land

MDPI

Review

Vegetation-Based Strategies for Urban Heat Mitigation and Outdoor Thermal Comfort Enhancement in Hot-Arid and Mediterranean Cities: A Scoping Review

Saeed Alhusaiki *, Simon Kilbane and Maria Ignatieva *

School of Design, The University of Western Australia, Perth, WA 6009, Australia; simon.kilbane@uwa.edu.au
* Correspondence: saeedsaadf.alhusaiki@research.uwa.edu.au (S.A.); maria.ignatieva@uwa.edu.au (M.I.); Tel.: +61-433-259-886 (S.A.)

Abstract

In the last century, urban growth has increased rapidly in most cities worldwide, contributing to the loss of natural areas, greater impervious surfaces, and urban density. This has led to elevated temperatures and the development of the urban heat island (UHI) effect. The UHI effect can significantly impact the environment, economy, public health, and overall urban livability. Abundant studies have proven that vegetation is the most effective strategy to mitigate urban heat through shading provision and evapotranspiration. However, despite the growing body of literature on vegetation-based cooling strategies, the influence of climatic conditions on its cooling performance remains insufficiently understood. This scoping review examines the UHI characteristics and maps the evidence on the effectiveness of vegetation-based strategies in reducing urban temperatures and enhancing outdoor thermal comfort in two different climates: hot arid (Köppen BWh) and Mediterranean (Köppen Csa). Peer-reviewed English language studies published between 2010 to 2026 were identified through Scopus, Web of Science, and ProQuest, with the final search conducted in April 2026. Following a screening and eligibility assessment, data from 127 included studies were synthesized quantitatively and qualitatively. The results show that, while hot-arid cities may exhibit nighttime canopy urban heat island (CUHI) and surface urban heat island (SUHI) effects and daytime canopy urban cool island (CUCI) and surface urban cool island (SUCI) effects, Mediterranean cities generally experience the CUHI and SUHI effects during both day and night. Moreover, the cooling capacity of vegetation varied according to vegetation type, configuration, density, local climate, water availability, and urban context. Consequently, developing a universal applicable solution for vegetation-based strategies with a consistent cooling performance across different climates and urban conditions is a real challenge.

Keywords: urban heat island (UHI); urban vegetation; vegetation-based strategies; urban heat mitigation; outdoor thermal comfort; hot-arid climate; Mediterranean climate; climate-responsive urban design; urban microclimate; scoping review

Check for updates

Academic Editors: Liliia Hebryn Baidy and Gareth Rees

Received: 10 September 2026
Revised: 12 October 2026
Accepted: 16 October 2026
Published: 21 October 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Massive urban expansion and global warming have significantly exacerbated thermal stress in most of the world's cities, putting the health of more than 1.7 billion people at risk [1]. Urbanization encourages people living in rural areas to move to cities in search of a better life, leading to intensified socioeconomic activities, increased energy consumption,

and, consequently, increased carbon dioxide emissions [2]. Indeed, the percentage of the global urban population increased from about 30% in 1950 to approximately 45% in 2014, and this is estimated to exceed 60% by 2050 [3,4] with cities now are responsible for 60–80% of energy consumption worldwide and 70% of CO_2 emissions [5]. Similarly, the global area of impermeable surface is projected to increase approximately threefold by 2030, to nearly 1.2 million km^2 [6].

On the other hand, global climate patterns have changed rapidly due to the rising levels of greenhouse gas emissions [7]. Based on the 2014 Intergovernmental Panel on Climate Change (IPCC) report, the global average temperature has shown an upward trend by 0.85 °C, and, by the end of the 21st century, is projected to rise by 1.5 °C with a strong likelihood of increasing extreme weather events. Such transformations have a significant negative impact on our life environmentally, socially, financially, and in public health, resulting in increased mortality [8–11]. Heat events, moreover, are taking place in the majority of urbanized regions [12]. The increasing frequency and intensity of extreme heat events pose substantial risks to human health. For instance, recent studies estimated that approximately 67,873, 50,789, and 60,775 heat-related deaths occurred in Europe due to severe heatwaves during the summers of 2022, 2023, and 2024, respectively [13,14]. Moreover, in Australia, a nationwide analysis projected 1009 heatwaves-attributable deaths between 2016 and 2019 [15].

In urban environments, the implications of these changes are intensified by the loss of natural surfaces with man-made ones, leading to a higher thermal conductivity, higher heat capacity, and lower surface albedo, along with an unsuitable urban canyon geometry for local climate and anthropogenic heat sources, making cities warmer than their surroundings [16–18]. During warm periods, sun-exposed surfaces such as pavements, roofs, and building facades absorb shortwave radiation during the day and release it into the air as longwave radiation, leading to a rise in ambient air temperature [19,20]. Differences in temperatures between urban areas and the surrounding countryside is a phenomenon known as the urban heat island (UHI) effect [21,22]. This phenomenon can be characterized through different thermal measures. The canopy-layer urban heat island (CUHI) refers to the differences in near-surface air temperature between urban and surrounding rural areas, whereas the surface urban heat island (SUHI) refers to the differences in land surface temperature (LST) [23].

The primary cause of the UHI effect is the aforementioned urban expansion, leading to extensive changes in land cover and land use in modern cities. For example, during hot seasons, the surface temperature of dark, dry urban materials in direct sun can reach up to 88 °C during the day, while green areas with moist soil can reach 18 °C at the same weather conditions [24]. Mirzaei and Haghighat [25] state that several phenomena contribute to the formation of the UHI effect, ranging from microscale mechanisms such as human activities to mesoscale interactions such as meteorological forces. Accordingly, the primary causes of UHI differ between cities and climatic contexts meaning that drawing a universal conclusion in terms of UHI formation is challenging. For example, anthropogenic heat sources can be the primary cause of nighttime UHI in urban high-density districts under cloudy conditions, while the primary cause of daytime UHI in tropical humid climate can be solar absorption under sunny conditions.

Therefore, several active and passive urban heat-mitigation strategies have been implemented by governments to tackle the UHI effect. These strategies include developing green and blue infrastructures, implementing urban geometry theories, and using high-albedo materials and sustainable transportation systems [16,26–31]. The main purpose of these mitigating practices is to achieve a balance between solar heat gain and radiative heat loss [32].

Although the literature has extensively investigated heat mitigation strategies, many researchers have conducted their investigations under specific climatic conditions where the cooling effect of each strategy varies depending on climatic peculiarities. Therefore, it is difficult to establish design principles for mitigation strategies applicable in all situations [32]. Moreover, existing literature reviews still lack an examination of the impact of climate on the cooling capacity of vegetation and few studies have also compared green spaces in different climates [33–38].

This study aims to examine the characteristics of UHI and evaluate the effectiveness of vegetation-based strategies in mitigating its impacts and enhancing outdoor thermal comfort in two climates, hot-arid and Mediterranean. These two climates were chosen because they both experience extreme summer temperatures, intense solar radiation, and periods of water limitations. These similarities make studying the UHI intensity, its influencing factors, and vegetation-based mitigation strategies substantially relevant. However, climates differ significantly in drought intensity, rainfall patterns, and water scarcity, which can greatly affect the UHI characteristics and the cooling performance of vegetation. Therefore, comparing these two climatically similar yet distinct environments enable an assessment of UHI characteristics. It also allows us to find out whether the effectiveness of vegetation-based strategies is influenced by climatic severity and water scarcity, providing valuable evidence for climate-sensitive urban planning in dry and warm regions.

Given the broad and heterogeneous nature of the existing evidence, encompassing different climatic contexts, spatial scales, research methods, thermal indicators, vegetation types, and cooling outcomes, a scoping review approach was considered appropriate to systematically map the available evidence, characterize existing research approaches, compare findings across the two climatic contexts, and identify knowledge gaps for future research.

Accordingly, the research seeks to address the following research questions:

1. How do the characteristics, drivers, and impacts of the UHI phenomenon differ between hot-arid and Mediterranean climates?
2. How effective are existing vegetation-based mitigation strategies in reducing urban heat and improving outdoor thermal comfort in hot-arid and Mediterranean climates, and what factors influence their effectiveness?
3. How are studies on UHI and vegetation-based mitigation strategies distributed geographically and temporally across hot-arid and Mediterranean climates, and what research methodologies and thermal comfort assessment indices have been employed?

2. Materials and Methods

This review conducted a structured examination of the literature associated with two main areas of investigation: UHI characteristics and vegetation-based strategies in two specific climates, hot-arid (Köppen BWh) and Mediterranean (Köppen Csa) (Figure 1). This scoping review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR). No formal review protocol was prepared or registered. The selected literature was then analyzed using both quantitative and qualitative synthesis to identify research trends, methodological approaches, UHI drivers and characteristics, and the effectiveness of vegetation-based mitigation strategies across both climates (Figure 2). An evidence-based approach with specific keyword combinations was then applied to ensure transparency, minimize bias, and identify key knowledge gaps related to UHI variations in both climates.

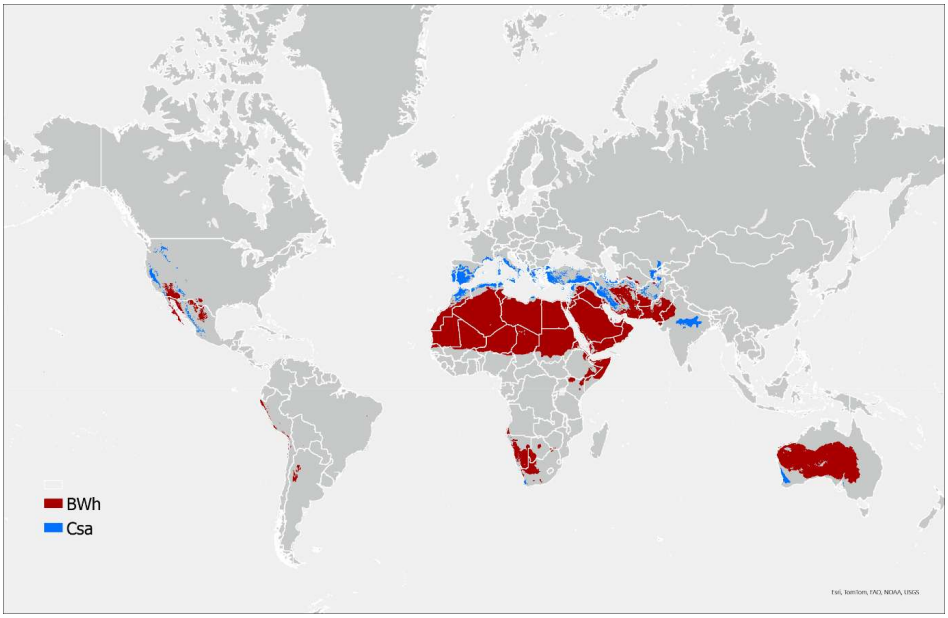


Figure 1. Distribution of BWh (hot-arid) and Csa (Mediterranean) climate zones based on the Köppen–Geiger climate classification system. The original map was modified by the authors to display and highlight only the BWh and Csa climate zones relevant to this review.

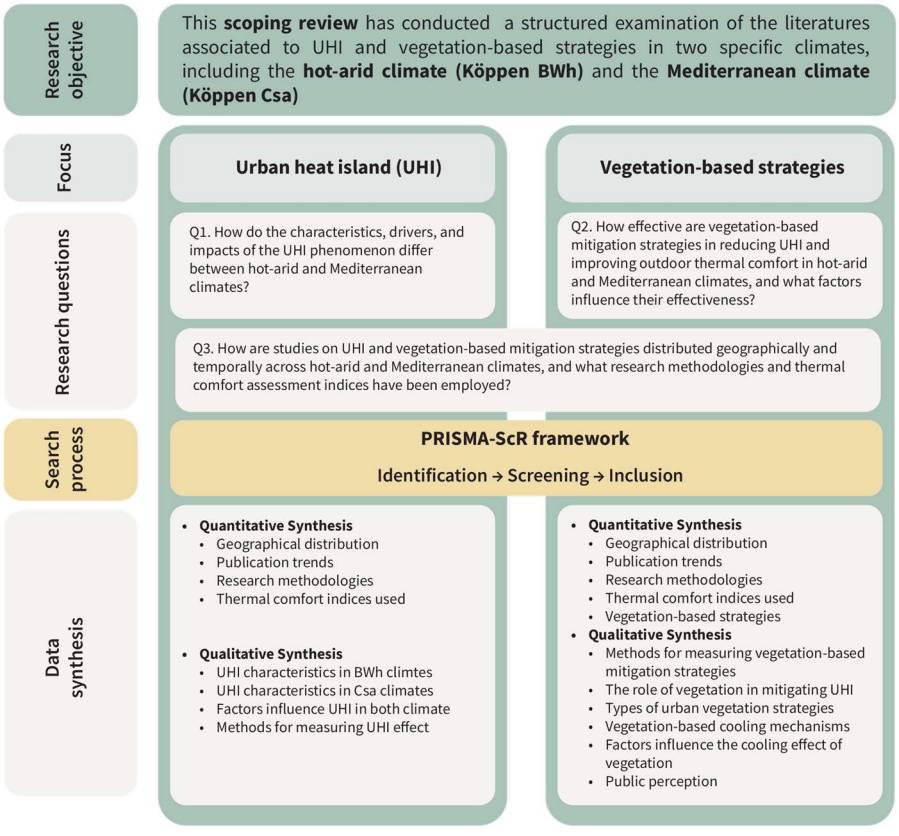


Figure 2. Research workflow.

2.1. Search and Selection Criteria

The literature search was conducted across three academic databases, Scopus, Web of Science, and ProQuest in April 2026, with the final database search completed on 8 April 2026. In addition to database searching, the reference lists of eligible studies were examined to identify additional relevant sources. The search structure was divided into

two main research clusters: (1) studies investigating UHI effects (Table 1), and (2) studies focusing on vegetation-based mitigation strategies (Table 2). For each cluster, structured keyword (noted in Tables 1 and 2) combinations were developed and combined using Boolean operators (AND, OR), to enhance and broaden the search.

Table 1. Keyword combinations for UHI effect in hot arid and Mediterranean climates scoping review.

Thematic Blocks	TITLE-ABS-KEY
Urban Heat Island & Thermal Comfort	((“urban heat island*” OR UHI OR “heat exposure” OR “surface urban heat island” OR “outdoor thermal comfort” OR “heat stress”))
Site Locations and Climate Classifications	((arid OR “hot arid" OR "BWh” OR mediterranean OR “Mediterranean climate” OR “Csa”))
Language	(LIMIT-TO (LANGUAGE, “English”))
Period	2010–2026

Table 2. Keyword combinations for vegetation-based mitigation strategies in hot arid and Mediterranean climates scoping review.

Thematic Blocks	TITLE-ABS-KEY
Vegetation-based Mitigation Strategies	((“heat reduction” OR “thermal regulat*” OR “heat mitigation” OR “green roof*” OR “urban greening” OR tree* OR canopy OR “street tree*” OR “green infrastructure” OR vegetation OR “shade tree*” OR shading OR “urban park*” OR “greenspace”))
Site Locations and Climate Classifications	((arid OR “hot arid” OR “BWh” OR mediterranean OR “Mediterranean climate” OR “Csa”))
Language	(LIMIT-TO (LANGUAGE, “English”))
Period	2010–2026

Studies were eligible for inclusion if they were peer-reviewed research articles published in English between 2010 and 2026 and investigated either (1) UHI characteristics, drivers, or impacts, or (2) vegetation-based urban heat mitigation and outdoor thermal comfort within hot-arid (BWh) or Mediterranean (Csa) climatic contexts. Studies conducted outside these climatic classifications, studies unrelated to UHI or vegetation-based heat mitigation, non-English publications, and publications outside the specified period were excluded. This approach ensured a transparent, replicable, and comprehensive identification of relevant literature addressing both causes of UHI and the role of vegetation in mitigating its impacts.

The complete electronic search strategies for each database, including the Boolean combinations and applied limits, are provided in Supplementary Table S1.

2.2. Literature Screening Process

All records identified through the database searches were screened by the first author (S.A.). Following duplicate removal, titles and abstracts were screened against the eligibility criteria, after which potentially relevant articles underwent full-text assessment. The screening and eligibility assessment were conducted by a single reviewer with further validation by two reviewers. Reference lists of eligible studies were subsequently examined to identify additional relevant sources.

Figure 3 illustrates the search process based upon UHI and thermal comfort, and vegetation-based mitigation strategies identified 355 initial records, 232 records, including 156, 103 from Scopus, 113, 64 from Web of Science, and 86, 65 from ProQuest, respectively.

After removing duplicate records, 207, 149 papers remained for further assessment, respectively. These records were then screened based on their abstracts to evaluate their relevance to hot-arid and Mediterranean climate contexts. Following this stage, 47, 102 papers were retained for detailed review, respectively. To ensure eligibility, a full-text screening process was applied, resulting in 38, 79 papers remaining for qualitative and quantitative synthesis. Moreover, reference list checking identified an additional 5 studies on UHI characteristics and 7 studies on vegetation-based mitigation strategies, which were incorporated into their respective clusters. The final records included were 129 papers, comprising 43 papers focused on the characteristics of UHI, and 86 addressing vegetation-based mitigation strategies. However, two publications contributed to both research streams and were therefore counted within each respective category. After accounting for these overlaps, the review included 127 unique publications.

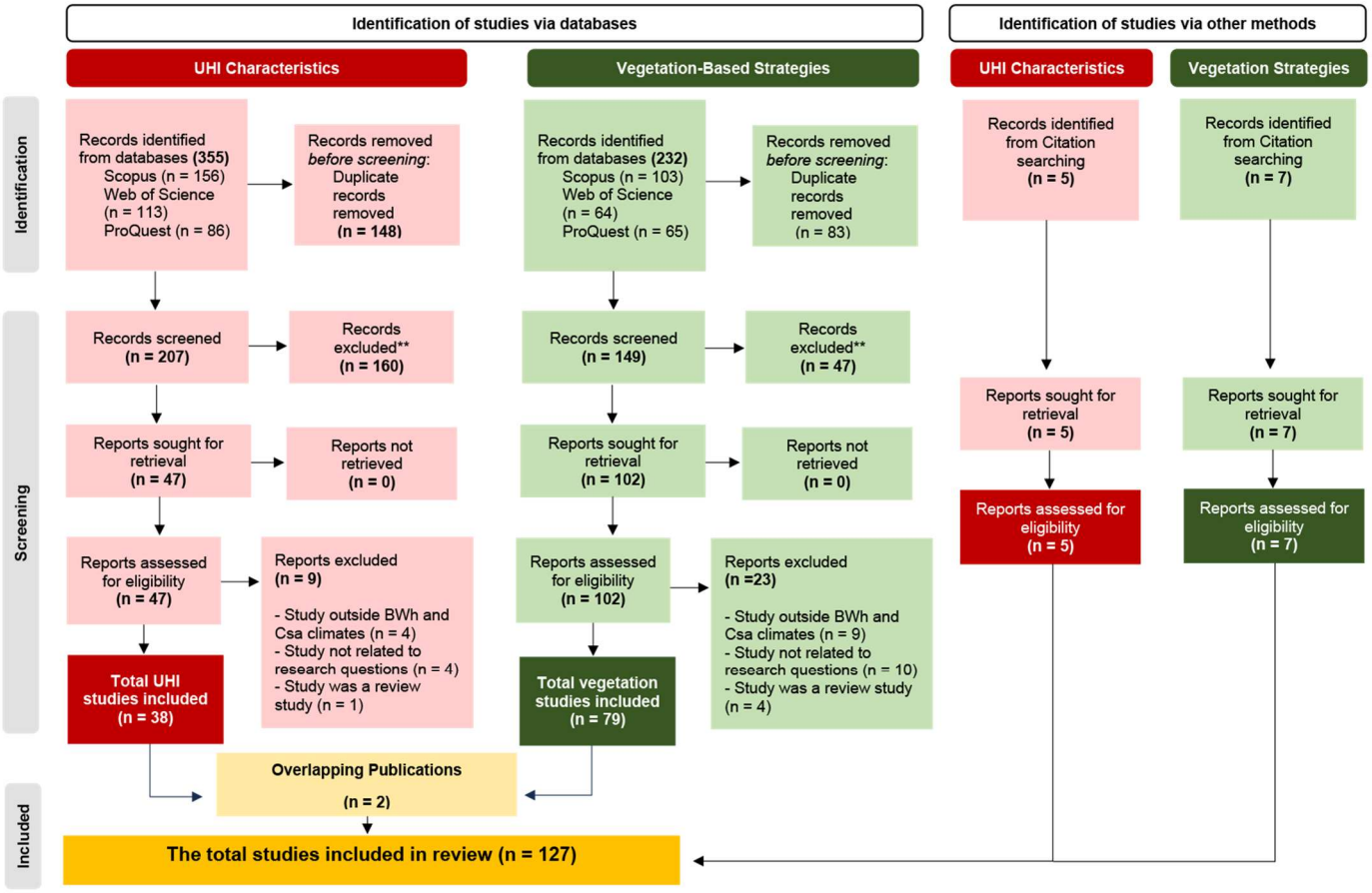


Figure 3. Scoping literature review flow diagram for UHI characteristics and vegetation-based mitigation strategies in hot-arid and Mediterranean climates. The PRISMA-ScR flow diagram was modified by the authors to present separate screening and selection processes for the UHI characteristics and vegetation-based strategy research clusters, including the corresponding numbers of identified, screened, excluded, and included studies.

2.3. Data Charting Process

Data from the included sources were charted by the first author (S.A.) using a structured Microsoft Excel spreadsheet. Information relevant to the review questions was systematically extracted from each included study and organized according to predefined categories to facilitate comparison between hot-arid (BWh) and Mediterranean (Csa) climates. Data charting was conducted by a single reviewer with further validation by other

2 reviewers. The charted data were subsequently used for quantitative descriptive analysis and qualitative synthesis.

The charted variables included publication year, study location, Köppen climate classification, research methodology, thermal comfort indices, vegetation-based mitigation strategy, cooling effects and outcomes associated with urban parks, street trees, green roofs, and green walls, and cooling mechanisms.

2.4. Data Synthesis

Both quantitative and qualitative methods were used to synthesis and analyze data in order to provide a comprehensive comparison of UHI properties and vegetation-based mitigation strategies between BWh and Csa climates.

The quantitative synthesis investigated the general characteristics and research patterns of the included studies. This approach provides findings, such as the distribution of the studies by country and climate classification, year of publication, research methodologies, thermal comfort indices (such as Physiological Equivalent Temperature (PET), Predicted Mean Vote (PMV), Universal Thermal Climate Index (UTCI), etc.), and vegetation-based mitigation strategies investigated. These results were displayed using charts and tables to highlight research trends and gaps across the two climate regions.

The qualitative synthesis examined the findings reported in each study with greater details to figure out common themes, similarities, and differences between the two climate types. This approach addressed the characteristics and causes of the UHI effect, the efficiency of different vegetation-based mitigation strategies, the role of each cooling mechanism associated with each strategy, and the impact of climate and urban morphology on the cooling capacity of vegetation. This qualitative synthesis also highlighted knowledge gaps and research opportunities identified across the reviewed literature.

3. Results

3.1. Quantitative Synthesis

The quantitative findings have been divided into five distinct result areas. These were (1) geographical distribution, (2) publication patterns, (3) research methodologies, (4) thermal comfort indices used, and (5) vegetation-based strategies. The first four areas are further divided into two categories: UHI studies and vegetation-based strategy studies. These areas primarily address the third research question by examining the geographical and temporal distribution of studies, the research methodologies employed, and the thermal comfort indices used across both climates. The two categories also contribute to the first and second research questions, respectively: first, to examine the causes, drivers, and factors shaping UHI across the two climates studied; and, second, to investigate the effectiveness of vegetation to mitigate UHI in each climate. Section 3.1.5 identifies the most frequently used and effective vegetation-based mitigation strategies in both BWh and Csa climates.

3.1.1. Geographical Distribution

- UHI studies

The distribution of reviewed studies focusing on the characteristics of UHI was relatively balanced in the number of published articles between the two climates (Figure 4). Of the 43 included studies, 22 (51.2%) were conducted in hot-arid (BWh) climates, while 18 (41.9%) addressed Mediterranean (Csa) climates. Only three studies (6.9%) investigated multiple climate types. Figure 5 shows the distribution of reviewed studies by country. The largest number of studies focused on BWh regions were conducted in Saudi Arabia and the UAE, with five studies (11.6%) each, followed by three studies (6.9%) in the USA, two studies (4.6%) in Qatar, and one study (2.3%) each in Kuwait, Iran, Morocco, and

Algeria. Among these countries, 13 studies were conducted in the Arabian Gulf countries (Saudi Arabia, UAE, Kuwait, and Qatar), representing 30.2% of the total sample. Moreover, three additional studies were conducted in several hot-arid cities across the Arab Peninsula and the Arabian Gulf countries, resulting in an increase in the total number of studies conducted in this region to 16 studies (37.2%).

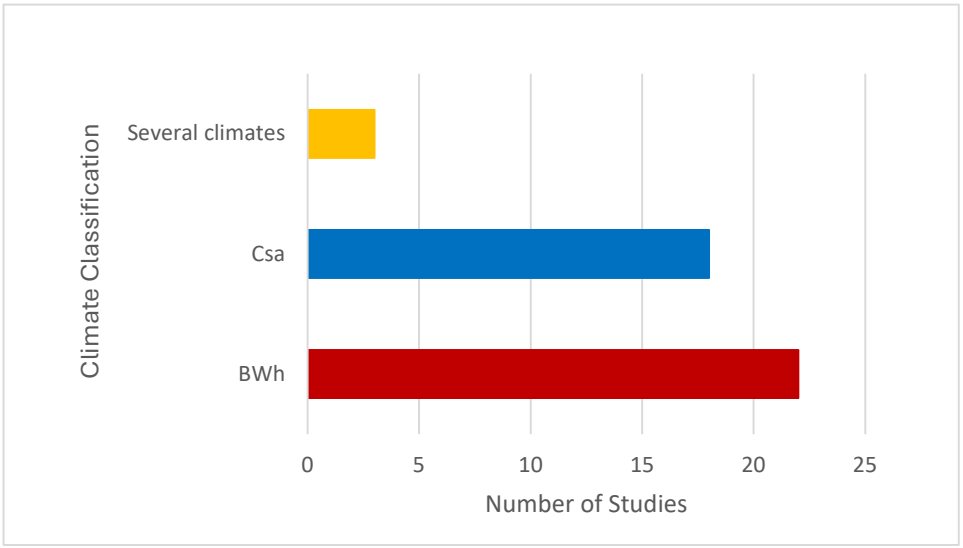


Figure 4. Distribution of reviewed studies focusing on UHI characteristics by climate classification.

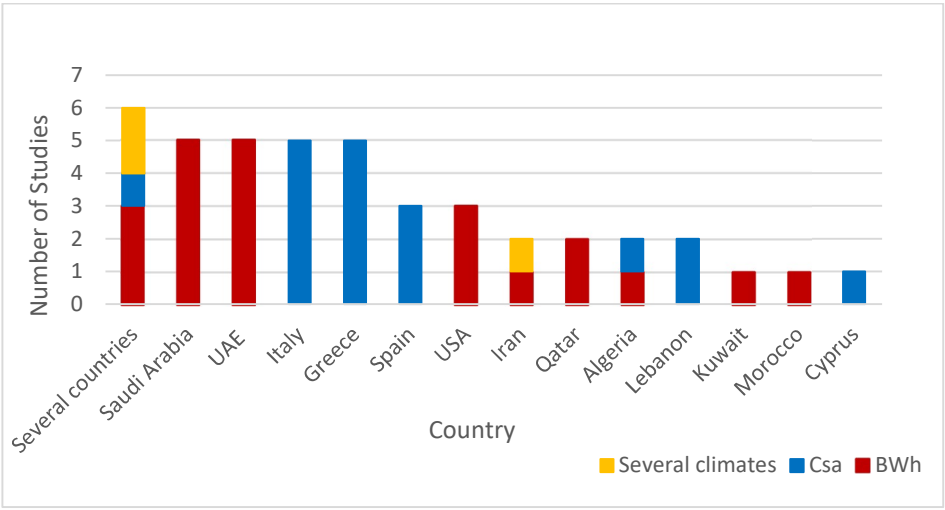


Figure 5. Distribution of reviewed studies focusing on UHI characteristics by country.

On the other hand, Italy and Greece shared the largest number of studies, focused on the Mediterranean regions, with five studies each (11.6%), followed by Spain with three studies (6.9%), then Lebanon with two studies (4.6%), and one study each (2.3%) was conducted in Algeria and Cyprus. Furthermore, one additional study was conducted across Athens, Madrid, and Rome. The three remaining studies were conducted across several countries with varying climate conditions. The first study assessed urban outdoor thermal discomfort across Iran, covering its major cities with diverse climate types [39]. The second study identified UHI behaviors in 10 dryland cities, including Cairo, Los Angeles, Phoenix, and Madrid. [40]. The third study investigated thermal stress over major Middle Eastern cities [41].

Figure 6 illustrates the geographical distribution of the reviewed studies on a world map, highlighting the significant interest in studying the behavior of the UHI phenomenon in major cities across the Middle East and Europe. Large hot-arid cities such as Jeddah and Riyadh in Saudi Arabia, Dubai in the UAE, Phoenix in the USA, Doha in Qatar, and Kuwait City in Kuwait have received the most attention in UHI studies, while Rome in Italy, Athens in Greece, and Beirut in Lebanon achieved the highest number of UHI studies in Mediterranean regions, as shown in Table S3.

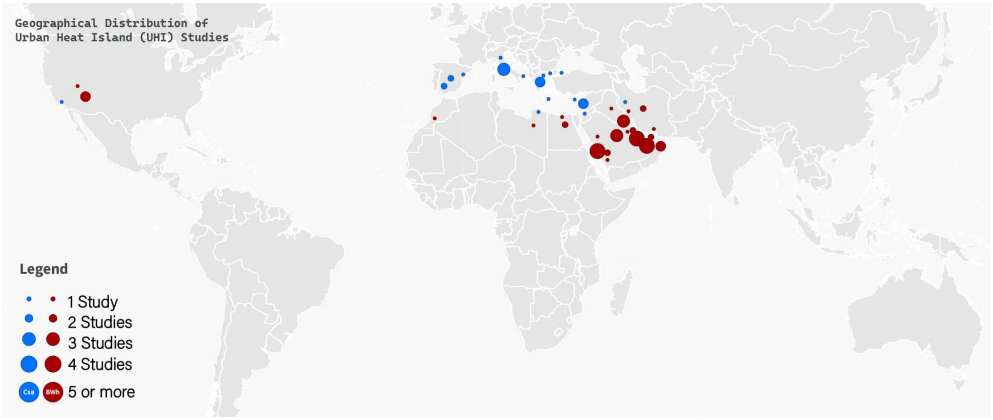


Figure 6. Geographical distribution of reviewed studies focusing on UHI characteristics across the BWh (red dots) and Csa (blue dots) climates.

- Vegetation-based strategies

Unlike the distribution of UHI studies by climate type, the highest records of the reviewed studies focusing on vegetation-based mitigation strategies were recorded in Mediterranean climates, totaling 41 studies (47.7%), while 39 studies (45.3%) were conducted in hot-arid climates (Figure 7). Moreover, only three studies (3.5%) compared the two climates (BWh and Csa), and three studies (3.5%) addressed multiple climates.

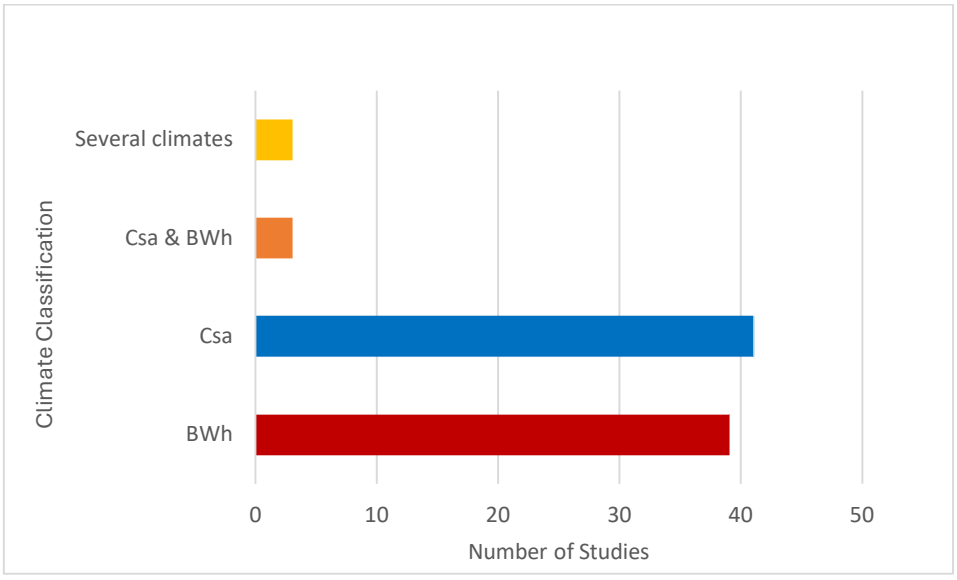


Figure 7. Distribution of reviewed studies focusing on vegetation strategies by climate classification.

Figure 8 illustrates the distribution of reviewed studies by countries. Italy achieved the highest number of published studies conducted in the Mediterranea regions, with fifteen studies (17.4%), followed by Spain with eight studies (9.3%), Greece with six studies

(7%), Turkey with four studies (4.7%), Australia with three studies (3.5%), Algeria with two studies (2.3%), and Portugal, France, and Jordan with one study each (1.2%). On the other hand, the highest number of published articles in the hot-arid regions was fourteen studies (16.3%) in USA, followed by eight studies (9.3%) in Egypt, then six studies (7%) in Saudi Arabia, two studies (2.3%) in UAE, Bahrain, and Iran each, and one study (1.2%) in Algeria, Qatar, Morocco, Iraq, Oman, and Mexico each. Five additional studies (5.8%) were conducted in several countries, three of which covered multiple climates, while only two compared those of BWh and Csa.

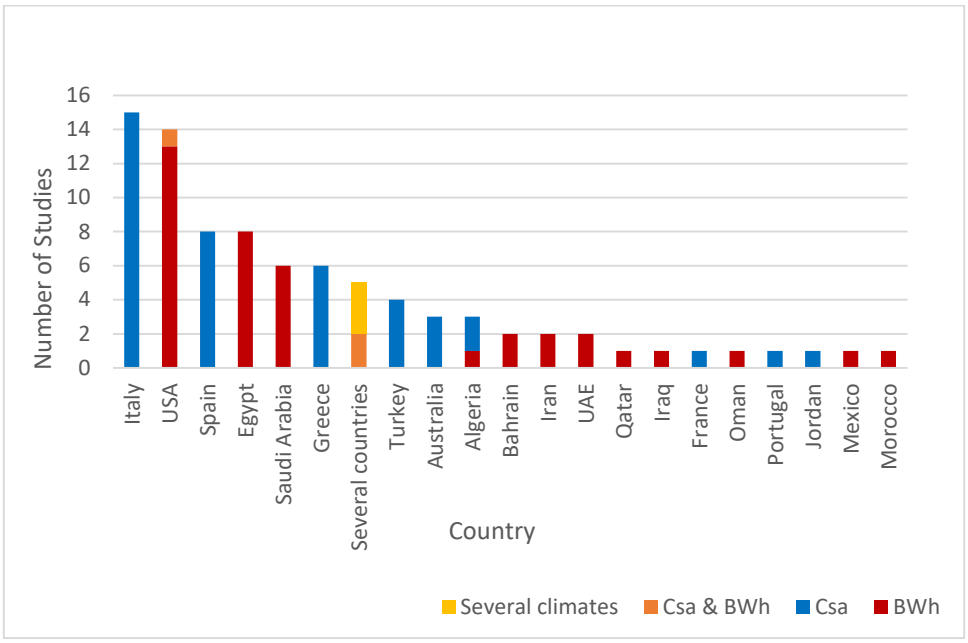


Figure 8. Distribution of reviewed studies focusing on vegetation strategies by country.

The geographical distribution of the reviewed studies highlights the significant interest shown in Europe, Arizona (USA), Egypt, and Saudi Arabia in studying vegetation-based strategies to mitigate the UHI effect over the past sixteen years (Figure 9). Moreover, Table S4 illustrates the geographical distribution by city, showing that Phoenix, Arizona, USA had the highest record of studies with eleven studies (12.6%), followed by Cario, Egypt with seven studies (6.9%), then Riyadh with five studies (5.7%), Barcelona, Spain and Catania, Italy with four studies each (4.6%), and Rome, Madrid, Jeddah, and Perth with three studies each (3.4%).

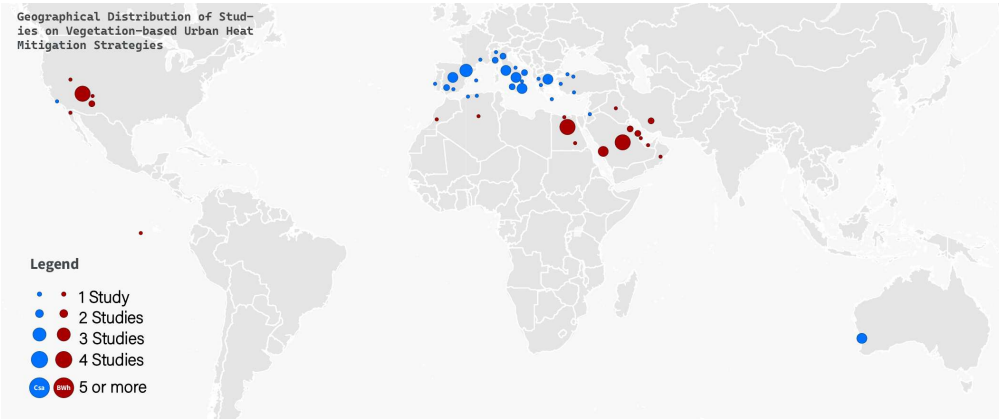


Figure 9. Geographical distribution of reviewed studies focusing on vegetation strategies across the BWh and Csa climates.

3.1.2. Publication Patterns

- UHI studies

The findings indicate that relatively few studies examining the characteristics of the UHI phenomenon in Mediterranean and hot-arid regions were published between 2010 and 2018 (Figure 10). The number of published studies then increased significantly from 2019, reaching a peak of seven studies in both 2022 and 2025, highlighting the growing concern about the intensification of UHI in both climates. Despite the increased rate of UHI studies over the past seven years, the number of studies published annually is still small compared to the huge area covered by the two climates. This indicates that fewer studies focused on the characteristics and behavior of the UHI phenomenon itself, while a greater proportion of the reviewed literature focused on mitigation strategies.

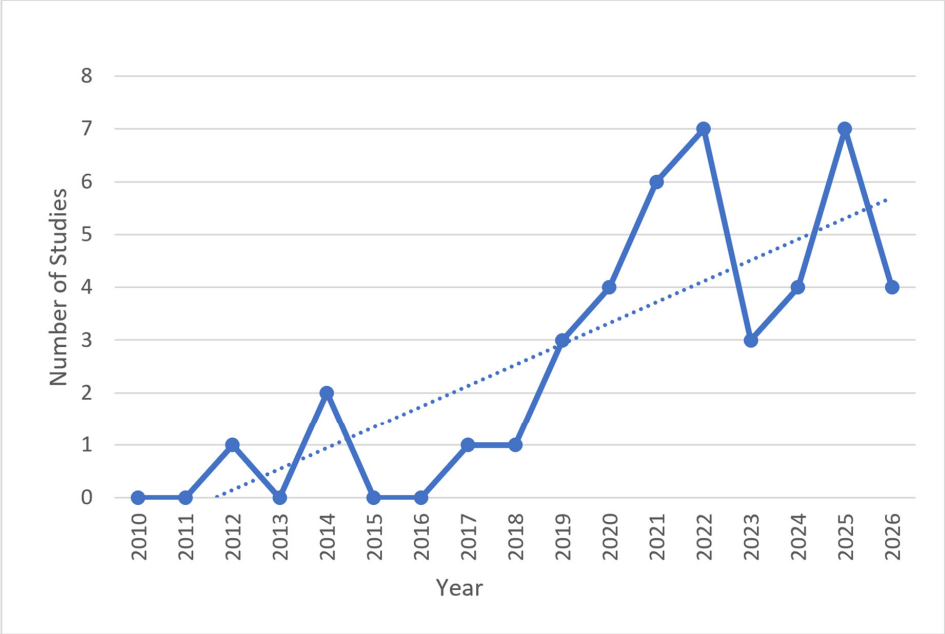


Figure 10. Distribution of reviewed studies focusing in UHI by year of publication (2010–2026). The solid blue line represents the annual number of published studies, while the dotted blue line indicates the linear trend over the study period.

- Vegetation-based strategies

The results demonstrate that there were no published studies on vegetation-based mitigation strategies published during 2010 and 2011 (Figure 11). The number of published studies then fluctuated between two and four studies annually in the period from 2012 to 2019. After that, the number of published studies experienced a sharp and sustained increase, except in 2022, reaching its peak in 2025 with 26 studies. However, the number of published studies in 2026 declined to 4 studies by April, expecting to reach the same level as in 2025 by the end of the year.

3.1.3. Research Methodologies

- UHI studies

Figure 12 illustrates how remote sensing technology dominated 19 studies (44.2%), with 12 conducted in hot-arid regions, only 4 in Mediterranean regions, and 3 in regions with several climates. Eight studies (18.6%) employed simulation method, with four studies conducted in each climate, followed by seven studies (16.3%) that used multiple methods, including four studies in BWh climates and three studies in Csa climates. Six studies (14%)

then utilized field measurements, with five studies in Mediterranean regions and only one study that is based in hot-arid regions. Finally, meteorological data were used less frequently than other methodological approaches in the reviewed studies, with only three studies (6.9%) using it.

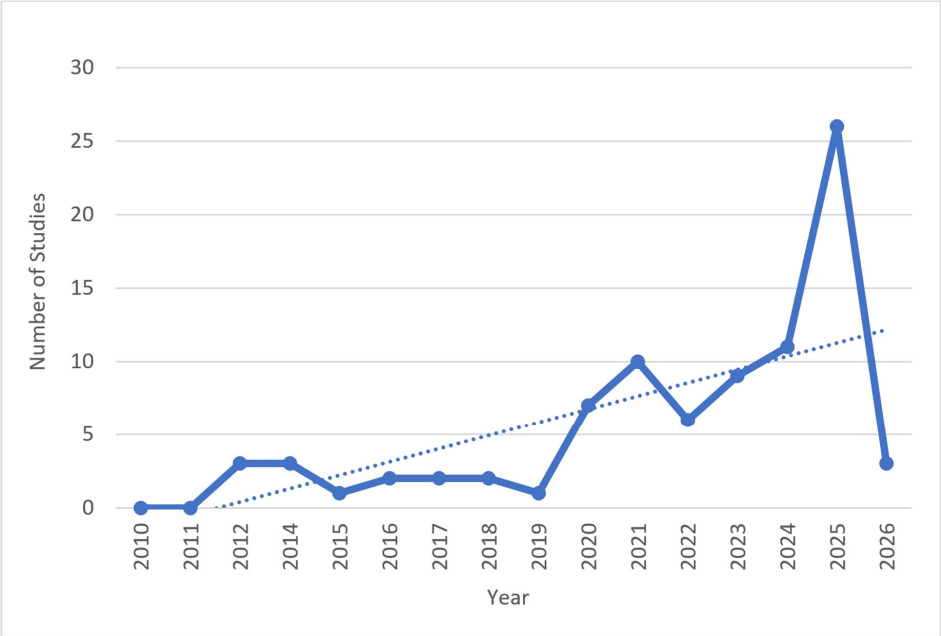


Figure 11. Distribution of reviewed studies focusing on vegetation strategies by year of publication (2010–2026). The solid blue line represents the annual number of published studies, while the dotted blue line indicates the linear trend over the study period.

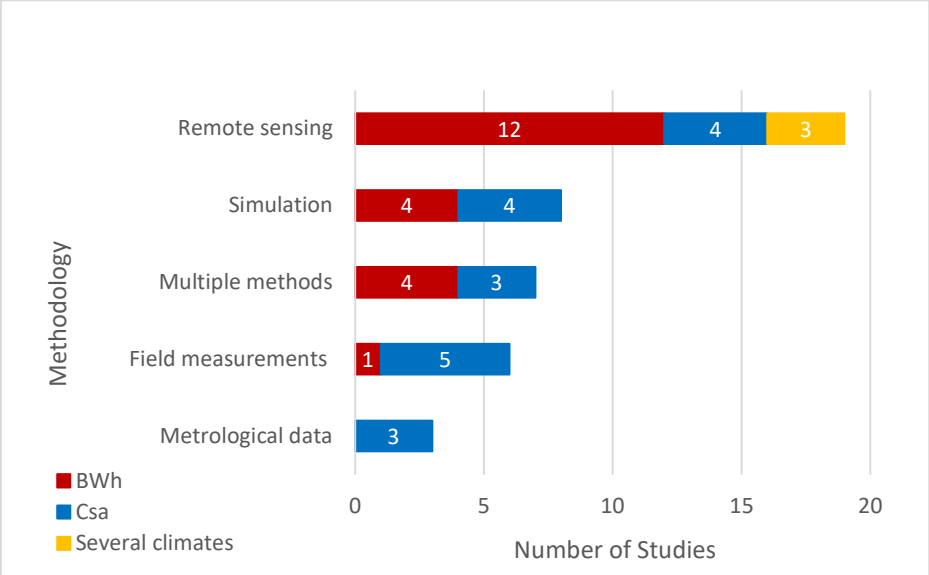


Figure 12. Distribution of reviewed studies focusing on UHI by methodology.

- Vegetation-based strategies

Unlike the UHI studies, the simulation method is dominant, accounting for 44 out of 86 studies, representing 51.2% of the total sample (Figure 13). This is attributed to its ability to test different scenarios without physical interventions and to integrate multiple factors in one framework, thus providing accurate evaluations of current conditions and reliable estimations for the future [42,43]. Thirteen studies (15.1%) then used field measure-

ments, with nine studies on Mediterranean climates and only three on hot-arid climates, followed by nine studies (10.5%) that employed remote sensing, and eight studies (9.3%) that integrated multiple methods. Most interestingly, seven studies (8.1%) were conducted in Mediterranean regions, while none of the articles in hot-arid regions used experiments. Finally, five studies (5.8%) conducted surveys and used GIS for spatial analysis.

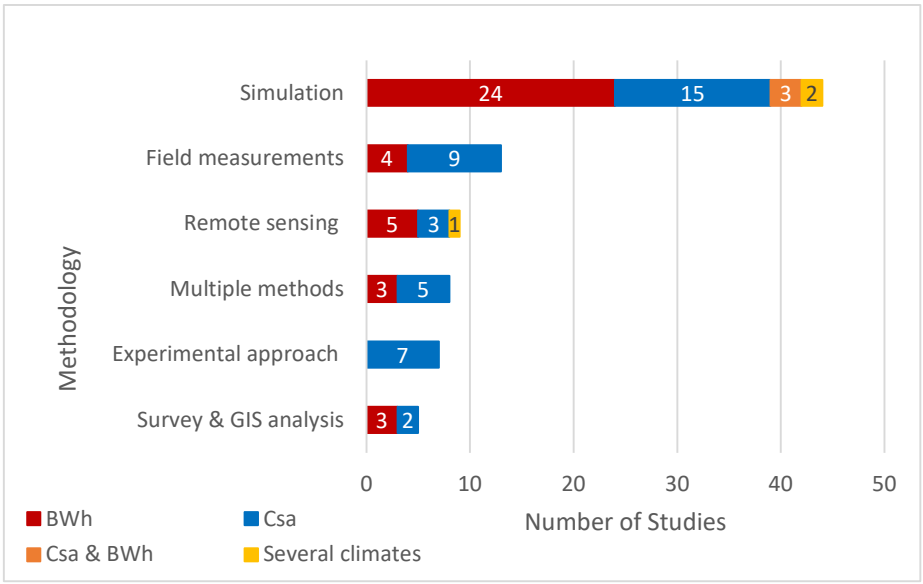


Figure 13. Distribution of reviewed studies focusing on vegetation strategies by methodology.

3.1.4. Thermal Comfort Indices Used

Thermal comfort indices are designed to illustrate exactly how people feel about factors such as temperature, wind speed, humidity, solar radiation, clothing, and activity level in measurable values [44]. These indices focused on the adverse impact of climate on thermal stress for people; therefore, some thermal indices were developed for hot conditions, whereas others were developed for cold conditions. [45].

- UHI studies

Because the majority of UHI studies relied on remote sensing technology for retrieving land surface temperature (LST), the thermal comfort measurements were lacking in both climates. However, 22 of the 43 studies used thermal comfort indices, with the PET index being the most frequently used in the reviewed studies, with five studies, three on hot-arid cities and two on Mediterranean cities (Figure 14). Three studies then used UTCI on Csa climates, three studies used UTFVI on BWh climates, and an additional three studies used AWBGT in both climates. Two studies utilized PMV on hot-arid regions and another two studies employed MOCI on Mediterranean regions. Finally, four additional indices, including WBGT, UTIR, ASV, and COMFA, were used only once each.

- Vegetation-based strategies

Regarding studies focusing on vegetation-based mitigation strategies, three thermal comfort indices dominated 38 studies, with 15 used PET, 13 used UTCI, and 8 used PMV across both climates (Figure 15). This is attributed to their suitability for evaluating different thermal microclimates, their broader classification range of thermal sensation and stress than other indices, and their calculations being easy using the available simulation software such as ENVI-met [45]. Moreover, the assessment of these indices does not only rely on air temperature and humidity measurements, as other simple indices do, but also includes other factors, including wind speed and direction, mean radiant temperature (MRT), the

thermal insulation of clothing, and human activity [46]. The remaining indices were used only once, except the HI index, which was used twice in all reviewed studies. However, not all studies measured thermal comfort, some because the research objective did not include thermal comfort [33,38,47–70], while the methodology of others did not enable authors to calculate thermal sensation, such as remote sensing, survey, and field observation [37,71–83]. Some articles also used multiple indices to increase the accuracy of the results [84–90].

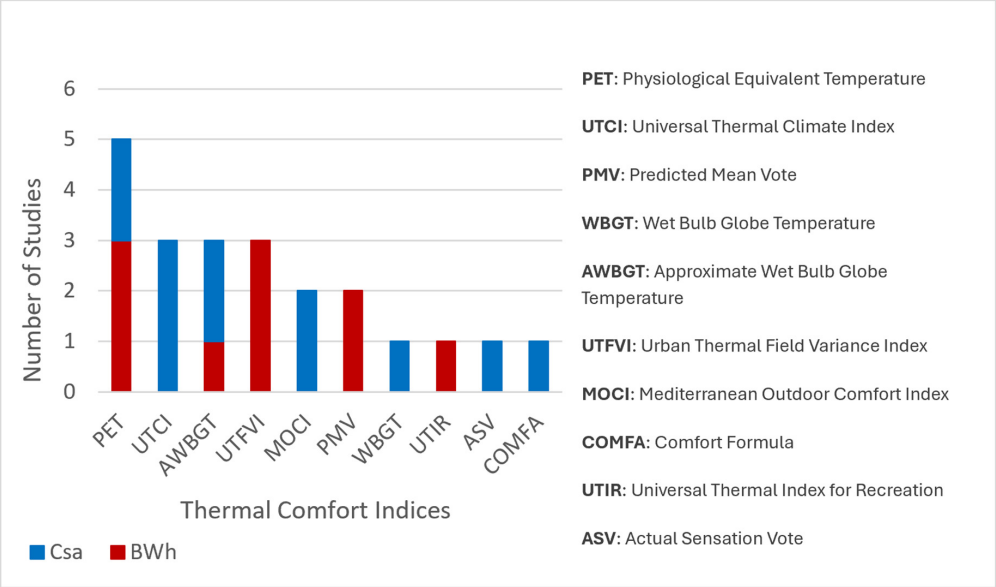


Figure 14. Distribution of thermal comfort indices in UHI studies.

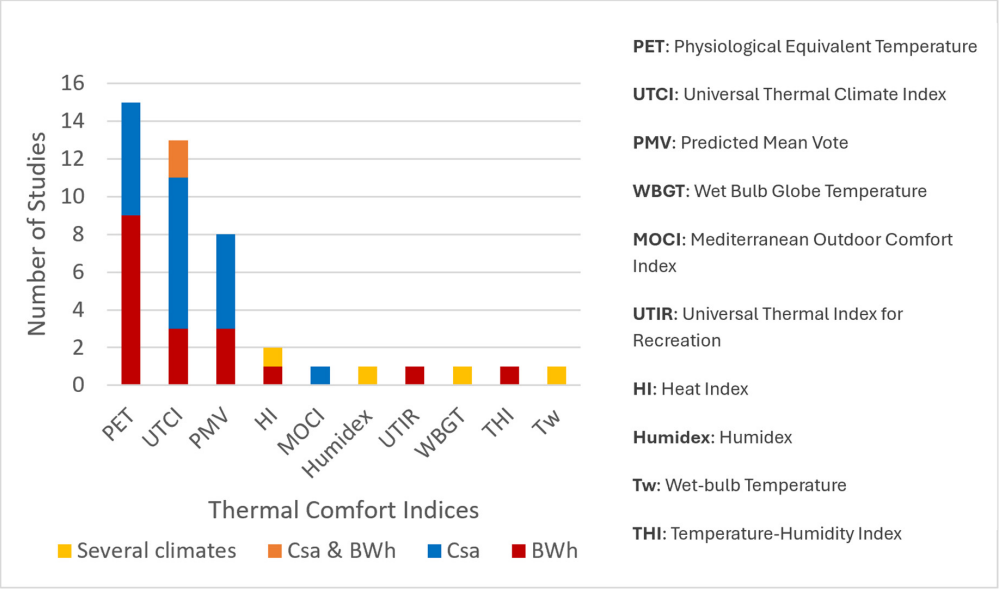


Figure 15. Distribution of thermal comfort indices in vegetation studies.

3.1.5. Vegetation-Based Strategies

There were 13 vegetation-based strategies identified across the reviewed studies to mitigate the UHI effect. These strategies were grouped according to their primary focus and are described in Table 3.

Table 3. Vegetation-based strategies used across the reviewed studies.

Strategy	Description
Greenspaces	Evaluation of the impact of increasing greenspace coverage on UHI mitigation at the city scale
Nature-based solutions (NBS)	Assessment of integrated nature-based strategies that combine vegetation with other strategies, such as permeable pavements, high albedo coatings, cool roofs, and recitative materials
Urban parks	Evaluation of the cooling performance of urban parks with different scales, small, medium, and large, and their impact of the surrounding areas
Trees	Evaluation of the cooling effects of urban trees, with particular focus on shading mechanism
Trees + Grass	Comparison of the individual and combined cooling effects of trees and grass, particularly shading and evapotranspiration mechanisms
Street trees	Investigation of the impact of street tree placement, arrangement, spacing, and canopy density on urban microclimate and thermal comfort
Green roofs	Evaluation of the cooling performance of green roof systems, including extensive and intensive roofs. At both building pedestrian levels
Green walls	Assessment of the cooling effectiveness of vertical greening systems, including green walls, green facades, and living walls
Green roofs and walls	Evaluating the combined application of green roofs and walls to improve cooling performance
Vegetation types	Comparison of the cooling performance of different landscaping approaches, such as xeriscaping, mesic, and oasis landscaping, and plant species, such as Acacia vs palm trees
Green courtyard	Assessment of the cooling effects of vegetated inner courtyards on microclimate and thermal comfort
Irrigation	Investigation of the additional cooling benefits provided by irrigation. Although irrigation is not a vegetation-based strategy itself, it is included in this review as a supporting strategy because it can maintain vegetation health and water availability, thereby sustaining evapotranspiration and the cooling performance of urban vegetation, particularly under water-limited conditions.
Several strategies	Evaluation of integrating multiple vegetation-based strategies to assess their combined effectiveness in mitigating UHI effects

Studies conducted in Mediterranean regions concentrated primarily on the cooling performance of urban parks with ten studies (11.6%), green roofs with six studies (7%), green walls and greenspaces with five studies each (5.8%), and trees and NBS with four studies each (4.7%) (Figure 16). A remarkable lack of application of diverse strategies, including street trees, vegetation types, and multiple strategies, was observed in Mediterranean climates, while no studies conducted the trees + grass strategy. In contrast, studies in hot-arid regions concentrated primarily on the influence of shading in mitigating UHI effects and enhancing outdoor thermal comfort with fifteen studies (17.4%) distributed across three strategies, (trees, trees + grass, and street trees), followed by urban parks and greenspaces with six studies each (7%), vegetation types with five studies (5.8%), and mixed strategies with four studies (4.7%). There was a noticeable shortage also in examining strategies, including green roofs, green roofs and walls, and irrigation, in hot-arid climates, while no studies were conducted for the NBS, green walls, and green courtyard strategies. Table S2 shows more details about each study investigating vegetation cooling strategies.

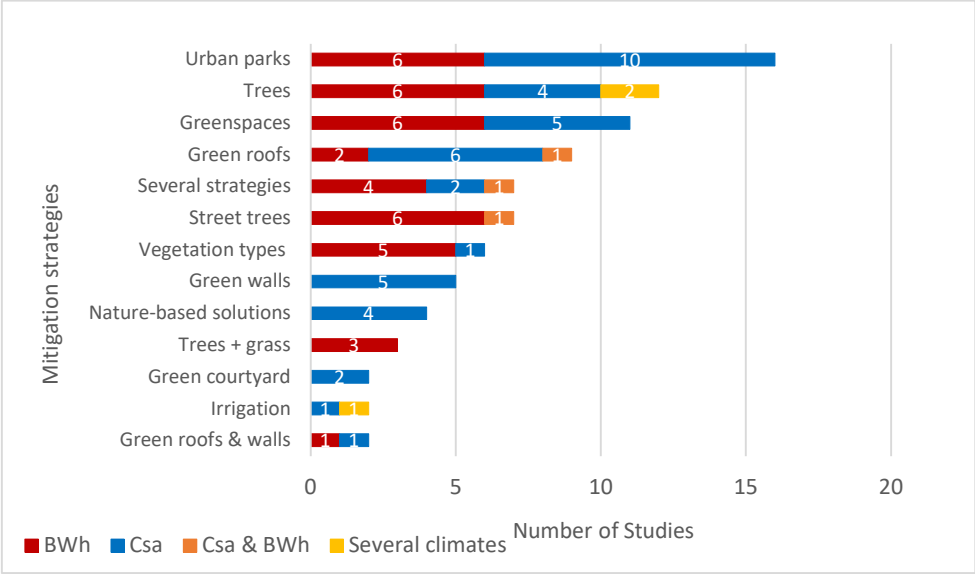


Figure 16. Distribution of vegetation-based mitigation strategies across the reviewed studies. Studies investigating multiple vegetation-based mitigation strategies are categorized under 'several strategies'; therefore, the individual strategy counts in this figure should not be interpreted as the total number of studies providing evidence for each strategy in subsequent cooling-performance analyses.

3.2. Qualitative Synthesis

3.2.1. Methods for Measuring UHI Effect and Its Mitigation Strategies in Both Climates

According to previous studies, there are three methods to investigate urban heat islands and the cooling effects of greenspaces in cities (Figure 17).

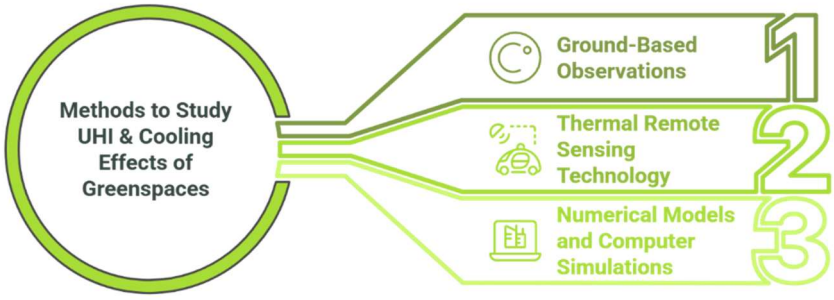


Figure 17. A diagram illustrating the three methods used in this research. Source: Authors.

- Ground-based observation

First, field measurement tools, the oldest method for assessing both CUHI effects, were used by Luck Howard in London in 1820 [22]. There are two common types of field measurements: installed weather stations and transect measurements [28]. Installed weather stations assess local climate factors such as air, LST, humidity, wind speed and direction, and total radiations, while transect measurements evaluate spatio-temporal variations in the city climate [46].

Moreover, on-site measurements are used to evaluate temperatures between urban and adjacent rural areas or between different urban forms and to study the effect of the built environment on thermal comfort at the micro or local scale [46]. This method features high accuracy and reliability, offering an excellent spatial resolution in measuring thermal heat differences between green and non-green areas compared to the other two methods. However, its spatial and temporal coverage is limited, making its application at the city level extremely difficult [91]. Moreover, it requires a substantial amount of equipment and

sometimes highly experienced labor for installation, maintenance, and monitoring, which costs time and money [25].

Nineteen articles employed field measurements across the reviewed studies in both UHI and vegetation-based strategies. [92,93] are examples that used weather stations and portable instruments, such as high-precision air temperature and humidity sensors, an anemometer for wind speeds, and a thermal imager to identify heat sources in both climates. On the other hand, Giannaros et al. [94] in a Mediterranean city and Saputra and Lai [95] in a hot-arid city used mobile measurements mounted on a vehicle equipped with air temperature, humidity, and wind speed sensors. These measurements assessed the impact of land use and land cover on climatic variables to measure fine-scale spatial variability. Some studied, furthermore, combined fixed weather stations and mobile sensors [96,97].

In addition, metrological data, another type of ground-based observation, is commonly used to measure CUHI effects, using long-time records from existing observation stations in urban and rural areas. This approach enables researchers to evaluate CUHI intensity and thermal comfort over long-term observation periods. However, only three articles applied this method across the reviewed studies, all of which were conducted in Mediterranean climates [98–100].

Moreover, survey-based methods are conducted to assess individuals' perceptions, thermal sensation, and adaptive behaviors in outdoor urban environments. Data collection was gathered through interviews or structured questionnaires [82]. Some studies combined survey and GIS-based analysis, enabling researchers to integrate spatial evaluation with subjective public awareness to provide a comprehensive assessment of the effectiveness of urban cooling strategies. Three studies conducted this approach in BWh climates [71,74,101] and three in Csa climate [76,82,102].

Experimental approaches, moreover, contribute to assessing the effectiveness of CUHI and SUHI mitigation strategies or to examining the impact of environmental parameters on urban environments. Even though this approach provides precise results, it takes a long time to collect them from a specific environmental condition, thus reducing its application and generalizability to other urban contexts. Therefore, only seven studies, all were conducted in Mediterranean regions, applied this method, and most of them investigated green roof and wall strategies [48,51,54,55,65,68,103].

- Thermal remote sensing technology

Second, thermal remote sensing technology is widely used to monitor urbanization through platforms such as Landsat, MODIS, ASTER, Sentinel-1 SAR, and Sentinel-2. This method facilitates comparative studies of investigating SUHI effects between cities, by extracting data from satellite images [2]. Previous studies have proven that remote sensing is an effective method to measure SUHI phenomenon and the cooling effect of greenspaces with the same accuracy as in situ measurement by assessing the differences in LST between greenspaces and their surroundings rather than air temperature [104]. This system provides broad spatial coverage, enabling an entire city to be mapped in a single image while also supporting analyses across a range of spatial scales [91]. However, its effectiveness is limited to clear and cloudless conditions [2]. Furthermore, vertical measurements, which represent a huge area of urban surface, cannot be provided through remote sensing images [25].

Landsat was the most frequently used satellite platform in reviewed studies in both climates. This is attributed to its long historical records and free accessibility, making it suitable for analyzing long-term spatial and temporal changes in cities. Studies used Landsat to derive LST values [101,105–109], monitor LULC changes [73,110–112], evaluate vegetation and building indices (NDVI, NDBI) [81,113–116], and assess SUHI dynamics over time [117,118]. Similarly, MODIS was the second most used platform, due to its high

temporal resolution, making it more valuable for analyzing diurnal [119,120], seasonal [121], and long-term variations [122] in SUHI intensity.

Moreover, ASTER was one of the least-used platforms among the reviewed studies, due to its spatial coverage being lower than MODIS and Landsat, respectively. However, ASTER provides a higher spatial resolution compared to other platforms, making it more suitable for a detailed analysis at the neighborhood and site scale [80]. In addition, both the Sentinel-1 SAR, and Sentinel-2 platforms were integrated with other platforms, particularly Landsat and MODIS, to improve the interpretation of SUHI patterns and enhance land-cover classification [83,120].

- Numerical models and computer simulations

Third, we have numerical models and computer simulations such as ENVI-met, WRF, and Rhino with the Grasshopper plug-in. Computational models are gradually used in urban climate studies because on-site experiments are difficult to control, and physical scale models are complex and costly [123]. High advance developments in computational capacity have increased their ability to evaluate heat mitigation strategies and assess climate change impacts in a scalable and cost-effective manner [123]. This approach allows researchers to test different scenarios without physical interventions, facilitating the implementation of climate best practices. Furthermore, it enables specialists to integrate multiple factors such as climate, vegetation, landscape composition, surface material, and anthropogenic heat in one framework, allowing for the accurate assessment of existing conditions and robust projections for the future [124,125]. Nevertheless, it needs field or remote sensing data for verification; otherwise, the results may be unreliable [18,43]. It also requires high-quality input data describing the climatic conditions, vegetation, urban geometry, and surface characteristics, leading to more accurate results between prediction and observation [126].

ENVI-met, a 3D modelling software based on Computational Fluid Dynamics (CFD) for urban microclimate studies, was the most widely used software in the reviewed studies. This software was used to assess the current conditions [127], test proposed scenarios [124], and predict future strategies [128]. Moreover, ENVI-met simulations can be carried out on multiple scales in urban settings, from the regional scale to microscale, including a single building and its surroundings [62,126,129]. Several green infrastructure strategies were investigated in both climates through ENVI-met, including NBS [130,131], urban parks [132,133], street trees [35,134], green roofs [70,135], green walls [53,69], different vegetation types [136], and inner green courtyard [86]. Moreover, some studies employed an integrated methodology combining ENVI-met and other simulation programs such as HAP and EnergyPlus, to evaluate outdoor thermal comfort and indoor energy savings [126,129].

The Weather Research and Forecasting (WRF) models are numerical-based models used to investigate UHI patterns and mitigation strategies at the regional scales [50,61]. However, their mesoscale resolution limits the simulation of street-level microclimates; therefore, they are usually coupled with microclimate models for detailed pedestrian-level assessments [88]. Moreover, Rhino with the Grasshopper plug-in enables researchers to simulate complex urban forms, evaluating multiple design scenarios effectively [84].

A numerical, physics-based simulation is another type of simulation in which fundamental physical equations are solved numerically to simulate how the urban settings respond under different mitigation or adaptation scenarios. This approach is more suitable with city-scale studies. For example, Song and Wang [58] examined the impact of green infrastructure strategies on the urban boundary layer, using an integrated methodology combining a Single-Layer Urban Canopy Model (SLUCM) with a Single-Column Model (SUM). The model was then validated using field measurements, showing good agreements with the simulation results. Moreover, Meili et al. [38] used the Urban Tethys-Chloris

(UT&C) model to separately evaluate the cooling mechanisms of trees, including shading and evapotranspiration. The model allows researchers to activate or deactivate each mechanism individually to assess its impact on reducing urban temperatures.

3.2.2. UHI Characteristics in Hot-Arid Climates

According to the Koppen–Geider climate classification, the hot-arid climate experiences intense summer heat, high evaporation, very low rainfall (less than 250 mm), and relatively moderate winters [46]. Urban areas in temperate climates generally experience both CUHI and SUHI effects during the day and night [59]. Conversely, hot-arid cities can experience nighttime CUHI and SUHI effects and daytime canopy urban cool island (CUCI) and surface urban cool island (SUCI) effects [40,97,110]. These daytime cooling phenomena is mainly attributed to the presence of green cover and, to some extent, built structures in hot-arid cities compared to surroundings located on bare sandy or rocky surfaces, where shading and evapotranspiration processes contribute to reducing both the daytime CUCI and SUCI [97,110]. Nevertheless, rural deserts cool rapidly after sunset, while urban surfaces and anthropogenic activities release heat at night, exacerbating the CUHI and SUHI effect. Examples of hot-arid cities experiencing daytime CUCI and/or SUCI and nighttime CUHI and/or SUHI include Jeddah [110] and Riyadh [137] in Saudi Arabia; Dubai, Sharjah, and Ajman [117], in UAE; Kuwait City [121], in Kuwait; Doha [97], in Qatar; and Morocco [119].

Rapid urban expansion and the significant loss of vegetation led to a decrease in cooling capacity in hot-arid regions. For example, in Yazd, Iran, the built-up areas increased by up to 29.6% and vegetation cover decreased by approximately 67% during the past four decades [111]. These changes led to a decrease in cooling capacity of approximately 26% and a decline in mitigating the SUHI effect by more than 50%. Another study examined the long-term changes in LST and urban heat risks across 21 Middle Eastern cities between 2003 and 2019 [41]. They found that rapid urban expansion has significantly contributed to the increase in hot-spot areas. In Phoenix, Arizona, moreover, urbanization contributed to an increase in the average intensity of CUHI by approximately 5 °C during the summer, with extreme cases reaching 11 °C [127].

In the Arabian Gulf countries, variables, including land use land cover (LULC), urban morphology, vegetation cover, and coastal ventilation, greatly influenced thermal environments [105]. For example, industrial activities and bare areas recorded the highest LST value, while vegetated areas had the lowest LST in these regions [105,110,112,117,118,121,137]. Greenspaces, furthermore, reduced LST by approximately 7 °C compared to the surrounding bare or built-up areas. Similarly, air temperature exhibited a similar pattern, with environments being cooler in vegetated sites and hotter in paved sites [114,115,118].

Furthermore, coastal cities in Arabian Gulf countries exhibited a lower daytime LST than inland desert cities due to the cooling effect of Arabian Gulf breezes [117]. Moreover, in Doha, Qatar, Ferwati et al. [97] indicated that the distance to the coast and traffic volume were the dominant drivers of urban heat along streets, with temperature variations of approximately 1–2 °C observed between the inland and the coast. In addition, Elhacham and Alpert [122] investigated the impact of rapid coastal urbanization on LST in Dubai, UAE, and demonstrated that inland urban expansion, particularly along the coastline, intensified SUHI, reaching up to 3.4 °C, while artificial islands exhibited a localized cooling effect from the surrounding sea surface.

Furthermore, hot-arid cities may experience strong seasonal variability and intense thermal discomfort. For example, in Biskara, Algeria, the LST exceeded 45 °C during the summer, while dropping below 20 °C in winter [115]. Moreover, Al-Ruzouq et al. [117] found an increase in LST by approximately 17% during summer nights between 2000 and

2022, while there was no significant change in daytime LST. In Kuwait, furthermore, the highest temperatures occurred in summer, while the lowest temperatures were recorded in winter and fall [121]. Moreover, Hedquist and Brazel [127] found that the highest levels of heat stress occur in summer, and unshaded areas cause significant discomfort. In winter, however, shaded built-up areas exhibit lower temperatures and become slightly less comfortable during the day, while, at night, the heat released from impermeable surfaces improves thermal comfort.

Table S5 shows further details regarding the reviewed studies focusing on UHI characteristics conducted in hot-arid climates.

3.2.3. UHI Characteristics in Mediterranean Climates

The Mediterranean climate is characterized by hot, dry summers and mild, wet winters, with pronounced seasonal precipitation variations, a hallmark of temperate coastal regions [138]. Unlike the hot-arid climate, the Mediterranean climate is considered a type of temperate climate, so it experiences CUHI and SUHI effects during the day and night [59]. Urbanization is the primary cause of both CUHI and SUHI phenomena in Mediterranean regions. In Annaba, Algeria, for example, Sayad et al. [92] demonstrated that the primary causes of CUHI are impermeable surfaces, urban geometry, and anthropogenic heat sources, increasing the intensity of CUHI by up to 6.9 °C. Moreover, across three Mediterranean cities, including Athens, Madrid, and Rome, Polydoros [109] indicated that increasing the urban density from low to medium leads to an approximately 20% increase in SUHI, and, from medium to high levels, an approximately 10% increase. Furthermore, medium-sized Mediterranean cities may experience a pronounced CUHI and SUHI like larger cities, due to the massive urban expansion and a lack of vegetation [120].

Several variables, including LULC, distance from water bodies, altitude, vegetation, and urban density, greatly influenced urban thermal environments in Csa climates [113]. The highest LST values are recorded in industrial areas, dense urban fabric, transportation infrastructures, and construction sites, while forest areas and greenspaces achieved the lowest [109,113]. Another study found that the urban temperature variations reached up to 10 °C between similar residential areas with a different urban form and varying land cover types [106]. The study also found that dense vegetation and a compact urban fabric can significantly reduce the SUHI intensity. Furthermore, shading by trees reduced solar radiation by 50 to 90%, significantly improving outdoor thermal comfort even under similar air temperatures [96,102].

According to the reviewed studies, Mediterranean regions experienced variations in both CUHI intensity and thermal comfort levels between day and night. For example, Falasca et al. [98] concluded that 26% of daytime thermal comfort values in urban areas of Rome, Italy, exceeded the comfort threshold, while only 0.1% of nighttime values showed heat discomfort. Another study demonstrated that the intensity of CUHI reached 1.6 °C at night and 3 °C during the day, exceeding 5–6 °C under extreme conditions [99]. However, in the coastal city of Thessaloniki, Greece, Giannaros and Melas [139] revealed that the nighttime CUHI intensity was considerably stronger than during the day, particularly in summer, reaching approximately 3 °C.

In terms of heat wave events, Salata et al. [125] indicated that heatwave events can intensify MRT by up to 40 °C in exposed areas. Another study demonstrated that the interaction between the heatwave and CUHI intensified the nighttime heat stress, increasing the air temperature by up to 31.6 °C and raising CUHI by approximately 9 °C at night [100]. The study also found that the frequency, duration, and intensity of heatwaves have significantly increased in the Mediterranean region.

Table S6 shows further details regarding the reviewed studies focusing on UHI characteristics conducted in Mediterranean climates.

3.2.4. Factors Influencing UHI in Both Climates

Numerous mitigation strategies are widely implemented, include urban design, green and blue infrastructure, and high-albedo materials [140–142].

- Urban Geometry

Globally, urban geometry with its elements, including surface texture, building configuration, Sky View Factor (SVF), and the aspect ratio (H/W) and orientation of street canyons, greatly influences the UHI effect in urban areas [101,107,127,143]. Adapting urban planning and design to suit climatic conditions is therefore crucial, as urban regulation in cold and temperate climates—characterized by a low-rise urban fabric and wide street patterns—have been widely implemented in hot-arid regions. However, the compact urban fabric highly recommended in hot-arid regions may contribute to decreased air temperature, LST, and solar radiation, and enhance outdoor thermal comfort. For example, in the hot-arid city of Makkah, Saudi Arabia, Mohamed et al. [107] found that the LST of the compact urban fabric was about 1.8 °C lower than that of the deformed iron-grid fabric. Moreover, the climate-responsive strategies, including a compact fabric, courtyards, and deep canyons, reduced the air temperature and MRT in hot-arid regions [128,144]. In contrast, Polydoros et al. [109] concluded that the intensity of SUHI may be exacerbated with the dense and compact urban fabric in Mediterranean cities during summer.

Sustainable urban geometry strategies play a crucial role in improving outdoor thermal comfort in both climates. For example, multistorey buildings in arid regions, deep canyons, and arcades in dry Mediterranean regions enhance shading effectiveness, contributing to a reduced SUHI effect [40]. In the hot-arid city of Jeddah, Saudi Arabia, the LST in lower-density areas was about 4 °C higher than in traditional high-density areas [110]. Moreover, the cooling effect of sustainable urban design in Dubai was higher than that of unsustainable designs in Sharjah, under similar climatic conditions [101].

In addition, SVF is an important factor in mitigating the effect of UHI. For example in a Mediterranean city, Speak and Salbitano [145] indicated that UTCI was reduced by 1 °C with each 12.5% reduction in the SVF. Similarly, in a hot-arid city, Salameh et al. [144] concluded that a lower SVF provides more shaded areas, therefore significantly reducing urban temperatures. Moreover, Hedquist and Brazel [127] stated that high built-up density areas with low SVF and deep urban canyons in Phoenix, Arizona, provide adequate shade during the day, reducing the CUHI effect. However, at night, these areas become about 2 °C warmer than their surroundings due to the amount of heat that is released by impervious surfaces.

The aspect ratio of a street canyon is another important factor influencing the UHI effect and thermal comfort. A high aspect ratio, with north–south or intermediate orientations (NW–SE) or (NE–SW), reduces the intensity of both CUHI and SUHI, due to the amount of shade they provide [40,127].

- Green Infrastructure

Green infrastructure enhances urban life by mitigating the impact of urban heat, supporting surface runoff management, improving public health and well-being, reducing energy consumption, bolstering ecological and environmental benefits, and boosting visual quality and economic value [146–148]. Urban green infrastructure consists of four types of green spaces: public parks and gardens, street trees, private greenspaces, and green roofs and walls [149]. Vegetation reduces air temperature directly by converting water

from its liquid state into vapor, and indirectly by blocking solar radiation, thus providing adequate shade.

In arid climates, variations in vegetation cover affect the spatial distribution of SUHI, with more vegetation showing a lower LST and reduced heat risk, and vice versa [41]. Furthermore, greenspaces can reduce LST in summer and winter by approximately 3.9 °C and 13.5 °C, respectively [110]. Similarly, in Mediterranean climates, greenspaces strongly contribute to lowering the air temperature, particularly at night [94]. Moreover, Dialesandro et al. [40] found that the cooling effect of vegetation in the hot-arid city of Phoenix was 10 °C stronger than that in the Mediterranean city of Madrid. However, water scarcity remains a major challenge in hot-arid climates.

Furthermore, the correlation between the Normalized Difference Vegetation Index (NDVI) and LST is negative in both climates [112,150]. In Dubai, for example, the cooling effect of the vegetation cover was significant due to green initiatives the city has launched since 2013 to address the SUHI phenomenon [112]. In Annaba, Algeria, urban trees are the most effective mitigation strategy in a city with a Mediterranean climate [92]. Furthermore, an increase of 0.1 in the NDVI value contributes to a reduction in the average air temperature of 2 °C in hot-arid climates, and of 1.6 °C in Mediterranean climates [150]. Moreover, Speak and Salbitano [145] concluded that every 25% increase in tree canopy leads to a 1 °C decrease in UTCI in Mediterranean regions, thus improving outdoor thermal comfort.

- Blue Infrastructure

In the Mediterranean city of Beirut, Lebanon, Fahed et al. [151] reported that the addition of water features (fountains and sprays) in a dense residential area reduced the air temperature and PET by approximately 7 and 4.3 °C, respectively, and increased humidity by up to 3.5 g/kg. Moreover, in Beirut, water bodies reduced the sensible load by approximately 4%, but they increased humidity, thus increasing the latent load by about 13–29% [126]. Another study conducted in Rome, Italy, a Mediterranean climate, indicated that overhead water mist systems significantly reduced air temperature and PET by about 5.5 and 4.2 °C, respectively, and increased humidity by about 3.7%, thus considerably improving outdoor thermal comfort [152].

Conversely, in hot-arid climates, greenspaces that contain water features are 3 °C cooler than those that contain only vegetation [89]. Moreover, in Doha, Qatar, air temperature increased by approximately 1–2 °C with increasing distance from the coast to the inland areas [97].

- Reflective Materials

Applying high-albedo materials on the ground can reduce the PET by approximately 15 °C in the Mediterranean city of Algiers [131]. However, increasing albedo on a building façade may increase heat due to radiation reflection, particularly in narrow street canyons. Furthermore, in a dense district with a Mediterranean climate, Fahed et al. [151] reported that cool materials can reduce air temperature, MRT, and PET by approximately 2.5, 20, and 3.9 °C, respectively. However, using high-albedo materials on walls and ground may increase heat stress and cooling demand due to radiation reflection, particularly with a low SVF [126,131,153].

On the other hand, in hot-arid environments, Habibi and Kahe [64] revealed that the use of 80% permeable pavement reduced air temperature by approximately 1.18 °C. Moreover, applying cool materials on roofs, facades, and pavements reduced the air temperature by up to 2.3 °C in the hot-arid city of Doha, Qatar [128]. However, the study also found that the combined cool material strategy increased MRT and PET by approximately 28.8 and 7.7 °C, respectively, significantly exacerbating thermal discomfort.

- Combination of multiple strategies

Combined mitigation strategies can help to significantly improve outdoor thermal comfort more than individual interventions in a hot-arid climate [124]. Similarly, Vurro et al. [129] evaluated combined mitigation strategies in a Mediterranean climate, and found that vegetation achieved the highest heat stress reduction, while cool materials resulted in the greatest reduction in cooling demands. Moreover, Salata et al. [125] indicated that integrated multiple mitigation strategies reduced the average MOCI value by −2.5, and decreased the health risk by approximately 60%.

In addition, urban morphology contributed to reducing air temperature and improving thermal comfort more than vegetation alone in hot arid climates [144], while, in Mediterranean climates, urban trees were the most effective mitigation measures, reducing air temperature by up to 1.9 °C [92].

3.2.5. The Role of Green Infrastructure in Mitigating Urban Heat in Both Climates

- The Effectiveness of Vegetation-Based Strategies to Mitigate UHI

Urban green infrastructures have a positive impact in heat mitigating, CO_2 isolation, air quality, water reserving, and economic development, while grey infrastructures do the opposite [154]. For example, the average surface temperature of shrubs and grass was approximately 16 °C cooler than that of paved surfaces and dry bare soil in Mediterranean climates [87,155]. Moreover, the air temperature above the shrubs and grass was 5.5 and 3.8 °C lower, respectively, than the actual air temperature, whereas the air temperature above the paved surfaces and bare soil was 12.5 and 10.8 °C higher, respectively [155].

Similarly in hot-arid climates, Song and Wang [58], for example, concluded that urban green infrastructure can reduce the boundary layer temperature, particularly during daytime due to shading and the evapotranspiration process. Moreover, Mohammed et al. [61] indicated that large-scale greening across Dubai can reduce the daytime air temperature by up to 1.7 °C and the nighttime air temperature by up to 2.4 °C during the summer, with significant reductions in sensible heat flux due to the evapotranspiration process. The study, however, demonstrated that increasing green infrastructure increases humidity levels, thus reducing outdoor thermal comfort.

Moreover, Khan et al. [50] demonstrated that expanding greenspaces across the Mediterranean city of Athens can reduce the maximum air temperature by approximately 1 °C during the day and 1.9 °C during the night. Another city-scale study in a Mediterranean climate revealed that greenspaces were 3–4 °C cooler than built-up areas, mainly due to the evapotranspiration process [52].

In addition, urban green infrastructure influences several parameters, including air temperature, relative humidity, LST, solar radiation, MRT, and thermal indices. For example, Addas [72] demonstrated that urban green infrastructure reduced local air temperature by up to 4.8 °C, in the hot-arid Saudi environments. Likewise, in the Mediterranean Italian environments, vegetation can reduce air temperature by up to 1.6 °C on the street and 3.5 °C inside greenspaces [156]. In addition, green infrastructure in Mediterranean climates significantly reduced air temperature, MRT, PET by approximately 2.1, 30, and 14.3 °C, respectively [151].

Combined multiple vegetation-based strategies achieved a greater cooling effect than individual ones. For example, in San Benedetto del Tronto, Italy, a Mediterranean city, Brownlee et al. [157] found that the implementation of integrated green infrastructure strategies, including vegetation optimization, rain garden systems, pavement de-sealing, and building-integrated greenery, reduced UTCI by approximately 1.17 °C at the neighborhood scale. Moreover, in Csa climates, trees and hedges can reduce PET by approximately 16.8 °C, while green roofs reduce it by approximately 14.7 °C at the building scale [131].

Another study in a Mediterranean climate reported that NBS significantly improve outdoor thermal comfort, with deciduous trees providing a great cooling effect, particularly in parking lots [130].

3.2.6. Types of Urban Vegetation Strategies

- Urban parks

➢ Small to medium urban parks

Small- and medium-sized urban parks can reduce air temperature and extend their cooling effect to surrounding urban areas in both climates. For example, in Mediterranean regions, pocket parks reduced the air temperature by approximately 0.5–3 °C, with a stronger cooling effect in parks characterized by more diversity in the vertical canopy [158–162]. Moreover, the cooling effect of small urban parks could extend up to 50–100 m outside their boundaries depending on the park size and tree canopy density [158,160,161]. Similarly, in hot-arid regions, Hussein [69] revealed that densely vegetated pocket parks reduced the air temperature by up to 7 °C between 12 and 3 pm. However, the cooling effect considerably decreased after 3 pm, due to the heat trapped underneath trees.

In addition to lowering the air temperature, small parks can significantly reduce LST. The reduction in LST in Mediterranean climates ranged from 4 to 20 °C [87,159]. Moreover, Delgado-Capel et al. [81] demostrarted that small, dispersed greenspaces had the lowest LST values in Csa climates, followed by medium-sized greenspaces, while the linear green corridors recorded the highest values. Likewise, in BWh climates, small greenspaces containing trees, grass, water bodies, and green walls could reduce LST by approximately 6.83 °C [89].

Small greenspaces with well-shaded areas can significantly reduce MRT and thermal indices. For example, pocket parks in Mediterranean cities reduced MRT and UTCI by about 3.7 and 3 °C, respectively, thus significantly increasing the comfortable hours to 75% of the simulated time from 10 am to 6 pm [84,159]. In hot-arid cities, moreover, adding a new small park could reduce MRT and PET by approximately 6–14 and 2 °C, respectively [89,128]. However, small parks slightly increased the relative humidity levels in both climates [128,160].

In addition, greening small open spaces in the compact urban fabric provides a significant cooling impact in outdoor thermal comfort, particularly in Mediterranean climates. For example, vegetated inner courtyards could reduce the air temperature, MRT, and PET by approximately 6.5, 15, and 3–6.5 °C, respectively, thus greatly improving outdoor thermal comfort [86,163].

- Large urban parks

Large urban parks have a higher cooling effect compared to small and medium urban parks, particularly in Mediterranean regions. For example, large parks reduced the air temperature, MRT, LST, and PET by approximately 1–3, 4.8, 4, and 3.9 °C, respectively, at a distance of 600 m from the park [42,159]. Moreover, Grace et al. [59] indicated that all park sizes, from small to large, reduced LST by approximately 10–15 °C compared to urban surroundings. Table S7 shows more details about each study investigating urban parks.

Figure 18a,b illustrates variations in the cooling performance of urban parks across both climatic contexts. The mean air-temperature reduction was approximately 4.4 °C in BWh climates, with a maximum of 7 °C, compared with approximately 2 °C in Csa climates, where reductions generally reached up to 3 °C, with one higher observation of 6.5 °C identified as an outlier. A similar difference was observed for MRT, with a mean

reduction of approximately 10.2 °C in BWh regions and 7.8 °C in Csa regions, while the maximum reported reductions reached 14 °C and 15 °C, respectively.

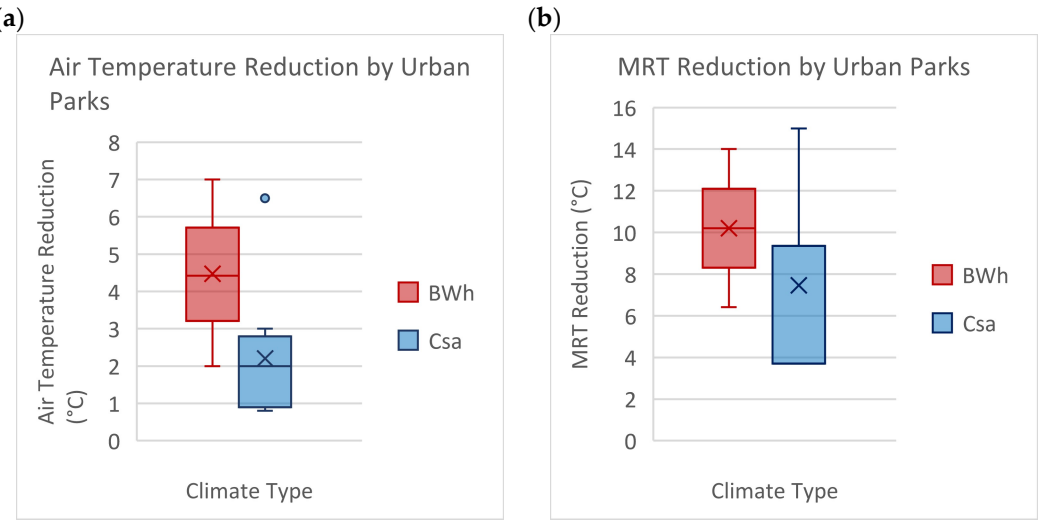


Figure 18. Cooling effects of urban parks across BWh and Csa climate types: (**a**) air temperature reduction and (**b**) mean radiant temperature (MRT) reduction. (The × symbol represents the mean, the horizontal line within each box represents the median, the box represents the interquartile range (Q1–Q3), the whiskers indicate the minimum and maximum non-outlier values. and the dot represents an outlier).

However, these differences should not be interpreted as evidence that urban parks are intrinsically more effective in BWh climates. The reported values were derived from heterogeneous studies with different park characteristics, vegetation configurations, irrigation regimes, climatic conditions, measurement periods, and methodological approaches. Importantly, all reviewed studies reporting park-cooling performance in BWh climates employed simulation methods using ENVI-met, whereas the studies conducted in Csa climates included a combination of simulation and field measurements. This methodological difference may partly contribute to the observed variation between the two climates, as simulated vegetation performance depends on prescribed model parameters and assumptions, and may not fully represent actual irrigation practices, water availability, and associated evapotranspirative constraints under hot-arid conditions. This is particularly relevant in BWh environments, where natural water availability is limited and irrigation can substantially influence evapotranspirative cooling. Therefore, the comparatively greater cooling reductions reported in the BWh studies may reflect differences in methodological approaches, modelling assumptions, irrigation conditions, and park characteristics rather than climatic classification alone.

- Street trees

Urban streets are highly exposed to solar radiation and are commonly paved with asphalt and concrete, which contributes to an increased ambient air temperature. Street trees, however, contribute significantly to reducing heat stress by blocking a large amount of solar radiation and cooling the ambient air temperature by evapotranspiration [164]. For instance, Lopez-Cabeza et al. [35] compared the cooling effect of street trees in the two climates, and found that, in the Mediterranean city, the compact and asymmetrical canyon with vegetation recorded the greatest reduction in UTCI due to shading and evapotranspiration. In contrast, in hot-arid cities, open configurations without vegetation were optimal, as vegetation increases humidity in a city suffering from high humidity levels.

Moreover, in hot-arid regions, street trees had a limited impact on reducing the air temperature, ranging from 0.4 to 0.8 °C [88,165,166]. However, a small increase in tree canopies from 2 to 4% along pedestrians could reduce LST by 10 °C, MRT by 10–15 °C, PET by 2 °C, and UTCI by 2.5 °C, achieving great improvements in thermal comfort [63,88,128,165]. Furthermore, street trees may increase the relative humidity by 10–20% [63].

Furthermore, the distribution of trees is as critical as the quantity of tress in enhancing outdoor thermal comfort in both climates. For example, in a hot-arid environment Binabid [134] concluded that trees that 5 m tall, densely spaced, and arranged in multiple rows reduced PET by approximately 17 °C at the street level. Another study found that clustered side trees cool more strongly than isolated trees [165]. In addition, Aboelata [166] found that the 50% tree scenario with an E–W orientation was the best for improving outdoor thermal comfort, reducing PET by about 5 °C, while the N–S-oriented street with the same percentage of tree cover was the worst, reducing PET by only about 2.7 °C.

On the other hand, a simulation study investigated the impact of a different spatial distribution of urban vegetation on reducing both CUHI and SUHI effects in a Mediterranean environment [159]. The results concluded that street trees reduced air temperature by up to 0.8 °C, MRT by up to 10.5 °C, and LST by up to 4.2 °C, achieving the greatest cooling effect compared to an urban forest and a medium urban park. This is primarily because shading was distributed throughout the district rather than placed in one area. Table S8 shows more details about each study focused on street tree strategies.

Figure 19a,b illustrates the effectiveness of street trees in reducing urban temperatures in both climatic contexts, although contrasting patterns were observed. The mean air-temperature reduction was approximately 1.8 °C in BWh climates, compared with approximately 1.3 °C in Csa climates. However, the median reduction was lower in BWh climates (approximately 0.6 °C) than in Csa climates (approximately 1.3 °C), indicating that the BWh mean was influenced by a relatively high cooling observation of 6 °C. The BWh reductions ranged from 0.1 to 6.0 °C, with the highest value represented as an outlier in Figure 19a. In contrast, Csa climates exhibited a narrower range of approximately 0.8–1.7 °C. These findings indicate a greater variability in the reported cooling performance of street trees in BWh climates, although comparisons should be interpreted cautiously due to the limited number of observations and differences in study conditions.

A different pattern was observed for MRT, where the cooling effect of street trees in hot-arid regions was stronger than in Mediterranean regions. In BWh climates, the median MRT reduction was approximately 14.5 °C, reaching up to 16 °C, while, in Csa climates, it was only around 9.5 °C, reaching up to 10.5 °C.

- Green roofs and green walls

Moving forward, due to the shortage of available land to implement green infrastructures in modern cities, green roofs, living walls, and vegetated facades are other possibilities to maximize vegetative coverage [31]. Conventional rooftop surfaces are commonly covered with low albedo materials, which absorb and release large amounts of heat, thus exacerbating both CUHI and SUHI effects. In contrast, green roofs absorb less heat compared to conventional ones and contribute to cooling the ambient air temperature through evapotranspiration and LST through shading [32].

Furthermore, green roofs have a limited impact on reducing air temperature at the pedestrian level in both climates. For example, in hot-arid regions, the air temperature reduction from green roofs ranged from 0.2 to 0.5 °C at the pedestrian level [58,62,64,69,128]. Similarly, in Mediterranean regions, green roofs provide a moderate cooling of between 0.2 and 0.5 °C at the pedestrian level [47,135]. However, the cooling effect of green roofs decreases with height, as buildings taller than 40 m showed a negligible impact at the pedestrian level.

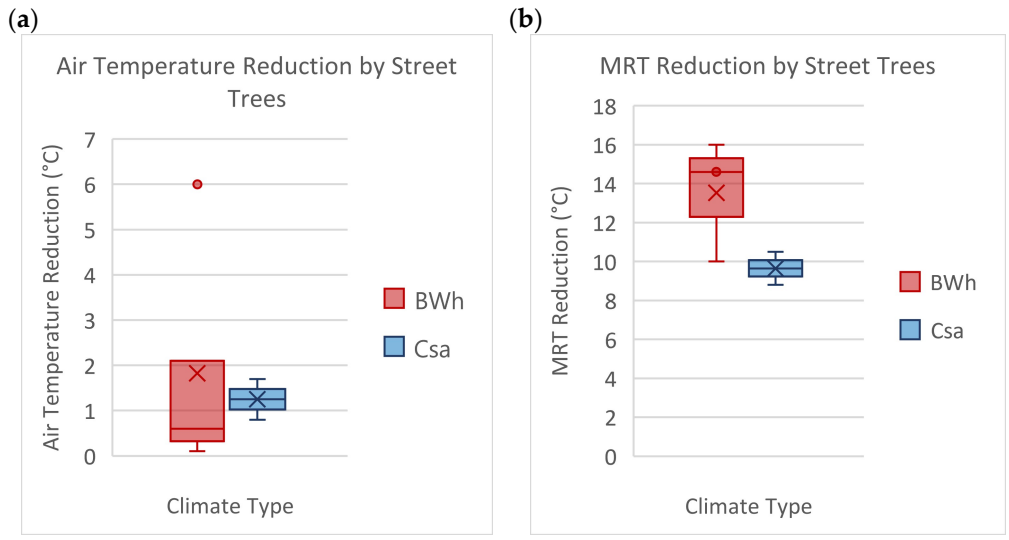


Figure 19. Cooling effects of street trees across BWh and Csa climate types: (**a**) air temperature reduction and (**b**) mean radiant temperature (MRT) reduction. (The × symbol represents the mean, the horizontal line within each box represents the median, the box represents the interquartile range (Q1–Q3), the whiskers indicate the minimum and maximum non-outlier values. and the dot represents an outlier).

In contrast, the reduction in roof surface temperature was significant in Mediterranean regions [49,54,57,68], while no study investigated hot-arid regions. Green roofs, moreover, could considerably reduce the cooling load in both climates [49,62,70].

In addition, green roofs outperform other roof-based strategies in mitigating CUHI in both climates. For example, in hot-arid climates, green roofs reduced air temperature and MRT by 1.6 and 3.6 °C at the canopy layer, outperforming other roof strategies, such as white, pond, cool, and dark roofs [58,167]. Likewise, in Mediterranean climates, Zinzi and Agnoli [33] demonstrated that green roofs can reduce heat transfer through thermal insulation from the soil layer, along with evapotranspiration from vegetation. This creates a balance between different seasons by reducing the need of cooling in summer and heating in winter, while the cool roofs increase the heating demand in winter.

On the other hand, green walls contribute to mitigating CUHI and SUHI in both climates. In Mediterranean climates, the cooling effect of green facades increases with increasing vegetation density [48]. However, the cooling effect of green walls at the pedestrian level was limited, with an air temperature reduction of approximately 0.5 to 0.6 °C, depending on the façade orientation and the season [47,65]. For example, southern and western green facades achieved the highest reduction in outer surface temperature, leading to a reduction in indoor air temperature [53,55,65]. Furthermore, the living walls maintained the wall surface temperatures during winter months, while non-vegetated walls dropped below freezing temperatures, thus acting as a thermal buffer [55].

Similarly, in the hot-arid climates, green walls have a limited cooling effect, with a reduction in air temperature of about 0.5 °C at the pedestrian level [64,67,69]. However, Al Hashim et al. [67] mentioned that green walls in narrow alleyways significantly reduced airflow, which may exacerbate thermal discomfort. Moreover, the impact of living walls was not restricted to reducing air temperature; they also reduced cooling demands, CO_2 emissions, and energy consumption by approximately 25%, 14.7%, and 53.4%, respectively [64]. They can also contribute to increasing biodiversity (providing habitats). Table S9 shows more details about each study focusing on green roofs and walls strategies.

Figure 20a,b shows great variations in the cooling performance of green roofs and walls between the two climates. Green roofs and walls provided a limited reduction in

air temperature in both climates, averaging approximately 0.5 and 0.3 °C in Csa and BWh climates, respectively. However, greater differences were observed in surface-temperature reductions. BWh climates exhibited a higher median surface-temperature reduction of approximately 13.5 °C, with values ranging from 8.7 to 18 °C. In contrast, Csa climates exhibited a lower median reduction of approximately 5.8 °C, although the results showed greater variability, including an extreme observation of approximately 37 °C. Overall, these findings indicate that green roofs and walls produced a modest air temperature reduction in both climates. However, their effects on surface temperature were substantially greater, particularly in hot-arid environments.

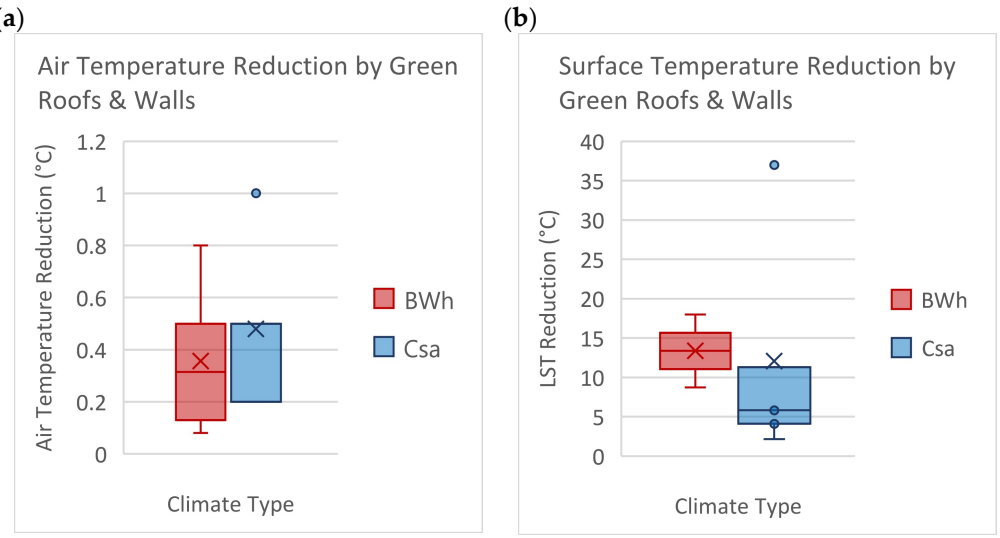


Figure 20. Cooling effects of green roofs and walls across BWh and Csa climate types: (**a**) air temperature reduction and (**b**) surface temperature reduction. (The × symbol represents the mean, the horizontal line within each box represents the median, the box represents the interquartile range (Q1–Q3), the whiskers indicate the minimum and maximum non-outlier values. and the dot represents an outlier).

3.2.7. Vegetation-Based Cooling Mechanisms

Vegetation contributes to cool urban areas through different mechanisms: providing shading and evapotranspiration [16,31]. In this review, the cooling effects of shading and evapotranspiration were categorized based on the findings reported in the original studies and the predominant cooling mechanism associated with each vegetation-based strategy. Studies examining trees and street trees were primarily considered under shading, as their cooling performance is largely associated with the interception of solar radiation by tree canopies, although evapotranspiration also contributes to their overall cooling effects. In contrast, studies investigating grass and low-growing shrubs were generally considered under evapotranspiration, as these vegetation types provide relatively limited shading and their cooling effects are more closely associated with evapotranspiration. Furthermore, studies that explicitly distinguished between these mechanisms were classified according to their reported results. For example, Meili et al. [38] employed the Urban Tethys-Chloris (UT&C) model to independently evaluate shading and evapotranspiration by activating and deactivating each mechanism. Nevertheless, since both processes often operate simultaneously, the cooling reductions presented in Figures 21 and 22 should be interpreted as effects primarily associated with each mechanism rather than their exclusively isolated contributions, except where the original studies explicitly separated them.

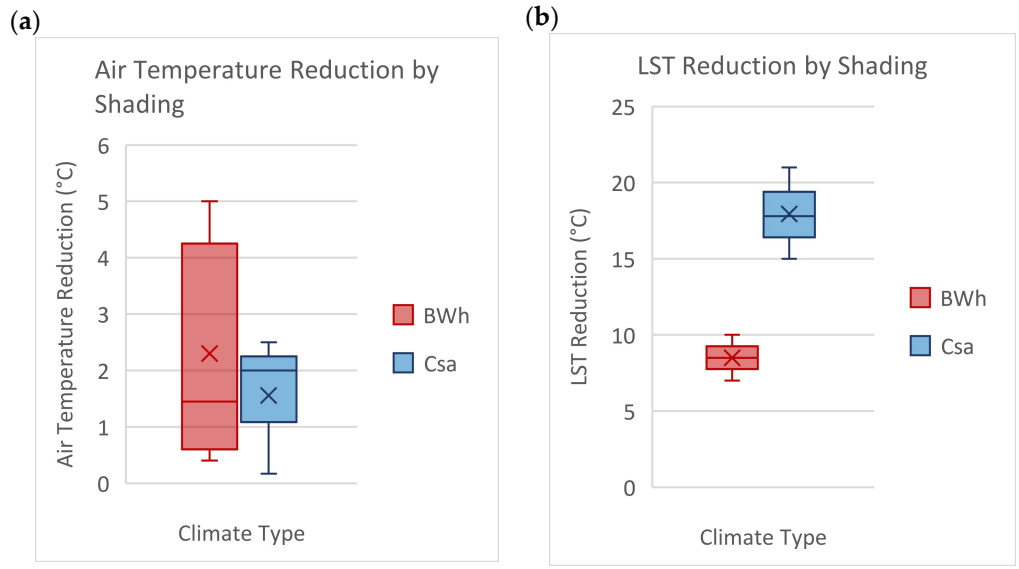


Figure 21. Cooling effects of shading across BWh and Csa climate types: (**a**) air temperature reduction and (**b**) LST reduction. (The × symbol represents the mean, the horizontal line within each box represents the median, the box represents the interquartile range (Q1–Q3), and the whiskers indicate the minimum and maximum non-outlier values).

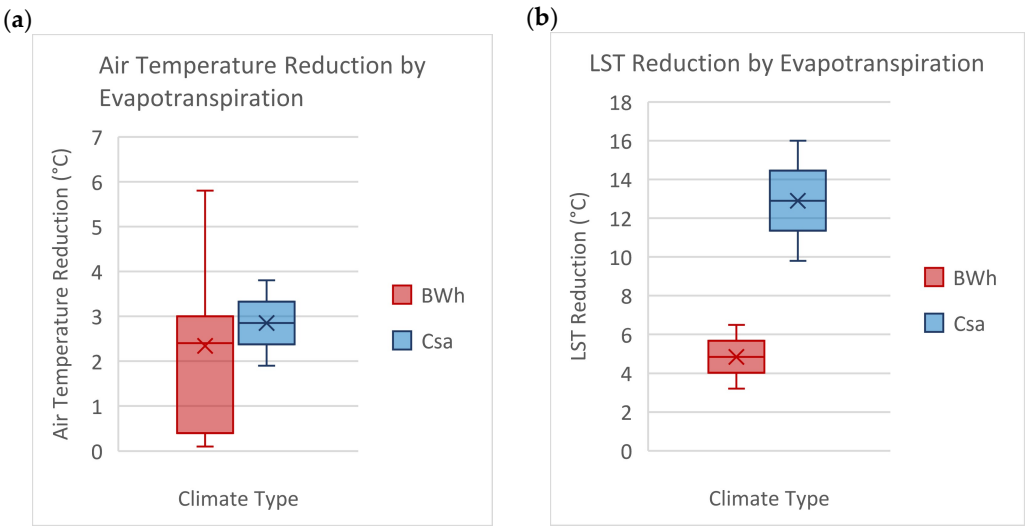


Figure 22. Cooling effects of evapotranspiration across BWh and Csa climate types: (**a**) air temperature reduction and (**b**) LST reduction. (The × symbol represents the mean, the horizontal line within each box represents the median, the box represents the interquartile range (Q1–Q3), and the whiskers indicate the minimum and maximum non-outlier values).

- Shading effect

Trees are the most efficient means of enhancing outdoor thermal comfort in all climatic classifications [168]. Compared to shrubs and turfs, trees are more effective in cooling impact due to shading and evapotranspiration [36,103] and are capable of blocking 70–90% of shortwave radiation [31]. For example, a simulation study compared the cooling effect of various green infrastructure types between Los Angeles, a Mediterranean city, and Phoenix, a hot-arid city [36]. This found that, in Los Angeles, trees were the most effective strategy reducing heat stress by 18.48%, due to the substantial shade they provided. In Phoenix, however, the cooling capacity of vegetation was significantly smaller, as the extreme heat conditions reduced the vegetation evapotranspiration process.

The air temperature reduction caused by shading from trees in Mediterranean regions reached up to 2.5 °C [130], while, in hot-arid regions, it ranged between 0.5 and 5 °C [95,169–171]. Furthermore, tree shade significantly contributed to reducing LST by approximately 11 to 20 °C in Csa climates [85,155], but only by approximately 7 °C in BWh climates [172]. Moreover, the cooling effect of tree shade is significantly higher than that of building shade because trees produce evapotranspiration in addition to providing shade [172].

Shade, moreover, may greatly influence MRT and thermal indices in both climates, thus significantly improving outdoor thermal comfort. For example, in Mediterranean environments, grass areas exposed to solar radiation remain very hot, while shaded areas by trees are significantly cooler, resulting in a reduction in MRT by 20 °C, PMV by 0.75 units, and UTCI by up to 17 °C [59,130,132,156,173]. In addition, Grilo et al. [160] concluded that a park, even a small one, with a dense tree canopy produces a stronger cooling effect compared to other vegetation types, extending its cooling to 60 m outside the park edges. Likewise, in hot-arid environments, tree shade reduced the average daytime MRT by about 17.4 °C, daytime PET by 3–7.5 °C, and daytime PMV by 2.5 units [167,171,174]. However, they may trap longwave radiation at night [58,174].

Figure 21a,b demonstrates the effectiveness of shading in the two climates. The mean air-temperature reduction associated with shading was approximately 2.3 °C in BWh climates and 1.6 °C in Csa climates. However, the BWh results showed substantially greater variability, with reductions ranging from approximately 0.4 to 5.0 °C, whereas the Csa values ranged from approximately 0.2 to 2.5 °C. A significant variation was observed in LST reduction. Csa climates exhibited considerably higher reductions, with an average of approximately 18 °C and values ranging from 15 to 21 °C, whereas BWh climates had an average reduction of approximately 8.5 °C, with values only ranging from 7 to 10 °C. Although MRT is particularly relevant for evaluating the impact of shading on outdoor thermal comfort, it was not included in this comparison because only a limited number of the reviewed shading studies reported this parameter. This provides insufficient data for a meaningful comparison between the two climates.

- Evapotranspiration

Impermeable surfaces in urban areas gain sensible heat due to the absence of water, thereby increasing the surrounding air temperature, while green infrastructure does the opposite [28,31]. For example, two studies conducted in Dubai, a hot-arid BWh city, and Athens, a Mediterranean Csa city, indicated that expanding green infrastructure across the city could significantly reduce the sensible heat flux and substantially increase the latent heat flux through an evapotranspiration process [50,61]. However, Abu Ali et al. [175] concluded that grass alone provided limited cooling benefits in hot-arid environments due to the low evapotranspiration rates in such harsh climates.

The evapotranspiration process could reduce the ambient air temperature in hot-arid climates by approximately 2–5 °C [38,169]. Moreover, Ed-dahmany et al. [119] demonstrated that irrigated vegetation in inland arid cities contributed to making urban areas cooler than the surrounding sandy or barren areas. For example, in the arid city of Las Vegas, drought-tolerant trees, such as Bur Oak, have a limited cooling effect, while high-transpiration species, such as Cherry, provide a significantly better cooling effect, particularly during the day, but require three times the amount of water [88]. On the other hand, in Mediterranean climates, Cascone and Vitaliano [51] indicated that the biochar-based model reduced LST by approximately 9.8 °C and increased water retention by 30–35%. The study also found a strong relationship between the water retention capacity and cooling efficiency, highlighting the crucial role of evapotranspiration in mitigating SUHI.

Figure 22a,b illustrates clear variations in the cooling effect of evapotranspiration between BWh and Csa climates. The evapotranspiration process reduced the average air temperature by approximately 2.8 °C in Csa climates, compared with around 2.4 °C in BWh climates. However, the variability was considerably greater in BWh climates, with values ranging from 0.1 to 5.8 °C, whereas it was less pronounced in the Csa climates, ranging from 1.9 to 3.8 °C. Regarding LST reduction, Csa climates exhibited higher reductions, with a median of approximately 12.8 °C, reaching up to 16 °C. In contrast, BWh climates had a median LST reduction of approximately 4.8 °C, reaching up to 6.5 °C, mainly due to the limited availability of water for irrigation. Overall, the results demonstrate that evapotranspiration produced a higher reduction in air temperature and a lower reduction in LST compared to shading in both climates.

Graphical comparisons were developed for vegetation-based strategies where sufficient and comparable quantitative data were available, such as urban parks, street trees, and green roof and wall strategies. In addition, trees, trees + grass, and some greenspace strategies are represented within the figures examining shading and evapotranspiration processes. However, similar figures were not developed for some other strategies. Studies examining green spaces, vegetation types, and combinations of several strategies often differed substantially in their research objectives and spatial scales, making it difficult to meaningfully combine their findings within a single comparative figure. For nature-based solutions (NBSs), green courtyards, and irrigation, the limited number of studies, together with variations in the reported thermal parameters, methodological approaches, and assessment conditions, prevented meaningful graphical comparisons. Therefore, findings for these strategies were presented through descriptive synthesis rather than additional quantitative figures.

3.2.8. Factors Influencing the Cooling Effect of Green Infrastructure to Reduce Air and Land Surface Temperature

The scale, geometry, time, urban context, and macroscale climate are crucial factors that influence the cooling capacity of greenspaces [176–180]. Furthermore, Maghrabi et al. [74] stated that the cooling intensity of green infrastructure in hot-arid climates varies depending on size, geometry, density, and connectivity.

- Scale

In terms of scale, Zegerek and Ortacesme [158] stated that, in a Mediterranean climate, the size of greenspaces plays a crucial role in increasing the cooling effect, with larger parks producing a greater cooling effect than smaller ones. Moreover, in the Mediterranean city of Perth, Australia, large-scale parks cool the air temperature by 1–2 °C, while the air temperature at the other small and medium scales was nearly identical to adjacent streets [59]. However, small, dispersed urban greenspaces can reduce LST more than large- and medium-sized greenspaces during heat waves in Mediterranean regions [81].

In addition, the effect of size is not limited to reducing heat stress within the park but can expand its ability to alleviate urban temperature beyond its edges depending on its size due to wind flow and thermal exchange [181]. For example, the cooling effect of small and medium parks in Mediterranean cities extends beyond their edges by 10 to 100 m depending on the size [158,161], while, in large parks, the cooling effect extends 600 m outside the park [42]. However, Grace et al. [59] demonstrated that the cooling effect beyond urban parks boundaries, regardless of their scale, dropped sharply to less than 1 °C and disappeared quickly with distance.

- Geometry

Just like scale, park geometry manipulates thermal reduction. For example, regular greenspaces can produce a stronger cooling effect than irregular spaces due to their lower perimeter-to-area ratio, reducing heat transfer, particularly in Mediterranean climates [158]. Similarly, in a hot-arid climate, Ojaghlou and Khahzand [133] simulated five greenspace configurations varying in their shapes, square and rectangular, and orientation, N–S and E–W. The study found that the rectangular garden with a pavilion that was located at the end of the east–west axis achieved the best thermal performance, reducing MRT and PET by approximately 13 and 4–5 °C, respectively.

- Time

As with size and shape, time is a significant factor that can influence Park Cool Island (PCI). In hot-arid regions, for instance, the maximum surface cooling intensity, based on an LST reduction, reached 8.4 °C in summer, with a cooling extent of 172.5 m, compared with only 2.1 °C in winter, with an extent of 127.5 m. [75]. However, the highest cooling effect of street trees in hot-arid climates were recorded in the afternoon hours in moderate seasons, while, in summer, the cooling effect was limited due to extreme heat conditions [134]. On the other hand, in Mediterranean regions, Sendra-Arranz [66] demonstrated that green walls can reduce the surface temperature of a building facade by approximately 20 °C in summer and 8 °C in winter.

In addition to the seasonal variation, there is also a diurnal variation between daytime and nighttime. In hot-arid climates, for example, greenspaces reduce LST by 4.17 °C during the day and 2.33 °C at night [80]. The study also showed that the cooling effect of greenspaces extends to their surroundings, reducing daytime and nighttime LST by up to 3.12 and 1.61 °C, respectively. Moreover, García-Haro et al. [83] examined the local surface cooling effects of urban parks in Mexicali, Mexico, and reported an average daytime surface cool-island intensity of approximately 0.81 °C, with a mean cooling extent of 120 m. At night, the average cooling intensity decreased to approximately 0.43 °C, with a mean cooling extent of 48 m. Furthermore, the maximum cooling effect of urban trees was during the early morning and late afternoon, while the minimum cooling effect was around midday [38]. On the other hand, in Mediterranean regions, the southern façade of green walls achieved the strongest cooling effect during midday, while, in the afternoon, the cooling effect was strongest in the western façade [66].

- Greenspace Composition

The richness and variety of vegetation are additional factors for mitigating SUHI effects. In Mediterranean regions, the cooling performance of greenspaces was strongly affected by plant height, connectivity, and proximity to water features. For example, Nguyen et al. [78] reported that, in golf courses, the LST of trees taller than 10 m was about 2 and 6 °C lower than low vegetation and turf, respectively. Moreover, the cooling effect of shrubs outperformed that of grass by 1.2 °C and climbing plants by 3 °C [103,155]. Similarly, in hot-arid regions, a 10% increase in trees could reduce LST by approximately 2.4 °C, while, in grass, only by up to 1.4 °C and, in shrubs, by up to 1.2 °C [79].

The spatial distribution, diversity, and density of vegetation play a significant role in influencing CUHI effects and outdoor thermal comfort. In Mediterranean climates, for example, a park with fewer trees but greater vegetation diversity may reduce air temperature more than a park with higher numbers of trees but a poorly arranged canopy cover [161]. Likewise, a configuration characterized by taller and denser trees in hot-arid climates can significantly improve outdoor thermal comfort by reducing air temperature, MRT, UTCI, and PET by up to 3.2, 64.7, 17.95, and 17 °C, respectively [134,182]. Furthermore, Atwa et al. [183] indicated that double rows of trees and an equal interval between them

reduced air temperature by approximately 1 °C and MRT by approximately 21 °C. In addition, the density of the vegetation cover is a significant factor in reducing MRT through blocking solar radiation in hot-arid environments. For example, in Phoenix, a hot-arid city, a tree in a front-yard reduced MRT by approximately 5.3 °C, while two trees reduced it by approximately 10.6 °C [184].

Moreover, García-Haro et al. [83] found a strong relationship between vegetation cover and the cooling intensity and extent in hot-arid climates. For example, a 10% increase in vegetation cover increased surface cooling intensity (LST reduction) by up to approximately 0.11 °C and extended the cooling distance by approximately 3–6 m. In addition, Ain [75] investigated the cooling effects of four urban parks with different sizes in the hot-arid city of Riyadh, Saudi Arabia. The study demonstrated that the highest cooling intensity and distance was recorded in two medium-sized parks, reducing LST by 8.4 C with a distance of 300 m, mainly due to its dense vegetation cover. However, the largest park at 32 ha exhibited a weaker cooling effect compared to the smallest one with an area of 5 ha. Moreover, the study concluded that the cooling intensity was primarily influenced by vegetation cover, whereas the cooling extent was significantly affected by wind direction.

Vegetation type was another important variable influencing the cooling capacity of vegetation, particularly in hot-arid environments due to water scarcity. For example, Middel et al. [136] investigated three categories of landscape design: mesic, characterized by high water demands vegetation and grass irrigated mainly by sprinkler; oasis, which combines drip-irrigated plants with limited sprinkler irrigated grass; and xeric, dominated by drought-tolerant native species requiring minimal irrigation. The study found that mesic landscapes have the greatest cooling effect, followed by oasis and then xeric. However, xeric landscapes require less irrigation water, which is consistent with arid regions. Moreover, Chow and Brazel [56] compared traditional landscaping, xeriscaping, and impervious surfaces. The results revealed that the surface temperature of xeriscaping was approximately 5–15 °C lower than impervious surfaces and approximately 5–10 °C higher than traditional vegetated areas (trees, shrubs, and grass—lawn), indicating a trade-off between water-efficient plants and the maximum cooling effect.

Plant selection was also a critical factor in improving urban thermal conditions while taking water scarcity in hot-arid regions into consideration. For example, Abedrabboh et al. [46] indicated that increasing the cover percentage of *Ziziphus spina-christi* (Sidra), a native tree in Qatar, from 0.48 to 3.14% on sidewalks reduced MRT and PET by approximately 14.6 and 2 °C, respectively. Moreover, the cooling effect of *Delonix regia* outperformed *Prosopis cineraria* (Ghaf), a native tree in Abu Dhabi, UAE [175]. This is because *Delonix regia* has a larger canopy, thus providing greater shade. Furthermore, in Oman, Al Hashim et al. [67] concluded that acacia trees significantly outperformed palm trees; this is because the crown of acacia is wider and closer to pedestrians compared to palms. However, Bencheikh and Rchid [93] concluded that dense palm groves provide a strong oasis cooling effect, reducing daytime air temperature by approximately 4.5 °C and nighttime air temperature by approximately 10 °C.

Similarly, in Mediterranean environments, a simulation study assessed three NBS scenarios, combining trees, shrubs, herbaceous species, climbers, and grass, integrated with reflection pavements in an existing parking area [185]. The plant selection strategy was based on ecological criteria, including drought resistance, climate suitability, low maintenance, and biodiversity support. The results showed that the most vegetated scenario reduced UTCI and MRT by approximately 5.4 and 17.3 °C, respectively.

- Urban Context and Climate

Studies have shown that the local climate and surrounding characteristics have a great influence on minimizing or maximizing extended PCI to their urban surroundings [31].

For example, Cheng et al. [37] found that urban-tree cooling efficiency varied significantly across climatic regions. However, their cooling-efficiency metric was based on the change in land surface temperature relative to the change in tree-cover percentage, rather than absolute air-temperature reduction. Their results showed a mean cooling efficiency of 0.4541 in arid cities compared with 0.2317 in temperate cities. The study also identified climate-dependent relationships between meteorological variables and tree-cooling efficiency, including differences in the effects of air temperature, humidity, and wind speed.

Regarding urban context, the best cooling performance of vegetation is in low-density areas in Mediterranean climates. [156]. Moreover, Lopez-Ordonez et al. [186] investigated the influence of the interactions between tree cover and urban form on heat stress by testing two urban models, including linear blocks and towers, in Mediterranean residential areas. The study concluded that trees reduced MRT by approximately 5.3 and 8.8 °C in linear blocks and towers, respectively, highlighting how urban context can significantly influence the cooling effectiveness of green infrastructure.

- Irrigation

Irrigation has been shown to greatly reduce the average daytime air temperature. Irrigation cools cities by increasing the latent heat flux through the evaporation process and decreasing sensible heat. For example, Chakraborty et al. [90] found stronger irrigation-induced cooling and moistening in arid urban clusters than in other climatic zones, partly because evapotranspiration in arid regions is more sensitive to soil moisture and irrigation. Similarly, Ed-dahmany et al. [119] demonstrated the importance of water availability in regulating vegetation cooling in arid and semi-arid environments. Their findings showed that hydrological stress can limit stomatal conductance and transpiration, thereby reducing the evaporative cooling capacity of vegetation. Conversely, irrigated urban green spaces can enhance evapotranspiration and surface cooling. In Dakhla, for example, irrigated parks and lawns contributed to a daytime urban heat sink of approximately 0.7 °C through enhanced evaporative cooling and shading. The study also found that approximately 80% of the variation in daytime urban-vegetation surface-temperature differences were explained by vegetation transpiration. However, irrigation also increases humidity, and its effects on heat stress vary depending on the thermal stress indicator considered.

Moreover, greater irrigation does not necessarily result in proportionally greater cooling. Wei et al. [60] found that excessive irrigation was not required for effective heat mitigation by urban trees in arid environments, with optimized irrigation strategies potentially reducing water use by 30–50% compared with conventional practices. Their findings further indicated that shading from low-height trees with expansive crowns can provide substantial cooling with relatively low irrigation requirements, highlighting the importance of balancing cooling performance with water conservation in hot-arid cities.

On the other hand, the influence of irrigation may differ under Mediterranean climatic conditions. Garcia de Cezar et al. [103], in an experimental street canyon in Montpellier, found that increasing irrigation from a deficit to well-watered conditions produced a moderate short-term reduction in air temperature and only marginally increased the relative humidity. More intensive irrigation also did not significantly improve UTCI, with shading and radiative effects of vegetation and canyon morphology having a greater influence on thermal comfort compared to irrigation.

3.2.9. Public Perception

Public perception is a vital factor to ensure an effective implementation of UHI mitigation strategies [187]. Nevertheless, there is insufficient attention in the urban climate literature about public awareness and perceptions of UHI mitigation and implementation

strategies. City governance and policy measures are responsible of the effectiveness of urban cooling strategies [188].

A survey was conducted in three hot-arid Saudi cities, indicated that 40% of participants expressed dissatisfaction with the condition of green infrastructure and the services it provides [71]. However, the results revealed a high awareness among respondents of the role of green infrastructures in regulating microclimate. Furthermore, around 86% of participants supported innovative approaches for enhancing urban greenspaces such as green roofs, green facades, rain gardens, vegetation corridors under electric cables, etc. Another survey in Jeddah, Saudi Arabia, demonstrated that most of participants acknowledged the important role of greenspaces in mitigating heat stress, with 92% confirming that greenspaces help control the local climate, 89% demonstrating their great role in reducing the air temperature, and 88% recognizing their effectiveness in mitigating UHI effects [74]. Moreover, a questionnaire was distributed in the hot-arid city of Dubai by Twarat [101] and revealed that approximately 81% of respondents recognized that increasing vegetation cover in conjunction with implementing sustainable urban design significantly improves outdoor thermal comfort.

Similarly, on the Greek island of Crete, with a Mediterranean climate, Tsitoura et al. [102] concluded that, according to participants' responses, sun exposure was the most important factor affecting thermal comfort by approximately 59%, followed by noise by approximately 25% and then temperature by approximately 17%. Furthermore, shaded areas by trees achieved the highest level of comfort satisfaction, particularly during hot seasons. Another survey was conducted in the Mediterranean city of Florence, Italy, by Speak and Salbitano [76], demonstrating that 98% preferred staying and spending more time in shaded areas during hot seasons. Moreover, a questionnaire conducted in the Mediterranean city of Barcelona investigated whether urban greenspaces can be used as cooling refuges for the elderly during hot seasons [82]. The survey included 291 older adults aged 65 and over. The results revealed that around 54% of respondents use greenspaces for cooling shelters, with 67.5% of them spending between 1–3 h in parks. Regarding the preferred characteristics of cooling greenspaces, approximately 80% of participants prioritized shaded areas by tree canopies, while about 65% preferred dense vegetation areas.

4. Discussion

4.1. UHI Studies

The results showed that urbanization is the primary driver of both CUHI and SUHI phenomena in both climates. Factors such as a lack of vegetation, unsuitable urban geometry, vast expanses of impermeable surfaces, and massive anthropogenic activities significantly contributed to cities being warmer than their surrounding rural areas. For example, industrial areas recorded the highest LST values, while greenspaces had the lowest LST values in both climates. Furthermore, other variables, including LULC and distance from water bodies (seas or rivers) considerably influenced urban thermal environments in both climates.

However, the characteristics of CUHI and SUHI phenomena may behave differently between the two climates. For example, hot-arid regions may experience daytime CUCI and SUCI effects and nighttime CUHI and SUHI effects. This is because the built structures and greenspaces in hot-arid cities provide shade and evapotranspiration, thus making cities cooler than the surrounding desert areas, particularly during the day. Moreover, impermeable surfaces in urban areas release the heat they gained during the day more slowly than natural surfaces in rural areas, exacerbating both phenomena at night. In contrast, Mediterranean cities typically experience daytime and nighttime CUHI and SUHI

effects, due to their lower vegetation cover and higher heat sources, such as impermeable surfaces and anthropogenic activities, compared to the surrounding rural areas.

In addition, hot-arid regions experienced a strong seasonal variability, with summers characterized by extreme heat stress, while winters and falls were more moderate. On the other hand, Mediterranean regions experienced diurnal variations in the intensity of CUHI, with nighttime temperatures being lower than daytime temperatures, particularly in summer.

Climate-adapted urban planning and design play a crucial role in mitigating CUHI and SUHI effects and improving outdoor thermal comfort. For example, a compact urban fabric was the optimal geometry in hot-arid cities, as it reduced urban temperatures by blocking a great amount of incoming solar radiation. On the other hand, deep canyons and arcades were well-suited to Mediterranean cities, where they improved shading effectiveness. Moreover, a low SVF and a high aspect ratio contributed to providing adequate shade, thus reducing heat stress, particularly during the day in both climates.

Green infrastructure, furthermore, has proven its effectiveness in reducing CUHI and SUHI effects and improving outdoor thermal comfort, with a stronger cooling effect in hot-arid environments. Nevertheless, the cooling effect resulting from urban geometry strategies was higher than that of vegetation alone in hot-arid climates, due to the scarcity of water. In contrast, vegetation, particularly urban trees, was the most effective mitigation strategy in Mediterranean climates.

Moreover, blue infrastructure and cool materials have shown a significant impact on reducing CUHI and SUHI effects and enhancing outdoor thermal comfort in both climates. However, water bodies increase humidity, so this strategy may pose a problem rather than a solution in cities already experiencing high humidity levels. Furthermore, integrated multiple strategies contribute significantly to mitigating the CUHI effect and improving outdoor thermal comfort compared to individual strategies in both climates.

4.2. Vegetation-Based Strategy Studies

Studies have shown that expanding greenspaces across cities resulted in a modest decrease in air temperature in both climates. However, other parameters, such as LST, MRT, solar radiation, and thermal indices, were significantly reduced, thus greatly improving outdoor thermal comfort. Conversely, greenspaces increased the relative humidity, potentially exacerbating thermal discomfort, particularly in cities with high humidity levels.

Vegetation is distinguished by its cooling mechanisms, shading and evapotranspiration. The cooling effect of shading was greatly higher than that of evapotranspiration during the day in both climates. However, tree shade may trap some heat radiation at night, thus reducing outdoor thermal comfort. On the other hand, grass provides a modest cooling effect both day and night. Overall, the air temperature reduction was slightly higher due to evapotranspiration, while the reduction in LST and MRT was much higher due to shading in both climates.

The differences in cooling performance reported between BWh and Csa climates should not be attributed to climatic classification alone. The reviewed studies varied in vegetation type and configuration, irrigation and water availability, urban morphology, spatial scale, and methodological approach, all of which may influence the reported cooling effects. These factors should therefore be considered when interpreting cross-climate comparisons.

Three types of green infrastructure, including urban parks, street trees, and green roofs and walls, were extensively investigated in the reviewed studies. Urban parks showed a significant cooling effect in both environments with the cooling ability varying based on size and tree canopy density. For instance, large, well-shaded parks provided a better cooling performance than small, open parks in both climates. Moreover, the cooling effect of urban

parks extended beyond their boundaries, reaching tens of meters into the surrounding urban areas. Overall, urban parks produced a greater cooling effect in hot-arid regions compared to those located in Mediterranean regions.

In addition, street trees provided substantial cooling effects in both climates, with stronger effects in hot-arid climates. This is primarily because of their ability to block a large amount of solar radiation. Moreover, most studies addressing this strategy were conducted in hot-arid regions, mainly because drought-resistant trees can provide substantial shade while requiring relatively low levels of irrigation. In contrast, planting grass over large areas requires large quantities of water, often difficult to provide in such a climate. Overall, street trees, like urban parks, had a limited impact on reducing air temperature in both climates. However, their influence on reducing other parameters, such as LST, MRT, and thermal indices, was much higher, achieving substantial improvements in thermal comfort.

Just like parks and street trees, green roofs and walls strategies contributed to a slight reduction in air temperature at the rooftop and pedestrian levels in both climates. However, their impacts on surface temperature were significantly higher, particularly in BWh climates. They can reduce the demand for cooling in summer and heating in winter, thus achieving a balance between different seasons, especially in Csa climates. Regarding living walls, the vegetation density and facade orientation were important variables influencing their cooling capacity.

Moreover, the scale and geometry of a park may affect its cooling performance, as larger parks with regular shapes produced a stronger cooling effect than smaller parks with irregular shapes in both climates. However, the landscape composition had a substantially greater impact on the cooling capacity of greenspaces in both climates. Plant height, greenspaces connectivity, and the distribution, density, and diversity of vegetation were among the most important factors in minimizing or maximizing the cooling performance of green infrastructure in both climates.

In addition, vegetation type, plant selection, and irrigation management are important factors in balancing the urban cooling performance with water conservation, particularly in hot-arid regions. While irrigation can enhance evapotranspirative cooling by increasing the latent heat flux and reducing the sensible heat flux, greater water use does not necessarily result in proportionally greater cooling. The contribution of irrigation to cooling may also vary according to climatic conditions, vegetation characteristics, soil moisture, and the relative roles of evapotranspiration and shading. Therefore, climate-sensitive plant selection and efficient irrigation management are essential for maximizing thermal benefits while minimizing water demand, particularly in water-scarce environments.

Furthermore, the cooling intensity of vegetation varied with seasons, being significantly higher in summer than in winter in both climates. Moreover, both climates experienced diurnal variations, with the cooling effect from vegetation being more intense during the day than at night. In addition to the cooling intensity, the cooling distance was affected by time, extending further in summer and during the day compared to in winter and at night.

Moreover, the cooling efficiency of urban trees varied depending on the local climate. For example, their cooling effect in hot-arid environments was almost twice that of Mediterranean environments. This is because the higher air temperature and lower humidity contributed to the increased efficiency of urban trees. Wind speed and direction can also influence the cooling capacity of trees, particularly in Mediterranean Csa climates. Furthermore, the urban context had a great impact on the cooling performance of vegetation in both climates.

Public perceptions play an important role in understanding the effectiveness and acceptance of vegetation-based cooling strategies. Surveys conducted in hot-arid cities focused

on residents' satisfaction with the current conditions of greenspaces, public awareness of green infrastructure's role in regulating microclimates, and the community willingness to support greenery innovations with clear implications for governments and policymakers. However, surveys conducted in Mediterranean regions concentrated more on public preferences of landscape configurations in greenspaces, helping urban designers and landscape architects create greenspaces tailored to local communities.

4.3. Methods for Measuring UHI Effect and Vegetation-Based Mitigation Strategies in Both Climates

The reviewed studies widely utilized individual methodological approaches, including thermal remote sensing, on-site measurements, and numerical simulation, across both climates. Remote sensing was the most frequently employed approach in studies focused on SUHI characteristics, particularly in BWh regions. On the other hand, numerical simulations accounted for half of the reviewed studies focusing on vegetation-based cooling strategies. ENVI-met software, moreover, has predominantly been used across both climates, due to its high capacity to test current conditions, proposed scenarios, and future strategies in a multi-scale manner. Despite the increasing use of remote sensing and simulation techniques across the reviewed studies, on-site measurements remain widely used, particularly in Mediterranean regions.

Moreover, the limited number of studies integrating multiple approaches has resulted in a significant methodological gap. This is because each method has its own strengths and limitations in studying UHI patterns and evaluating the cooling effect of vegetation. Combining multiple methods can provide a broader understanding of the assessment by leveraging the strengths of each approach.

4.4. Research Gaps and Future Directions

Although vegetation-based strategies have been widely examined for their effectiveness in mitigating UHI, several research gaps remain.

1. Greater focus on outdoor thermal comfort:

Many of the reviewed studies focused primarily on assessing cooling performance using air temperature and LST, while insufficient attention has been given to MRT and outdoor thermal indices in both climates. These parameters are important for accurately assessing how people feel in outdoor spaces. Future studies should therefore place greater emphasis on using MRT and outdoor thermal indices to evaluate the influence of vegetation on pedestrian-level heat exposure.

2. Water availability and irrigation requirements:

The relationship between the cooling efficiency of vegetation and water availability is another significant gap, particularly in hot-arid environments. Issues, such as irrigation demands, drought tolerance, water-use efficiency, and the trade-offs between cooling benefits and water consumption remain insufficiently investigated in both climates. Future research should assess vegetation strategies according to their cooling capacity and water requirements, particularly in hot-arid regions.

3. Interactions between vegetation and urban morphology:

Although the urban morphology plays an important role in shaping urban thermal conditions, relatively few of the reviewed studies examined how the urban form interacts with vegetation-based mitigation strategies. Some studies considered morphological characteristics or Local Climate Zones (LCZs); however, evidence specifically addressing how vegetation cooling effectiveness varies across different LCZs and urban morphological configurations remained limited. Further research should integrate vegetation characteristics

with LCZ classifications and morphological parameters, such as the building density, street geometry, and sky view factor, to better understand how the urban form influences the cooling performance of vegetation-based strategies across hot-arid and Mediterranean climates.

4. Integration of field measurements, remote sensing, and simulation:

Methodological limitations also are another crucial research gap. Reviewed studies extensively employed individual methods in both climates. Remote sensing is valuable for investigating city-scale heat patterns, while field measurements and numerical simulations are more beneficial for the neighborhood, street, and pedestrian scales. Nevertheless, the inadequate combination of these methods limits the connection between city-scale urban heat patterns with the cooling effect of vegetation at the pedestrian scale. Future studies should adopt integrated approaches combining the three methods to provide a broader and multi-scale understanding of vegetation-based mitigation strategies.

5. Public perception and community acceptance:

In addition to these environmental and methodological gaps, the social aspects of vegetation-based strategies remain relatively undiscovered. Reviewed studies, in both climates, have widely focused on the cooling intensity and distance of vegetation, with less consideration given to how communities, in all their diversity, interact with these strategies. Knowing that residents' perceptions, preferences, and acceptance can significantly influence the successful implementation and long-term maintenance of green interventions, future studies should therefore integrate the public perceptions and social equity considerations of vegetation-based strategies to guarantee that green interventions are publicly supported and accessible to local communities, especially those experiencing heat exposure.

6. Urbanization, climate change, and future extreme heat:

The combined effects of rapid urbanization and climate change represent another important area for future research. Continued urban growth and the expansion of impervious surfaces are expected to intensify urban heat, while climate change is increasing the frequency, intensity, and duration of extreme heat events. However, limited attention has been given to whether current vegetation-based mitigation strategies will maintain their cooling effectiveness under future urban and climatic conditions. Future studies should therefore assess the vegetation cooling performance under projected urban growth and climate change scenarios, considering the changes in temperature, extreme heat, urban density, water availability, and vegetation performance. Such research is essential for developing climate-responsive vegetation strategies that remain effective and resilient as cities continue to grow and experience increasingly severe heat conditions.

4.5. Limitations of the Review

This scoping review has several limitations. First, the search was restricted to peer-reviewed English-language studies published between 2010 and 2026 and indexed in Scopus, Web of Science, and ProQuest, which may have excluded relevant evidence available in other languages, databases, or grey literature. Second, the review focused specifically on BWh and Csa climatic classifications; therefore, the findings may not be directly generalizable to other climatic contexts. Third, the study selection and data charting were conducted by a single reviewer, which may have increased the potential for selection or extraction errors, although the charted data and review process were subsequently reviewed and validated by the other authors. Fourth, although the search strategy employed multiple combinations of terms related to UHI and vegetation-based mitigation, the predefined search terms may not have captured all relevant studies. In particular, terms such as "Local Climate Zone" and "LCZ" were not explicitly included in the search strategy, and some studies focusing primarily on urban morphology or LCZ classifications may therefore have

been missed, although a small number of studies addressing these interactions were identified through the applied search terms. Finally, no formal critical appraisal of the included sources was undertaken; consequently, the findings should be interpreted as a mapping and synthesis of the available evidence rather than an assessment of its methodological quality or certainty.

5. Conclusions

This systematic review provides a thorough synthesis of research on UHI characteristics and the efficiency of vegetation-based mitigation strategies in hot-arid and Mediterranean climates. The results indicate that the characteristics of UHI vary depending on climatic conditions, urban morphology, LULC, and surrounding environments. For example, hot-arid regions may experience daytime CUCI and SUCI effects and nighttime CUHI and SUHI effects, while Mediterranean regions generally exhibit CUHI and SUHI effects during both day and night. These variations highlight the important role of climatic context on shaping UHI; therefore, greater attention to climatic context may contribute to the development of appropriate mitigation strategies.

The reviewed evidence indicates that vegetation can contribute to reducing urban temperatures and improving outdoor thermal comfort through shading and evapotranspiration mechanisms. The shade provided by trees was particularly important in reducing pedestrian heat exposure, while the latent heat flux resulting from evapotranspiration contributed to additional cooling, particularly at night. However, the cooling capacity of vegetation varied according to vegetation type, configuration, density, spatial distribution, local climate, water availability, and urban context. As a result, it is challenging to develop a universal applicable solution for vegetation-based strategies with consistent cooling performance across different climates and urban contexts.

This review also identified great methodological diversity in the evaluation of UHI and vegetation cooling strategies. Although field measurements, remote sensing, and numerical simulations were extensively adopted across both climates, the integrations between them remain relatively limited. Moreover, greater focus has been placed on climatic factors than thermal sensation parameters. Therefore, future research should focus more on integrating multiple methodological approaches and spatial scales, increasing the assessment of pedestrian-level thermal comfort and public perceptions, and investigating the interactions between landscape configurations, urban morphology, climatic conditions, and water availability.

Overall, this review indicates that vegetation represents a vital element of urban heat mitigation in both BWh and Csa climates. However, its effectiveness is highly dependent on context. Understanding these climatic and spatial differences is critical for moving toward evidence-based vegetation strategies rather than generalized greening recommendations. This review provides a foundation for urban planners, landscape architects, urban designers, and policymakers to develop more thermally comfortable and sustainable urban environments, particularly in hot-arid and Mediterranean climates as we move into an era of ever-changing climates with even greater numbers of urban citizens than before.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land15102008/s1. The following supporting information can be found in the supplementary materials: Table S1. Full electronic search strategies, search dates, and limits applied across the databases for the UHI characteristics and vegetation-based mitigation literature searches. Table S2. Reviewed studies focusing on vegetation-based mitigation strategies; Table S3. The distribution of UHI studies by country, city, and climate classification; Table S4. The distribution of studies focusing on vegetation strategies by country, city, and climate classification; Table S5. More details on studies focusing on UHI characteristics conducted in hot-arid climates; Table S6. More

details on studies focusing on UHI characteristics conducted in Mediterranean climates; Table S7. Studies investigated the cooling effect of urban parks; Table S8. Studies investigated the cooling effect of street trees; Table S9. Studies investigated the cooling effect of green roofs and walls; File S1. Figures 18–22 Numerical Data.

Author Contributions: Conceptualization, S.A., S.K. and M.I.; methodology, S.A., S.K. and M.I.; validation, S.A., S.K. and M.I.; formal analysis, S.A.; investigation, S.A.; data curation, S.A.; writing—original draft preparation, S.A.; writing—review and editing, S.A., S.K. and M.I.; visualization, S.A.; supervision, S.K. and M.I.; project administration, S.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data is open-source and can be extracted from the Scopus, Web of Science, and ProQuest databases.

Acknowledgments: We thank the anonymous reviewers for their valuable comments and suggestions on our manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

UHI	Urban Heat Island
UCI	Urban Cool Island
BWh	Hot-Arid Desert Climate (Köppen climate classification)
Csa	Mediterranean Climate (Köppen climate classification)
PET	Physiological Equivalent Temperature
UTCI	Universal Thermal Climate Index
PMV	Predicted Mean Vote
NBS	Nature-Based Solutions
NDVI	Normalized Difference Vegetation Index
NDBI	Normalized Difference Built-up Index
LULC	Land Use/Land Cover
LST	Land Surface Temperature
MRT	Mean Radiant Temperature
SVF	Sky View Factor
PCI	Park Cool Island
MODIS	Moderate Resolution Imaging Spectroradiometer
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
WRF	Weather Research and Forecasting

References

1. Tuholske, C.; Caylor, K.; Funk, C.; Verdin, A.; Sweeney, S.; Grace, K.; Peterson, P.; Evans, T. Global Urban Population Exposure to Extreme Heat. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, e2024792118. [CrossRef]
2. Aflaki, A.; Mirnezhad, M.; Ghaffarianhoseini, A.; Ghaffarianhoseini, A.; Omrany, H.; Wang, Z.-H.; Akbari, H. Urban Heat Island Mitigation Strategies: A State-of-the-Art Review on Kuala Lumpur, Singapore and Hong Kong. *Cities* **2017**, *62*, 131–145. [CrossRef]
3. United Nations. *World Urbanization Prospects, the 2011 Revision*; UN Department of Economic and Social Affairs, Population Division: New York, NY, USA, 2011.
4. Wang, Y.; Chen, L.; Kubota, J. The Relationship between Urbanization, Energy Use and Carbon Emissions: Evidence from a Panel of Association of Southeast Asian Nations (ASEAN) Countries. *J. Clean. Prod.* **2016**, *112*, 1368–1374. [CrossRef]
5. Kamal-Chaoui, L.; Robert, A. *Competitive Cities and Climate Change*; OECD Regional Development Working Papers; Organisation for Economic Co-Operation and Development (OECD): Paris, France, 2009.
6. Oleson, K. Contrasts between Urban and Rural Climate in CCSM4 CMIP5 Climate Change Scenarios. *J. Clim.* **2012**, *25*, 1390–1412. [CrossRef]

7. Ng, E.; Ren, C. China's Adaptation to Climate & Urban Climatic Changes: A Critical Review. *Urban Clim.* **2018**, *23*, 352–372. [CrossRef]
8. Demuzere, M.; Orru, K.; Heidrich, O.; Olazabal, E.; Geneletti, D.; Orru, H.; Bhave, A.G.; Mittal, N.; Feliu, E.; Faehnle, M. Mitigating and Adapting to Climate Change: Multi-Functional and Multi-Scale Assessment of Green Urban Infrastructure. *J. Environ. Manag.* **2014**, *146*, 107–115. [CrossRef]
9. Heltberg, R.; Siegel, P.B.; Jorgensen, S.L. Addressing Human Vulnerability to Climate Change: Toward a 'No Regrets' Approach. *Glob. Environ. Change* **2009**, *19*, 89–99. [CrossRef]
10. Ebi, K.L.; Paulson, J.A. Climate Change and Children. *Pediatr. Clin. N. Am.* **2007**, *54*, 213–226. [CrossRef]
11. Khanian, M.; Marshall, N.; Zakerhaghighi, K.; Salimi, M.; Naghdi, A. Transforming Agriculture to Climate Change in Famenin County, West Iran through a Focus on Environmental, Economic and Social Factors. *Weather Clim. Extrem.* **2018**, *21*, 52–64. [CrossRef]
12. Pachauri, R.K.; Mayer, L.; Intergovernmental Panel on Climate Change. (Eds.) *Climate Change 2014: Synthesis Report*; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2015; ISBN 978-92-9169-143-2.
13. Gallo, E.; Quijal-Zamorano, M.; Méndez Turrubiates, R.F.; Tonne, C.; Basagaña, X.; Achebak, H.; Ballester, J. Heat-Related Mortality in Europe during 2023 and the Role of Adaptation in Protecting Health. *Nat. Med.* **2024**, *30*, 3101–3105. [CrossRef]
14. Janoš, T.; Quijal-Zamorano, M.; Shartova, N.; Gallo, E.; Méndez Turrubiates, R.F.; Denisse Beltrán Barrón, N.; Peyrusse, F.; Ballester, J. Heat-Related Mortality in Europe during 2024 and Health Emergency Forecasting to Reduce Preventable Deaths. *Nat. Med.* **2025**, *31*, 4065–4074. [CrossRef]
15. Xu, Z.; Xu, R.; Yang, Z.; Huang, W.; Muray, S.; Guo, Y.; Li, S. Mapping Heatwave-Related Mortality across 2288 Local Communities in Australia: A Nationwide Time-Series Analysis. *Environ. Int.* **2025**, *203*, 109747. [CrossRef]
16. Taha, H. Urban Climates and Heat Islands: Albedo, Evapotranspiration, and Anthropogenic Heat. *Energy Build.* **1997**, *25*, 99–103. [CrossRef]
17. Sani, S. Urban Climatology in Malaysia: An Overview. *Energy Build.* **1990**, *15*, 105–117. [CrossRef]
18. Aram, F.; Higueras García, E.; Solgi, E.; Mansournia, S. Urban Green Space Cooling Effect in Cities. *Heliyon* **2019**, *5*, e01339. [CrossRef]
19. Oke, T.R. *Boundary Layer Climates*, 2nd ed.; Methuen & Co.: London, UK, 1987; ISBN 978-0-203-40721-9.
20. Fernández, F.J.; Alvarez-Vázquez, L.J.; García-Chan, N.; Martínez, A.; Vázquez-Méndez, M.E. Optimal Location of Green Zones in Metropolitan Areas to Control the Urban Heat Island. *J. Comput. Appl. Math.* **2015**, *289*, 412–425. [CrossRef]
21. Akbari, H.; Kolokotsa, D. Three Decades of Urban Heat Islands and Mitigation Technologies Research. *Energy Build.* **2016**, *133*, 834–842. [CrossRef]
22. Oke, T.R. The Energetic Basis of the Urban Heat Island. *Q. J. R. Meteorol. Soc.* **1982**, *108*, 1–24. [CrossRef]
23. Oke, T.R.; Mills, G.; Christen, A.; Voogt, J.A. *Urban Climates*, 1st ed.; Cambridge University Press: Cambridge, UK, 2017; ISBN 978-1-139-01647-6.
24. Deilami, K.; Kamruzzaman, M.; Liu, Y. Urban Heat Island Effect: A Systematic Review of Spatio-Temporal Factors, Data, Methods, and Mitigation Measures. *Int. J. Appl. Earth Obs. Geoinf.* **2018**, *67*, 30–42. [CrossRef]
25. Mirzaei, P.A.; Haghighat, F. Approaches to Study Urban Heat Island—Abilities and Limitations. *Build. Environ.* **2010**, *45*, 2192–2201. [CrossRef]
26. Compagnon, R. Solar and Daylight Availability in the Urban Fabric. *Energy Build.* **2004**, *36*, 321–328. [CrossRef]
27. Ratti, C.; Di Sabatino, S.; Britter, R. Urban Texture Analysis with Image Processing Techniques: Winds and Dispersion. *Theor. Appl. Climatol.* **2006**, *84*, 77–90. [CrossRef]
28. Bowler, D.E.; Buyung-Ali, L.; Knight, T.M.; Pullin, A.S. Urban Greening to Cool Towns and Cities: A Systematic Review of the Empirical Evidence. *Landsc. Urban Plan.* **2010**, *97*, 147–155. [CrossRef]
29. Sailor, D.J. A Review of Methods for Estimating Anthropogenic Heat and Moisture Emissions in the Urban Environment. *Int. J. Climatol.* **2011**, *31*, 189–199. [CrossRef]
30. Lin, Y.; Wang, Z.; Jim, C.Y.; Li, J.; Deng, J.; Liu, J. Water as an Urban Heat Sink: Blue Infrastructure Alleviates Urban Heat Island Effect in Mega-City Agglomeration. *J. Clean. Prod.* **2020**, *262*, 121411. [CrossRef]
31. Wong, N.H.; Tan, C.L.; Kolokotsa, D.D.; Takebayashi, H. Greenery as a Mitigation and Adaptation Strategy to Urban Heat. *Nat. Rev. Earth Environ.* **2021**, *2*, 166–181. [CrossRef]
32. Han, D.; Zhang, T.; Qin, Y.; Tan, Y.; Liu, J. A Comparative Review on the Mitigation Strategies of Urban Heat Island (UHI): A Pathway for Sustainable Urban Development. *Clim. Dev.* **2023**, *15*, 379–403. [CrossRef]
33. Zinzi, M.; Agnoli, S. Cool and Green Roofs. An Energy and Comfort Comparison between Passive Cooling and Mitigation Urban Heat Island Techniques for Residential Buildings in the Mediterranean Region. *Energy Build.* **2012**, *55*, 66–76. [CrossRef]
34. Li, H.; Zhao, Y.; Wang, C.; Ürge-Vorsatz, D.; Carmeliet, J.; Bardhan, R. Cooling Efficacy of Trees across Cities Is Determined by Background Climate, Urban Morphology, and Tree Trait. *Commun. Earth Environ.* **2024**, *5*, 754. [CrossRef]

35. Lopez-Cabeza, V.P.; Loor-Vera, M.J.; Diz-Mellado, E.; Rivera-Gomez, C.; Galan-Marin, C. Decoding Outdoor Thermal Comfort: The Role of Location in Urban Canyon Microclimate. *Sustain. Energy Technol. Assess.* **2024**, *72*, 104095. [CrossRef]
36. Yang, S.; La Roche, P. Microclimate Analysis of Tree Canopies and Green Surface Combinations for Urban Heat Island Mitigation in Los Angeles and Phoenix. *Buildings* **2025**, *15*, 1573. [CrossRef]
37. Cheng, X.; Peng, J.; Dong, J.; Liu, Y.; Wang, Y. Non-Linear Effects of Meteorological Variables on Cooling Efficiency of African Urban Trees. *Environ. Int.* **2022**, *169*, 107489. [CrossRef]
38. Meili, N.; Manoli, G.; Burlando, P.; Carmeliet, J.; Chow, W.T.L.; Coutts, A.M.; Roth, M.; Velasco, E.; Vivoni, E.R.; Fatichi, S. Tree Effects on Urban Microclimate: Diurnal, Seasonal, and Climatic Temperature Differences Explained by Separating Radiation, Evapotranspiration, and Roughness Effects. *Urban For. Urban Green.* **2021**, *58*, 126970. [CrossRef]
39. Karamoozian, A.; Gholamalizadeh, A.; Shorabeh, S.N.; Karamoozian, A.; Firozjaei, M.K. Assessing Urban Outdoor Thermal Discomfort across Scales and Climates: Implications for Sustainable Urban Management in Iran. *Sustain. Cities Soc.* **2026**, *136*, 107085. [CrossRef]
40. Dialesandro, J.M.; Wheeler, S.M.; Abunnasr, Y. Urban Heat Island Behaviors in Dryland Regions. *Environ. Res. Commun.* **2019**, *1*, 081005. [CrossRef]
41. El Kenawy, A.M.; Aboelkhair, H.; Mohamed, E.K.; Gaber, I.M.; Fernández-Duque, B.; Peña-Angulo, D.; Abdelaal, M.M. Modes of Summertime Thermal Urban Stress over Major Cities in the Middle East: A Comprehensive Assessment of Heat Exposure Risks. *Sustain. Cities Soc.* **2024**, *102*, 105236. [CrossRef]
42. Aram, F.; Solgi, E.; Baghaee, S.; Higueras García, E.; Mosavi, A.; Band, S.S. How Parks Provide Thermal Comfort Perception in the Metropolitan Cores; a Case Study in Madrid Mediterranean Climatic Zone. *Clim. Risk Manag.* **2020**, *30*, 100245. [CrossRef]
43. Morakinyo, T.E.; Ouyang, W.; Lau, K.K.-L.; Ren, C.; Ng, E. Right Tree, Right Place (Urban Canyon): Tree Species Selection Approach for Optimum Urban Heat Mitigation—Development and Evaluation. *Sci. Total Environ.* **2020**, *719*, 137461. [CrossRef]
44. Binarti, F.; Koerniawan, M.D.; Triyadi, S.; Utami, S.S.; Matzarakis, A. A Review of Outdoor Thermal Comfort Indices and Neutral Ranges for Hot-Humid Regions. *Urban Clim.* **2020**, *31*, 100531. [CrossRef]
45. Potchter, O.; Cohen, P.; Lin, T.-P.; Matzarakis, A. Outdoor Human Thermal Perception in Various Climates: A Comprehensive Review of Approaches, Methods and Quantification. *Sci. Total Environ.* **2018**, *631–632*, 390–406. [CrossRef]
46. Abedrabboh, O.; Alfarra, M.R.; Al-Ansari, T.; Fountoukis, C. Enhancing Human Thermal Comfort in Hot Arid Cities: A Systematic Review of Urban Heat Island Observations and Mitigation Strategies. *Build. Environ.* **2025**, *283*, 113398. [CrossRef]
47. Susca, T.; Iaria, J.; Zanghirella, F. Development of Predictive Indices for Evaluating the UHI Adaptation Potential of Green Roof- and Wall-Based Scenarios in the Mediterranean Climate. *Sci. Rep.* **2024**, *14*, 21675. [CrossRef]
48. Convertino, F.; Schettini, E.; Blanco, I.; Bibbiani, C.; Vox, G. Effect of Leaf Area Index on Green Facade Thermal Performance in Buildings. *Sustainability* **2022**, *14*, 2966. [CrossRef]
49. Mazzeo, D.; Matera, N.; Peri, G.; Scaccianoce, G. Forecasting Green Roofs' Potential in Improving Building Thermal Performance and Mitigating Urban Heat Island in the Mediterranean Area: An Artificial Intelligence-Based Approach. *Appl. Therm. Eng.* **2023**, *222*, 119879. [CrossRef]
50. Khan, A.; Papazoglou, E.G.; Cartalis, C.; Philippopoulos, K.; Vasilakopoulou, K.; Santamouris, M. On the Mitigation Potential and Urban Climate Impact of Increased Green Infrastructures in a Coastal Mediterranean City. *Build. Environ.* **2022**, *221*, 109264. [CrossRef]
51. Cascone, S.; Vitaliano, S. Innovative Green Roof Technologies in Mediterranean Climate: Implications for Sustainable Design of the Built Environment. *Build. Environ.* **2025**, *273*, 112715. [CrossRef]
52. Pace, R.; Chiocchini, F.; Sarti, M.; Endreny, T.A.; Calfapietra, C.; Ciolfi, M. Integrating Copernicus Land Cover Data into the I-Tree Cool Air Model to Evaluate and Map Urban Heat Mitigation by Tree Cover. *Eur. J. Remote Sens.* **2023**, *56*, 2125833. [CrossRef]
53. Lombardo, G.; Moschella, A.; Nocera, F.; Salemi, A.; Sciuto, G.; Lo Faro, A.; Detommaso, M.; Costanzo, V. The Impact of a Vertical Greening System on the Indoor Thermal Comfort in Lightweight Buildings and on the Outdoor Environment in a Mediterranean Climate Context. In *Sustainability in Energy and Buildings 2022*; Littlewood, J., Howlett, R.J., Jain, L.C., Eds.; Smart Innovation, Systems and Technologies; Springer Nature: Singapore, 2023; Volume 336, pp. 37–46, ISBN 978-981-19-8768-7.
54. Maiolo, M.; Pirouz, B.; Bruno, R.; Palermo, S.A.; Arcuri, N.; Piro, P. The Role of the Extensive Green Roofs on Decreasing Building Energy Consumption in the Mediterranean Climate. *Sustainability* **2020**, *12*, 359. [CrossRef]
55. Yüksel, E.Ö.; Türkeri, N. Thermal Performance of Felt Type Vegetated Facade Systems in a Temperate Climate During Heating and Cooling Periods. *J. Green Build.* **2021**, *16*, 199–225. [CrossRef]
56. Chow, W.T.L.; Brazel, A.J. Assessing Xeriscaping as a Sustainable Heat Island Mitigation Approach for a Desert City. *Build. Environ.* **2012**, *47*, 170–181. [CrossRef]

57. İokhim, P.; Ekşi, M. Thermal Regulation Capacity of a Green Roof in the Mediterranean Climate of Istanbul. *Build. Serv. Eng. Res. Technol.* **2024**, *45*, 185–201. [CrossRef]
58. Song, J.; Wang, Z.-H. Diurnal Changes in Urban Boundary Layer Environment Induced by Urban Greening. *Environ. Res. Lett.* **2016**, *11*, 114018. [CrossRef]
59. Grace, B.; Bolleter, J.; Barghchi, M.; Lund, J. Unpacking Park Cool Island Effects Using Remote-Sensed, Measured and Modelled Microclimatic Data. *Land* **2025**, *14*, 1686. [CrossRef]
60. Wei, S.; Wang, Y.; Xu, T.; Buzzard, V.R.; McCormick, G.; Yang, B.; Xia, T.; Wang, Z.-H. Machine Learning-Based Multi-Objective Optimization of Smart Irrigation of Urban Trees in Arizona. *Landsc. Urban Plan.* **2026**, *267*, 105539. [CrossRef]
61. Mohammed, A.; Khan, A.; Santamouris, M. Numerical Evaluation of Enhanced Green Infrastructures for Mitigating Urban Heat in a Desert Urban Setting. *Build. Simul.* **2023**, *16*, 1691–1712. [CrossRef]
62. Elnabawi, M.H.; Saber, E. A Numerical Study of Cool and Green Roof Strategies on Indoor Energy Saving and Outdoor Cooling Impact at Pedestrian Level in a Hot Arid Climate. *J. Build. Perform. Simul.* **2023**, *16*, 72–89. [CrossRef]
63. Upreti, R.; Wang, Z.-H.; Yang, J. Radiative Shading Effect of Urban Trees on Cooling the Regional Built Environment. *Urban For. Urban Green.* **2017**, *26*, 18–24. [CrossRef]
64. Habibi, A.; Kahe, N. Evaluating the Role of Green Infrastructure in Microclimate and Building Energy Efficiency. *Buildings* **2024**, *14*, 825. [CrossRef]
65. Oquendo-Di Cosola, V.; Olivieri, F.; Olivieri, L.; Ruiz-García, L. Assessment of the Impact of Green Walls on Urban Thermal Comfort in a Mediterranean Climate. *Energy Build.* **2023**, *296*, 113375. [CrossRef]
66. Sendra-Arranz, R.; Oquendo, V.; Olivieri, L.; Olivieri, F.; Bedoya, C.; Gutiérrez, A. Monitorization and Statistical Analysis of South and West Green Walls in a Retrofitted Building in Madrid. *Build. Environ.* **2020**, *183*, 107049. [CrossRef]
67. Al Hashim, J.; Khan, H.; Al Khatri, H.; Al Saadi, S.N. The Role of Vegetation in Outdoor Thermal Comfort of Traditional Alleyways in Hot Arid Climates. *E3S Web Conf.* **2025**, *672*, 02028. [CrossRef]
68. Azeñas, V.; Cuxart, J.; Picos, R.; Medrano, H.; Simó, G.; López-Grifol, A.; Gulías, J. Thermal Regulation Capacity of a Green Roof System in the Mediterranean Region: The Effects of Vegetation and Irrigation Level. *Energy Build.* **2018**, *164*, 226–238. [CrossRef]
69. Hussein, M. Mitigation Strategies of the Urban Heat Island over Greater Cairo Metropolitan Area, Egypt Utilizing ENVI-Met Model. *Catrina Int. J. Environ. Sci.* **2021**, 35–47. [CrossRef]
70. Alaa, R.; Elbalazi, A.; Ismaeel, W.S.E. Optimal Roof Strategy for Mitigating Urban Heat Island in Hot Arid Climates: Simulation and Python-Based Multi-Criteria Decision Analysis. *Urban Sci.* **2025**, *9*, 310. [CrossRef]
71. Addas, A.; Maghrabi, A. Role of Urban Greening Strategies for Environmental Sustainability—A Review and Assessment in the Context of Saudi Arabian Megacities. *Sustainability* **2021**, *13*, 6457. [CrossRef]
72. Addas, A. Evaluating the Impact of Urban Green Spaces on Public Well-Being and Environmental Sustainability in Saudi Arabian Megacities. *Discov. Sustain.* **2025**, *6*, 277. [CrossRef]
73. Morale, D.; Falchi, U.; Mercogliano, P.; Parente, C. Assessing the Role of Urban Green Vegetation in Mitigating Land Surface Temperature in Naples (Italy) Using Landsat-9 and GIS Techniques. *Earth* **2025**, *37*, 2580729. [CrossRef]
74. Maghrabi, A.; Alyamani, A.; Addas, A. Exploring Pattern of Green Spaces (GSs) and Their Impact on Climatic Change Mitigation and Adaptation Strategies: Evidence from a Saudi Arabian City. *Forests* **2021**, *12*, 629. [CrossRef]
75. Ain, J. Measuring the Efficiency and Intensity of the Cooling Impact of Urban Parks in Riyadh, Saudi Arabia: Seasonal Analysis and Proposed Approach to the Parks Cooling Direction Index. *Appl. Geogr.* **2025**, *179*, 103619. [CrossRef]
76. Speak, A.F.; Salbitano, F. Thermal Comfort and Perceptions of the Ecosystem Services and Disservices of Urban Trees in Florence. *Forests* **2021**, *12*, 1387. [CrossRef]
77. Li, H.; Li, S.; Yang, B.; Baldwin, E.; Dimond, K.; Jackson, G.; Boyer, S.; Gillett, N.; Mendenhall, A. Association between Relative Surface Temperature and Urban Park Visits during Excessive Heat. *Environ. Res. Commun.* **2025**, *7*, 065011. [CrossRef]
78. Nguyen, T.T.; Eslick, H.; Barber, P.; Harper, R.; Dell, B. Cooling Effects of Urban Vegetation: The Role of Golf Courses. *Remote Sens.* **2022**, *14*, 4351. [CrossRef]
79. Wang, C.; Turner, V.K.; Wentz, E.A.; Zhao, Q.; Myint, S.W. Optimization of Residential Green Space for Environmental Sustainability and Property Appreciation in Metropolitan Phoenix, Arizona. *Sci. Total Environ.* **2021**, *763*, 144605. [CrossRef]
80. Zhang, Y.; Murray, A.T.; Turner, B.L. Optimizing Green Space Locations to Reduce Daytime and Nighttime Urban Heat Island Effects in Phoenix, Arizona. *Landsc. Urban Plan.* **2017**, *165*, 162–171. [CrossRef]
81. Delgado-Capel, M.J.; Cariñanos, P.; Escudero-Viñolo, M. Capacity of Urban Green Infrastructure Spaces to Ameliorate Heat Wave Impacts in Mediterranean Compact Cities: Case Study of Granada (South-Eastern Spain). *Land* **2023**, *12*, 1076. [CrossRef]
82. Vasconcelos, L.; Langemeyer, J.; Cole, H.V.S.; Baró, F. Nature-Based Climate Shelters? Exploring Urban Green Spaces as Cooling Solutions for Older Adults in a Warming City. *Urban For. Urban Green.* **2024**, *98*, 128408. [CrossRef]
83. García-Haro, A.; Arellano, B.; Roca, J. Integrating Multi-Source Remote Sensing and Spatial Metrics to Quantify Urban Park Design Effects on Surface Cool Islands in Mexicali, Mexico. *Remote Sens.* **2025**, *17*, 3296. [CrossRef]

84. Mannucci, S.; Ciardiello, A.; Ferrero, M.; Rosso, F. A Parametric Integrated Workflow to Assess Multi-Domain Heat- and Flood-Related Performance of Small Outdoor Urban Spaces in a Changing Climate: A Case Study in the Mediterranean Region. *City Environ. Interact.* **2025**, *27*, 100215. [CrossRef]
85. Proutsos, N.D.; Solomou, A.D.; Stefanidis, S.P.; Tsiros, I.X. Reflectance and Thermal Micrometeorological Characteristics of an Urban Green Space in the Mediterranean During July's 2023 Heatwave. *Land* **2025**, *14*, 194. [CrossRef]
86. Gargiulo, C.; Stiuso, T.; Zucaro, F. Reducing UHI in Historical Centres: The Greening Transformation of Open Small Spaces in San Lorenzo District in the City of Naples (Italy). *TeMA-J. Land Use Mobil. Environ.* **2025**, 67–87. [CrossRef]
87. Proutsos, N.D.; Solomou, A.D.; Stefanidis, S.P. From Bare Soil to Green Infrastructure: Micrometeorological Benefits from the Restoration of a Small Urban Park in a Mediterranean City. *Land* **2025**, *14*, 1681. [CrossRef]
88. Henao, J.J.; Mejia, J.F.; Krayenhoff, E.S.; Jiang, T.; Martilli, A. Effectiveness of Street Trees in Reducing Air Temperature and Outdoor Heat Exposure in Las Vegas. *Environ. Res. Clim.* **2025**, *4*, 025015. [CrossRef]
89. Hmoud, S.M.; Ibrahim, H.A.; Hasan, S.A. Transforming Grey to Green: Enhancing Microclimates in Hot Arid Regions with Green Open Spaces. *Edelweiss Appl. Sci. Technol.* **2025**, *9*, 315–330. [CrossRef]
90. Chakraborty, T.; Qian, Y.; Li, J.; Leung, L.R.; Sarangi, C. Daytime Urban Heat Stress in North America Reduced by Irrigation. *Nat. Geosci.* **2025**, *18*, 57–64. [CrossRef]
91. Fu, J.; Dupre, K.; Tavares, S.; King, D.; Banhalmi-Zakar, Z. Optimized Greenery Configuration to Mitigate Urban Heat: A Decade Systematic Review. *Front. Archit. Res.* **2022**, *11*, 466–491. [CrossRef]
92. Sayad, B.; Helmi, M.R.; Osra, O.A.; Abed, A.M.; Alhubashi, H.H. Microscale Investigation of Urban Heat Island (UHI) in Annaba City: Unveiling Factors and Mitigation Strategies. *Sustainability* **2024**, *16*, 747. [CrossRef]
93. Bencheikh, H.; Rchid, A. The Effects of Green Spaces (Palme Trees) on the Microclimate in Arides Zones, Case Study: Ghardaia, Algeria. *Energy Procedia* **2012**, *18*, 10–20. [CrossRef]
94. Giannaros, C.; Papagiannaki, K.; Kyriakou, P.; Agathangelidis, I.; Vafeiadis, V.; Bezes, A.; Kotroni, V.; Lagouvardos, K. Built Environment Dynamics, Atmospheric Circulations, and Geographical Context Shaping Urban Microclimates: Mobile Observational Insights from Athens's Complex Basin, Greece. *Urban Clim.* **2025**, *64*, 102627. [CrossRef]
95. Saputra, W.E.; Lai, L.Y. Identification of Landscape Components for Heat Mitigation in Bahrain's Arid Climate Urban Waterfront Parks. *IOP Conf. Ser. Earth Environ. Sci.* **2024**, *1384*, 012019. [CrossRef]
96. Amores, T.P.; Gutiérrez, M.M.; Palma, R.M.; Delgado, M.G.; Ramos, J.S.; Domíguez, S.Á. Redefining Human Thermal Perception for the Mediterranean Climates. *Sci. Talks* **2023**, *7*, 100241. [CrossRef]
97. Ferwati, S.; Skelhorn, C.; Shandas, V.; Voelkel, J.; Shawish, A.; Ghanim, M. Analysis of Urban Heat in a Corridor Environment—The Case of Doha, Qatar. *Urban Clim.* **2018**, *24*, 692–702. [CrossRef]
98. Falasca, S.; Di Bernardino, A.; Ciancio, V.; Curci, G.; Salata, F. A Preliminary Study of Summer Thermo-Hygrometric Comfort under Different Environmental Conditions in a Mediterranean City. *Urban Sci.* **2022**, *6*, 51. [CrossRef]
99. Donateo, A.; Palusci, O.; Pappaccogli, G.; Esposito, A.; Martilli, A.; Santiago, J.L.; Buccolieri, R. Analysis of Urban Heat Island and Human Thermal Comfort in a Mediterranean City: A Case Study of Lecce (Italy). *Sustain. Cities Soc.* **2023**, *98*, 104849. [CrossRef]
100. Founda, D.; Katavoutas, G.; Pierros, F.; Mihalopoulos, N. The Extreme Heat Wave of Summer 2021 in Athens (Greece): Cumulative Heat and Exposure to Heat Stress. *Sustainability* **2022**, *14*, 7766. [CrossRef]
101. Tawrat, M. Urban Cool Island Effect through Innovative Architecture and Sustainable Urban Design. *SSRN Electron. J.* **2023**, *8*, 100123. [CrossRef]
102. Tsitoura, M.; Tsoutsos, T.; Daras, T. Evaluation of Comfort Conditions in Urban Open Spaces. Application in the Island of Crete. *Energy Convers. Manag.* **2014**, *86*, 250–258. [CrossRef]
103. Garcia De Cezar, M.; Tomas, S.; Cheviron, B.; Liron, F.; Aprin, L. Microclimatic Analysis of the Impact of Irrigated Vegetation in an Experimental Street Canyon. *Curr. Res. Environ. Sustain.* **2025**, *10*, 100318. [CrossRef]
104. Weng, Q.; Lu, D.; Schubring, J. Estimation of Land Surface Temperature–Vegetation Abundance Relationship for Urban Heat Island Studies. *Remote Sens. Environ.* **2004**, *89*, 467–483. [CrossRef]
105. Miky, Y.H. Remote Sensing Analysis for Surface Urban Heat Island Detection over Jeddah, Saudi Arabia. *Appl. Geomat.* **2019**, *11*, 243–258. [CrossRef]
106. Sola-Caraballo, J.; Serrano-Jiménez, A.; Rivera-Gomez, C.; Galan-Marin, C. Multi-Criteria Assessment of Urban Thermal Hotspots: A GIS-Based Remote Sensing Approach in a Mediterranean Climate City. *Remote Sens.* **2025**, *17*, 231. [CrossRef]
107. Mohamed, M.; Othman, A.; Abotalib, A.Z.; Majrashi, A. Urban Heat Island Effects on Megacities in Desert Environments Using Spatial Network Analysis and Remote Sensing Data: A Case Study from Western Saudi Arabia. *Remote Sens.* **2021**, *13*, 1941. [CrossRef]
108. Yasmin, N.; Waleed, M.; Ullah, S.; Al-Ghamdi, S.G. Increased Urban Thermal Discomfort in Major Cities of the Arabian Peninsula. *Urban Ecosyst.* **2026**, *29*, 58. [CrossRef]

109. Polydoros, A.; Cartalis, C.; Santamouris, M.; Kolokotsa, D. Use of Landscape Metrics for the Mitigation of the Surface Urban Heat Island Effect in Mediterranean Cities. In *Global Urban Heat Island Mitigation*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 95–108, ISBN 978-0-323-85539-6.
110. Parvez, I.M.; Aina, Y.A.; Balogun, A.-L. The Influence of Urban Form on the Spatiotemporal Variations in Land Surface Temperature in an Arid Coastal City. *Geocarto Int.* **2021**, *36*, 640–659. [CrossRef]
111. Shoja, F.; Shamsipour, A.; Hamidianpour, M.; Veisi Nabikandi, B.; Gomes, E.; Ansari-Golenji, R.; Beheshti, N. Urban Land Use Transformation and Declining Cooling Services: A 40-Year Assessment of Heat Stress Mitigation in a Hot and Arid City. *Earth Syst. Environ.* **2025**, *10*, 6639–6662. [CrossRef]
112. Patel, S.; Indraganti, M.; Jawarneh, R.N. Comparative Analysis of Land Cover Changes on Outdoor Thermal Comfort in Doha, Dubai, Kuwait City, Manama, Muscat, and Riyadh. *Ann. GIS* **2025**, *31*, 163–180. [CrossRef]
113. Lemus-Canovas, M.; Martin-Vide, J.; Moreno-Garcia, M.C.; Lopez-Bustins, J.A. Estimating Barcelona's Metropolitan Daytime Hot and Cold Poles Using Landsat-8 Land Surface Temperature. *Sci. Total Environ.* **2020**, *699*, 134307. [CrossRef]
114. Goldblatt, R.; Addas, A.; Crull, D.; Maghrabi, A.; Levin, G.G.; Rubinyi, S. Remotely Sensed Derived Land Surface Temperature (LST) as a Proxy for Air Temperature and Thermal Comfort at a Small Geographical Scale. *Land* **2021**, *10*, 410. [CrossRef]
115. Abdelkrim, Z.; Eslamian, S. An Evaluation of Spatial and Temporal Variations of Land Surface Temperature in Biskra, Algeria Using Remote Sensing and GIS. *J. Afr. Earth Sci.* **2026**, *235*, 105942. [CrossRef]
116. Wang, Z.; Fan, C.; Zhao, Q.; Myint, S.W. A Geographically Weighted Regression Approach to Understanding Urbanization Impacts on Urban Warming and Cooling: A Case Study of Las Vegas. *Remote Sens.* **2020**, *12*, 222. [CrossRef]
117. Al-Ruzouq, R.; Shanableh, A.; Khalil, M.A.; Zeiada, W.; Hamad, K.; Abu Dabous, S.; Gibril, M.B.A.; Al-Khayyat, G.; Kaloush, K.E.; Al-Mansoori, S.; et al. Spatial and Temporal Inversion of Land Surface Temperature along Coastal Cities in Arid Regions. *Remote Sens.* **2022**, *14*, 1893. [CrossRef]
118. Abulibdeh, A. Analysis of Urban Heat Island Characteristics and Mitigation Strategies for Eight Arid and Semi-Arid Gulf Region Cities. *Environ. Earth Sci.* **2021**, *80*, 259. [CrossRef]
119. Ed-dahmany, N.; Bounoua, L.; Lachkham, M.A.; Yacoubi Khebiza, M.; Bahi, H.; Messouli, M. Interplay Between Vegetation and Urban Climate in Morocco—Impact on Human Thermal Comfort. *Urban Sci.* **2025**, *9*, 289. [CrossRef]
120. Kalogeropoulos, G.; Dimoudi, A.; Toumboulidis, P.; Zoras, S. Urban Heat Island and Thermal Comfort Assessment in a Medium-Sized Mediterranean City. *Atmosphere* **2022**, *13*, 1102. [CrossRef]
121. Alahmad, B.; Tomasso, L.P.; Al-Hemoud, A.; James, P.; Koutrakis, P. Spatial Distribution of Land Surface Temperatures in Kuwait: Urban Heat and Cool Islands. *Int. J. Environ. Res. Public Health* **2020**, *17*, 2993. [CrossRef]
122. Elhacham, E.; Alpert, P. Temperature Patterns along an Arid Coastline Experiencing Extreme and Rapid Urbanization, Case Study: Dubai. *Sci. Total Environ.* **2021**, *784*, 147168. [CrossRef]
123. Lai, D.; Liu, W.; Gan, T.; Liu, K.; Chen, Q. A Review of Mitigating Strategies to Improve the Thermal Environment and Thermal Comfort in Urban Outdoor Spaces. *Sci. Total Environ.* **2019**, *661*, 337–353. [CrossRef]
124. Elnabawi, M.H.; Hamza, N.; Ahmed, T.M.; Santamouris, M. Integrated Passive Cooling Strategies for Neighborhood-Scale Urban Heat Mitigation in a Hot-Arid City: ENVI-Met Simulations in Al Ain, UAE. *Results Eng.* **2026**, *29*, 109840. [CrossRef]
125. Salata, F.; Golasi, I.; Petitti, D.; De Lieto Vollaro, E.; Coppi, M.; De Lieto Vollaro, A. Relating Microclimate, Human Thermal Comfort and Health during Heat Waves: An Analysis of Heat Island Mitigation Strategies through a Case Study in an Urban Outdoor Environment. *Sustain. Cities Soc.* **2017**, *30*, 79–96. [CrossRef]
126. Fahed, J.; Kinab, E.; Ginestet, S.; Adolphe, L. Impact of Urban Cool Strategies on Energy Performance of HVAC Systems in a Dense Urban District of a Mediterranean City, Beirut, Lebanon. In *Global Urban Heat Island Mitigation*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 363–379, ISBN 978-0-323-85539-6.
127. Hedquist, B.C.; Brazel, A.J. Seasonal Variability of Temperatures and Outdoor Human Comfort in Phoenix, Arizona, U.S.A. *Build. Environ.* **2014**, *72*, 377–388. [CrossRef]
128. Abedrabboh, O.; Fountoukis, C.; Al-Ansari, T.; Alfarra, M.R. Simulating Microclimate Adaptation: Evaluating Heat Mitigation Strategies for Doha, Qatar, under Current and Future Climate Conditions. *Sustain. Cities Soc.* **2025**, *132*, 106777. [CrossRef]
129. Vurro, G.; Martilli, A.; Hadjinicolaou, P.; Carlucci, S.; Constantinidou, K.; Lelieveld, J. Adaptation and Mitigation of Outdoor Heat Stress and Building Energy Consumption During a Heat Wave in Nicosia, Cyprus. *Urban Clim.* **2025**, *62*, 102507. [CrossRef]
130. Kaçmaz, G.; Şemsiyeci, S. Evaluation of Nature-Based Solutions to Improve the Urban Microclimate in Mediterranean Climate Conditions: A Case Study of Izmir-Karsıyaka. *Sustainability* **2024**, *16*, 2646. [CrossRef]
131. Arrar, H.F.; Kaoula, D.; Santamouris, M.; Foufa-Abdessemed, A.; Emmanuel, R.; Matallah, M.E.; Ahriz, A.; Attia, S. Coupling of Different Nature Base Solutions for Pedestrian Thermal Comfort in a Mediterranean Climate. *Build. Environ.* **2024**, *256*, 111480. [CrossRef]
132. Barghchi, M.; Grace, B.; Edwards, N.; Bolleter, J.; Hooper, P. Park Thermal Comfort and Cooling Mechanisms in Present and Future Climate Scenarios. *Urban For. Urban Green.* **2024**, *101*, 128533. [CrossRef]

133. Ojaghlou, M.; Khakzand, M. Thermal Comfort Characteristic of 5 Patterns of a Persian Garden in a Hot-Arid Climate of Shiraz, Iran. *J. Landsc. Ecol.* **2019**, *12*, 1–33. [CrossRef]
134. Binabid, J. Greenery Impact on Physiological Equivalent Temperature for Pedestrians in Residential Zones in Hot and Arid Climates. *J. Archit. Plan.-King Saud Univ.* **2025**, *37*, 55–77. [CrossRef]
135. Karaiskaki, R.; Tseliou, A.; Tousi, E.; Mela, A.; Zervas, E. Evaluating the Microclimate Impact of Extensive Green Roofs on School Buildings in Mediterranean Environments: A Case Study in Athens, Greece. *E3S Web Conf.* **2025**, *669*, 03005. [CrossRef]
136. Middel, A.; Häb, K.; Brazel, A.J.; Martin, C.A.; Guhathakurta, S. Impact of Urban Form and Design on Mid-Afternoon Microclimate in Phoenix Local Climate Zones. *Landsc. Urban Plan.* **2014**, *122*, 16–28. [CrossRef]
137. Alghamdi, A.S.; Alzhrani, A.I.; Alanazi, H.H. Local Climate Zones and Thermal Characteristics in Riyadh City, Saudi Arabia. *Remote Sens.* **2021**, *13*, 4526. [CrossRef]
138. Seager, R.; Osborn, T.J.; Kushnir, Y.; Simpson, I.R.; Nakamura, J.; Liu, H. Climate Variability and Change of Mediterranean-Type Climates. *J. Clim.* **2019**, *32*, 2887–2915. [CrossRef]
139. Giannaros, T.M.; Melas, D. Study of the Urban Heat Island in a Coastal Mediterranean City: The Case Study of Thessaloniki, Greece. *Atmos. Res.* **2012**, *118*, 103–120. [CrossRef]
140. Tan, Z.; Lau, K.K.-L.; Ng, E. Urban Tree Design Approaches for Mitigating Daytime Urban Heat Island Effects in a High-Density Urban Environment. *Energy Build.* **2016**, *114*, 265–274. [CrossRef]
141. Matthews, T.; Lo, A.Y.; Byrne, J.A. Reconceptualizing Green Infrastructure for Climate Change Adaptation: Barriers to Adoption and Drivers for Uptake by Spatial Planners. *Landsc. Urban Plan.* **2015**, *138*, 155–163. [CrossRef]
142. Santamouris, M. Using Cool Pavements as a Mitigation Strategy to Fight Urban Heat Island—A Review of the Actual Developments. *Renew. Sustain. Energy Rev.* **2013**, *26*, 224–240. [CrossRef]
143. Cilek, A.; Unal, M.; Middel, A. The Effects of 2-D and 3-D Urban Landscape Metrics on Mean Radiant Temperature in Hot-Arid Phoenix and Tempe, Arizona, USA. *Sustain. Cities Soc.* **2024**, *101*, 105116. [CrossRef]
144. Salameh, M.; Elkhazindar, A.; Awad, J.; Baba, F. Effect of Sustainable Cities on the Urban Heat Island and Human Thermal Comfort-Dubai Sustainable City as A Case Study. *Future Cities Environ.* **2025**, *11*, 1–26. [CrossRef]
145. Speak, A.F.; Salbitano, F. Summer Thermal Comfort of Pedestrians in Diverse Urban Settings: A Mobile Study. *Build. Environ.* **2022**, *208*, 108600. [CrossRef]
146. Kim, D.; Song, S.-K. The Multifunctional Benefits of Green Infrastructure in Community Development: An Analytical Review Based on 447 Cases. *Sustainability* **2019**, *11*, 3917. [CrossRef]
147. Kilbane, S. Green Infrastructure: Planning a National Green Network for Australia. *J. Landsc. Archit.* **2013**, *8*, 64–73. [CrossRef]
148. Kilbane, S. Green Infrastructure in Hornsby, NSW. In *Creating Resilient Landscapes in an Era of Climate Change*; Routledge: London, UK, 2022; pp. 136–165, ISBN 978-1-003-26644-0.
149. Kleerekoper, L.; Van Esch, M.; Salcedo, T.B. How to Make a City Climate-Proof, Addressing the Urban Heat Island Effect. *Resour. Conserv. Recycl.* **2012**, *64*, 30–38. [CrossRef]
150. Ouria, M.; Almeida, A.; Yaghoubi Kondelaji, S.; Moura, P.; De Almeida, A.T. Sustainable Urban Mitigation Strategies Regarding Heat-Related Mortalities and Thermal Discomfort: An Overview and Comparative Analysis. *Theor. Appl. Climatol.* **2025**, *156*, 326. [CrossRef]
151. Fahed, J.; Kinab, E.; Ginestet, S.; Adolphe, L. Impact of Urban Heat Island Mitigation Measures on Microclimate and Pedestrian Comfort in a Dense Urban District of Lebanon. *Sustain. Cities Soc.* **2020**, *61*, 102375. [CrossRef]
152. Ulpiani, G.; Di Giuseppe, E.; Di Perna, C.; D'Orazio, M.; Zinzi, M. Thermal Comfort Improvement in Urban Spaces with Water Spray Systems: Field Measurements and Survey. *Build. Environ.* **2019**, *156*, 46–61. [CrossRef]
153. Salata, F.; Golasi, I.; Vollaro, A.D.L.; Vollaro, R.D.L. How High Albedo and Traditional Buildings' Materials and Vegetation Affect the Quality of Urban Microclimate. A Case Study. *Energy Build.* **2015**, *99*, 32–49. [CrossRef]
154. Du, H.; Cai, W.; Xu, Y.; Wang, Z.; Wang, Y.; Cai, Y. Quantifying the Cool Island Effects of Urban Green Spaces Using Remote Sensing Data. *Urban For. Urban Green.* **2017**, *27*, 24–31. [CrossRef]
155. Proutsos, N.D.; Solomou, A.D.; Petropoulou, M.; Chatzipavlis, N.E. Micrometeorological and Hydraulic Properties of an Urban Green Space on a Warm Summer Day in a Mediterranean City (Attica–Greece). *Land* **2022**, *11*, 2042. [CrossRef]
156. Perini, K.; Magliocco, A. Effects of Vegetation, Urban Density, Building Height, and Atmospheric Conditions on Local Temperatures and Thermal Comfort. *Urban For. Urban Green.* **2014**, *13*, 495–506. [CrossRef]
157. Brownlee, T.D.; Malavolta, S.; Marchesani, G.E. Bridging the Theory–Practice Gap: A Design Methodology for Green Infrastructure Implementation in Mid-Adriatic Coastal Cities. *Sustainability* **2026**, *18*, 1690. [CrossRef]
158. Zeğerek, P.; Ortaçeşme, V. An Investigation on Cooling Potential of Micro Scale Parks in Antalya (Türkiye). *Ege Üniversitesi Ziraat Fakültesi Derg.* **2025**, *62*, 365–380. [CrossRef]
159. Bachir, N.; Bounoua, L.; Aiche, M.; Maliki, M.; Nigro, J.; El Ghazouani, L. The Simulation of the Impact of the Spatial Distribution of Vegetation on the Urban Microclimate: A Case Study in Mostaganem. *Urban Clim.* **2021**, *39*, 100976. [CrossRef]

160. Grilo, F.; Pinho, P.; Aleixo, C.; Catita, C.; Silva, P.; Lopes, N.; Freitas, C.; Santos-Reis, M.; McPhearson, T.; Branquinho, C. Using Green to Cool the Grey: Modelling the Cooling Effect of Green Spaces with a High Spatial Resolution. *Sci. Total Environ.* **2020**, *724*, 138182. [CrossRef]
161. Antenucci, E.; Di Pirro, E.; Van Den Bosch, M.; Pace, R.; Lasserre, B.; Marchetti, M.; Garfì, V. Beyond Tree Cover: Vertical Canopy Structure Is Associated with the Cooling Impact of Pocket Parks in Mediterranean Cities. *Urban For. Urban Green.* **2026**, *119*, 129371. [CrossRef]
162. Anas, T.; Ágnes, S. Temperature as an Urban Metabolic Indicator: Simulating Spatial Configurations in Hot and Arid Neighborhoods. *Urban Clim.* **2025**, *62*, 102509. [CrossRef]
163. Tsiros, I.X.; Hoffman, M.E. Thermal and Comfort Conditions in a Semi-Closed Rear Wooded Garden and Its Adjacent Semi-Open Spaces in a Mediterranean Climate (Athens) during Summer. *Archit. Sci. Rev.* **2014**, *57*, 63–82. [CrossRef]
164. Fahmy, M.; Sharples, S.; Yahiya, M. LAI Based Trees Selection for Mid Latitude Urban Developments: A Microclimatic Study in Cairo, Egypt. *Build. Environ.* **2010**, *45*, 345–357. [CrossRef]
165. Elbardisy, W.M.; Salheen, M.A.; Fahmy, M. Solar Irradiance Reduction Using Optimized Green Infrastructure in Arid Hot Regions: A Case Study in El-Nozha District, Cairo, Egypt. *Sustainability* **2021**, *13*, 9617. [CrossRef]
166. Aboelata, A. Vegetation in Different Street Orientations of Aspect Ratio (H/W 1:1) to Mitigate UHI and Reduce Buildings' Energy in Arid Climate. *Build. Environ.* **2020**, *172*, 106712. [CrossRef]
167. Abd El-Razik, M.M.; Hafez, Y.K.; Hendy, A.H.; Fawzy, M.M. Methodology for Microclimatic Urban Canyon Design Case Study Surrounding MUST University Campus in Cairo. *HBRC J.* **2024**, *20*, 589–603. [CrossRef]
168. Tan, P.Y.; Wong, N.H.; Tan, C.L.; Jusuf, S.K.; Chang, M.F.; Chiam, Z.Q. A Method to Partition the Relative Effects of Evaporative Cooling and Shading on Air Temperature within Vegetation Canopy. *J. Urban Ecol.* **2018**, *4*, juy012. [CrossRef]
169. Wang, Z.-H.; Zhao, X.; Yang, J.; Song, J. Cooling and Energy Saving Potentials of Shade Trees and Urban Lawns in a Desert City. *Appl. Energy* **2016**, *161*, 437–444. [CrossRef]
170. Middel, A.; Chhetri, N.; Quay, R. Urban Forestry and Cool Roofs: Assessment of Heat Mitigation Strategies in Phoenix Residential Neighborhoods. *Urban For. Urban Green.* **2015**, *14*, 178–186. [CrossRef]
171. Aboelata, A.; Sodoudi, S. Evaluating the Effect of Trees on UHI Mitigation and Reduction of Energy Usage in Different Built up Areas in Cairo. *Build. Environ.* **2020**, *168*, 106490. [CrossRef]
172. Park, Y.; Zhao, Q.; Guldmann, J.-M.; Wentz, E.A. Quantifying the Cumulative Cooling Effects of 3D Building and Tree Shade with High Resolution Thermal Imagery in a Hot Arid Urban Climate. *Landsc. Urban Plan.* **2023**, *240*, 104874. [CrossRef]
173. La Rosa, D.; Li, J. High-Resolution Greening Scenarios for Urban Climate Regulation Based on Physical and Socio-Economical Factors. *Sustainability* **2023**, *15*, 7678. [CrossRef]
174. Gomaa, M.M.; Nabil, J.; Berkouk, D.; Ragab, A. A Comparative Study of Vegetation Strategies for Outdoor Thermal Comfort in High- and Low-Density Urban Areas. *Urban Sci.* **2025**, *9*, 416. [CrossRef]
175. Abu Ali, M.; Alawadi, K.; Khanal, A. The Role of Green Infrastructure in Enhancing Microclimate Conditions: A Case Study of a Low-Rise Neighborhood in Abu Dhabi. *Sustainability* **2021**, *13*, 4260. [CrossRef]
176. Honjo, T.; Takakura, T. Simulation of Thermal Effects of Urban Green Areas on Their Surrounding Areas. *Energy Build.* **1990**, *15*, 443–446. [CrossRef]
177. Spronken-Smith, R.A.; Oke, T.R. The Thermal Regime of Urban Parks in Two Cities with Different Summer Climates. *Int. J. Remote Sens.* **1998**, *19*, 2085–2104. [CrossRef]
178. Zhao, C.; Fu, G.; Liu, X.; Fu, F. Urban Planning Indicators, Morphology and Climate Indicators: A Case Study for a North-South Transect of Beijing, China. *Build. Environ.* **2011**, *46*, 1174–1183. [CrossRef]
179. Takebayashi, H. Influence of Urban Green Area on Air Temperature of Surrounding Built-Up Area. *Climate* **2017**, *5*, 60. [CrossRef]
180. Yan, H.; Wu, F.; Dong, L. Influence of a Large Urban Park on the Local Urban Thermal Environment. *Sci. Total Environ.* **2018**, *622–623*, 882–891. [CrossRef]
181. Lin, W.; Yu, T.; Chang, X.; Wu, W.; Zhang, Y. Calculating Cooling Extents of Green Parks Using Remote Sensing: Method and Test. *Landsc. Urban Plan.* **2015**, *134*, 66–75. [CrossRef]
182. Binabid, J.; Anteet, Q. Numerical Study of Vegetation Effects on Thermal Comfort for Outdoor Spaces at a Public School in Hot and Arid Climate. *Environ. Adv.* **2024**, *15*, 100482. [CrossRef]
183. Atwa, S.; Ibrahim, M.G.; Murata, R. Evaluation of Plantation Design Methodology to Improve the Human Thermal Comfort in Hot-Arid Climatic Responsive Open Spaces. *Sustain. Cities Soc.* **2020**, *59*, 102198. [CrossRef]
184. Zhao, Q.; Sailor, D.J.; Wentz, E.A. Impact of Tree Locations and Arrangements on Outdoor Microclimates and Human Thermal Comfort in an Urban Residential Environment. *Urban For. Urban Green.* **2018**, *32*, 81–91. [CrossRef]
185. Perini, K.; Calise, C.; Castellari, P.; Roccotiello, E. Microclimatic and Environmental Improvement in a Mediterranean City through the Regeneration of an Area with Nature-Based Solutions: A Case Study. *Sustainability* **2022**, *14*, 5847. [CrossRef]
186. Lopez-Ordoñez, C.; Garcia-Nevado, E.; Coch, H.; Morganti, M. Heat Stress in Social Housing Districts: Tree Cover–Built Form Interaction. *Build. Cities* **2025**, *6*, 415–432. [CrossRef]

187. Wang, C.; Wang, Z.-H.; Kaloush, K.E.; Shacat, J. Perceptions of Urban Heat Island Mitigation and Implementation Strategies: Survey and Gap Analysis. *Sustain. Cities Soc.* **2021**, *66*, 102687. [CrossRef]
188. Parsaee, M.; Joybari, M.M.; Mirzaei, P.A.; Haghighat, F. Urban Heat Island, Urban Climate Maps and Urban Development Policies and Action Plans. *Environ. Technol. Innov.* **2019**, *14*, 100341. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.