SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 12, No. 5, (2026), pp. 1825-1838
Open Access. Online & Print

DOI: 10.5281/zenodo.21204998

A SYSTEMATIC ANALYSIS OF TREE SPATIAL ARRANGEMENTS AND THEIR IMPACT ON URBAN THERMAL ENVIRONMENTS

Mohd. Firoz Anwar[1*] and Mazharul Haque[2]

[1]Research Scholar, Department of Architecture and Planning, National Institute of Technology Patna, Patna, Bihar 800005, India; Email: mohda.ph21.ar@nitp.ac.in, Orcid ID: 0009-0003-3766-6113
[2]Associate Professor, Department of Architecture and Planning, National Institute of Technology Patna, Patna, Bihar 800005, India; Email: mazharul@nitp.ac.in, Orcid ID: 0000-0002-5224-8636

Received: 12/04/2026
Accepted: 26/05/2026

Corresponding Author: Mohd. Firoz Anwar (mohda.ph21.ar@nitp.ac.in)

ABSTRACT

Rapid urbanization and climate change have worsened the urban heat island (UHI) effect, underscoring the need for strategic vegetation placement to promote sustainable development. Although the cooling benefits of urban trees are well-recognised, the influence of different spatial arrangements on microclimate regulation remains fragmented. This review consolidates evidence on how tree placement strategies grouped, linear, and individual—impact microclimate, thermal comfort, and heat mitigation across various climatic zones. Following the PRISMA guidelines, we searched the Web of Science, Scopus, and Google Scholar databases for peer-reviewed articles published between 2015 and 2025. From an initial pool of 279 papers, 49 peer-reviewed articles were analysed, focusing on microclimate outcomes such as tree configuration types, climatic parameters, cooling metrics, and comfort indices. Results showed that grouped trees achieve the highest cooling, lowering ambient temperatures by up to 5°C through evapotranspiration and canopy overlap. Linear tree arrangements effectively cool corridors, reducing surface temperatures by 2-4°C along pathways. Individual trees provide targeted cooling, especially when positioned 5-10 meters from buildings, leading to indoor cooling reductions of 10-15%. Research has been primarily conducted in East Asia (38%), with notable gaps in South Asia and Africa. Tree configuration plays a significant role in microclimate regulation, influencing thermal outcomes through shading, evapotranspiration, and wind flow modifications. This review goes beyond thermal outcomes to identify critical implementation challenges, highlighting urgent gaps in translating evidence into practice. This review provides a framework for urban planners to optimise the placement of trees. Future research should investigate the long-term impacts, species responses, and integration of green infrastructure.

KEYWORDS: Urban Heat Islands, Microclimate Regulation, Tree Configuration, Thermal Comfort.

Copyright: © 2026. This is an open-access article distributed under the terms of the Creative Commons Attribution License. (https://cre-ativecommons.org/licenses/by/4.0/).

1. INTRODUCTION

Rapid urbanization has led to significant changes in the urban microclimate, particularly through the urban heat island (UHI) effect, which poses numerous challenges to public health and welfare (Ronchi, Salata, and Arcidiacono, 2020; Gupta et al., 2025). The UHI phenomenon, characterized by higher temperatures in urban areas compared to their rural surroundings, not only diminishes the comfort and health of city dwellers but also threatens urban biodiversity (Gupta and Haque, 2025). With global urbanization [4] on the rise and climate change driving temperatures even higher, the need to address these challenges is more pressing than ever. Research indicates that for every 1°C increase in daily maximum temperatures above 32°C in urban settings, there is a 1%- 3% rise in illness and death rates [5]. A stark example of this was seen during the scorching summer of 2003 in Western Europe, where an estimated 52,000 additional deaths were linked to heat stress[6]. Sudden urbanization of global cities is a well-documented phenomenon. These cities attract many people, and as the population grows, more structures are built [7] and more land is paved, exacerbating the UHI effect. The need to look at how to counteract this effect is becoming more pressing [8], [9], [10], [41]. One increasingly recognised way to do that is to install urban green spaces. Green space lowers local temperatures and brings other benefits, crucial for any conversation about sustainable cities [11], [12], [13]. However, the specific ways in which various tree placement strategies influence the microclimate are still not well understood. By consolidating global case studies and analyses, this study aims to bridge that gap. However, the translation of this evidence into broader urban forestry practice remains underexplored in the current literature. Thus, this study addresses this knowledge gap.

Urban green infrastructure is recognised as a core nature-based solution for reducing heat stress and enhancing climate resilience, requiring decision-support tools that operate across multiple spatial and governance scales [43]. Urban greenery is an important aspect of growing urban areas. Trees, by providing shade and cooling the air, make urban environments healthier and sustainable (Shashua-Bar, Pearlmutter, and Erell, 2011; Winbourne et al., 2020). Trees are described as the “lungs of the city” for these reasons [16]. Transpiration is the process by which trees cool the surrounding atmosphere. The water moves upward from the roots of the tree to its trunk, branches, and then eventually evaporates through its leaves. This water vapour cools the atmosphere around it as it enters the air. A significant reduction in temperature can be noticed around a properly placed tree when transpiration occurs in combination with other tree processes, like shading and radiation absorption [17]. One of the research studies interestingly suggests that trees with lower densities regulate the microclimate better than the densely packed ones [18]. Wang et al. found that the cooling effect of trees peaks and temperatures can drop by as much as 4°C just at the point before crown closure [18], [19]. Hence, proper placement of the trees is important, along with the species selection to ensure optimal cooling effects in urban areas. Studies done by Sharmin in different cities with diverse climates suggest that different tree arrangements with different spacing patterns affect the microclimate differently [16]. Another study done by Qunshan Zhao and his coauthors employed the ENVl met model to evaluate various tree configurations for their impacts on the climate of Phoenix, Arizona, suggesting that different tree layouts have different impacts on the urban microclimate [20]. Their study shows that pairs of trees spaced evenly apart were the most effective in boosting thermal comfort in the city's hot, dry weather [20]. Sahar Sodoudi and her team conducted a study where 25 green spaces in Berlin, Germany, were analyzed through simulations [21]. They found that cooling of the urban environment is largely dependent on the arrangement of trees and the type of vegetation. The most effective in reducing heat were the linear tree layouts. Due to this, the authors indicate that the cooling effects are not just determined by the green areas but by their specific arrangements. Urban trees offer many benefits to cities and their residents, particularly in their ability to improve local air quality, but the mechanisms by which tree spacing, arrangement, and proximity to buildings affect the microclimate are still not understood [22], [23].

Thus, this study addresses this knowledge gap. Research on urban trees has focused on canopy coverage, the leaf area index (LAI), and crown dimensions as the key factors impacting the microclimate. Spatial arrangement of trees and how that affects urban temperatures and thermal comfort has been emphasized recently. For example, group plantings form cooling pockets, while linear plantings enhance thermal comfort along streets. Such spatial layouts can modulate airflow, increase or decrease ventilation, and alter the extent of shaded areas [24]. In this study, we closely look at these findings and their implications for tree planting in urban areas. Research on how tree spacing and arrangement affect microclimatic conditions like temperature, humidity, and wind behaviour is still developing. What we do know is that trees can have a significant impact on these parameters. For example, the shade cast by trees can lower surface temperatures during the day, while at night, tree cover can reduce radiative cooling and help maintain warmer surface temperatures [23]. But how does the specific layout of trees influence these outcomes? The authors of this study conducted a 'Systematic Literature Review' to get a handle on that question. Initially, 279 articles were found using Boolean combinations. After applying a strict set of exclusion and inclusion criteria, 28 articles were selected for a full review. From these, 11 case studies were chosen because they best support the approach taken in this study. These case studies reinforce the relevance and applicability of the findings to contexts similar to those in which they were conducted. The detailed methodology is presented under the Methodology section. This study offers evidence-based guidance for improving tree arrangements to reduce Urban Heat Island effects and increase thermal comfort.

1.1. Spatial Distribution of Trees

The Urban Heat Island (UHI) effect is counteracted by the spatial arrangement of trees in urban areas. Tree layouts also impact the microclimate in several ways and enhance thermal comfort. Majorly, there are three types of tree arrangements: Grouped Planting, Linear Planting, and Individual Planting. The clustering of trees in certain areas, namely 'Grouped Planting', generates "cooling pockets" that significantly impact the local temperature. In Urban areas that are very tightly packed, this arrangement is very potent in lowering air temperatures and enhancing thermal comfort [25], [26];[44];[45];[46] Group planting is an essential strategy in landscape design, according to Li et al. (2019). This type of planting enables architects and designers to form aesthetically pleasing environments and set up natural edges. A few fundamental principles must be followed to achieve these effects, such as choosing the right species, arranging them appropriately, and maintaining them to ensure sustainability and visual coherence of the landscape. 'Linear Planting', on the other hand, is the arrangement of trees, shrubs, and other plants in orderly, linear patterns. This effective method can be used to provide shade and improve the comfort of pedestrians. The linear arrangement of trees can also act as a 'green wall', blocking an unpleasant view or enhancing the visual imagery [27].

Architects use this to create organized and visually appealing environments, used to line walkways, frame vistas, or set off spaces. This method can be highly effective if a few basic principles are followed. With proper plant selection, spacing, and maintenance, these features can offer both aesthetic and environmental payoffs.[41] This setup offers shade in specific areas, but it does not significantly alter the overall microclimate compared to other planting methods, like group or linear arrangements. [43] However, when trees are planted around structures, they provide significant localized cooling that can reduce energy demands for air conditioning. The shading from these trees cools the indoor air and, in effect, lowers utility bills while also decreasing demand on urban energy systems during high load periods. Trees in a single plantation are also used for beautification and as markers in the urban environment. Figure 1 shows a typical conceptual layout of Grouped, Linear, and Individual trees.

(a) (b) (c)

Figure 1: Sketches Showing (A) Grouped, (B) Linear, And (C) Individual Tree Layouts, respectively.

The spatial arrangement of trees and their influence on the microclimate are studied using various tools and techniques. One widely used tool is ENVI Met, a software program that simulates urban microclimates. It models how vegetation, buildings, and the atmosphere interact, giving detailed information about temperature, humidity, and wind flow patterns. Researchers in Xian used ENVI Met to understand how different tree layouts can impact cooling in the outdoor spaces of a city [27]. Lux meters are used to quantify light intensity and the effectiveness of shading. The amount of daylight that could get through the various tree canopies was measured using Lux meters in a Kuala Lumpur study. How effective different kinds of trees were at reducing sunlight and the kind of heat that could make people uncomfortable was investigated through this study [28]. In Berlin, another study used a different tool to study human comfort in outdoor spaces. They used the Physiological Equivalent Temperature (PET) index to assess how well linear green spaces cooled their city [21]. Research conducted by Höppe (1999) [29] and Sun et al. (2024) [30] employed the Physiological Equivalent Temperature (PET) to analyse how vegetation influences human thermal comfort. Tools like the Kestrel 5500 Weather Meter are generally used for collecting meteorological data in urban microclimate studies [30]. This impact is significant, as people perceive their surrounding environment based on its temperature, humidity, wind speed, and solar radiation levels. The significance and the limitations of these tools and techniques have been summarized in Table 1.

Table 1: Tools And Techniques: Significance and Limitations.

Tool/Technique	Significance	Limitations
ENVI- Met	A software that simulates how trees, buildings, and the atmosphere interact. It helps predict temperature, humidity, and wind flow in urban areas, making it easier to plan greener, cooler cities.	While ENVI-met is detailed, it requires a lot of data and can be complex to use. It also struggles to simulate long-term effects, like how trees grow and change over decades.
Lux Meters	These devices measure light intensity, helping researchers understand how much shade trees provide. This is crucial for designing spaces that stay cool and comfortable, especially in sunny urban areas.	Lux meters only measure light at specific points and times, so they don't give a full picture of how shading works over larger areas or throughout the day.
Physiological Equivalent Temperature (PET)	PET is a comfort index that considers temperature, humidity, wind, and sunlight to show how people feel outdoors. It's great for evaluating how trees improve comfort in parks, streets, and other public spaces.	PET relies on assumptions about human activity and clothing, which might not match real-life conditions. It also doesn't account for personal preferences, like some people preferring warmer or cooler weather.
Field Measurements (e.g., Kestrel 5500 Weather Meter)	These tools collect real-world data on temperature, humidity, and wind speed, which is essential for validating simulations and understanding actual microclimate conditions.	Field measurements can be time-consuming and limited to specific locations and times. They also depend on weather conditions, which can vary from day to day.

2. METHODOLOGY

This research analyzed articles identified from Web of Science, Google Scholar, and Scopus to investigate the possible research directions of the impact of tree layouts on the urban microclimate. The stages followed in carrying out the research are shown in Figure 2. Several sources and research areas were looked into for the different topics covered in this review to create a literature database for this study. Consequently, a list of search terms and their synonyms was finalized, which helped find the related literature. This study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach for a clear and organized approach. This structured guideline was originally outlined by Moher et al. [31] and later implemented in several systematic review studies. It helped in conducting a thorough review. Further details of the PRISMA guidelines are mentioned in the subsequent sections.

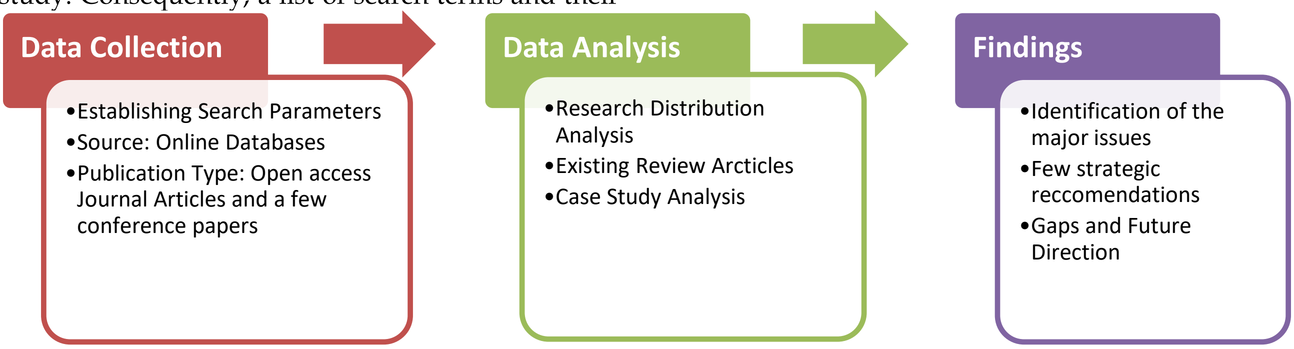

Figure 2: Methodological Approach for the Review.

2.1. Establishing Search Parameters

This research adopted the PRISMA framework to guide a thorough literature review across multiple academic fields, including urban studies, construction and building technology, regional urban planning, environmental science, ecology, geography, sustainable technologies, plant sciences, biodiversity and conservation, remote sensing, architecture, forestry, and Public Environmental and Occupational health. Relevant literature was identified through an extensive search in the Web of Science (WoS), Google Scholar, and Scopus databases. The review focused exclusively on peer-reviewed journal articles published in English between 2015 and 2025. Over the last ten years, there has been a noticeable rise in scholarly interest in this area, particularly in developing South Asian nations, likely driven by the increasing Urban Heat Island (UHI) Effect. Many of these countries have implemented effective tree layouts in their different cities and have achieved a considerable drop in temperature and experienced improvement in the other microclimatic conditions. This growing momentum in Urban Microclimate-related research limited the review to studies from the past decade.

The role of tree arrangements in the urban microclimate is an important research area. To delve into this topic, a set of search terms was developed through a constant iterative process involving all co-authors. These terms were applied to three databases—Web of Science (WoS), Google Scholar, and Scopus to locate pertinent literature. The chosen search terms reflect key elements of the research interests: "urban microclimates," "tree configuration," "thermal comfort," and "urban heat islands." Using these keywords with Boolean connectors ("AND," "OR"), four main search phrases were formed. These phrases were used to query the databases mentioned above. As a result, the papers identified had at least two of the key terms. This approach ensured that the papers not relevant to the research field were excluded.

2.2. Screening Process

An extensive literature review was conducted, drawing from a wide range of academic disciplines to ensure a focused and relevant selection. These fields included urban studies, construction and building technology, regional urban planning, environmental science, ecology, geography, sustainable technologies, plant sciences, biodiversity and conservation, remote sensing, architecture, forestry, and Public Environmental and Occupational Health. During the screening process, studies that did not explicitly address Urban Microclimate in the context of tree layout or placement, or that originated from unrelated fields such as medicine, energy fuels, general biology, chemical engineering, agriculture, general physics, etc, were excluded to maintain the study's relevance and focus. The initial screening of articles was based on their titles, keywords, and abstracts to ensure their alignment with the objectives of this review. Research addressing tree spacing, groupings, along with measurable microclimatic outcomes (e.g., temperature, humidity, and wind), was prioritized. Studies employing empirical, simulation-based, or analytical methods were included, while works outside the scope of the study or those focusing solely on vertical canopy stratification and unrelated tree physiology were excluded. Grey literature, opinion pieces, retracted literature, and editorials were also disregarded. Only open-access journals were considered for the final study. After this multi-stage review process, the final set of selected articles was organized thematically based on their key topics and issues.

The detailed steps followed during the literature screening process are illustrated in Figure 3. Peer-reviewed journal articles published between 2015 and 2025 were reviewed as part of this study. In total, 28 articles were selected from the Web of Science, with supplementary searches using Google Scholar adding 11 more case studies. This brought the total records to 39. Only English-language publications were included in the selection to maintain consistency and clarity. To enhance the robustness of this review, we also evaluated the applicability and equity implications of each tree arrangement strategy.

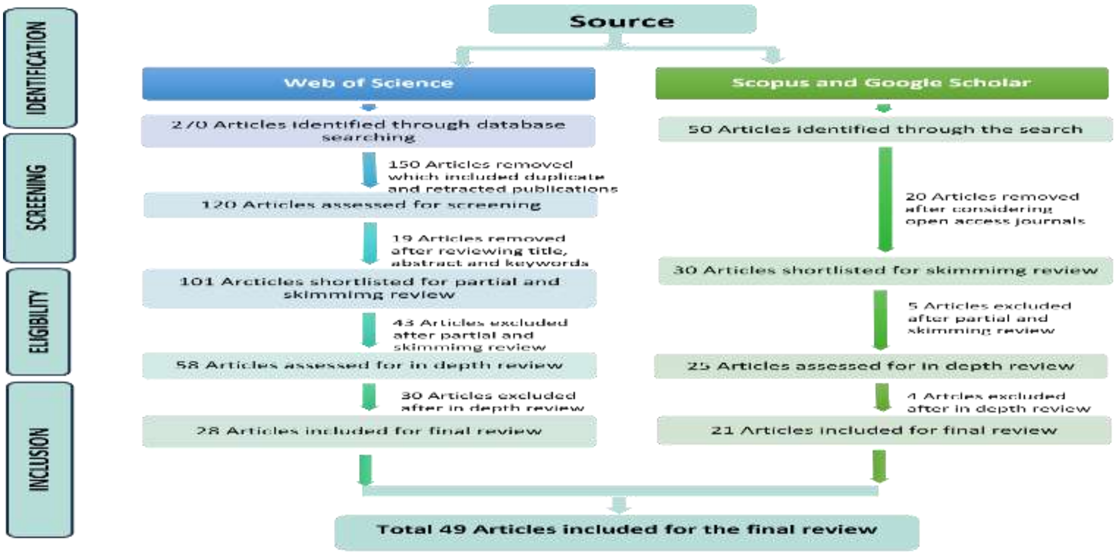

Figure 3: Outline Of the Selection Procedure Employed for the Identified Papers.

2.3. *Meta Analysis*

A meta-analysis was conducted to better understand current research areas related to urban microclimate and tree configuration. The findings were analyzed statistically and presented using graphs, tables, diagrams, and illustrative examples. 39 relevant articles were thoroughly reviewed as part of this analysis. Each study was examined for critical information, including the type of tree placement (grouped, linear, or individual), climatic and geographic context. The cooling performance, thermal comfort, and air quality results were compiled and evaluated. This thematic synthesis identified recurring patterns in tree layout impacts, variations between urban environments, and existing research gaps. These findings contributed to a structured classification of planting strategies and their associated microclimatic benefits, forming the analytical foundation for the conclusions and recommendations presented in later sections.

3. RESULTS

A comprehensive analysis was performed on the articles finalized for the review. A meta-analytic comparison was conducted across the identified studies to quantitatively link tree arrangement configurations with measured cooling effectiveness, thereby connecting thermal efficacy with practical implementation considerations. The concept of urban heat stress holds a lot of relevance in the current academic search and is frequently used across various scientific disciplines. Researchers commonly examine it through interconnected themes such as thermal comfort, the urban heat island effect, climate resilience, and sustainable urban development. Also, significant differences were observed in the Geographical Context, Climate, Type of Article, and Tree Placement Type amongst the various articles. Hence, analyses were conducted to examine and filter the number of articles by category (Fig. 4), the highest number of keywords used to understand the most explored research topics (Fig. 5), comparison of the number of publications according to their geographical context (Fig. 6) and climate (Fig. 7), and the tree placement type discussed in the articles (Fig. 8).

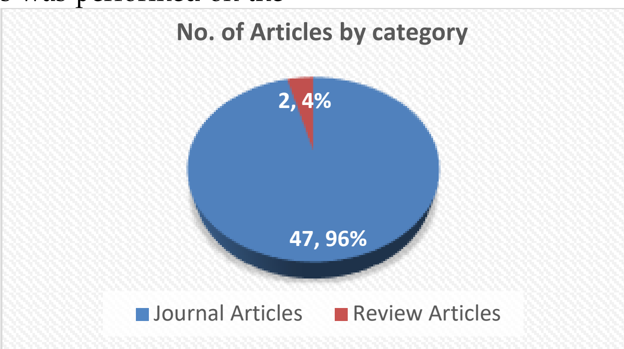

Figure 4: Distribution Of the Articles by Their Category.

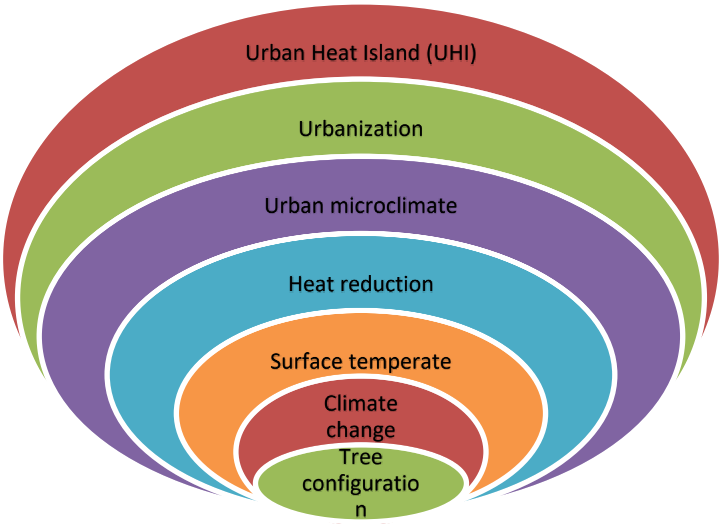

Figure 5: Frequency of Keyword Occurrence.

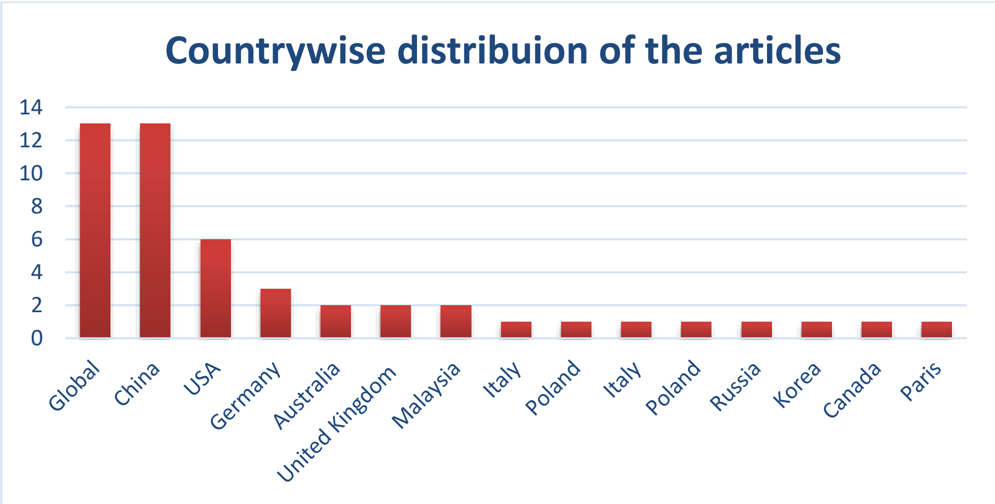

Figure 6: Distribution of the Articles by Their Geographical Location.

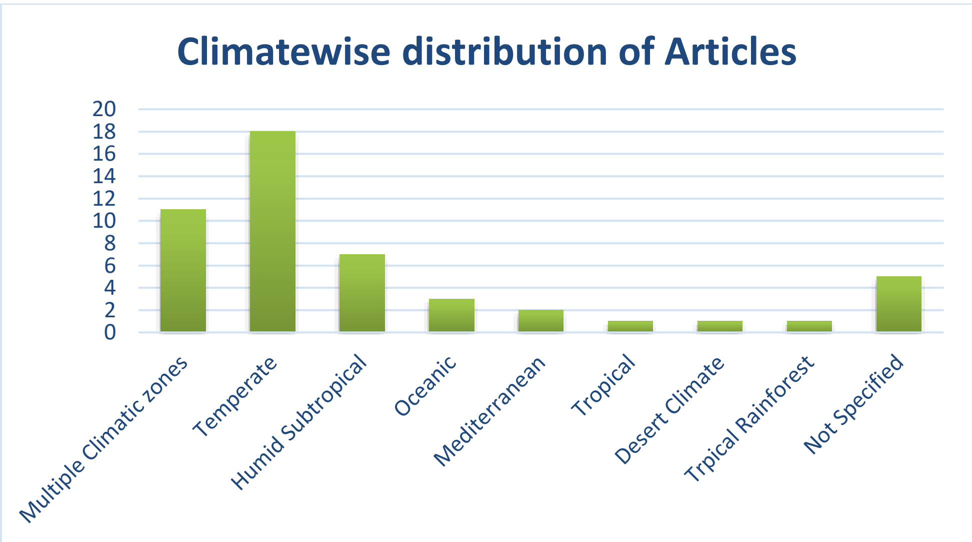

Figure 7: Distribution of the Articles by Their Climatic Zones of Study.

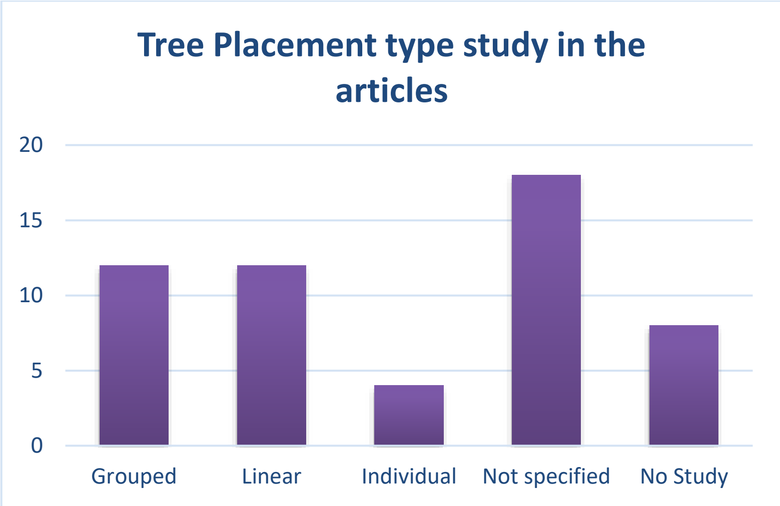

Figure 8: Distribution of the Articles by the Type of Tree Placement in the Study.

The distribution analysis of the 49 studies (Fig. 4) shows that only 2 were review articles, while the rest were original research. This considerable lack of review-based literature in tree placement and urban microclimate regulation reveals an urgent need for more synthesis-oriented research. Comprehensive review articles can bridge knowledge gaps, suggest comparative frameworks, and conduct future studies by compiling findings across different geographical locations. The illustration in Fig. 5 assisted in visualizing the analysis of keywords. The minimum number of occurrences of each keyword was taken as 3. The variation in the circle size represents the term's frequency. This aided in identifying the main themes and connections between various topics and issues. The majority of the simulation-based studies are concentrated in East Asia, particularly China, thus suggesting a bias in the current urban climatic research (Fig.6). On the contrary, the Indian Subcontinent, a region facing rapid urbanization and severe urban heat stress, shows an absence of relevant investigations in this field. This geographic gap underlines the need to direct future research efforts towards South Asia to generate context-specific insights and policy interventions. While many studies have been conducted in the temperate climatic zones such as the U.K., Canada, Australia and China, an in-depth analysis reveals that many of these studies focus mainly on the green cover or canopy density instead of the specific spatial arrangement of trees (e.g., grouped, linear, or individual placement). This lack of detailed analysis on the tree placement type reveals the research gap. Addressing this could improve the understanding of how tree placement could affect the urban microclimate.

4. DISCUSSION

This section underlines a combined assessment of the way trees are arranged in urban areas and how that affects local microclimates. It draws analysis from academic studies as well as evidence-based studies. The authors look at how effective various tree planting strategies, specifically, trees planted in groups, lined up along a street, or standing alone, are in providing thermal comfort, controlling surface temperatures, and affecting wind behaviour. This section concludes by identifying the research gap and limitations and proposing directions for long-term urban design solutions.

4.1. Spatial Arrangement of Trees

Combining results from different studies gives a clear picture of how trees affect urban microclimates. The way trees are arranged (in groups, in lines, or as individuals) influences shade, wind, and humidity conditions. Groupings of trees can create "cooling" effects with increased canopy density and evapotranspiration that lower air temperatures in some locations by up to 4°C [27]. Along the streets and pathways, where hardscapes meet the tree line, linear arrangements of trees are very effective at reducing surface temperatures up to 2-4 °C. Linear planting provides consistent shade along streets and pathways. The cooling performance of urban green areas can be significantly improved through these two ways [21]. These tree lines are also effective in directing the wind flow by either channeling or blocking it. On the contrary, individual or isolated plantations offer localized shade but do not affect the microclimate significantly. Group planting, on the other hand, is very effective in creating cooling zones, especially in open areas and parks. Their overlapping canopies block direct sunlight and improve evapotranspiration, thus reducing the temperature beneath them. The distance of the trees from the building is also a key factor in how effectively trees reduce cooling costs. The indoor cooling costs can be reduced by 10 to 15% by planting trees 5-10 meters from buildings, and outdoor thermal comfort can be improved by lowering temperatures near building facades [32], while improper placement of trees can disturb airflow and contribute to the UHI effect instead [33].

The arrangement of trees in cities significantly influences temperature regulation, comfort, and the heat island effect. Densely planted trees with overlapping leaves are especially effective in creating cool air near the ground and reducing temperatures overall. Trees planted in lines along streets and pathways provide excellent shading for those walking along the tree-lined path, but do not have as much of an impact on reducing temperatures away from the path. Individual trees provide shade but do not have much influence beyond their immediate vicinity. Tools like ENVI met and thermal comfort indices help analyze tree arrangements to optimize their cooling effect in urban landscapes. Table 2 below shows a comparative study of the different tree layouts.

Table 2: Comparative Analysis of the Different Layouts.

Factor	Group Planting	Linear Planting	Individual Planting
Definition	Trees are arranged in dense clusters, forming compact green pockets.	Trees are aligned in straight or gently curved rows, typically along streets or walkways.	Single trees are planted in isolation, often used for targeted shading or visual features.
Cooling Effects	Highly effective; reduces ambient temperatures significantly—up to 5°C in some cases—due to increased evapotranspiration and overlapping canopy cover.	Offers moderate cooling, especially along corridors; effective at reducing radiant temperature in linear pedestrian routes.	Provides localized cooling; can reduce surface temperature by up to 11.7°C near facades, but the impact is limited in wider spatial contexts.
Wind Flow Patterns	Disrupts and slows wind, creating calmer, cooler zones; can enhance comfort but may impede ventilation in dense areas.	Can channel or block wind based on orientation; aligns with urban ventilation strategies in many street designs.	Slows wind locally; improves comfort but has minimal effect on broader wind dynamics.
Humidity and Moisture	Increases local humidity through high transpiration rates; beneficial in dry climates, but may raise discomfort in humid areas.	Moderately influences humidity depending on the density and length of the planting strip.	Slightly increases humidity through localized evapotranspiration, especially in shady spots.
Shading	Offers continuous and uniform shade, suitable for parks, courtyards, and open spaces.	Provides linear shade along movement paths, enhancing pedestrian comfort, but is less effective for large-area coverage.	Delivers focused shading, ideal for benches or small public zones; not uniform over large areas.
Tools and Techniques Used	Frequently assessed using ENVI-met simulations, field measurements, and humidity sensors to gauge cluster effects.	Often evaluated using PET (Physiological Equivalent Temperature), lux meters for light exposure, and thermal comfort indices.	Studied through direct field measurements and energy-saving analyses in buildings due to façade shading.
Urban Design Implications	Ideal for creating thermally comfortable communal areas; useful in parks, plazas, and residential courtyards.	Best suited for urban corridors, pedestrian streets, and transit pathways where consistent shading and airflow direction are needed.	Effective when planted near buildings or public furniture, it complements architectural design and visual aesthetics.
Case Studies & Inference	Xi'an, China, and London, UK, demonstrated significant temperature reduction and improved comfort in dense, high-use areas.	Melbourne and Vancouver studies highlighted the cooling benefits in street canyons and walking zones.	Paris and Toronto cases confirmed effectiveness in regulating façade heat and improving local thermal comfort in constrained urban spaces.
Limitations	It may obstruct airflow if overused; it requires more space and maintenance to avoid overcrowding and root conflict.	Effectiveness varies by orientation and spacing; poorly designed rows can create wind tunnels or leave gaps in shading.	Limited cooling influence beyond the immediate vicinity; less effective in addressing urban-scale heat challenges.

4.2. Case Specific Analysis

Urban greenery mitigates heat and improves microclimates in densely built environments. Different tree-planting strategies—grouped, linear, or individual—offer unique benefits in regulating temperature and enhancing comfort. 23 out of the 49 journal articles have highlighted the impact of strategic tree placement on the urban microclimate. A compilation of these studies has been done and displayed in Table 3 below.

Table 3: Key Inferences from the Case Studies.

Location	Climatic Zone	Tree Placement Type	Key Inferences
London, U.K. [34]	Temperate Oceanic	Grouped	Clustered tree placement enhanced shade and thermal comfort in dense urban areas.
Brisbane, Australia [35]	Subtropical	Grouped	Optimization models showed that tree clustering reduced urban temperatures by up to 5°C.
Melbourne, Australia [36]	Temperate Oceanic	Linear	East-west linear tree plantings led to significant cooling; alignment plays a vital role.
Vancouver, Canada [37]	Temperate Marine West Coast	Linear	Linear street trees significantly lowered mean radiant temperature, enhancing pedestrian comfort.
Toronto, Canada [38]	Temperate Continental	Individual	Single trees near buildings reduced surface temperatures by up to 11.7°C, especially on west sides.
Paris, France [39]	Temperate Oceanic	Individual	Solitary street trees reduced daytime temperatures by 2.8–4.1°C, confirming their cooling efficacy.
Phoenix, Arizona, USA [20]	Arid Subtropical	Linear (Paired)	Evenly spaced tree pairs improved thermal comfort and wind buffering in hot, dense environments.
Xi'an, China [27]	Temperate Continental	Grouped, Linear, Individual	Grouped deciduous trees had the strongest cooling effect (−5.0°C); canopy density was crucial.
Kuala Lumpur, Malaysia [28]	Tropical Rainforest	Grouped	Dense-foliage trees reduced daylight intensity and improved shading and comfort.
Tsim Sha Tsui, Hong Kong [32]	Humid Subtropical	Linear, Grouped	Strategic tree alignment and crown size improved pedestrian thermal comfort significantly.
Singapore [40]	Tropical Rainforest	Individual, Grouped, Green Roofs	Trees with dense canopies near buildings effectively reduced solar heat and indoor temperatures.

The reviewed case studies reveal that urban tree configuration is not a one-size-fits-all solution; rather, its success depends on climate context, tree species, spatial constraints, and urban design goals. Grouped trees offer the most significant cooling in open plazas or wide streets, while linear arrangements work well in corridors and along transport routes. Individually placed trees, especially when positioned close to buildings, play a targeted but powerful role in moderating surface and air temperatures. Together, these findings highlight the need for climate-sensitive urban forestry strategies to enhance livability and resilience in cities facing rising temperatures. The findings above highlight the cooling potential of various tree configurations. However, practical implementation challenges must be considered.

4.3. Implementation Challenges and Barriers

While the reviewed studies demonstrate the cooling benefits of grouped, linear, and individual tree arrangements, practical implementation faces significant constraints. Key barriers include land availability limitations in dense urban areas, financial and maintenance costs of large-scale plantings, and potential conflicts with existing infrastructure or urban design priorities. For example, securing space for tree canopies may require trade-offs with road expansions or new developments. These factors were not fully addressed in the reviewed literature. Future work should incorporate these considerations to translate tree-based cooling strategies into effective practice.

5. RESEARCH GAP AND LIMITATIONS

The spatial arrangement of trees in urban environments has a strong impact on the microclimatic conditions, influencing temperature, humidity, wind flow, and thermal comfort. Group planting is highly effective in creating localized cooling zones, while linear planting is more suitable for streets and pathways. Proximity to buildings is critical, with trees planted within 5-10 meters of structures providing significant energy savings and improved thermal comfort. While current research provides valuable insights into the impact of tree placement on urban microclimates, several limitations and gaps remain.

Most research emphasizes the immediate or short-term effects of tree growth and seasonal changes, providing little understanding of their long-term impacts. There is also a significant geographic imbalance in the research: while East Asia—especially China—has been well covered, much less attention has been paid to tropical regions and the Indian subcontinent. Adding to these gaps, many studies use advanced tools like ENVI met that are ill-suited to capturing long-term dynamic interactions between vegetation and urban form. Furthermore, tree characteristics are often generalized in these studies rather than investigating how specific species affect microclimatic performance. Finally, tree placement is frequently considered in isolation rather than as part of integrated urban design strategies that also involve green roofs, vertical gardens, and public landscaping. Collectively, these deficiencies underscore the demand for more comprehensive, regionally varied, and long-term studies to inform the successful climate adaptation of urban areas.

Building on these findings, it becomes clear that strategic tree placement is not just a matter of aesthetics but a crucial tool for enhancing urban resilience. Group planting should be prioritized in parks, courtyards, and larger open spaces to maximize their cooling potential. Dense canopies can form natural cooling pockets, easing thermal stress in high-density areas. Linear planting offers a practical way to deliver continuous shade and moderate surface temperatures, along streets and walkways, although attention must be paid to tree orientation to either channel or buffer prevailing winds. Equally important is the thoughtful positioning of trees near buildings—ideally within 5 to 10 meters—where they can significantly reduce heat gain and improve both indoor and outdoor comfort. Yet, this must be balanced carefully to avoid blocking natural ventilation in tightly built environments. Finally, tree planting should not stand alone—it must be woven into the broader fabric of urban design. Whether through integration with green roofs, tree-lined balconies, or vertical greening systems, embedding trees into the architectural and spatial layout of cities can amplify their environmental and social benefits, contributing to more livable, breathable, and climate-ready urban spaces.

6. CONCLUSION

This review emphasises the crucial role of tree placement and spatial arrangement in regulating urban microclimates. The authors' findings make clear that urban forestry is not just an ecological or aesthetic pursuit but a strategic tool for counteracting the Urban Heat Island (UHI) effect and improving thermal comfort in outdoor spaces. The most effective way to use trees for localised cooling is grouped plantings, which create "pocket" coolers. Linear plantings along streets and pathways provide reliable shade and airflow modulation. Individual trees near buildings have a more limited spatial impact but can reduce surface temperatures and indoor cooling loads. Even with this growing knowledge base, important research gaps remain, particularly concerning long-term effects, tree species-specific cooling performance, and the integration of tree layout with other urban design elements (e.g., green roofs, ventilation corridors). Moreover, the literature shows a significant geographic imbalance, with not much empirical data coming from rapidly urbanising places like South Asia. These cities are experiencing an intensifying heat stress due to climate change and densification. The insights from this review lead to a clear call for action: the strategic, evidence-based placement of trees must become an integral part of urban design that aims to make cities livable under these conditions. Future studies should take up interdisciplinary and longitudinal approaches to fill in the many gaps that currently exist and help develop resilient cities around the world.

REFERENCES

S. Ronchi, S. Salata, and A. Arcidiacono, ‘Which urban design parameters provide climate-proof cities? An application of the Urban Cooling InVEST Model in the city of Milan comparing historical planning morphologies’, Sustain Cities Soc, vol. 63, p. 102459, Dec. 2020, doi: 10.1016/j.scs.2020.102459.

A. Gupta, B. De, S. Das, and M. Mukherjee, ‘Thermal hazards in urban spaces: A review of climate-resilient planning and design to reduce the heat stress’, Urban Clim, vol. 59, p. 102296, Feb. 2025, doi: 10.1016/j.uclim.2025.102296.

K. Gupta and M. Haque, ‘Optimizing Microclimatic Design in Urban Environments: Study of Methods and Strategies for Residential Clusters’, Civil Engineering and Architecture, vol. 13, no. 3, pp. 1858–1874, May 2025, doi: 10.13189/cea.2025.130330.

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K., & Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas. Landscape and Urban Planning, 151, 1–13. https://doi.org/10.1016/j.landurbplan.2016.02.001

S. Sareen and M. Haque, ‘Re-Imagining High-Density Mixed-Use Streets’, Proceedings of the International Conference of Contemporary Affairs in Architecture and Urbanism-ICCAUA, vol. 7, no. 1, pp. 787–800, Jun. 2024, doi: 10.38027/ICCAUA2024IN0325.

S. Hajat and T. Kosatky, ‘Heat-related mortality: a review and exploration of heterogeneity’, J Epidemiol Community Health (1978), vol. 64, no. 9, pp. 753–760, Sep. 2010, doi: 10.1136/jech.2009.087999.

G. Brücker InVS et al., ‘Topic: 2003 Heat Wave’, Jul. 2005. [Online]. Available: www.eurosurveillance.org

M. Salem et al., 'Managing the urban-rural transition: A review of approaches and policies for peri-urban land use', Journal of Urban Management, May 2025, doi: 10.1016/j.jum.2025.04.006.

(P. Antoszewski, D. Świerk, and M. Krzyżaniak, 'Statistical Review of Quality Parameters of Blue-Green Infrastructure Elements Important in Mitigating the Effect of the Urban Heat Island in the Temperate Climate (C) Zone', Int J Environ Res Public Health, vol. 17, no. 19, p. 7093, Sep. 2020, doi: 10.3390/ijerph17197093.

M. S. Khan, S. Ullah, and L. Chen, 'Variations in Surface Urban Heat Island and Urban Cool Island Intensity: A Review Across Major Climate Zones', Chin Geogr Sci, vol. 33, no. 6, pp. 983–1000, Dec. 2023, doi: 10.1007/s11769-023-1375-8.

T. Sun, R. Sun, M. S. Khan, and L. Chen, 'Urbanization increased annual precipitation in temperate climate zone: A case in Beijing-Tianjin-Hebei region of North China', Ecol Indic, vol. 126, p. 107621, Jul. 2021, doi: 10.1016/j.ecolind.2021.107621.

D. E. Bowler, L. Buyung-Ali, T. M. Knight, and A. S. Pullin, 'Urban greening to cool towns and cities: A systematic review of the empirical evidence', Landsc Urban Plan, vol. 97, no. 3, pp. 147–155, Sep. 2010, doi: 10.1016/j.landurbplan.2010.05.006.

S. Sareen and M. Haque, 'The Dynamics of Peri-Urban Spatial Planning: An Overview', J Urban Plan Dev, vol. 149, no. 3, Sep. 2023, doi: 10.1061/JUPDDM.UPENG-4275.

P. Sukhdev et al., 'Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities A Global Assessment', 2013.

L. Shashua-Bar, D. Pearlmutter, and E. Erell, 'The influence of trees and grass on outdoor thermal comfort in a hot-arid environment', International Journal of Climatology, vol. 31, no. 10, pp. 1498–1506, Aug. 2011, doi: 10.1002/joc.2177.

J. B. Winbourne et al., 'Tree Transpiration and Urban Temperatures: Current Understanding, Implications, and Future Research Directions', Bioscience, vol. 70, no. 7, pp. 576–588, Jul. 2020, doi: 10.1093/biosci/biaa055.

M. Sharmin, M. G. Tjoelker, S. Pfautsch, M. Esperón-Rodriguez, P. D. Rymer, and S. A. Power, 'Tree Traits and Microclimatic Conditions Determine Cooling Benefits of Urban Trees', Atmosphere (Basel), vol. 14, no. 3, p. 606, Mar. 2023, doi: 10.3390/atmos14030606.

S. S. Parmar, V. Bansal, S. Bansal, N. Abid, J. Sen, and M. Haque, 'City Core and Urban Sprawl', in Urban Metabolism and Climate Change, Cham: Springer International Publishing, 2023, pp. 93–109. doi: 10.1007/978-3-031-29422-8_5.

Z. Wang et al., 'Modelling and optimizing tree planning for urban climate in a subtropical high-density city', Urban Clim, vol. 43, p. 101141, May 2022, doi: 10.1016/j.uclim.2022.101141.

A. Hami, B. Abdi, D. Zarehaghi, and S. Bin Maulan, 'Assessing the thermal comfort effects of green spaces: A systematic review of methods, parameters, and plants' attributes', Sustain Cities Soc, vol. 49, p. 101634, Aug. 2019, doi: 10.1016/j.scs.2019.101634.

Q. Zhao, D. J. Sailor, and E. A. Wentz, 'Impact of tree locations and arrangements on outdoor microclimates and human thermal comfort in an urban residential environment', Urban For Urban Green, vol. 32, pp. 81–91, May 2018, doi: 10.1016/j.ufug.2018.03.022.

S. Sodoudi, H. Zhang, X. Chi, F. Müller, and H. Li, 'The influence of spatial configuration of green areas on microclimate and thermal comfort', Urban For Urban Green, vol. 34, pp. 85–96, Aug. 2018, doi: 10.1016/j.ufug.2018.06.002.

M. A. Rahman, D. Armson, and A. R. Ennos, 'A comparison of the growth and cooling effectiveness of five commonly planted urban tree species', Urban Ecosyst, vol. 18, no. 2, pp. 371–389, Jun. 2015, doi: 10.1007/s11252-014-0407-7.

C. D. Ziter, E. J. Pedersen, C. J. Kucharik, and M. G. Turner, 'Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer', Proceedings of the National Academy of Sciences, vol. 116, no. 15, pp. 7575–7580, Apr. 2019, doi: 10.1073/pnas.1817561116.

N. Abid, 'EXPLORING AND ASSESSING USER PERCEPTION AND PREFERENCES FOR OPEN SPACES IN A UNIVERSITY CAMPUS: A CASE STUDY OF IIT ROORKEE, INDIA', New Design Ideas, vol. 8, no. 2, pp. 412–432, Aug. 2024, doi: 10.62476/ndi82412.

H. Li, Y. Zhao, C. Wang, D. Ürge-Vorsatz, J. Carmeliet, and R. Bardhan, 'Cooling efficacy of trees across cities is determined by background climate, urban morphology, and tree trait', Commun Earth Environ, vol. 5, no. 1, p. 754, Dec. 2024, doi: 10.1038/s43247-024-01908-4.

S. Yan et al., 'Cooling Effect of Trees with Different Attributes and Layouts on the Surface Heat Island of Urban Street Canyons in Summer', Atmosphere (Basel), vol. 14, no. 5, p. 857, May 2023, doi: 10.3390/atmos14050857.

D. Zhao et al., 'Role of Species and Planting Configuration on Transpiration and Microclimate for Urban Trees', Forests, vol. 11, no. 8, p. 825, Jul. 2020, doi: 10.3390/f11080825.

M. Adam, N. Ab Ghafar, and T. Mustapha, 'An Investigation of the Significant Criteria of Vegetation Selection and Planting Arrangement in Designing Urban Nodes', Journal of Design and Built Environment, vol. 16, no. 2, pp. 1–14, Dec. 2016, doi: 10.22452/jdbe.vol16no2.4.

P. Höppe, 'The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment', Int J Biometeorol, vol. 43, no. 2, pp. 71–75, Oct. 1999, doi: 10.1007/s004840050118.

F. Sun, J. Zhang, S. Takeda, J. Cui, and R. Yang, 'Vertical Plant Configuration: Its Impact on Microclimate and Thermal Comfort in Urban Small Green Spaces', Land (Basel), vol. 13, no. 10, p. 1715, Oct. 2024, doi: 10.3390/land13101715.

D. Moher, A. Liberati, J. Tetzlaff, and D. G. Altman, 'Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement', BMJ, vol. 339, no. jul21 1, pp. b2535–b2535, Jul. 2009, doi: 10.1136/bmj. b2535.

L. Kong et al., 'Regulation of outdoor thermal comfort by trees in Hong Kong', Sustain Cities Soc, vol. 31, pp. 12–25, May 2017, doi: 10.1016/j.scs.2017.01.018.

M. Park, A. Hagishima, J. Tanimoto, and K. Narita, 'Effect of urban vegetation on outdoor thermal environment: Field measurement at a scale model site', Build Environ, vol. 56, pp. 38–46, Oct. 2012, doi: 10.1016/j.buildenv.2012.02.015.

Anne Jaluzot, 'Wise microclimate tree selection for Cheapside City of London, England'.

A. Shaamala, T. Yigitcanlar, A. Nili, and D. Nyandega, 'Strategic tree placement for urban cooling: A novel optimisation approach for desired microclimate outcomes', Urban Clim, vol. 56, p. 102084, Jul. 2024, doi: 10.1016/j.uclim.2024.102084.

R. Sanusi, D. Johnstone, P. May, and S. J. Livesley, 'Street Orientation and Side of the Street Greatly Influence the Microclimatic Benefits Street Trees Can Provide in Summer', J Environ Qual, vol. 45, no. 1, pp. 167–174, Jan. 2016, doi: 10.2134/jeq2015.01.0039.

J. Xu, A. Psikuta, J. Li, S. Annaheim, and R. M. Rossi, 'Influence of human body geometry, posture and the surrounding environment on body heat loss based on a validated numerical model', Build Environ, vol. 166, p. 106340, Dec. 2019, doi: 10.1016/j.buildenv.2019.106340.

A. A. Millward, M. Torchia, A. E. Laursen, and L. D. Rothman, 'Vegetation Placement for Summer Built Surface Temperature Moderation in an Urban Microclimate', Environ Manage, vol. 53, no. 6, pp. 1043–1057, Jun. 2014, doi: 10.1007/s00267-014-0260-8.

J. Thierry, S. Herpin, F. Rodriguez, M. Renard, M. Gantois, and P. E. Bournet, 'Climatic benefits of street trees on the microclimate and thermal comfort: an in-situ experiment in Paris', Acta Hortic, no. 1374, pp. 197–204, Sep. 2023, doi: 10.17660/ActaHortic.2023.1374.25.

N. H. Wong and S. K. Jusuf, 'Study on the microclimate condition along a green pedestrian canyon in Singapore', Archit Sci Rev, vol. 53, no. 2, pp. 196–212, May 2010, doi: 10.3763/asre.2009.0029.

Gillner, S., Vogt, J., Tharang, A., Dettmann, S., & Roloff, A. (2015). The role of street trees in mitigating effects of heat and drought at highly sealed urban sites. Urban Forestry & Urban Greening, 14(4), 642–654. https://doi.org/10.1016/j.ufug.2015.06.005

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K., & Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas. Landscape and Urban Planning, 151, 1–13. https://doi.org/10.1016/j.landurbplan.2016.02.001

Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landscape and Urban Planning, 134, 127–138. https://doi.org/10.1016/j.landurbplan.2014.10.018

Xu, H., Lin, X., Shi, K., Lin, S., Zheng, G., Wang, Q., Dong, J., & Wang, M. (2022). Research Progress and Hotspot Evolution Analysis of Landscape Microclimate: Visual Analysis Based on CNKI and WOS. International Journal of Environmental Research and Public Health, 19(22), 15118.

https://doi.org/10.3390/ijerph192215118

Yin, Y., Li, S., Xing, X., Zhou, X., Kang, Y., Hu, Q., & Li, Y. (2024). Cooling Benefits of Urban Tree Canopy: A Systematic Review. Sustainability, 16(12), 4955. https://doi.org/10.3390/su16124955

Zhao, Q., Sailor, D. J., & Wentz, E. A. (2018b). Impact of tree locations and arrangements on outdoor microclimates and human thermal comfort in an urban residential environment. Urban Forestry & Urban Greening, 32, 81–91. https://doi.org/10.1016/j.ufug.2018.03.022

STATEMENTS & DECLARATIONS

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests: The authors have no potential conflicts of interest or such divergences linked with this research study.

Author Contributions: This paper was written by the author based on the ongoing PhD work. The corresponding author is the PhD advisor of the main author.

Data Availability Statement: Data are available from the authors upon request.