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ASSESSING THE INDICATORS OF OUTDOOR THERMAL COMFORT ON PEDESTRIAN BEHAVIOR IN THE URBAN STREETS.

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Abstract.

Background:

Outdoor Thermal Comfort (OTC) plays a crucial role in shaping pedestrian behaviour, influencing outdoor activity, mobility choices, social interactions, and overall urban liveability. Although extensive research exists globally, gaps remain in how different countries prioritise physical, physiological, psychological, and behavioural indicators, particularly in developing contexts like India.

This study compares OTC indicators used in developed and developing countries to understand how these parameters affect pedestrian behaviour in urban streets. It also identifies gaps in current assessment frameworks and proposes context-specific behavioural approaches for Indian cities.

A systematic literature review was conducted on peer-reviewed studies from the past decade using Scopus and Google Scholar databases. Indicators were categorised into four criteria—Physical, Physiological, Psychological, and Behavioural—and assigned scores to analyse their frequency and relative importance across contexts. Comparative analysis was performed to evaluate indicator prioritisation and methodological patterns.

Physical indicators such as temperature, relative humidity, mean radiant temperature, solar radiation, wind velocity, height-to-width ratio, sky view factor, and thermal sensation vote dominate global OTC studies (≈90% usage) due to their measurability and modelling frameworks. Developed countries frequently incorporate behavioural and physiological factors, whereas developing countries—especially India—focus largely on basic climatic parameters. Psychological and behavioural indicators remain significantly underrepresented. Vegetation, shading, and water features consistently enhance pedestrian comfort across climates. Current OTC research heavily favours physical indicators, limiting the understanding of human adaptation and behaviour in outdoor environments. Indian studies, in particular, lack behavioural and cultural considerations, reducing practical relevance for real-world pedestrian comfort planning.

The study highlights the need for balanced OTC frameworks that integrate perception-based, behavioural, and socio-cultural factors. It encourages researchers to move beyond climatic data toward holistic models that reflect how people actually interact with urban streets.

Urban planners and designers can improve street-level comfort by incorporating behavioural insights, such as clothing adaptation, activity patterns, and route choices. Strategies like shading,

dense vegetation, reflective materials, and water elements can be more effectively designed when informed by local behaviour patterns.
Future research should extend to tier-2 and tier-3 Indian cities, employ wearable sensors, conduct behavioural mapping, and explore socio-economic influences on outdoor comfort. Developing region-specific behavioural indicators will support more inclusive and climate-responsive street design.
Keywords: Outdoor Thermal Comfort, Pedestrian Behaviour, Urban Streets, Physical Indicators, Behavioural Indicators, Psychological Factors, Developing Countries, Developing Countries, Microclimate, Street Design.

1.Introduction

Outdoor thermal comfort refers to the subjective perception of thermal conditions experienced by individuals in outdoor environments. It is a measure of how comfortable or uncomfortable people feel in relation to the surrounding outdoor climate. Outdoor thermal comfort is influenced by various physical and physiological factors, such as air temperature, humidity, wind speed, and solar radiation, as well as psychological and behavioural factors like clothing, activity levels, and social context. The consideration of thermal comfort in outdoor spaces can be traced back to ancient civilizations. The ancient Greeks designed their public spaces, such as the Agora, with shaded areas and water features to provide relief from the heat. Similarly, traditional Persian gardens incorporated cooling elements like fountains, vegetation, and water channels to mitigate high temperatures. The development of modern outdoor thermal comfort concepts gained momentum during the 20th century, when researchers like P.O. Fanger introduced the concept of thermal comfort in indoor environments, which later expanded to outdoor settings.Studies have shown that comfortable outdoor environments promote social interactions, encourage outdoor activities, and contribute to improved overall well-being [1], [2]. Moreover, outdoor thermal comfort directly affects pedestrian choices, including walking duration, route selection, and recreational activity engagement. Sustainable urban development aims to create energy-efficient cities with better outdoor microclimates, reducing energy consumption and enhancing human comfort. Emerging technologies such as environmental sensors, wearable devices, and weather forecasting models have enabled more precise assessments of outdoor thermal conditions. This data-driven approach allows planners and architects to make informed decisions to improve outdoor comfort, particularly in dense urban streets where microclimatic variability is high [3].
Outdoor thermal comfort in the Indian context has gained particular significance due to the country’s diverse climate, ranging from extreme summer heat in northern and western regions to humid tropical conditions in the south and cold winters in the Himalayan regions. Although some studies have addressed thermal comfort in Indian cities such as Chennai, Delhi, and Kolkata, large parts of the country [2], [4]. Cultural practices, clothing habits, and socio-economic diversity in India further influence thermal perception, highlighting the need for context-specific studies. Unlike earlier reviews that primarily compile indicators; the present study contributes by systematically identifying how physical, physiological, psychological, and behavioural indicators are prioritised differently in developed and developing contexts, highlighting gaps in Indian research. By focusing on pedestrian behaviour in urban streets, the study bridges existing

literature with the practical needs of Indian cities, where rapid population growth, climatic variability, and cultural practices demand localized and context-sensitive strategies for outdoor comfort [5], [6], [2], [7]. This study incorporates a **prioritisation framework and scoring methodology,** enabling a comparative understanding of indicators across global and Indian contexts.The estimated world population in cities will reach 81% by 2030 [8], with 91% concentrated in developing countries. In India, the annual urban population growth rate is 3.35%, increasing pressure on the built environment and existing urban morphology. Rapid urbanisation has led to reduced outdoor open spaces and declining environmental quality [9]. India is vulnerable to extreme weather events, such as heatwaves, which can pose severe health risks. Outdoor thermal comfort becomes critical during such events, as it can reduce heat-related illnesses and improve public safety [10], [11],[12],[13]. Given the combination of high population density, urban heat, and limited green spaces, strategies to enhance pedestrian comfort are essential for creating walkable, resilient, and socially inclusive streets [14], [9],[15],[16],[17].The present study aims to systematically analyse indicators used to assess outdoor thermal comfort and their relationship with pedestrian behaviour in urban streets. The literature suggests that thermal comfort can be assessed across four levels**: physical and physiological factors** (using heat/energy balance models), **psychological factors**, and **behavioural factors**, which include activity patterns, clothing adaptation, and social interactions (Chen & Ng, 2012; Golasi et al., 2018) [18],[19],[20]. Additionally, this study seeks to address cities and proposes a methodology to prioritise behavioural indicators that are culturally and regionally relevant.

2. Method

The methodology adopted for this study comprises four systematic steps: 1) Literature review and data extraction, 2) Data processing, 3) Analysis and results, and 4) Discussion and conclusion. Initially, a comprehensive literature search was conducted using databases such as Google Scholar and Web of Science, focusing on studies assessing outdoor thermal comfort in urban environments, particularly urban streets. After applying inclusion criteria—peer-reviewed studies from the last ten years, addressing pedestrian behaviour and urban outdoor settings—22 studies were shortlisted for detailed analysis.The selected studies were categorised according to four major factors: Physical, Physiological, Psychological, and Behavioural. From these studies, a total of 43 indicators were extracted: 25 physical, 4 physiological, 6 psychological, and 8 behavioural. To reduce redundancy and enhance comparability, similar indicators were condensed, resulting in a final list of 24 indicators (8 physical, 4 physiological, 6 psychological, and 6 behavioural). Each indicator was assigned a unit of measurement to ensure traceability.A quantitative scoring system was applied to evaluate the relative importance of each indicator. For every study, each indicator used was given a score of 1, and the cumulative scores were calculated for both developed and developing countries to identify differences in prioritisation. Similarly, scores were aggregated across the four criteria to determine the overall focus of studies on physical, physiological, psychological, and behavioural factors. This approach enabled a systematic comparison of how different indicators influence outdoor thermal comfort assessments, particularly in the context of pedestrian behaviour in urban streets.

2.1 Literature Searches

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The concept of outdoor thermal comfort is not new, and many studies have already been undertaken by researchers globally. A thorough literature search was conducted on Google Scholar to find relevant peer-reviewed research papers comprising an assessment of outdoor thermal comfort and Urban streets. These papers assessed the various indicators used for outdoor thermal comfort. The current study emphasizes outdoor thermal comfort primarily urban street. Thus, ten studies involving both are shortlisted. These studies are further classified as i) indicators assessed; ii) research context - developed or developing countries and; iii) pedestrian behavior criteria. Outdoor Thermal Comfort assessment involving climatic, urban morphological, and human-related factors can be broadly classified into two quantitative groups of empirical and numerical methods. The empirical models are based on observations, measurements, and data collection by the researcher. The numerical methods use computer power and modeling techniques to answer research questions. The shortlisted studies are therefore classified as per their context- developed and developing countries.Although this study is primarily a literature review, it also highlights research gaps across different climatic regions of India. Many areas beyond metropolitan cities remain underexplored, particularly smaller urban centres that represent the majority of India's urban growth. A framework for future research should therefore include tier-2 and tier-3 cities and cover diverse climate zones, ensuring a more representative understanding of outdoor thermal comfort.

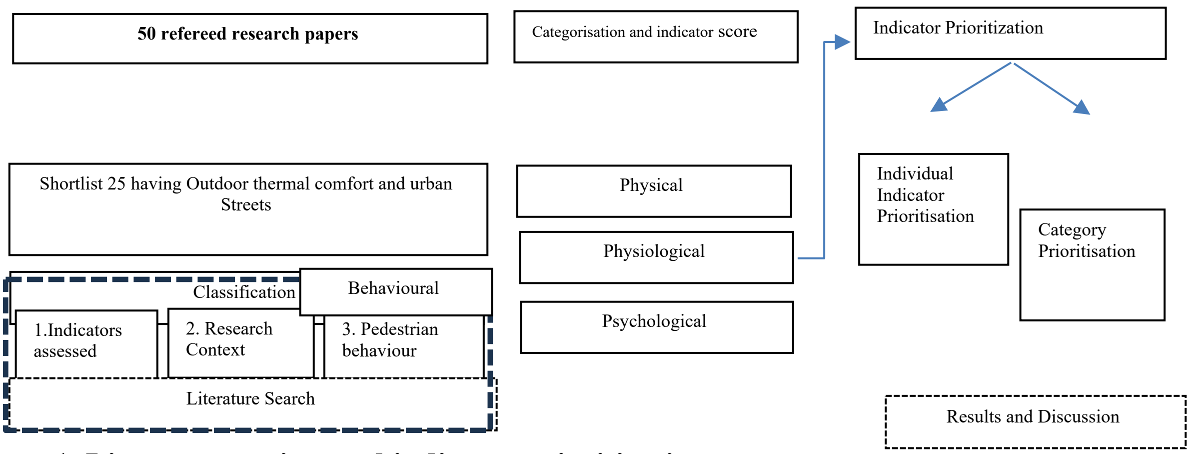


Figure 1. Literature review and indicator prioritization

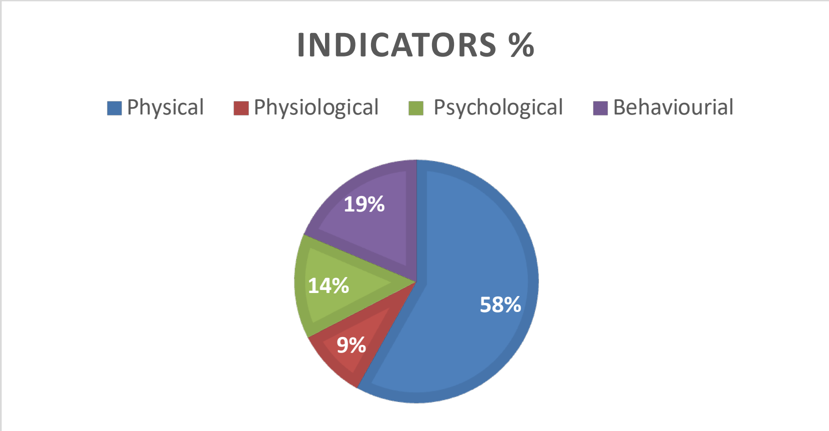
2.2 Identified Indicators

From the shortlisted studies, a **comprehensive list of 43 indicators** was extracted, including:

- Physical (8)
- Physiological (4)
- Psychological (6)
- Behavioural (6)

Indicators were then **condensed by merging similar measures** to reduce redundancy. Each indicator was recorded along with its **unit of measurement**, ensuring quantitative traceability. For example, "activity level" and "metabolic rate" were combined under a single behavioural indicator, while solar radiation and mean radiant temperature were retained separately under physical factors.

Figure2. Distribution of Indicator percentage wise



The Subjective criteria account for 67% of the indicators, while the objective criteria account for 23%. Twenty-two of the shortlisted studies used as a result, a comprehensive list of indicators and sub-indicators was further filtered according to the outdoor thermal comfort indicators under the four criteria—physical, physiological, Psychological and Behaviour. The list of indicators was further condensed by combining similar indicators **(refer Table 2**). The condensed list contained 08 Physical, 04Physiological, and 06psychological, 06 behavioural indicators that were abbreviated according to the criteria.The climatic and physiological assessment consists of objective factors; i.e., measurable climatic atmospheric parameters, biometeorological conditions, and physiological factors that could be measured at any given time using instrumentation and other quantitative assessment methods. The way we experience our thermal environments is also affected by subjective physiological and socio-behavioural factors (Chen & Ng, 2012) such as thermal history, cultural background, and acclimatization. Figure 1 lists four groups of factors for assessment in OTC models. Many of these factors are shared with the indoor thermal comfort models.

TABLE 1CATEGORISED INDICATOR LIST

CATEGORISED INDICATOR LIST		
STUDY 1 - COCCOLO, KAMPF, SCARTEZZINI, & PEARLMUTTER, 2016[21]		
CRITERIA	**Indicator**	**Unit**
PHYSICAL FACTORS	Temperature	Deg C/Deg F
	Relative Humidity	%
	Wind Velocity	m/s
	Mean radiant Temperature	MRT (W/m2)
	Radiation	1 rad
PHYSIOLOGICAL FACTORS	Age	
	Gender	
	Active thermoregulation	
	Passive thermoregulation	
PSYCHOLOGICAL FACTORS	Naturalness of climate	
	Expectations	

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	Experience	
	Time of exposure	
	Perceived control	
	Environmental Stimuli	
BEHAVIORAL FACTORS	Clothing insulation	
	Activity level & metabolic rate	
	Type of activity/Human Posture and position	
	Culture	
	Social (individual or Companion)	
	Metabolic Rate	Met or W/m

Source -Nikolopoulou & Steemers, 2003),[22],(ASHRAE, 2013)

Physical factors -physical factors in the research studies often refers to the **physical parameters that can be measured directly using sensors** such as Air temperature, Sun radiation, wind speed and humidity. [21]

Physiological factors -The temperature on **human skin, sweat rate to assess the human reaction to the ambient temperature**. The response generated by the human body are the physiological factors that are assessed. These factors influence the thermal comfort of the people in the region. [21]

Psychological factors - Psychological factors are **non-climatic and non-physiological factors that affect the comfort sensation** in the human brain. Research studies have often considered the **thermal experience, thermal expectations, perceived control, mood, and emotion** as the psychological factors during the thermal comfort study. (Chen, Wen, Zhang, & Xiang, 2015),[24], (Holland, 2016;[9],Jedritzky et al., 2012),[25].

Behavioural factors - There are some social factors that influences the **thermal comfort like the position in the space, number of Companion, and the Socio-economical variable** which directly affects the **type of clothing**. Also, the activity done by the individual influences the thermal comfort of the individual like jogging, walking, workout, and shopping. Coccolo, Kampf, Scartezzini, & Pearlmutter, 2016),[21]

Table 2Condensed List of Similar Indicators

Condensed List of Similar Indicators							
Physical (8)		Physiological (4)		Psychological (6)		Behavioural (6)	
P1	Air Temperature (Deg C/Deg F)	**PH1**	Age	**PS1**	Naturalness of climate	**B1**	Clothing insulation
P2	Relative Humidity (%)	**PH2**	Gender	**PS2**	Expectations	**B2**	Activity level & metabolic rate

P3	Mean radiant Temperature (MRT (W/m2)	**PH3**	Active thermoregulation	**PS3**	Experience	**B3**	Type of activity/Human Posture and position
P4	Solar Radiation (W/m²)	**PH4**	Passive thermoregulation	**PS4**	Time of exposure	**B4**	Culture
P5	Wind Velocity (m/s)			**PS5**	Perceived control	**B5**	Social (individual or Companion)
P6	height-to-width ratio (H/W) Aspect Ratio			**PS6**	Environmental Stimuli	**B6**	Metabolic Rate (Met or W/m)
P7	Sky View factor (SVF)						
P8	Thermal sensation vote (TSV)						

2.3 Data Processing

The analysis begins with the comparison of the condensed list of indicators with each study, as seen in Table 3. Each indicator was allotted a single point score if it was used for assessment in the respective study. To determine the importance given to each indicator by developed and developing countries, each study was scored respectively. To understand the overall priority for an indicator, a cumulative score that included studies from both developed and developing countries was calculated.

Indicator Score.The indicator score has determined the importance of the particular indicator. The condensed list of indicators was individually scored on the basis of its use in the shortlisted studies (Eq. 1). The developed and developing countries' score was calculated separately to understand the difference in priority of the indicator selection. Therefore, to see the overall priority for an indicator, a cumulative score for each indicator was calculated (Eq. 2).

Table 3Factors Influencing Thermal Comfort

Environmental/Physical factor	**Physiological factors**	**Psychological factors**	**Behavioural/Social factors**
Physical factors in the research studies often refer to the physical parameters that can be	The temperature on human skin, sweat rate to assess the human reaction	Psychological factors are non-climatic and non-physiological factors	There are some social factors that influence the **thermal comfort**

measured directly using sensors such as Air temperature, Sun radiation, wind speed and humidity	to the ambient temperature. The response generated by the human body are the physiological factors that are assessed. These factors influence the thermal comfort of the people in the region	that affect the comfort sensation in the human brain. Research studies have often considered the thermal experience, thermal expectations, perceived control, mood, and emotion as the psychological factors during the thermal comfort study.	**like the position in the space, number of companion, and socio-economic variables** which directly affect the **type of clothing**. Also, the activity done by the individual influences the thermal comfort (e.g., jogging, walking, workout, shopping).
Temperature	Age	Naturalness of climate	Clothing insulation
Relative Humidity	Gender	Expectations	Activity level & metabolic rate
Wind Velocity	Active thermoregulation	Experience	Type of activity
Mean Radiant Temperature	Passive thermoregulation	Time of exposure	Culture
		Perceived control	Social (individual or companion)
		Environmental stimuli	
References • Coccolo, Kampf, Scartezzini, & Pearlmutter (2016)[21][18] • Chen, Wen, Zhang, & Xiang (2015); Holland (2016)[24][26]			

Equation 1 Indicator Score

$$I = \sum_{n=1}^{25} s_n,$$

$$I_c = I_{dx} + I_{dy},$$

where Iis the indicator score, s is the point score given to the study, n is the respective study number, Ic is the cumulative score for each indicator, Idx is the indicator score for developed countries, and Idy is the indicator score for developing countries.

To quantify the importance of each indicator, a **scoring system** was implemented:

- **Indicator Score (I):** Each indicator received a score of 1 if it was used in a given study.

$$I = \sum s_n$$

- **Cumulative Score (Ic):** The total score of each indicator across all studies, representing its overall priority. Separate cumulative scores were calculated for **developed (Idx)** and **developing countries (Idy)** to identify differences in prioritization.

$$Ic = \sum_{all\ studies} I$$

- **Criteria Score:** For each study, scores were aggregated across four criteria—physical (SP), physiological (SPH), psychological (SPS), and behavioural (SB).

$$SP = \sum Pi, \quad SPH = \sum PHi, \quad SPS = \sum ESi, \quad SB = \sum Bi$$

This framework enables **quantitative comparison of indicator usage** across different contexts and highlights the relative focus on behavioural factors.The prioritization for outdoor thermal comfort criteria is equally important. Therefore, the score for each study was calculated individually to understand the importance given to the behaviour criteria by studies conducted by developed countries and India. Where SP, SPH, SPS and SB are the cumulative scores of each study in the Physical, physiological, psychological and behavioural criteria respectively; n is the respective indicator and, Pi, PHi ,ESi and Bi are the point score given to the study for using indicator in Physical, physiological, psychological and behavioural criteria respectively.

Table 4Criteria score Developed / Developing

Developed																					
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**S19**	**S20**	**Idx**
P1	1	1	1	1	1	1		1	1	1	1	1	1		1	1	1	1	1	1	18
P2	1	1	1			1		1	1	1		1	1		1	1	1	1	1	1	15
P3		1		1	1	1				1	1	1		1	1	1		1	1		12
P4					1				1	1									1		4
P5	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1		1		1	17
P6						1	1	1		1				1	1	1			1		8
P7			1		1	1		1	1	1	1		1	1			1	1	1		12
P8			1			1			1											1	4

SP																					
PH1	**1**					**1**			**1**	**1**	**1**	**1**	**1**				**1**			**1**	**9**
PH2	**1**					**1**				**1**	**1**	**1**	**1**				**1**			**1**	**8**
PH3																					
PH4																					
SPH																			**1**		**1**
PS1	**1**	**1**	**1**		**1**			**1**		**1**	**1**	**1**	**1**					**1**			
PS2		**1**	**1**	**1**		**1**	**1**	**1**		**1**					**1**		**1**		**1**		
PS3	**1**			**1**		**1**		**1**	**1**		**1**		**1**								
PS4	**1**											**1**						**1**			
PS5						**1**										**1**					
PS6		**1**																			
SPH																					
B1		**1**	**1**	**1**		**1**		**1**	**1**	**1**			**1**				**1**			**1**	**10**
B2						**1**	**1**		**1**	**1**											**4**
B3		**1**	**1**	**1**				**1**	**1**						**1**		**1**			**1**	**7**
B4									**1**				**1**		**1**						**1**
B5		**1**														**1**					

B6				1									1								
SB																					
Developing																					
	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40	Idy
P1	1	1	1	1	1	1	1	1	1	1		1	1	1		1		1			15
P2	1	1	1	1	1		1	1	1			1	1	1	1	1					13
P3	1	1	1		1		1	1	1	1			1		1	1		1	1	1	14
P4	1	1	1	1	1		1	1	1			1	1	1	1	1					13
P5																					
P6	1	1	1		1			1						1	1	1		1	1	1	11
P7					1			1													2
P8								1	1						1	1					4
SP																					
PH1					1			1	1							1					4
PH2					1			1	1							1					4
PH3									1												1
PH4									1												1
SPH																					

PS1		**1**			**1**					**1**		**1**		**1**			**1**		**1**		**1**
PS2							**1**				**1**				**1**						
PS3		**1**		**1**		**1**		**1**		**1**						**1**		**1**		**1**	**1**
PS4												**1**		**1**							
PS5							**1**														
PS6					**1**						**1**					**1**			**1**		**3**
SPH																					
B1	**1**	**1**			**1**			**1**	**1**						**1**	**1**					**7**
B2	**1**	**1**	**1**		**1**			**1**	**1**							**1**					**7**
B3	**1**	**1**						**1**	**1**						**1**	**1**					**6**
B4								**1**				**1**				**1**					**3**
B5	**1**							**1**								**1**					**3**
B6	**1**	**1**																			**2**
SB																					

2.4 Scope and Contextual Relevance

This methodology emphasizes the **inclusion of tier-2 and tier-3 cities**, which are often underrepresented in OTC studies, and covers diverse climatic regions. By combining **objective climatic measurements** with **subjective behavioural assessments**, the framework supports a **holistic evaluation of pedestrian thermal comfort** that is sensitive to both global standards and local Indian conditions.

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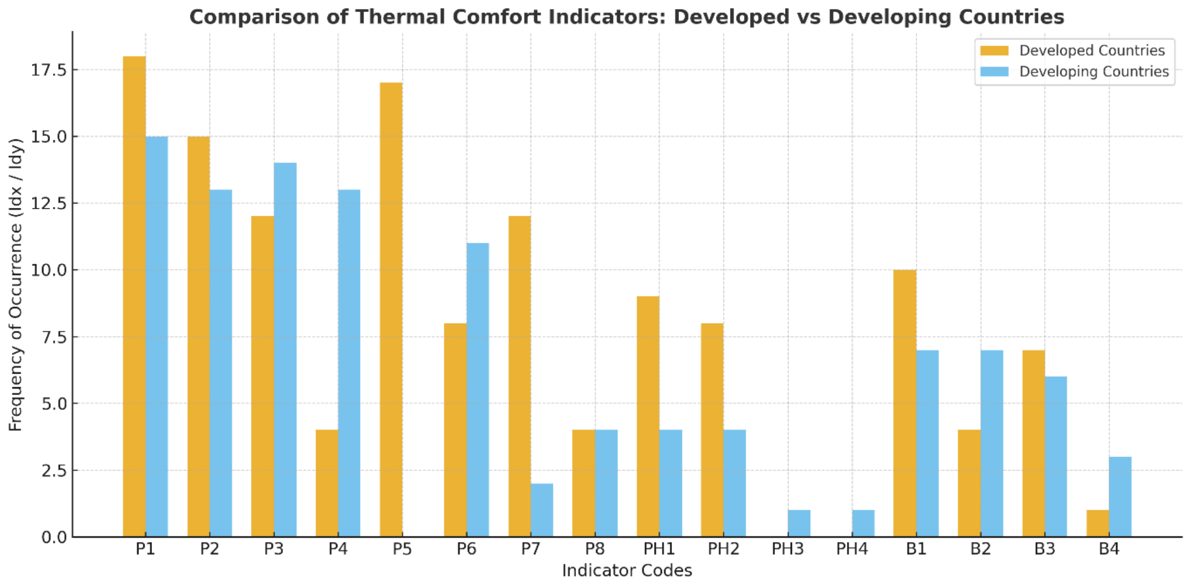

Figure 1 Comparison of Thermal Comfort Indicators

The comparative analysis reveals that physical indicators dominate thermal comfort studies in both developed and developing contexts, though their emphasis differs. Developed-country studies prioritize quantifiable parameters such as solar radiation (P5), air temperature (P1), and street geometry (P7), reflecting data-driven and instrument-based methodologies. In contrast, developing-country research focuses more on surface temperature (P4), mean radiant temperature (P3), and wind velocity (P6), emphasizing direct exposure and practical field measurements. Physiological indicators such as clothing insulation and metabolic rate appear more frequently in developed studies, while behavioural indicators, including clothing adaptation and activity type, are more prominent in developing contexts, highlighting adaptive strategies to cope with outdoor heat. Overall, while both contexts underline the importance of physical parameters, psychological and social indicators remain underrepresented, indicating the need for a more integrated, perception-based approach to outdoor thermal comfort assessment.

3 Results and Discussion

To understand the impact of outdoor thermal comfort on pedestrian behaviour in urban streets, a **quantitative scoring approach** was applied to the condensed list of indicators across the shortlisted studies. The **indicator score** reflects the relative importance of each indicator in both developed and developing countries. Similarly, each study's **percentage contribution** to the four criteria—Physical, Physiological, Psychological, and Behavioural—was calculated.The analysis reveals that methods for measuring **physical and physiological indicators** are well-established, whereas **behavioural indicators** remain underdeveloped for urban street assessments. While numerous urban indicators exist for outdoor thermal comfort, few are specifically designed to capture **pedestrian behaviour**. Consequently, behaviour indicators compatible with this study were identified and included.Across the shortlisted studies, **physical criteria were consistently prioritised** over physiological and behavioural criteria, regardless of the research context. The prominence of physical indicators such as **Sky View Factor (SVF), Height-to-Width (H/W) ratio, and Thermal Sensation Vote (TSV)** is attributed to their measurability and well-established modelling frameworks. Developed countries frequently integrate these indicators with advanced urban morphology models, whereas Indian studies often rely on basic climatic data due to limited resources. Neglecting behavioural factors—such as clothing choices or activity patterns—limits the practical applicability of research for **pedestrian comfort in Indian cities**.

Table 5Comparison of Indicator Prioritization between Developed and Developing Countries

Indicator Type	Indicator Code / Description	Developed Countries (% Usage)	Developing Countries (% Usage)	Remarks / Observations
Physical Indicators	P1 – Temperature (°C/°F)	90.91	90.91	Most commonly used across all studies
	P2 – Relative Humidity (%)	90.91	90.91	Core parameter for microclimatic analysis
	P3 – Mean Radiant Temperature (MRT, W/m²)	90.91	90.91	Essential for assessing radiant heat load
	P5 – Solar Radiation (W/m²)	57.14	81.82	Highly prioritized in both contexts
	P7 – Wind Velocity (m/s), H/W Ratio, SVF, TSV	90.91	90.91	Dominant indicators reflecting street geometry and comfort
Behavioural Indicators	B1 – Clothing Insulation	90.91	54.55	Commonly included; fewer studies in India
	B2 – Activity Level / Type of Activity	90.91	54.55	Widely considered in developed nations
	B3 – Social Companions, Culture, Posture, Metabolic Rate	90.91	54.55	Broader behavioural factors less considered in developing countries
Psychological Indicators	Acceptance, Preference, Thermal Sensation Vote (TSV)	42.86 (P5)	81.82 (P5)	Moderate emphasis in both contexts; higher in developing countries

Overall Pattern	—	Physical Indicators dominate (90.91%)	Physical Indicators dominate (90.91%)	Psychological and behavioural factors remain underrepresented
Notable Exceptions	—	Some studies (e.g., S3, S13) omit social indicators	Most developing-country studies include all three criteria	Reflects broader inclusivity in developing contexts

Existing research on outdoor microclimate emphasizes the role of **street geometry, canyon orientation, and neighbourhood morphology** in shaping thermal comfort. Various mitigation strategies—such as trees, shrubs, grasses, high-albedo materials, and urban water bodies—offer case-specific resilience against urban heat islands (O'Malley et al., 2015 [27]; Taleghani, 2018 [28]). Strong correlations exist between **outdoor thermal comfort and pedestrian behaviour**, highlighting the importance of integrating microclimatic considerations into urban planning (Nourl et al., 2017 [29]).Studies indicate that **full vegetation cover, higher aspect ratios, and shaded canopies** are most effective in improving outdoor thermal comfort, followed by **water bodies, wet soils, and grasses** (Chatzidimitriou & Yannas, 2016 [30][31]). However, these methods remain largely generic and are often **not adapted to Indian cultural and climatic contexts**. To strengthen behavioural assessments in Indian cities, this study proposes **region-specific approaches**:

1. **Clothing adaptation surveys** reflecting local attire.
2. **Wearable sensors and mobile-based tracking** to monitor pedestrian exposure.
3. **Behavioural mapping** of pedestrian movement between shaded and unshaded areas.
4. **Community-specific analysis** to evaluate socio-economic influences on outdoor comfort.

Implementing these methods would enable **behavioural factors** to play a more central role in urban comfort models, moving beyond secondary consideration to provide more context-sensitive and socially responsive insights.

Conclusion

This study critically examined the indicators of outdoor thermal comfort (OTC) and their influence on pedestrian behaviour in urban streets, with a focus on both developed and developing country contexts, including India. By systematically reviewing and scoring indicators across four dimensions—Physical, Physiological, Psychological, and Behavioural—the analysis highlights that physical factors dominate current research due to their measurability and established modeling frameworks. Key indicators such as Temperature, Relative Humidity, Mean Radiant Temperature, Solar Radiation, Wind Velocity, Height-to-Width Ratio, Sky View Factor, and Thermal Sensation Vote are consistently prioritised across studies, reflecting their importance in assessing urban microclimates.In contrast, psychological and behavioural indicators remain underrepresented, particularly in Indian contexts, where cultural practices, clothing choices, activity patterns, and socio-economic diversity strongly influence pedestrian comfort. Developed countries increasingly integrate behavioural considerations, while Indian studies primarily focus on basic climatic parameters. This gap limits the practical applicability of OTC research for real-world urban planning and design in rapidly urbanising Indian cities.The study further demonstrates that urban morphology—such as street geometry, canyon orientation, vegetation cover, shading, and the presence of water bodies—significantly affects pedestrian comfort. Mitigation strategies, including high albedo materials, vegetation, and water features, can enhance outdoor comfort, yet current methodologies often lack adaptation to local cultural and climatic conditions.To address these gaps, the study proposes region-specific, behaviour-focused assessment methods, including clothing adaptation surveys, wearable sensor monitoring, behavioural mapping of pedestrian movements, and socio-economic analyses. Integrating such approaches into OTC evaluation can strengthen urban design policies, making streets more inclusive, resilient, and climate-sensitive.Finally, the study emphasises the need to expand research beyond metropolitan centres to include tier-2 and tier-3 cities across diverse climatic zones in India. By combining quantitative climatic data with qualitative behavioural assessments, future studies can provide a more holistic and context-sensitive understanding of pedestrian comfort, thereby supporting healthier, safer, and more sustainable urban environments.

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