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Review

A Review of methodologies for analyzing thermal comfort in urban pedestrian pathways

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ABSTRACT

According to the ANSI/ASHRAE Standard 55, thermal comfort is a subjective evaluation of thermal environment satisfaction. Therefore, the most challenging issue about thermal comfort is the assessment by subjective evaluation and addressing the case as a mental condition. Hence, The primary goal of the study is to determine which of the well-known thermal comfort indices is most suited for studying urban pedestrian movement. The present research method is based on the study of a wide range of research related to climatic comfort on the scale of urban space. The research has a review character and is set to analyze the different indices comparatively. In the analytical approach, the most significant factors which are compared are 1- PMV (predicted mean vote), 2- P4SR (four-hour predicted transpiration index), 3- HSI (heat stress index), 4- SET (standard effective temperature), 5- E.T.* (new effective temperature), 6- PPD (predicted percentage of dissatisfied) and 7- PET (Physiological Equivalent Temperature). The results show each component's advantages and disadvantages in analyzing thermal comfort in urban pedestrian pathways. The findings also underscored the importance of incorporating mixed methodologies to assist designers in making more accurate selections during urban planning. The most difficult issues that should be reconsidered in order to gain a better understanding of thermal comfort as an "adaptive" issue in urban pedestrian pathways are 1- Resetting the reference temperatures, 2- Readdressing the equations for upper and lower limits, 3- Providing more comprehensive databases (age, weight, gender, and thermal history), and 4- Reprogramming the acceptable temperature ranges based on individual expectations. Controls, layout, airflow, and humidity, among other design considerations, would be better emphasized by urban designers.

1. Introduction

As a result of climate change, extreme weather phenomena such as heatwaves, droughts, floods, and tropical cyclones are becoming more frequent and intense. This makes it more challenging to manage water resources, reduces agricultural output and food security, increases health risks, destroys essential infrastructure, and hinders water and sanitation, education, energy, and transportation services [1]. Nearly half of the world's inhabitants live in urban areas, and this is likely to grow to more than two-thirds by 2030. Cities consume a substantial proportion of the world's energy supply and are accountable for about 70% of global energy-related greenhouse gas emissions, absorbing heat and contributing to global warming [2]. The significant changes in climate variables predicted for the 21st Century, and the documented impacts of recent extreme weather and climate disasters mean that adapting to climate change remains a pressing problem for metropolitan communities over the coming decades [3]. For many, the supply of basics like fresh water, food security, and electricity is anticipated to be impacted by a climate warming system. Concurrently, efforts to mitigate and adapt to climate change will equally inform and influence the global development agenda. It is crucial to understand how climate change and sustainable development are related. The least developed countries, which comprise the majority of poor and developing nations, will be the ones most negatively impacted and least equipped to handle the expected shocks to their social, economic, and natural systems [4]. In comparison, this rise is exceeded by an increase in the number of families, which means that the total number of individuals per household decreases. So, our cities will grow even further, placing more pressure on the available urban space. Current urbanization trends significantly affect how our communities are planned, developed, and lived. The transition from rural to urban areas has various human-induced effects, such as the lack of biodiversity or water supply [5]. Every environment that fits the definition of urban space—indeed, any environment where people's presence is crucial—must-have elements that maintain a person's presence and sense of fulfillment. Thermal comfort is one of the suggested methods for estimating and measuring a person's level of satisfaction with their environment following their wishes when placed in that environment. Many cities have put the topic of thermal comfort on their agendas in response to climate challenges, including cold, heat, thermal stress, etc. The current study was conducted using a review methodology to achieve each indicator's benefits and drawbacks through an analytical interpretation of what has been published thus far. This was done to gather information and examine the strengths and weaknesses of each of the mentioned indicators derived from the previous studies in this field. This research starts with the introduction of the research method and continues with the introduction of the most critical components obtained from the review of related research. In the end, after examining and verifying the desired components, a summary of the primary goal of the research has been done (Figure 1).

2. Research Methodology

Following a thorough review of the thermal comfort literature, the field of research was defined as "the entire body of documentation to be generalized in this report." This study's methodological measurements of thermal emissions in constructed environments were limited to personal exposure. The idea of thermal comfort was broadened to refer to a mental state representing contentment with the thermal conditions [6]. Beyond the scope and practicality of this review, the experiments in this field benefited from the examination of the literature on this subject. The research applications for this study were then resolved by defining a set of eligibility standards. This is a crucial phase in systemic reviews to ensure that the arguments are truthful and representative. The article's material has then been divided into two pieces, a literature review and a discussion, and an effort has been made to explain each of these sub-sections to establish a conclusion for making decisions that will be utilized as a conclusion (Figure 2).

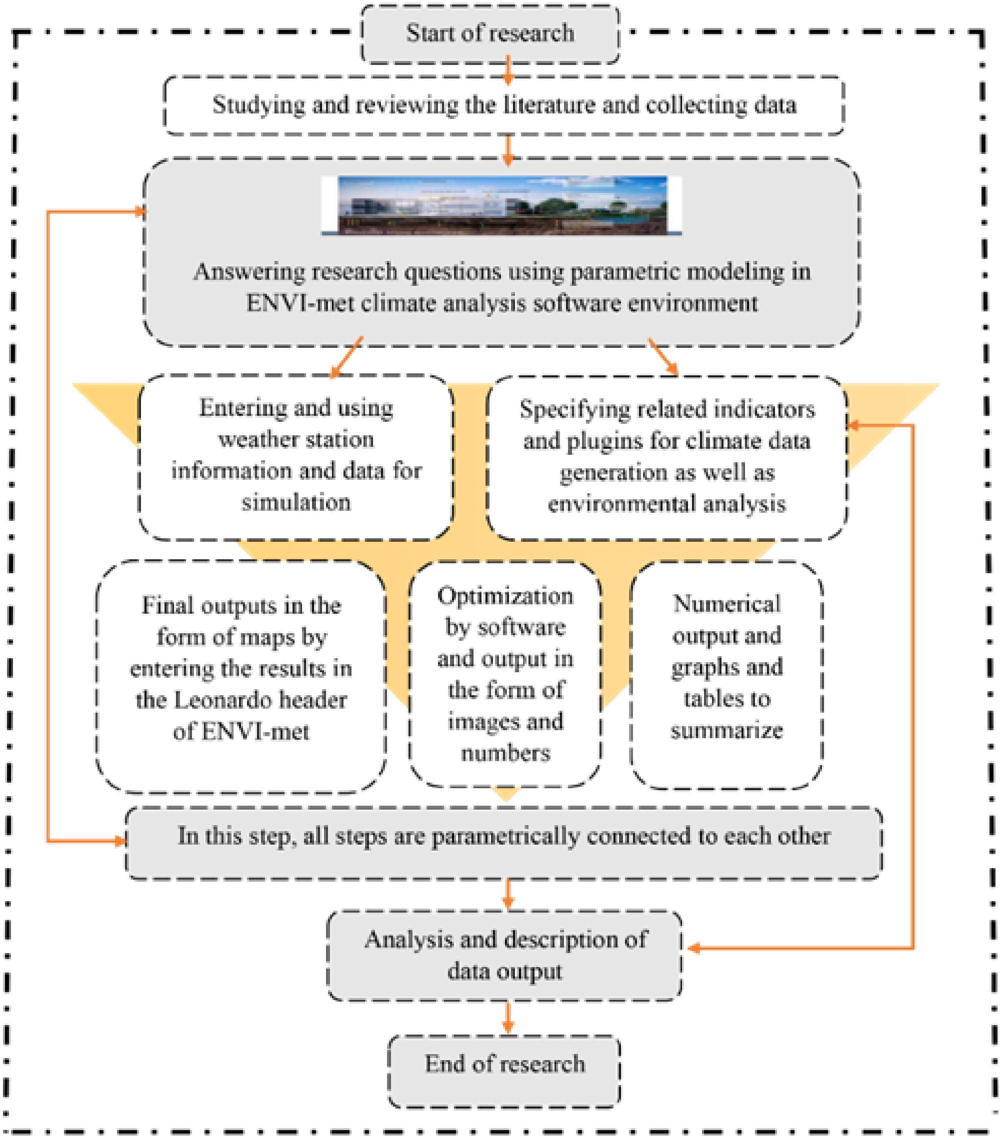

Figure 1. Research structure diagram

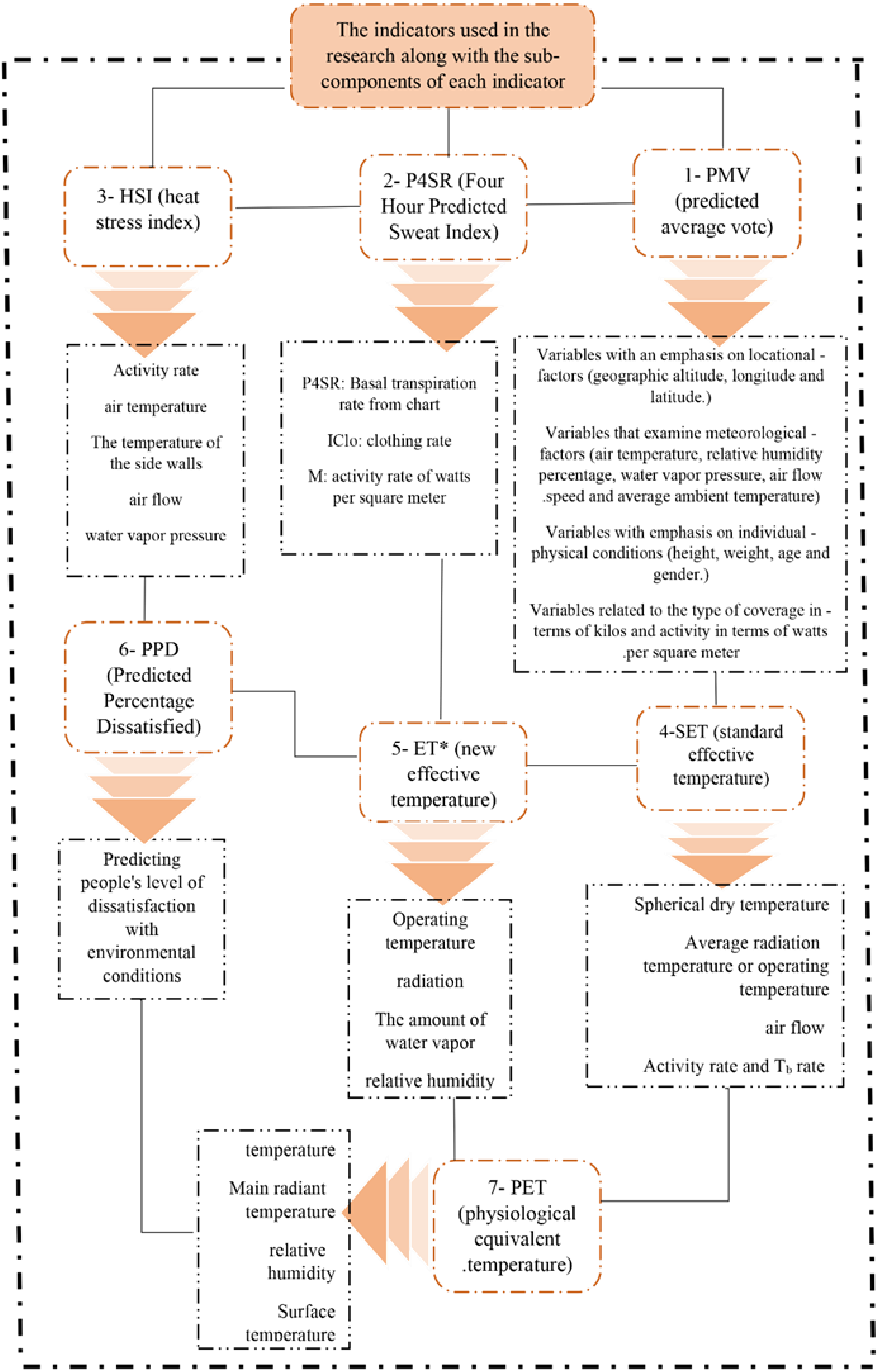

Figure 2. Flowchart demonstrating the research process

3. Literature Review

Thermal comfort based on climatic conditions is one of the subsets of environmental comfort, as covered in earlier sections. This topic is significant and complex. Let us assume that we agree that the climate is a critical factor in determining activities and allocating outdoor use. In that situation, it is essential to comprehend how environmental conditions impact comfort, which is one of the objectives of climate change planning. Indicators that can be compared to the general climatic conditions on the pedestrian scale are necessary for measuring comfort. For example, a body without discrete receptors to grasp the ambient temperature does not represent the environment's thermal comfort condition as a single climate trait. Together, all climatic factors consider how a person perceives the surroundings. Therefore, it is vital to ascertain the thermal parameters to measure thermal comfort. Before examining the content of the literature review, it is necessary to introduce the specialized vocabulary used in this research. Table 1 presents these phrases and their brief explanation.

3.1 PMV

In 1972, Fanger researched weather elements' effect on thermal comfort. The analysis is based on the equation of the energy balance of the body and its environment (the MEMI model), from which human comfort is also derived, and today it has a special place in human bioclimatic studies [7]. In 1972, Fanger conducted comprehensive and complete research on the effect of weather elements on the feeling of thermal comfort. His analysis is based on the equation of the energy balance of the human body and its Environment (MEMI model), from which human comfort is also derived. This index is designed based on the following formula of the energy balance equation of the human body, and it has a special place in human climate studies today [8]. ASHRAE 55 and ISO 7730 standards were compiled based on the use of the above equations in order to provide solutions for quantifying thermal comfort conditions. In order to provide thermal comfort conditions for about 90% of people, conditions with a calculated tolerance of + 0.5 to - 0.5 degrees, conditions were determined in ASHRAE 55 standard. The amount of index and environmental conditions are defined according to Table 2 [9].

3.2 P4SR

In this definition, the sweating of a healthy person is said to be adapted to a warm environment. In 4 hours, the thermal pressure of the environment causes a person to sweat, the amount of which indicates the thermal action of the person in front of the hot environment. The measurement in this environment should be without radiation, and the person should be with activity rate, stillness, cool, and summer clothes [10].

3.3 HSI

This index is based on the maximum evaporative cooling and is determined by the individual for the balance required in the environment. Low airflow is the essential component in measuring this index [11].

3.4 SET

The standardization of conditions for the "new effective temperature" was done by Gage et al. in 1986. In the first place, it was to standardize the rate of clothing. This index depends on the average body temperature (Tb) [12].

Table 1. Terminology of the thermal comfort components in this research

	Component	Abbreviation	Definition
1	Predicted Mean Vote	PMV	The PMV index predicts the mean value of votes cast by a group of inhabitants on a seven-point thermal sensation scale.
2	Predicted 4-hour sweat rate	P4SR	The sweating of a healthy person is said to be adapted to a warm environment in 4 hours.
3	Heat Strain Index	HSI	The ratio of demand for sweat evaporation to the capacity of evaporation.
4	Standard effective temperature	SET	The SET index is defined as the equivalent dry bulb temperature in an isothermal environment at 50% relative humidity where a subject would experience the same heat stress and thermoregulatory strain while wearing apparel standardized for the activity in question.
5	Effective Temperature	E.T.	The temperature of a 50% relative humidity environment in which a person experiences the same amount of losses as in the circumstance under consideration.
6	Predicted Percentage of Dissatisfied	PPD	the percentage of the inhabitants sensing discomfort in that particular environment using the seven-point thermal sensation scale of ASHRAE (-3 to +3).
7	Physiological Equivalent Temperature	PET	A thermal comfort index based on a prognostic model of the human energy balance computes the skin temperature, the body core temperature, the sweat rate, and as an auxiliary variable, the clothing temperature.

Table 2. Classification of environmental conditions based on the PMV index

Environment conditions	Index limit
Sweltering	3
Hot	2
A little warm	1
Comfort	0
A little cool	-1
Cool	-2
Cold	-3

3.5 E.T.

This index has a broader range of applications than other analysis indices in such a way that the issue of radiation is crucial, and humidity has been given enough attention. In the revision in 1947, it addressed its effect at lower temperatures, and then more attention was paid to the issue of radiation in this index [13].

3.6 PPD

The prediction of people's dissatisfaction with the environmental conditions is emphasized in percentage, and referring to the controlled experimental conditions does not provide the ability to obtain satisfaction and 100% satisfaction from all people. Fanger believed that the range of satisfaction should be increased to ten percent. It means to provide a condition where the dissatisfaction is ten percent or less [14].

3.7 PET

It is possible to consider the temperature during which the thermal balance of the human body in a non-open space and at rest (no wind and sunlight) with a rate of activity and light work (80 watts), the thermal resistance of clothing is about 0.9, with skin temperature And the core temperature of the body is in balance [15]. One of the external thermal comfort indices based on the steady-state thermal balance model (MEMI) is the physiological equivalent temperature (PET) index. This index was introduced by Mayer and Hope (1987) and compared the complex conditions of the external environment with the steady-state internal environment settings. This index is in degrees Celsius, which makes it understandable for everyone (Pijpers-van Esch, 2015; 115). PET index includes airflow, radiation, and humidity.

For this reason, it is the best indicator of external thermal comfort [16]. The Physiological Equivalent Temperature Index (PET) can be considered as the temperature at which the human thermal balance in a closed environment and a sitting position (without wind and solar radiation) with a light metabolic rate (80 W) and thermal resistance of clothing is about 0.9 K to be in balance with skin temperature and core body temperature [15]. Local environment measurements strongly influence PET index measurement. PET changes more than air temperature: PET can change a lot at a distance of one meter, while air temperature does not. Therefore, the measurement method is significant for PET analysis. More receiver points lead to better estimation and evaluation. The average PET of multiple receptor points shows the overall effect of a region [16].

4. Discussion

There are various reasons for making cities' outdoor spaces more comfortable. Making urban areas more appealing and accessible has grown in importance in recent years due to the social, cultural, and economic benefits. If the outside environment is thermally comfortable, the utilization of the metropolitan region is more likely to increase. Thermal comfort is also crucial for people's well-being. This is especially significant in hot regions, where the risk of heat-related sickness increases as temperatures rise [17].

Furthermore, outdoor activities are feasible most of the year in friendly countries where sufficient outdoor areas increase outdoor livability. A thermally suitable outside environment will also positively impact the indoor climate, resulting in lower energy consumption for space cooling. Recent ecosystem changes have damaged the viability of outside developed habitats. The cumulative effects of these changes in urban outdoor spaces put thoughtful urban planning, which aims to build successful and useable outdoor places, to the test. The thermal environment is emphasized as a factor of outdoor environmental quality. As a result, urban planners and designers strive to investigate how people perceive and interact with external climatic conditions. Thermally comfortable urban environments let individuals interact with their surroundings while meeting their daily needs. On the other hand, thermally uncomfortable environments may discourage outdoor activity participation and increase indoor cooling energy consumption [18]. According to the studies conducted on well-known thermal comfort indices for the analysis of suitable urban pedestrian routes, a comparative table of the advantages and disadvantages of the indices was obtained, which can be seen in Table 3.

Different categories of climatic components were explained in terms of two critical factors and how to use each one, which was mentioned by the studies, how to use each component in specific conditions, and the order of covering all the different environmental dimensions, which is summarized. Moreover, the summary of the advantages and disadvantages of each is described in the table above. The PMV index is based on the energy balance equation of the body and its environment (the MEMI model). However, its calculations are very extensive and time-consuming, and this complexity in the calculations has caused analysis software such as Rayman or ENVI-met after simulation and direction [19]. The analysis output of this software should be used. The P4SR index checks the amount of sweating of a person in a warm environment in a four-hour sequence, and to use this index, the environment must be free of radiation, and the humidity should be less than 40%. The HSI index examines the maximum evaporative cooling of a person and is a function of the person's clothing and activity, and is suitable for cold spots. The SET index standardizes the activity rate with the clothing rate but directly depends on the human body temperature model. The E.T.* index is used considering the humidity and radiation issue, provided that the air is stable and the activity rate is low. The PPD index is effective in controlled laboratory conditions and predicts people's dissatisfaction in percentage, and if we test the isolated environment in a free environment, the error percentage will increase. The PET index is based on the steady-state thermal balance model and compares the external environment's conditions and the internal environment's settings; PET is one of the most complete and reliable components in climate studies, especially in urban design. As it has been said, each component can respond to the needs related to the individual's concerns in defined environments such as heating, cooling, etc., according to the different microclimates in the geographical location of each one. Due to the rapid climate changes, one should be very careful in choosing the type of method to create the thermal comfort of a defined urban space. Only one variable cannot be taken into account. However, in certain circumstances, it is possible to pay attention to one comfort variable over another. Climate variables are preferred, but each should be analyzed in line with the other.

Table 3. Advantages and disadvantages of each index

	Advantages	Disadvantages
PMV	Use in human bioclimatic studies	- The extent of calculations - Being time-consuming - Complexity of equations
P4SR	- The amount of sweat of a healthy person in a warm environment - Four-hour sequence	- Radiation-free Environment - Environments with humidity less than 40%.
HSI	- Maximum evaporative cooling of the individual for thermal equilibrium - A function of activity rate, air temperature, side wall temperature, air flow, and water vapor pressure	- Little attention to the cooling properties of airflow. - Little attention to the thermal properties of moisture.
SET	- Standardize the activity rate with the clothing rate	- Dependence on the body temperature model
E.T.*	- Attention to the issue of radiation - Attention to humidity	- almost constant airflow - Low credit activity rate
PPD	- Prediction of people's dissatisfaction in terms of the percentage - controlled laboratory conditions	- controlled conditions in the laboratory
PET	- Based on the steady-state thermal balance model - Comparison of outdoor environment conditions with indoor environment settings	- Index measurement affected by local environment measurement - The importance of the measurement method, such as air temperature, distance

5. Conclusion

This article has been trying to take a comprehensive approach to put together the practical components of thermal comfort. Therefore, a specific path consisting of studying a wide range of related research has been followed so that all possible variables in climate studies can be considered. The thermal comfort methods for achieving a sustainable environment should be coordinated with goals for sustainable development while also considering any potential risks and unfavorable side effects that may result from their implementation. The municipal agencies should collaborate with civil society, locals, and international organizations throughout formulating and implementing the climate change consideration plans. Urban areas are made up of several interrelated systems that support efficient urban planning and governance to slow down climate change. In order to estimate the heat sensitivity of the building environment, this study offers a complete classification of the literature, cutting-edge methods, and the primary dangers and future objectives. The results are described in more detail below:

- The formation and advancement in thermal comfort measurement methodologies to access various sizes, flexible, economical, and technically sound testing and modeling solutions.
- The assessment of trustworthy findings and the standardization of research. The research found that very few studies provide a comparative accuracy evaluation, and more crucially, there are no metrics, suggestions, or criteria for creating a comparative evaluation of personal thermal exposures across different scales, sites, and targeted groups.
- The increase of studies to examine how vulnerable populations are affected by thermal comfort settings. We observe that disadvantaged persons and the microclimate in working contexts are particularly susceptible to heat exposure. In order to progress the study of cities' thermal exposure and the associated health effects in urban climate, new technology, and extensive geographical databases need to be developed.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

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