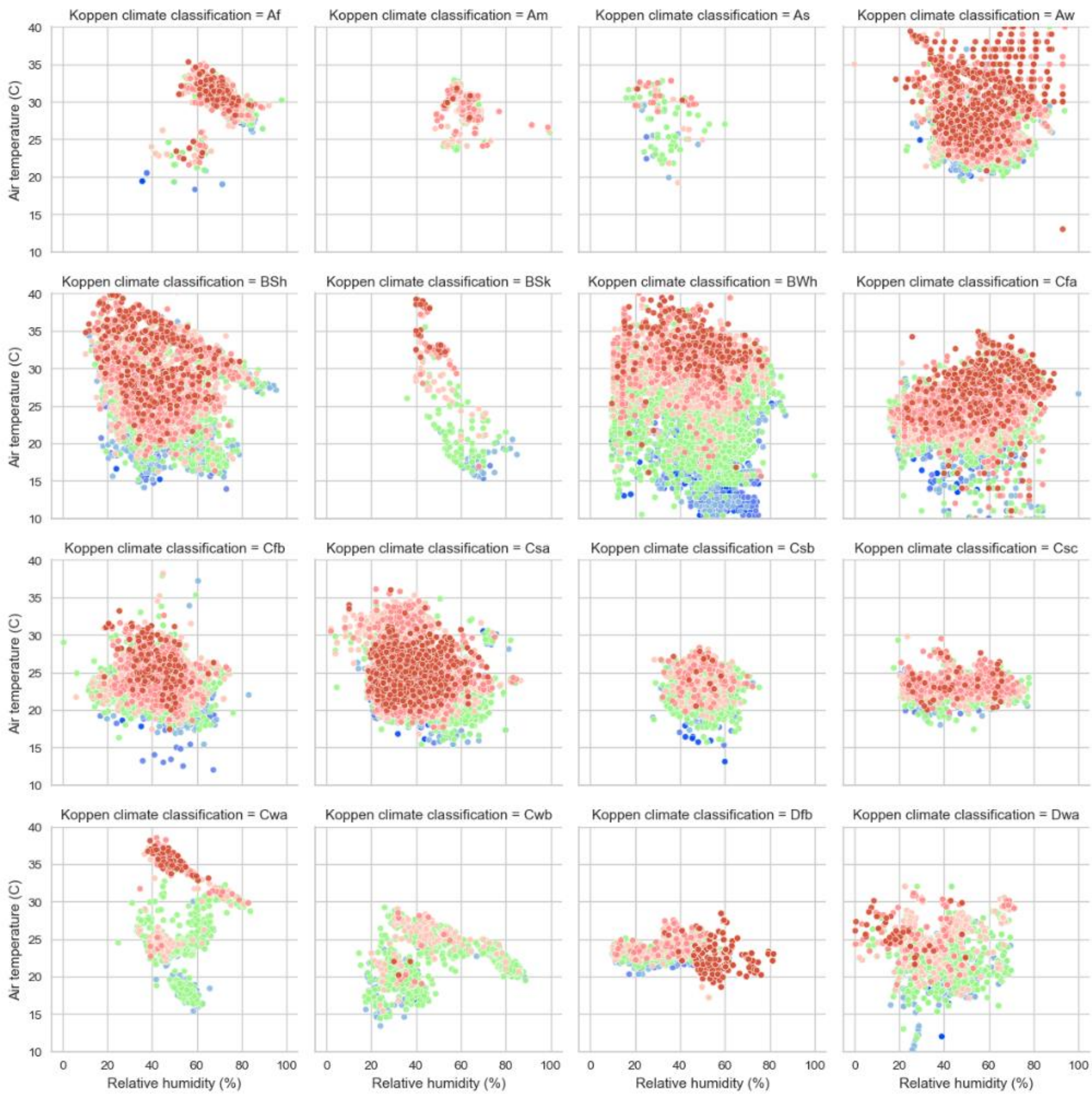

Figure 2. Relationships between Air temperature, relative humidity, and thermal sensation

I. The Koppen Climate Classification System

The Koppen Climate Classification System is a widely used method of categorizing climate zones across the world, which was first developed by the German meteorologist and climatologist Wladimir Koppen in the late 19th century (Kottek et al., 2006; *The Koppen Climate Classification*, n.d.). The classification system divides the Earth's climate into five main groups: A (tropical), B (dry), C (temperate), D (continental), and E (polar). The main factors that determine the climate category are temperature and precipitation. The Koppen Climate Classification System has undergone several modifications since its initial development, but the five major categories remain the same (Beck et al., 2018).

The five major categories are subdivided by seasonal precipitation and heat, creating more specific subcategories. For example, the tropical climate category (A) is divided into two subcategories: Af and Am, as shown in Figure 1. Af is characterized by rainforest conditions, with high temperatures and heavy precipitation throughout the year, while Am is a tropical monsoon climate, with rainfall concentrated in a distinct wet season and temperatures that change little throughout the year (Kappen Climate Classification System, n.d.).

One of the factors that is considered in the Koppen Climate Classification System is temperature, which has a direct impact on thermal comfort. The Koppen system uses temperature and other factors such as precipitation and wind to determine the climate type, which affects the thermal comfort of those living in that area.

II. Geographical Variations in Thermal sensation and acceptability

Geographical variations have been shown to play a significant role in thermal comfort preferences. While there are a few field studies have evaluated the effect of climate or cultural background on thermal comfort. These studies are limited by small sample sizes (Wang et al., 2020).

To address this limitation, the ASHRAE Global Thermal Comfort Database II provides a large and unified dataset that compares the thermal demands of subjects from different countries and climate zones. The dataset includes subjects from 28 countries, with the top three datasets collected from the United Kingdom, the United States, and India, followed by China, Australia, and Brazil. However, only a marginal proportion of the data are from Africa.

1) Results

The thermal sensation is typically assessed to determine whether a particular thermal condition is comfortable for individuals. A seven-point thermal sensation scale has been widely used, suitable for describing a one-dimensional relationship between the physical parameters of indoor environments and subjective thermal sensation (Nakano et al., n.d.; Yang & Zhang, 2008). It is influenced by several factors, including air temperature, humidity, and air velocity, among others. In different climate zones, the relative importance of these factors varies, leading to differences in thermal sensation and comfort preferences (Lin, 2009).

Variations in thermal sensation patterns can be observed in different geographical locations, as evident from the relationship between air temperature and relative humidity depicted in Figure 2. (Kaggle, n.d.). Additionally, thermal acceptability is influenced by multiple variables, such as air temperature, relative humidity, and air movement, as demonstrated in Figures 3, 4, and 5. These variables play crucial roles in determining comfort levels. Using the Koppen classification system and the ASHRAE database II. The following findings summarize the acceptable ambient air temperature, relative humidity, and air velocity for various climate zones.

The Tropical Rainforest climate is characterized by persistent high temperatures, humidity, and abundant rainfall. According to the study, 82.86% of participants reported feeling thermally comfortable, while 17.14% felt uncomfortable. The comfortable temperature range in this climate is between 29 to 31°C, and the comfortable humidity range is from 65 to 75%.

Participants in the Tropical Wet Savannah climate reported a high level of thermal comfort, with 90.5% feeling comfortable within the air temperature range of 20 to 25°C. Although there were a relatively large number of outliers for air velocity, the general airspeed was below 0.2 m/s. The comfortable humidity range is from 50 to 60%.

In the Hot Semi-Arid climate, 75% of participants felt thermally comfortable, while 25% felt uncomfortable. The majority of participants reported thermal comfort at air temperatures ranging from 22 to 29°C. The airspeed was below

0.2 m/s, and the comfortable humidity range was from 40 to 60%.

In the Humid Subtropical climate, 85.2% of participants felt thermally comfortable, while 14.8% felt uncomfortable. The comfortable temperature range is from 20 to 27°C, with airspeed below 0.3 m/s, except for a few outliers. The comfortable humidity range is from 50 to 70%.

A few participants were involved in the Temperate Oceanic climate study, with 67.9% feeling thermally comfortable and 32.1% feeling uncomfortable.

The Hot Summer Mediterranean climate had a thermal comfort level of 72.6%, with 27.4% of participants feeling uncomfortable. The comfortable temperature range for this climate is between 23 to 26°C. Despite a relatively large number of outliers for air velocity, the general airspeed was below 0.1 m/s. The comfortable humidity range is from 30 to 45%.

In the Warm-Summer Mediterranean climate, 85.3% of participants reported thermal comfort, with 14.7% feeling uncomfortable. The typical temperature range was 23 to 25°C, and air velocity in air-conditioned rooms ranged from 0 to 0.2 m/s.

In the Cool-Summer Mediterranean climate, 44.5% of participants felt thermally uncomfortable with air temperatures fluctuating between 22 to 26°C. The comfortable humidity range is usually between 35 and 40%, with a few outliers.

The Monsoon-Influenced Humid Subtropical climate had a thermal comfort level of 75.8%, with 10.1% of participants feeling uncomfortable. The comfortable temperature range is between 23 to 26°C, with air speeds mostly below 0.2 m/s, except for a few outliers. The comfortable humidity range is from 50 to 60%.

The Subtropical Highland climate recorded a high thermal comfort level of 89.1%, with a temperature range from 20 to 25°C.

In the Warm-Summer Humid Continental climate, the comfortable air temperature range is typically between 22 and 24°C, while the comfortable humidity range is between 25 and 45%. A majority of participants (90.9%) felt thermally comfortable, while 9.1% felt uncomfortable.

The Monsoon-Influenced Hot-Summer Humid Continental climate typically has a thermal comfort level of 75.3%, with 24.7% of participants feeling uncomfortable. The comfortable air temperature range is from 19 to 26°C, while the comfortable humidity range is between 30 and 45%. Most air speeds were below 0.1 m/s, with a few outliers.

Table 2 compares thermal acceptability ranges in different climatic zones and countries according to the Köppen climatic classification. The table is divided into several columns representing different Köppen climate classifications. Each row provides information on the range of temperatures considered thermally acceptable in various climatic zones and countries. The temperature ranges are given in degrees Celsius and cover zones from 17°C to 32°C. The table also includes additional information on the climatic characteristics of each listed country.

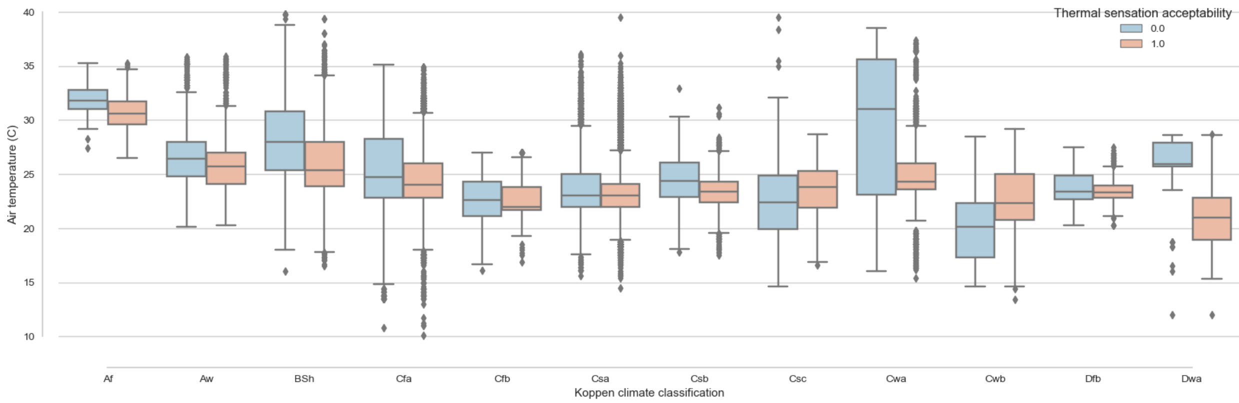

Figure 3. boxplot of Thermal Sensation Acceptability with air temperature Koppen Climate Classification.

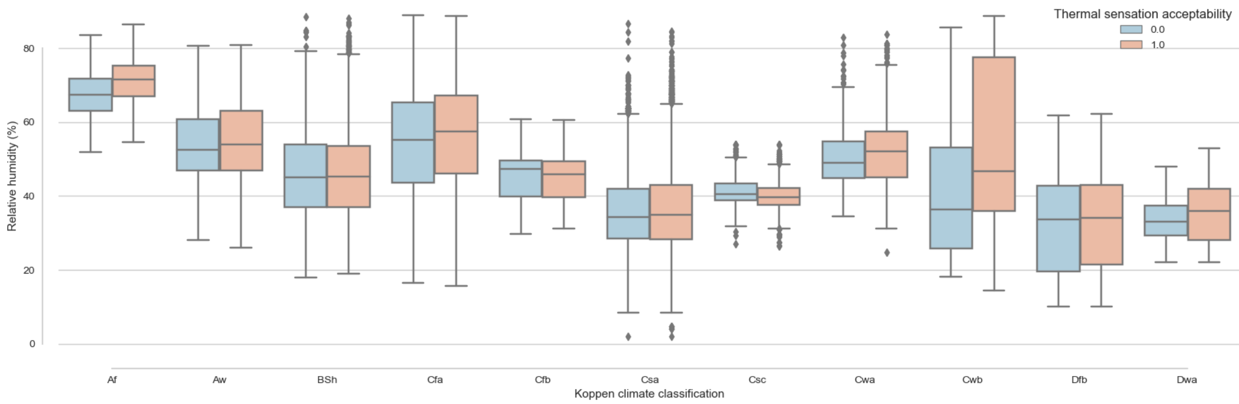

Figure 4. boxplot of Thermal Sensation Acceptability with relative humidity, and Koppen Climate Classification.

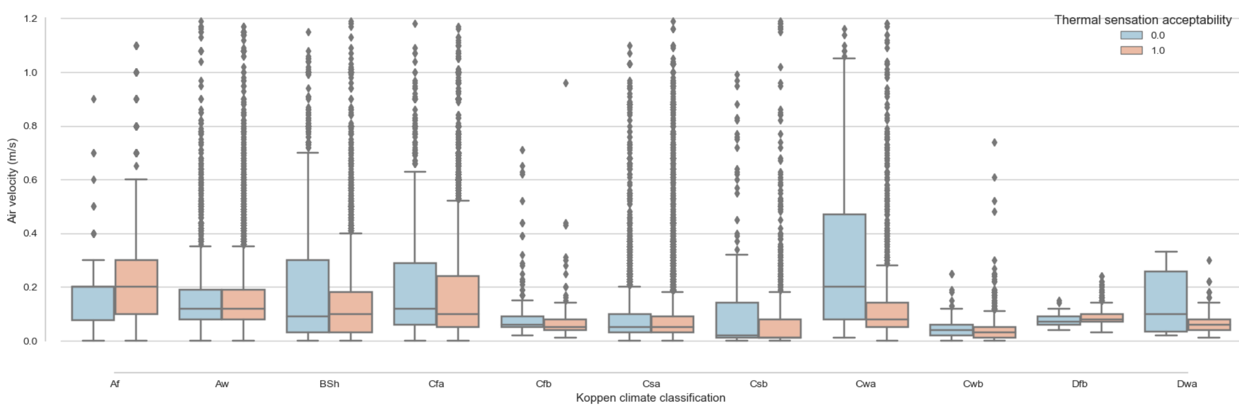

Figure 5. boxplot of Thermal Sensation Acceptability with air velocity and Koppen Climate Classification.

2) Discussion

a) Findings and contributions

This study investigated the influence of climatic factors on thermal comfort preferences. We analyzed data from participants residing in various climate zones, focusing on air temperature, humidity, and air velocity. The findings reveal that these physical parameters significantly impact thermal comfort across different regions.

Interestingly, thermal comfort preferences can also exhibit variations within a single country, as demonstrated by studies in China, India, and the UK (Erlandson et al., 2003; Gaffoor et al., 2022; Lai et al., 2021; R. de Dear, n.d.). For example, in China, individuals from the northern regions (continental climate) prefer warmer indoor temperatures compared to those in the south (subtropical climate) due to differing outdoor temperatures. Similarly, residents of dry regions (e.g., northwest China) favor lower indoor temperatures and higher humidity levels compared to those in humid regions (e.g., southern China).

India presents a compelling case with its five distinct climate types (tropical monsoon, tropical wet and dry, humid subtropical, semi-arid, and arid). Each of these climatic zones possesses unique characteristics that influence thermal comfort preferences.

Table 2. Thermal acceptability temperature ranges in different climatic zones and countries.

KCC	Climate	Country	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Af	Tropical rainforest	Malaysia													■	■	■	
Aw	Tropical wet savanna	Australia						■	■	■								
		India								■	■	■	■					
BSh	Hot semi-arid	Australia						■	■	■								
		India								■	■	■	■	■				
Cfa	Humid subtropical	USA						■	■	■								
		Australia						■	■	■	■							
		Brazil							■	■	■							
		China						■	■	■	■	■	■	■	■			
		Japan								■	■	■	■	■				
Cfb	Temperate oceanic	Denmark							■	■	■							
		Slovakia						■	■	■								
		UK						■	■	■								
Csa	Hot-summer Mediterranean	UK					■	■	■	■								
Csb	Warm-summer Mediterranean	USA						■	■	■	■							
Csc	Cool-summer Mediterranean	USA					■	■	■	■	■							
Cwa	Monsoon-influenced humid subtropical	India							■	■	■	■						
Cwb	Subtropical highland	India				■	■	■	■	■	■							
Dfb	Warm-summer humid continental	Canada					■	■	■	■								
Dwa	Monsoon-influenced hot-summer humid continental	China		■	■	■	■	■	■	■								

The combination of both relative humidity and air temperature significantly impacts thermal sensation. In humid regions, high air temperatures coupled with high humidity levels can create an oppressively hot environment, leading to discomfort and reduced productivity. Conversely, low air temperatures and low humidity levels can make the environment feel uncomfortably dry. In these regions, the use of humidifiers and air conditioners can help enhance indoor comfort levels.

The findings of this study have important implications for architects, engineers, and building designers involved in creating indoor environments that promote thermal comfort. By taking into account the specific climatic conditions of a location and considering variables such as air temperature, humidity, and air velocity, indoor spaces can be designed to optimize thermal comfort and enhance occupant's well-being.

These results highlighted the importance of location-specific approach to building design and climate control. Rather than applying a one-size-fits-all solution, designers should tailor their approaches to the unique climatic challenges of each region. This may involve implementing adaptive comfort models that account for local climate patterns and cultural expectations, integrating passive design strategies that work in harmony with the local environment to maintain comfort, and utilizing smart building technologies that can dynamically adjust indoor conditions based on real-time environmental data and occupant feedback.

By incorporating these findings into the design process, it becomes possible to create more comfortable, energy-efficient, and sustainable indoor environments that are specifically suited to their geographical and cultural contexts. This approach not only improves occupant comfort and productivity but also has the potential to reduce energy consumption associated with heating, cooling, and humidification systems.

b) Limitation

While this study provides valuable insights into the factors influencing thermal comfort across different climate zones, several limitations should be acknowledged and addressed in future research. Firstly, the sample size in some climate zones was relatively small, potentially impacting the generalizability of the results. Future studies should aim to recruit larger and more geographically diverse participant pools. Secondly, the study focused on air temperature, relative humidity, and air velocity as key factors. However, other variables like clothing insulation, metabolic rate, and radiant temperature can also influence thermal comfort. Expanding the scope to include these factors in future research would provide a more comprehensive understanding of thermal comfort preferences.

III. Conclusion

Thermal comfort is a critical factor in our daily lives, especially in spaces like homes, schools, and workplaces, where people spend extended periods. Understanding the contributors to thermal comfort, including air temperature, humidity, air velocity, and even individuals' backgrounds, is essential for designing comfortable and safe thermal environments.

While field studies exploring the impact of climate and cultural background on thermal comfort preferences are limited, the ASHRAE Global Thermal Comfort Database provides a valuable resource. This comprehensive dataset allows for comparisons of thermal preferences across diverse countries and climate zones.

Our findings reveal variations in thermal sensation patterns across geographical locations. Notably, the range of comfortable temperatures and humidity levels differs significantly between climates. Additionally, the study highlights that the influence of relative humidity and air temperature on thermal sensation varies across climate zones. Factors like clothing choices and activity levels likely contribute to these observed differences in thermal comfort preferences.

The results of this study provide a valuable summary of acceptable ranges for ambient air temperature, relative humidity, and air velocity across various climate zones. These findings can be applied to the design of comfortable and energy-efficient indoor environments tailored to specific climatic conditions.

Key implications of this research include:

1. The necessity for climate-specific approaches to building design and HVAC systems.
2. The potential for energy savings through more precise thermal comfort management.
3. The importance of considering cultural and individual factors in thermal comfort strategies.

This research contributes to the growing body of knowledge on thermal comfort and provides practical guidelines for architects, engineers, and building managers. By applying these insights, it is possible to create indoor environments that not only enhance occupant comfort and well-being but also optimize energy efficiency.

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