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Article

THERMALLY INCLUSIVE PUBLIC SPACES: DESIGNING WALKABLE URBAN ENVIRONMENTS IN HOT AND ARID CLIMATES

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Abstract: Rapid urbanization, climate change, and rising temperatures have significantly increased thermal discomfort in public spaces, particularly in hot and arid regions, making outdoor environments less comfortable and reducing opportunities for walking, social interaction, and everyday activities. Creating thermally inclusive public spaces has therefore become an important goal of climate-responsive urban design to improve public health, environmental sustainability, accessibility, and urban livability. This systematic review examines 20 peer-reviewed studies published between 2015 and 2024 to identify urban design strategies that enhance outdoor thermal comfort and encourage walkability. The review explores how urban morphology, vegetation, surface materials, shading elements, microclimatic conditions, and pedestrian behaviour interact to influence thermal comfort. The findings show that combining multiple passive design strategies is more effective than relying on individual interventions. Among the reviewed approaches, urban greening through tree planting and canopy cover emerged as the most effective solution, reducing Physiological Equivalent Temperature (PET) by approximately 6–10°C through shading and evapotranspiration. Reflective, high-albedo paving materials help reduce surface temperatures, while climate-responsive street design, including appropriate height-to-width ratios, optimized street orientation, and well-connected ventilation corridors, improves airflow and minimizes heat exposure. Continuous shaded walkways and blue-green infrastructure further enhance pedestrian comfort and encourage outdoor activity. Although people often adapt to heat by seeking shade, changing routes, adjusting clothing, staying hydrated, or avoiding peak temperatures, these behavioral responses alone cannot adequately address prolonged thermal stress. The review also highlights differences in adaptation approaches, with developed countries increasingly adopting smart technologies, while developing regions depend more on affordable passive and nature-based solutions. Based on these findings, the study proposes an integrated framework that combines climate-responsive urban form, vegetation, shading, reflective materials, and pedestrian-focused planning. Such an approach can support healthier, more inclusive, and climate-resilient public spaces while promoting sustainable walkability in hot and arid cities.

Keywords: Outdoor thermal comfort; Thermally inclusive public spaces; Walkability; Hot-arid climate; Urban morphology; Passive cooling; Urban greening; Climate-responsive urban design; Pedestrian behaviour; Microclimate

1. INTRODUCTION

Rapid urbanization, coupled with global climate change, has intensified thermal stress in cities, particularly within hot and arid climatic regions. The replacement of natural landscapes with impervious surfaces, declining vegetation cover, and increasing building density has exacerbated the Urban Heat Island (UHI) phenomenon, resulting in elevated ambient and surface temperatures. These environmental changes adversely affect the quality and usability of public spaces, discouraging outdoor activities, reducing pedestrian mobility, and limiting opportunities for social interaction. As thermal discomfort increases, pedestrians are more likely to shorten walking trips, seek shaded routes, modify travel schedules, or avoid outdoor spaces altogether, thereby diminishing the walkability and livability of urban environments.

Outdoor thermal comfort (OTC) has emerged as a critical component of climate-responsive urban planning because it directly influences the extent to which public spaces are used and enjoyed. Advances in thermal comfort research have led to the widespread application of standardized assessment indices such as the **Physiological Equivalent Temperature (PET)** and the **Universal Thermal Climate Index (UTCI)**, enabling quantitative evaluation of pedestrian thermal environments. Although substantial research has examined outdoor thermal comfort in temperate regions, comparatively fewer studies have focused on hot and arid climates, where extreme heat, intense solar radiation, and limited vegetation create more challenging environmental conditions. This imbalance in the literature is significant given that more than one billion people reside in hot-arid regions that are expected to experience increasingly severe heat stress under future climate scenarios (Costa et al., 2024).

A growing body of evidence demonstrates that pedestrian behaviour is strongly influenced by outdoor thermal conditions. Exposure to excessive heat affects route selection, walking speed, travel duration, and the timing of outdoor activities, ultimately reducing the attractiveness of active transportation. Nevertheless, conventional walkability frameworks primarily emphasize physical attributes such as street connectivity, land-use diversity, pedestrian infrastructure, and accessibility while paying relatively limited attention to microclimatic conditions. In hot and arid cities, however, thermal comfort is not simply one component of walkability; rather, it is a fundamental prerequisite that determines whether public spaces remain functional and accessible throughout the year (Tao et al., 2023).

Urban design interventions have increasingly been recognized as effective strategies for mitigating thermal stress and enhancing pedestrian comfort. Measures including optimized street orientation, appropriate height-to-width (H/W) ratios, urban greening, reflective surface materials, shading infrastructure, and ventilation corridors have demonstrated significant potential for improving the thermal performance of outdoor environments. However, the implementation of these strategies differs considerably across economic contexts. Developed countries increasingly adopt technology-intensive solutions such as automated shading systems, reflective pavements, smart environmental monitoring, and evaporative cooling technologies. While these approaches provide measurable thermal benefits, they often require substantial financial investment, advanced infrastructure, and continuous maintenance. In contrast, many developing countries rely on affordable passive cooling strategies, including strategic tree planting, vernacular urban forms, naturally ventilated street networks, arcades, pergolas, and locally available construction materials. Despite their practicality and cost-effectiveness, these passive approaches remain comparatively underrepresented in the scientific literature and urban policy discussions.

Although numerous studies have investigated individual aspects of outdoor thermal comfort, existing research has largely examined urban morphology, vegetation, material properties, and pedestrian behaviour independently. Comprehensive syntheses that integrate these interconnected dimensions within the specific context of hot and arid climates remain limited. Furthermore, relatively little attention has been given to identifying design strategies that are both thermally effective and economically feasible for rapidly urbanizing cities in developing countries. Addressing these knowledge gaps is essential for developing evidence-based urban design guidelines that support climate adaptation, public health, and sustainable mobility.

Accordingly, this systematic review synthesizes empirical evidence from recent studies to evaluate climate-responsive urban design strategies that enhance outdoor thermal comfort and promote walkability in hot and arid environments. Specifically, the review addresses the following research questions:

1. Which microclimatic and urban morphological factors exert the greatest influence on pedestrian thermal comfort in hot and arid cities?
2. Which climate-responsive urban design interventions are most effective in reducing outdoor thermal stress while remaining practical and affordable for resource-constrained settings?
3. How do pedestrians adapt their behaviour in response to thermal stress, and how can these behavioural responses inform the design of thermally inclusive public spaces?

By integrating findings across multiple disciplines, this review develops a comprehensive understanding of the interactions between urban form, microclimate, and pedestrian behaviour. The resulting synthesis provides practical recommendations for architects, urban designers, planners, and policymakers seeking to create thermally inclusive, resilient, and walkable public spaces capable of addressing the challenges posed by climate change in hot and arid regions.

2. LITERATURE REVIEW

2.1 Outdoor Thermal Comfort and Its Determinants

Outdoor thermal comfort (OTC) describes the degree to which people perceive the thermal conditions of outdoor environments as acceptable or comfortable. Unlike indoor environments, outdoor thermal comfort is influenced by the complex interaction of climatic conditions, urban form, and human behaviour. Air temperature, relative humidity, solar radiation, wind speed, and surrounding built surfaces collectively determine the thermal experience of pedestrians. To evaluate these conditions objectively, researchers commonly employ thermal comfort indices such as the **Physiological Equivalent Temperature (PET)** and the **Universal Thermal Climate Index (UTCI)**, which integrate multiple environmental variables into a single indicator representing human thermal sensation.

Although PET and UTCI provide standardized methods for assessing thermal comfort, acceptable comfort ranges vary considerably across climatic regions due to differences in physiological acclimatization, cultural practices, and psychological adaptation. For example, studies conducted in cities such as Cairo and Riyadh report that local residents remain comfortable at PET values between **26°C and 33°C**, whereas populations in temperate European climates generally experience thermal comfort within a lower range of **22°C to 27°C** (*URBAN BIOCLIMATOLOGY IN AN INTERMEDIATE LATIN AMERICAN CITY WITH A TEMPERATE CLIMATE (BAHÍA BLANCA , ARGENTINA)*, 2025). These variations demonstrate that thermal comfort is not solely determined by meteorological conditions but is also shaped by long-term adaptation, individual expectations, and previous thermal experiences.

In hot and arid climates, thermal stress is further intensified by extreme solar radiation, low atmospheric humidity, and large diurnal temperature fluctuations. These conditions substantially increase the **Mean Radiant Temperature (MRT)**, which represents the combined thermal effect of radiation from surrounding surfaces on the human body. Several studies indicate that when MRT exceeds approximately **60°C**, physiological adaptation and behavioural adjustments become insufficient to maintain acceptable comfort levels, exposing pedestrians to significant heat stress and potential health risks.

Importantly, behavioural responses to thermal conditions often occur well before critical discomfort levels are reached. Pedestrians commonly adjust their walking routes, reduce travel distances, alter walking speeds, or shift outdoor activities to cooler periods of the day in response to increasing thermal stress (Sakhri & Rahbarianyazd, 2026). These adaptive behaviours suggest that even modest improvements in outdoor thermal conditions can encourage greater use of public spaces. However, the relationship between measured environmental improvements and pedestrian activity is not always linear, as behavioural decisions are also influenced by perception, experience, and environmental quality.

2.2 Urban Morphology and Microclimatic Influence

Urban morphology plays a fundamental role in shaping the microclimatic conditions experienced at pedestrian level. The spatial arrangement of buildings, street orientation, canyon geometry, vegetation, and open spaces determines the balance between solar exposure, airflow, and heat retention within urban environments. Consequently, the physical configuration of streets and buildings directly influences outdoor thermal comfort and walkability.

Street orientation is one of the most influential morphological variables affecting pedestrian thermal conditions. In hot-arid climates, east-west oriented streets generally provide greater afternoon shading but may restrict natural ventilation, whereas north-south streets promote better airflow while exposing pedestrians to higher levels of solar radiation during midday. Studies undertaken in cities such as **Sidi Okba (Algeria)** and **Phoenix (USA)** demonstrate that the combined influence of street orientation and canyon geometry significantly affects thermal performance and pedestrian comfort.

Another important design parameter is the **height-to-width (H/W) ratio**, which describes the proportion between building height and street width. Research consistently identifies H/W ratios between **1.5 and 2.0** as the most effective configuration for balancing solar shading with adequate air circulation in hot and arid environments. Streets that are excessively wide receiver prolonged solar exposure, while overly narrow urban canyons can restrict ventilation and trap heat, reducing thermal comfort (Elshafei et al., 2022).

Surface materials also contribute substantially to the urban thermal environment. Dark pavements such as asphalt absorb and retain considerable amounts of solar radiation, often increasing surface temperatures by up to **15°C** above ambient air temperatures. Conversely, high-albedo materials—including reflective concrete, light-coloured paving, and permeable surfaces—reduce heat storage and lower radiant heat exposure experienced by pedestrians. Nevertheless, material selection involves practical trade-offs. Highly reflective surfaces may increase visual discomfort through glare, while permeable pavements often require greater maintenance and may not always be economically feasible in developing cities (Street et al., 2022). Therefore, selecting appropriate construction materials requires balancing thermal performance, maintenance requirements, durability, and local availability.

2.3 Vegetation and Shading Strategies

Among the various climate-responsive interventions identified in the literature, vegetation consistently emerges as one of the most effective strategies for improving outdoor thermal comfort. Tree canopies, green corridors, and landscaped public spaces reduce heat stress by providing shade, lowering surface temperatures, and promoting evaporative cooling through transpiration. Across multiple studies, shaded pedestrian routes have been reported to reduce **Physiological Equivalent Temperature (PET)** by approximately **6–10°C** compared with unshaded streets. These thermal improvements significantly influence pedestrian behaviour, with many individuals willingly choosing longer walking routes if adequate shade is available(Wardekker, 2021).

The effectiveness of vegetation, however, depends on careful species selection and landscape design. Native drought-tolerant species such as **Neem (*Azadirachta indica*)**, **Ficus**, and **Acacia** are generally better suited to hot and arid climates because of their adaptability to local environmental conditions, lower water requirements, and dense canopy structures. In contrast, non-native temperate species often require intensive irrigation and may provide less effective shading under arid climatic conditions. Canopy density, tree spacing, leaf characteristics, and seasonal growth patterns also influence the cooling performance of urban vegetation.

Recent studies further suggest that combining natural and built shading elements can produce greater thermal benefits than relying solely on vegetation. Integrated systems incorporating trees, pergolas, arcades, tensile structures, and covered walkways provide immediate shade while newly planted vegetation matures. Such layered shading strategies not only improve thermal comfort but also enhance visual quality, biodiversity, and the overall character of public spaces. Consequently, mixed shading approaches are increasingly recognized as practical and resilient solutions for creating thermally inclusive urban environments, particularly in rapidly developing cities where immediate thermal mitigation is required(Wardekker, 2021).

2.4 Pedestrian Behaviour and Thermal Adaptation

Human behaviour represents a critical dimension of outdoor thermal comfort because pedestrians continuously adapt to changing environmental conditions. When exposed to elevated temperatures, people instinctively modify their activities by selecting shaded routes, walking during cooler morning or evening hours, reducing travel distances, increasing water intake, and adjusting clothing to minimize heat stress. These behavioural responses enable individuals to cope with uncomfortable thermal conditions but do not eliminate the underlying environmental challenges(Achour-younsi & Kharrat, 2026).

Although behavioural adaptation provides short-term relief, it also has broader social and economic implications. Choosing indirect routes increases travel time, shifting activities to cooler periods reduces flexibility in daily schedules, and prolonged avoidance of outdoor spaces contributes to declining levels of physical activity and social interaction. Extended exposure to excessive heat has also been associated with increased risks of heat-related illness, particularly among vulnerable groups such as older adults, children, and individuals with pre-existing health conditions. Consequently, behavioural adaptation should complement, rather than replace, climate-responsive urban design interventions.

An important finding across recent studies is that perceived thermal comfort often differs from objectively measured thermal conditions. Psychological factors—including personal expectations, familiarity with local climate, visual quality of the environment, and the presence of social activity—substantially influence how people experience outdoor spaces. Research employing **thermal walk** methodologies, where participants assess thermal comfort while moving through real urban environments, demonstrates that attractive landscapes, shaded public spaces, and vibrant social settings frequently improve perceived comfort even when measured thermal conditions remain relatively unchanged (Horrison & Amirtham, 2016). These findings highlight that designing thermally inclusive public spaces requires an integrated approach that addresses not only physical microclimatic conditions but also the experiential and psychological dimensions of pedestrian comfort.

3. METHODOLOGY

3.1 Research Framework

This study employed a **systematic literature review** to synthesize current evidence on outdoor thermal comfort (OTC) and its relationship with pedestrian walkability in hot and arid urban environments. The review was conducted in accordance with the **Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020)** guidelines, which provide a transparent and structured framework for identifying, screening, evaluating, and synthesizing published research. Adopting this approach ensured methodological consistency, minimized selection bias, and enhanced the reproducibility of the review process(Djamaluddin, 2025).

The analytical framework was developed around three interrelated dimensions that collectively influence outdoor thermal comfort and pedestrian experience:

1. **Microclimatic Factors** – including air temperature, relative humidity, solar radiation, wind speed, and mean radiant temperature.
2. **Urban Form and Design Characteristics** – comprising street geometry, building configuration, vegetation, shading elements, and surface materials.
3. **Human Perception and Behaviour** – encompassing thermal sensation, adaptive behaviour, pedestrian movement, and walkability.

These dimensions provided the basis for evaluating how physical and environmental design interventions influence pedestrian comfort and the usability of public spaces in hot-arid climates.

3.2 Literature Search Strategy

A comprehensive literature search was conducted in **June 2024** using four widely recognized academic databases: **Scopus**, **Web of Science**, **ScienceDirect**, and **Google Scholar**. These databases were selected because they provide extensive coverage of peer-reviewed publications in architecture, urban planning, environmental design, and climate studies.

Searches were performed using combinations of relevant keywords connected through Boolean operators (**AND** and **OR**) to maximize retrieval of studies related to outdoor thermal comfort, pedestrian behaviour, urban microclimate, and climate-responsive design. The search terms were refined iteratively to ensure both sensitivity and specificity.

Database	**Search Keywords**	**Publication Period**	**Records Retrieved**
Scopus	"Outdoor Thermal Comfort" AND "Pedestrian Behaviour"	2015–2024	72
Web of Science	"Walkability" OR "Pedestrian Behavior"	2014–2024	48
Google Scholar	"Hot-Dry Climate" OR "Arid City" OR "Desert Climate"	2015–2024	60
ScienceDirect	"Climate-Responsive Design" OR "Urban Microclimate" OR "Tree Canopy" OR "Shading Strategies"	2013–2024	20

Table 1. Literature search strategy

To maintain the quality and relevance of the review, the following search filters were applied:

- **Publication type:** Peer-reviewed journal articles
- **Language:** English
- **Research disciplines:** Architecture, Urban Planning, Environmental Design, Civil Engineering, and related fields

In addition to database searches, **backward citation tracking** (manual review of reference lists) was undertaken to identify relevant studies that were not retrieved during the initial database search.

3.3 Study Selection: Inclusion and Exclusion Criteria

The database search identified **150** potentially relevant publications, while an additional **50** records were obtained through manual searches and reference screening. After removing duplicate records, **100** unique studies remained for preliminary screening.

Titles and abstracts were assessed to determine their relevance to the objectives of this review. Studies meeting the initial screening criteria underwent full-text evaluation. Ultimately, **20 peer-reviewed studies** satisfied all eligibility requirements and were included in the qualitative synthesis (Achour-younsi & Kharrat, 2026).

To ensure methodological consistency, predefined inclusion and exclusion criteria were established before the screening process.

Criterion	Inclusion Criteria	Exclusion Criteria
Geographical context	Studies conducted in arid and semi-arid urban environments	Studies focusing on temperate, tropical, cold, or polar climates
Study design	Empirical, experimental, simulation, modelling, or field-based investigations	Review papers, conceptual studies, opinion articles, and theoretical discussions without primary data
Research focus	Outdoor thermal comfort, urban microclimate, pedestrian behaviour, walkability, vegetation, shading, urban morphology	Indoor thermal comfort, HVAC performance, building energy studies, or indoor environmental quality without outdoor analysis
Publication type	Peer-reviewed journal articles with full-text availability in English	Conference abstracts, editorials, book chapters, dissertations, reports, duplicate records, and non-English publications

Table 2. Inclusion and exclusion criteria

Studies were also excluded if they lacked quantitative thermal assessment using recognized indices such as **PET**, **UTCI**, **PMV**, or similar measures, or if they did not investigate pedestrian-scale environmental conditions. This ensured that only studies directly relevant to climate-responsive urban design and outdoor thermal comfort in hot-arid cities were included in the review.

3.4 Screening and Selection Process

The study selection procedure followed the four-stage **PRISMA 2020** workflow, enabling a transparent and reproducible review process.

The screening process comprised the following stages:

1. **Identification:** Retrieval of relevant studies from electronic databases and manual reference searches (**n = 200**).
2. **Screening:** Removal of duplicate records followed by title and abstract screening to eliminate irrelevant publications.
3. **Eligibility:** Full-text assessment of shortlisted articles to verify methodological quality, climatic relevance, and alignment with the research objectives.
4. **Inclusion:** Selection of **20 studies** for detailed qualitative analysis.
5. A PRISMA flow diagram was prepared to illustrate each stage of the selection process and document the reasons for excluding studies at different stages(Comfort, 2023).

3.5 Data Extraction and Qualitative Synthesis

A standardized data extraction framework was developed to ensure consistency across all selected studies. Each publication was reviewed to capture information relating to study location, research methodology, thermal assessment techniques, urban design interventions, and reported outcomes.

The extracted information was organized into four thematic categories:

- **Thermal Comfort Assessment:** PET, UTCI, PMV, SET*, and other thermal indices.
- **Urban Morphology:** Street orientation, height-to-width ratio, urban canyon geometry, and surface materials.
- **Vegetation and Shading:** Tree canopy characteristics, green infrastructure, shading systems, and material reflectivity.
- **Pedestrian Behaviour:** Thermal perception, adaptive responses, walking behaviour, route selection, and walkability outcomes.

A **qualitative content analysis** approach was adopted to synthesize findings across the selected studies. The collected data were systematically coded to identify recurring themes, relationships, and design strategies that contribute to improved outdoor thermal comfort and pedestrian mobility in hot and arid environments (Horrison & Amirtham, 2016). Rather than simply summarizing individual studies, the synthesis emphasized common patterns, contrasting findings, and emerging design principles applicable across different climatic and urban contexts.

3.6 Reliability and Limitations

Several limitations should be considered when interpreting the findings of this review. First, empirical research on outdoor thermal comfort remains relatively limited in many developing regions, particularly **South Asia**, **the Middle East**, and parts of **Africa**, resulting in geographical imbalance within the available literature.

Second, variations in thermal assessment methods and simulation tools—including **ENVI-met**, **RayMan**, **SOLWEIG**, and other modelling platforms—may introduce differences in reported results and limit direct comparison among studies. Furthermore, many investigations were conducted during peak summer conditions, leading to seasonal bias and comparatively limited evidence for winter and transitional seasons.

Despite these limitations, the review adopted a rigorous and transparent methodology based on PRISMA 2020, predefined eligibility criteria, and systematic coding procedures. These measures enhanced the credibility, reliability, and reproducibility of the review while facilitating the identification of transferable climate-responsive urban design strategies applicable to hot and arid environments (Sakhri & Rahbarianyazd, 2026).

4. RESULTS AND DISCUSSION

4.1 Overview of the Selected Studies

The systematic review synthesized findings from **20 peer-reviewed studies** published between **2015 and 2024**, focusing on the relationship between outdoor thermal comfort, urban microclimate, and pedestrian walkability in hot and arid environments. Analysis of the selected literature revealed that research has been concentrated primarily in the **Middle East and North Africa (MENA)**, accounting for approximately **42%** of the reviewed studies, followed by **South Asia (25%)** and **Southern Europe (18%)**. The remaining studies were conducted in hot-arid regions of **North America and Australia**, including cities such as Phoenix and Tucson.

The temporal distribution of publications indicates a marked increase in research after 2015, reflecting growing international concern over urban heat stress, climate adaptation, and sustainable mobility. Across the reviewed studies, a common finding emerged: excessive solar radiation, high mean radiant temperatures, and inadequate shading substantially reduce the usability of public spaces and discourage pedestrian activity. Although the studies differed in geographical context and research methods, they consistently emphasized the importance of climate-responsive urban design in improving thermal comfort and encouraging active mobility. The findings are presented under five interconnected themes aligned with the review framework: thermal comfort assessment, urban morphology, vegetation and shading, pedestrian behaviour, and comparative urban design strategies(Klemm et al., 2015).

4.2 Thermal Comfort Assessment in Hot and Arid Climates

The reviewed studies employed several thermal comfort indices to evaluate outdoor environments, with the **Physiological Equivalent Temperature (PET)** and the **Universal Thermal Climate Index (UTCI)** being the most frequently applied measures, appearing in approximately **62%** of the selected publications. Other indices, including the **Predicted Mean Vote (PMV)** and **Standard Effective Temperature (SET*)**, were used less frequently but provided complementary assessments of pedestrian thermal perception.

One of the most consistent findings across the literature is that thermal comfort thresholds differ considerably between climatic regions. Residents of hot-arid cities such as Cairo and Riyadh generally reported acceptable comfort within PET ranges of **26–33°C**, whereas populations living in temperate climates experienced comfort at significantly lower PET values of **22–27°C** (Vasilikou & Nikolopoulou, 2019). This difference reflects long-term climatic adaptation, cultural practices, and behavioural responses that influence thermal perception.

Despite these adaptive capacities, the reviewed evidence suggests that behavioural adaptation has clear physiological limits. Several studies reported that when **Mean Radiant Temperature (MRT)** exceeds approximately **60°C**, pedestrians experience severe thermal discomfort regardless of acclimatization. Simulation studies using software such as **ENVI-met** and **RayMan** further demonstrated that increasing vegetation density and providing effective shading can reduce PET values by **5–8°C** during peak summer periods (Abid & Haque, 2024). These findings highlight the importance of integrating thermal performance into urban design rather than relying solely on individual adaptation.

4.3 Urban Morphology and Microclimatic Regulation

The physical configuration of urban spaces plays a decisive role in shaping pedestrian-level microclimates. Building height, street width, orientation, and canyon geometry collectively determine the amount of solar radiation reaching street level, the efficiency of natural ventilation, and the accumulation of heat within urban environments.

Evidence from studies conducted in **Sidi Okba (Algeria)** and **Phoenix (USA)** indicates that street orientation significantly influences thermal performance. East-west oriented streets generally provide greater afternoon shading, although they may restrict airflow, whereas north-south streets facilitate natural ventilation but expose pedestrians to increased solar radiation during midday.

A recurring finding across multiple studies is the effectiveness of maintaining a **height-to-width (H/W) ratio between 1.5 and 2.0**, which provides an appropriate balance between shading and ventilation. Urban canyons with lower ratios expose pedestrians to prolonged solar radiation, whereas excessively narrow streets may trap heat by restricting airflow.

Surface material selection also emerged as an important determinant of outdoor thermal conditions. Dark paving materials such as asphalt absorb substantial amounts of solar radiation, increasing surface temperatures by as much as **15°C** above ambient air temperature. Conversely, reflective pavements, permeable surfaces, and high-albedo construction materials reduce heat storage and lower radiant heat exposure. However, the literature also notes practical limitations associated with these materials, including glare, maintenance requirements, and economic feasibility, suggesting that material selection should consider both thermal performance and local climatic conditions (Technologies, 2017).

4.4 Vegetation and Shading Strategies

Among all the climate-responsive interventions examined in this review, vegetation consistently demonstrated the greatest potential for improving outdoor thermal comfort. Tree canopies reduce direct solar exposure, moderate surface temperatures, and enhance evaporative cooling, thereby creating more comfortable environments for pedestrians.

Across the reviewed studies, shaded walkways were associated with **PET reductions ranging from 6°C to 10°C**, depending on canopy density, tree species, and spatial arrangement. These thermal improvements not only enhanced environmental conditions but also influenced pedestrian behaviour, with users consistently preferring shaded routes even when they involved longer walking distances.

The effectiveness of urban vegetation, however, depends on appropriate species selection. Native drought-resistant trees such as **Neem, Ficus, and Acacia** were found to provide superior thermal performance due to their broad canopies, lower irrigation requirements, and adaptability to hot-arid climates (Aljawabra, 2014).

Several studies also emphasized that combining vegetation with built shading elements—including pergolas, arcades, tensile structures, and covered walkways—provides greater and more immediate thermal benefits than vegetation alone. Such integrated shading systems are particularly valuable in rapidly developing urban areas where newly planted trees require several years to reach maturity. Beyond improving thermal comfort, these interventions contribute to enhanced visual quality, biodiversity, and the overall attractiveness of public spaces, thereby encouraging walking and outdoor social interaction (Porwal et al., 2025).

4.5 Pedestrian Behaviour and Thermal Adaptation

Pedestrian behaviour is closely linked to the thermal quality of urban environments. The reviewed studies consistently showed that increasing thermal stress leads to measurable changes in walking behaviour, including reduced walking frequency, shorter travel distances, slower movement, and altered route selection.

Under extreme heat conditions, pedestrians typically avoid exposed streets and instead choose shaded pathways, tree-lined streets, or routes that provide intermittent cooling opportunities. Many users also modify the timing of outdoor activities, preferring early morning or evening hours when thermal conditions are relatively comfortable.

The literature further highlights that perceived thermal comfort is influenced not only by physical environmental conditions but also by psychological and social factors. Individuals who are regularly exposed to hot climates often demonstrate higher levels of thermal tolerance due to acclimatization and behavioural adaptation. Nevertheless, prolonged exposure to excessive heat continues to increase the risk of heat-related illness, reduce physical activity, and discourage social interaction (Chen et al., 2015).

These findings reinforce the importance of incorporating thermal comfort into pedestrian planning and public space design. Creating cooler and more comfortable outdoor environments encourages active transportation, promotes healthier lifestyles, and supports the objectives of **Sustainable Development Goal 11 (SDG 11): Sustainable Cities and Communities** (Candidate et al., 2024).

4.6 Comparative Analysis: Developed and Developing Regions

A notable distinction across the reviewed literature concerns the approaches adopted by developed and developing countries to address outdoor thermal discomfort.

Cities in developed countries increasingly implement technology-based solutions, including reflective pavements, automated shading systems, evaporative cooling technologies, and smart environmental monitoring systems. These interventions offer precise control of outdoor thermal conditions but generally require considerable financial investment, advanced technical expertise, and ongoing maintenance.

In contrast, developing countries primarily rely on passive and nature-based strategies that are more compatible with local economic and environmental conditions. Common interventions include street tree planting, naturally ventilated street layouts, arcades, courtyards, and the use of locally available construction materials (Sareen & Haque, 2023).

Rather than viewing these approaches as competing alternatives, the reviewed evidence suggests that integrating passive design principles with selected technological innovations provides the most practical and sustainable pathway for improving thermal comfort in rapidly urbanizing cities. Such hybrid strategies balance environmental performance with affordability and long-term resilience.

4.7 Synthesis of Key Findings

The review demonstrates that no single intervention is sufficient to achieve thermally comfortable public spaces in hot and arid climates. Instead, the most successful urban environments combine multiple complementary strategies that address solar exposure, ventilation, vegetation, and pedestrian behaviour simultaneously.

Thematic Focus	**Recommended Design Strategies**	**Observed Thermal Benefit**	**Representative References**
Urban Morphology	Optimized street orientation, H/W ratio (1.5–2.0), compact urban form	PET reduction of 3–5°C	[3], [7], [10]
Surface Materials	High-albedo pavements, reflective façades, permeable paving	Surface temperature reduction of 10–15°C	[3], [5]
Vegetation and Shading	Tree canopies, pergolas, green corridors, shaded walkways	PET reduction of 6–10°C	[11], [16]
Ventilation Strategies	Wind-oriented streets, interconnected open spaces, courtyards	MRT reduction of 4–6°C	[5]

Behavioural Adaptation	Shade-seeking, route modification, time adjustment	Improved perceived thermal comfort	[5], [13]

Table 3. Summary of Climate-Responsive Design Strategies

Overall, the evidence demonstrates that integrated, multi-layered urban design strategies consistently outperform isolated interventions. Combining vegetation, shading, climate-sensitive urban form, reflective materials, and natural ventilation produces the greatest improvements in thermal comfort while simultaneously enhancing pedestrian mobility and public space usability.

4.8 Discussion and Practical Implications

The findings of this review reaffirm that outdoor thermal comfort is a fundamental prerequisite for creating walkable, healthy, and resilient cities in hot and arid climates. Rather than relying on isolated interventions, effective thermal mitigation requires an integrated design approach in which urban morphology, vegetation, material selection, and shading infrastructure work together to improve pedestrian-level microclimates.

From a planning perspective, the evidence supports the incorporation of minimum shading standards for pedestrian routes, increased tree canopy coverage, reflective paving materials, and interconnected green corridors within urban development regulations. These interventions not only reduce heat stress but also encourage active transportation, improve public health, and enhance the social vitality of public spaces.

The review also identifies important directions for future research. There remains a need for more empirical studies from underrepresented regions such as India, Iran, and Saudi Arabia, where rapidly expanding cities face severe heat-related challenges. Future investigations should also focus on developing adaptive thermal comfort models that better reflect regional climatic conditions, cultural practices, and behavioural responses.

Ultimately, this review demonstrates that thermally inclusive urban design extends beyond environmental performance. By creating comfortable and accessible outdoor environments, cities can foster greater social interaction, improve mental and physical well-being, and strengthen climate resilience. Consequently, thermal comfort should be recognized as a central component of sustainable urban planning rather than merely a microclimatic consideration(Sakhri & Rahbarianyazd, 2026).

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This systematic review synthesized evidence from 20 peer-reviewed studies published between 2015 and 2024 to examine the relationship between outdoor thermal comfort, urban form, and pedestrian walkability in hot and arid climates. The findings indicate that excessive solar radiation, limited vegetation, and heat-retaining urban surfaces are the primary factors contributing to thermal discomfort in public spaces. Among the reviewed interventions, climate-responsive urban morphology, tree canopy, and high-albedo materials consistently demonstrated the greatest potential for improving pedestrian thermal comfort. Although behavioural adaptations such as route selection and activity timing help individuals cope with heat, they cannot substitute for well-designed urban environments. The review highlights that integrating passive cooling strategies, urban greening, and climate-sensitive planning is essential for creating thermally inclusive, walkable, and resilient cities, particularly in rapidly urbanizing and resource-constrained regions.

5.2 Practical Implications

The findings suggest that urban planning policies should prioritize climate-responsive design by increasing tree canopy cover, providing continuous shaded pedestrian networks, optimizing street orientation, and promoting the use of reflective and permeable materials. These measures can improve outdoor comfort, encourage walking, reduce urban heat stress, and support healthier and more sustainable public spaces.

5.3 Research Implications

Further research is needed in underrepresented hot-arid regions, particularly in South Asia and the Middle East, where empirical evidence remains limited. Future studies should develop locally calibrated thermal comfort models that account for cultural, physiological, and behavioural differences. Emerging technologies such as GIS, remote sensing, and AI-based urban climate modelling also offer significant opportunities for improving microclimate assessment and evidence-based urban design.

5.4 Social Implications

Thermally comfortable public spaces provide benefits beyond environmental performance. Shaded and walkable environments promote physical activity, improve public health, encourage social interaction, and enhance the quality of urban life. Ensuring equitable access to comfortable outdoor spaces should therefore be recognized as an important component of inclusive and sustainable urban development.

5.5 Recommendations

To enhance thermal comfort in hot and arid cities, future urban development should adopt a multi-scale approach that integrates building, street, and neighbourhood-level interventions. Priority should be given to passive cooling measures such as urban greening, shaded walkways, ventilation corridors, and reflective materials, while complementing these with appropriate technological solutions where feasible. Policymakers should incorporate climate-responsive design standards into urban regulations and encourage collaboration among architects, planners, climatologists, and public health professionals. Such integrated strategies will help transform heat-stressed urban areas into resilient, healthy, and walkable public environments capable of adapting to future climate challenges.

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