



KAPITEL 12 / CHAPTER 12¹²

EXPLORING THE ROLE OF URBAN GREEN SPACES IN REDUCING HEAT ISLAND EFFECTS

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Introduction

Global climate change, coupled with the accelerating pace of urbanization, has significantly intensified urban temperatures, thereby amplifying the urban heat island (UHI) effect and posing serious threats to urban sustainability [1,2]. Effectively addressing these interconnected challenges is crucial for safeguarding public health, reducing energy demands, and enhancing the resilience of urban ecosystems [3]. The UHI phenomenon refers to the elevated temperatures observed in densely built urban areas compared to surrounding rural regions, a disparity primarily driven by extensive impervious surfaces, limited vegetation, and the prevalence of anthropogenic heat sources [4–6].

Urban sustainability efforts often face considerable barriers in mitigating UHI impacts, as these effects compound existing issues such as thermal discomfort, increased energy consumption for cooling, and heightened environmental stress. Empirical studies consistently attribute the development of UHIs to urban morphologies characterized by widespread concrete infrastructure, minimal green coverage, and concentrated heat emissions from buildings and vehicles. The interplay between urban form and human-environment interactions underscores the importance of holistic urban design strategies. Consequently, city planning emerges as a key intervention tool capable of mitigating the adverse consequences of urban thermal stress through integrated, ecologically informed approaches.

Initial research on UHIs primarily aimed at documenting the temperature gradient between urban and non-urban areas. However, the field has since evolved to encompass advanced methodologies, including high-resolution climate modeling, remote sensing

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technologies, and the incorporation of ecosystem services into planning frameworks. Recent studies highlight the multifaceted benefits of green infrastructure—not only for moderating urban temperatures but also for enhancing air quality, promoting biodiversity, and strengthening social cohesion.

The UHI effect is intricately linked to increased demand for air conditioning, elevated levels of environmental stress, and greater public health risks in urban areas [1,2]. Numerous investigations have demonstrated that areas with sparse vegetation and a high percentage of impervious surfaces are particularly vulnerable to extreme temperature events, which in turn escalate energy consumption and heat-related illnesses. In this context, urban green spaces (UGSs)—including parks, green roofs, and roadside vegetation—play a pivotal role in mitigating UHI impacts.

UGSs achieve cooling through several key mechanisms: evapotranspiration, shading, and increased surface reflectivity (albedo). Research shows that well-designed green areas can reduce local temperatures by as much as 4 °C. The integration of water features with vegetation—such as in blue-green infrastructure—can further amplify these cooling effects through enhanced evaporation and moisture retention [1]. Besides thermal benefits, UGSs contribute to ecological restoration, air purification, and improved urban livability, making them indispensable to sustainable city planning. The effectiveness of UGSs in mitigating UHI effects varies based on structural characteristics and spatial configurations. Green roofs, in particular, are well-suited for compact urban settings due to their insulation properties and capacity to provide localized thermal relief. Larger green areas, such as urban parks, offer more extensive cooling zones and recreational benefits, thereby contributing to both environmental and community well-being. Street trees and linear green corridors provide critical shade and facilitate airflow, improving pedestrian comfort and lowering surface temperatures in densely built environments.

Optimal heat mitigation requires the strategic integration of various UGS types into a cohesive urban fabric. By leveraging the unique strengths of different green infrastructure elements, urban planners can design multifunctional systems that deliver enhanced and scalable cooling outcomes. Understanding the spatial, ecological, and



social dimensions of each UGS type allows for more targeted and effective interventions. This review aims to systematically examine the typologies, operational mechanisms, and performance metrics of urban green spaces in mitigating UHI impacts. By synthesizing empirical research, the study provides a comparative evaluation of green roofs, urban parks, and street-level vegetation in terms of their cooling effectiveness, adaptability, and scalability. Furthermore, the review identifies existing knowledge gaps and suggests directions for future research, with the goal of advancing practical applications of UGSs in climate-resilient urban development. Ultimately, this comprehensive analysis contributes to the development of a robust framework for utilizing urban green infrastructure as a nature-based solution to the UHI phenomenon. The insights derived from this review are intended to support urban planners, landscape architects, and policymakers in implementing evidence-based strategies that foster environmental sustainability and improve quality of life in urban settings. This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological transparency, consistency, and academic rigor throughout the research process. The scope of the review encompassed peer-reviewed literature published between 1998 and 2024, sourced primarily from two comprehensive academic databases: Web of Science and Scopus. A targeted search strategy was employed using key terms such as “*urban heat island*”, “*urban green space*”, “*heat mitigation*”, “*green infrastructure*”, “*cooling effects*”, and “*thermal comfort*”. These terms were combined using Boolean operators (AND/OR) to refine the search results and maximize relevance.

This structured approach ensures that the resulting synthesis is both comprehensive and grounded in high-quality, evidence-based research, offering valuable insights for urban planners, environmental policymakers, and sustainability practitioners.



12.1. Urban Heat Island (UHI) potentials

Urban green spaces (UGSs) play a vital role in mitigating the urban heat island (UHI) effect through several key biophysical processes, including shading, evapotranspiration, albedo modification, and improved ventilation. While the spatial configuration and structural diversity of urban vegetation have long been acknowledged, recent research has increasingly focused on quantifying their cooling potential and associated environmental co-benefits across diverse urban contexts.

One of the most effective and well-documented mechanisms through which UGSs combat UHI is **shading**. Vegetation, particularly trees with broadleaf canopies, intercepts solar radiation and prevents heat absorption by impervious urban surfaces. Numerous studies have demonstrated that areas with dense tree coverage can reduce land surface temperatures (LST) by up to 2 °C in densely developed city zones.

Street trees and expansive urban parks are particularly effective in this regard, offering substantial reductions in surface and ambient air temperatures. For instance, Cheela et al. [8] documented that strategic tree placement in Los Angeles significantly lowered pavement temperatures and improved pedestrian thermal comfort. Shading not only enhances the microclimate but also reduces the energy demand for cooling buildings, thereby contributing to lower greenhouse gas (GHG) emissions.

Jamei et al. [9] further analyzed shading performance in relation to street orientation and urban form, demonstrating that appropriate building-vegetation configurations can yield substantial temperature decreases, especially in tropical and highly urbanized regions. However, the cooling efficacy of shading is highly dependent on canopy density and spatial coverage. Open areas with sparse vegetation offer limited protection from heat, highlighting the importance of carefully planned tree placement and density. Overall, shading strategies are instrumental in improving thermal comfort, reducing energy consumption, and contributing to broader climate adaptation goals in urban environments.

Evapotranspiration represents another fundamental cooling mechanism employed by vegetation. This process involves the release of water vapor from plant surfaces into



the atmosphere, accompanied by a latent heat exchange that cools the surrounding environment. It is particularly effective in urban parks, community gardens, and other vegetated open spaces that serve as moisture reservoirs—especially in arid and subtropical regions.

Qiu et al. [10] showed that evapotranspiration can decrease urban temperatures by several degrees, with even greater effects observed when green spaces are integrated with water features. The combined impact of evapotranspiration and shading significantly extends the spatial reach of urban cooling, as evidenced by Jandaghian and Colombo [7]. Studies from subtropical cities such as Guangzhou report temperature reductions of up to 5 °C due to evapotranspiration processes in urban parks and gardens. Nevertheless, the effectiveness of this cooling strategy is heavily contingent on the availability of water resources. In water-scarce regions, such as arid cities, maintaining high evapotranspiration rates requires sustainable water management practices. As such, while highly beneficial, evapotranspiration-based strategies must be adapted to local hydrological contexts to remain viable and effective. A third pathway by which green infrastructure contributes to UHI mitigation is through albedo enhancement. Albedo refers to a surface's reflectivity; increasing this reflectivity reduces heat absorption by urban materials. Green roofs and green walls—composed of dense and diverse vegetation—can increase the albedo of building surfaces, thereby moderating indoor and outdoor temperatures.

Razzaghmanesh et al. [11] demonstrated that conventional urban surfaces tend to exhibit low albedo and high thermal retention. In contrast, green roofs with intensive plant coverage substantially increase surface reflectivity while providing insulation. These systems have been successfully implemented in dense metropolitan areas like Hong Kong and Singapore, where they have been shown to lower surrounding temperatures by as much as 2 °C.

In arid environments such as Phoenix, the application of reflective pavements and materials on sidewalks has emerged as a complementary strategy to increase urban albedo and reduce surface heat accumulation. These techniques, while effective, generally produce more moderate cooling effects compared to shading and



evapotranspiration. Their performance is also constrained in areas where population density is low and expansive open spaces allow natural reflection, limiting their thermal impact. Despite these limitations, albedo-enhancing solutions—such as green roofs and reflective pavements—remain valuable components of integrated urban cooling strategies. Their effectiveness is maximized when used in tandem with other interventions such as strategic shading and vegetation-based ventilation systems, particularly in highly developed urban zones with limited ground-level greening opportunities.

Ventilation represents another essential mechanism for mitigating the urban heat island (UHI) effect, primarily by facilitating the circulation of air and redistribution of thermal loads across urban environments. Green spaces, particularly expansive areas such as urban parks, green corridors, and vegetated boulevards, play a pivotal role in enhancing urban airflow. These open spaces function as natural ventilation pathways, promoting cooler air movement and diminishing localized heat accumulation.

The significance of ventilation corridors has been highlighted in studies such as that by He et al. [12], which demonstrated how urban planning strategies incorporating linear green corridors can substantially alleviate localized heat stress. In cities like Tokyo, green-lined streets and vegetated ventilation routes create conduits for air exchange, thereby improving microclimatic conditions and pedestrian thermal comfort. These corridors help dissipate heat and distribute cooler air throughout high-density urban zones. Additionally, the integration of water features—such as ponds, fountains, and wetlands—within green spaces has been shown to enhance evaporative cooling and complement ventilation processes. The synergistic interaction between vegetation and water elements is crucial for achieving substantial temperature reductions in urban settings. In East Asian cities such as Seoul, the combined implementation of tree cover and water features—sometimes referred to as the "pond-tree complex"—has proven effective in lowering peak temperatures and improving ambient air quality.

These findings suggest that coupling ventilation corridors with water-integrated green infrastructure offers a robust and multifunctional approach to UHI mitigation.



However, the successful implementation of such systems hinges on the availability of sufficient open space, which is often limited in highly built-up urban environments. This spatial constraint underscores the importance of rethinking urban design to incorporate functional air-exchange networks within existing infrastructure. Innovative urban planning must explore opportunities to retrofit or reclaim spaces for ventilation corridors, particularly in compact cities facing increased thermal stress.

UHI mitigation mechanisms, highlighting their individual effectiveness, operational benefits, and inherent limitations. The following summarizes the primary mechanisms:

- **Shading:** Primarily facilitated by tree canopies in parks and along streets, shading can reduce surface temperatures by approximately 2–3 °C. However, its impact is spatially constrained and most effective in areas with dense, continuous canopy cover. Thus, careful spatial planning is required to ensure optimal distribution.
- **Evapotranspiration:** This mechanism leverages latent heat exchange through moisture release from vegetation and can lower temperatures by 2–5 °C, particularly in humid and subtropical climates. Common applications include green roofs and urban parks. Nonetheless, evapotranspiration requires a steady water supply, posing challenges in arid or water-scarce regions.
- **Albedo Modification:** Implemented through reflective surfaces such as green roofs, green walls, and cool pavements, this strategy reduces surface heat absorption by 1–2 °C. It is especially effective in high-insolation regions, although its cooling capacity diminishes in compact urban areas with limited sky view and airflow.
- **Ventilation:** Green corridors and strategically designed open spaces can facilitate air movement and reduce local temperatures by up to 3 °C. Their success depends heavily on the availability of sufficient spatial corridors to allow unimpeded airflow, which may be restricted in densely constructed urban environments.

These findings underscore the need for a strategic integration of multiple UHI



mitigation mechanisms, as each offers unique benefits while also presenting specific spatial and operational constraints. Combining approaches—such as shading with evapotranspiration, or albedo enhancement with ventilation corridors—enables cities to leverage the synergistic effects of urban greenery and infrastructure, thereby maximizing cooling outcomes and supporting resilient urban development.

12.2. Urban green spaces variations

This systematic literature review seeks to elucidate the current discourse surrounding the European electricity market model and its underlying mechanisms, as well as to examine the range of reform proposals aimed at improving its design. The review categorizes findings according to distinct electricity market mechanisms and, additionally, assesses the modelling methodologies employed in the literature. To provide context, the temporal distribution of the selected publications was analyzed, revealing a consistent increase in the volume of research over recent years which presents both absolute and relative annual publication counts. The rise of renewable energy has increased grid congestion and management costs, prompting regulators to consider structural solutions like bidding zone reconfiguration. In Europe, the CACM regulation sets criteria for bidding zones focused on network security, market efficiency, and stability.

Urban green spaces (UGSs) represent one of the most effective strategies for mitigating the urban heat island (UHI) effect. Through a combination of shading, evapotranspiration, and surface albedo modification, these green infrastructure elements contribute significantly to cooling urban environments, enhancing thermal comfort, and delivering both ecological and social co-benefits. Different typologies—including urban parks, green roofs, street trees, vertical greenery systems, community gardens, and urban forests—offer distinct mechanisms and magnitudes of impact based on their design, scale, and spatial distribution.

Urban parks play a vital role in moderating urban temperatures through the dual mechanisms of shading and evapotranspiration. Their cooling performance is closely



linked to factors such as tree density, species diversity, canopy coverage, and spatial configuration. For instance, a study by Zhang et al. [2] revealed that large, vegetatively diverse parks can reduce land surface temperatures (LSTs) by up to 9 °C. Another investigation conducted in the Gold Coast, Australia, emphasized that tree density, rather than park size, was the most critical factor influencing temperature reduction.

Further research in Xi'an, China, found that the cooling effects of urban parks could extend up to 241 meters beyond their boundaries, thereby improving thermal comfort for adjacent urban areas. These findings highlight the importance of vegetation density and strategic layout in maximizing the cooling potential of urban parks. However, the implementation of such parks requires substantial land area—often a limiting factor in highly urbanized cities. Despite spatial constraints, urban parks remain essential components of climate-resilient urban design due to their capacity to reduce heat loads and promote public health. In high-density urban areas where horizontal space is limited, green roofs provide a practical and impactful solution to mitigate UHI effects. These systems lower rooftop surface temperatures, enhance thermal insulation, and contribute to building energy efficiency. Wong et al. [13] documented that green roofs in Singapore and Tokyo reduced rooftop temperatures by up to 17 °C, making them critical assets in sustainable urban development.

The performance of green roofs varies depending on plant species selection, substrate depth, and irrigation practices. Research by Han et al. [6] indicated that well-maintained rooftop gardens can achieve temperature reductions of up to 5 °C (9 °F). Integrating water features within green roofs further enhances their cooling effect through additional evapotranspiration. Green roofs not only reduce ambient heat but also lower indoor cooling demands, contributing to reduced greenhouse gas emissions and greater energy conservation.

However, the broader adoption of green roofs faces practical challenges. These include structural reinforcement requirements, initial installation costs, and ongoing maintenance needs such as regular irrigation—particularly critical in water-scarce regions. Nevertheless, in compact metropolitan environments lacking space for traditional parks, green roofs remain a key strategy for achieving localized cooling and



improving urban thermal comfort. Street trees, strategically planted along urban roadways and pedestrian corridors, significantly improve the urban microclimate by offering shade and intercepting solar radiation. Their cooling benefits are especially pronounced in arid and semi-arid cities, where they reduce surface temperatures and mitigate heat stress for both pedestrians and vehicles.

For example, Wang et al. [14] reported that street trees were particularly effective in dry environments, where they lowered land surface temperatures by approximately 2 °C. In cities such as Phoenix, USA, trees planted along streets and sidewalks provide essential shading for residents and road users, thereby decreasing both ambient and surface temperatures. When combined with other interventions—such as high-albedo pavements—the cooling effects of street trees can be further enhanced, creating a synergistic solution for UHI mitigation. Street trees also improve walkability, comfort, and aesthetic value in urban neighborhoods. However, their effectiveness depends on species selection, planting density, and adequate access to water, especially in drought-prone areas. Despite these considerations, street trees remain one of the most cost-effective and widely applicable tools for enhancing urban resilience to heat.

Conclusion

The role of urban green spaces in mitigating the urban heat island (UHI) effect is unequivocal. Their cooling impact—achieved through mechanisms such as shading, evapotranspiration, and albedo enhancement—has been well-documented across various urban contexts. This review underscores the transformative potential of green infrastructure as a climate adaptation strategy, particularly when supported by emerging technologies such as remote sensing and Geographic Information Systems (GIS). These tools allow for precise assessment of urban heat distribution and vegetation cover, thereby informing strategic placement of green interventions to maximize cooling benefits.

Remote sensing provides critical insights into spatial patterns of urban heat and vegetation health, while GIS-based spatial analysis enables data-driven identification of optimal sites for implementing green infrastructure. This evidence-based approach



ensures that conservation and greening initiatives are both effective and equitable, targeting areas with the greatest need for heat mitigation and public health support. In doing so, such technologies enhance thermal comfort, reduce urban heat stress, and support more livable cities.

The integration of urban parks, green roofs, and street trees forms the backbone of a comprehensive urban heat mitigation strategy. These interventions not only contribute to reducing surface and ambient temperatures but also deliver wide-ranging co-benefits—including improved air quality, biodiversity support, and enhanced mental and physical well-being. As cities continue to face increasing pressures from climate change and urban densification, the strategic deployment of green infrastructure becomes not only beneficial but essential.

The broader implications of this approach extend deeply into urban policy and planning. Municipal governments must begin to recognize urban green spaces as critical assets that intersect environmental sustainability, social equity, and public health. Integrating green infrastructure into the urban fabric requires intentional policy frameworks that prioritize equitable distribution, long-term maintenance, and community engagement. Moreover, embracing technological tools for monitoring and evaluating the performance of green infrastructure can significantly improve the efficiency and accountability of such interventions.

Looking ahead, there is a pressing need for further interdisciplinary research to build a robust, context-sensitive evidence base. Future studies should explore the effectiveness of green infrastructure across different climatic zones, socio-economic settings, and urban typologies. By integrating insights from environmental science, urban planning, and social justice, researchers and practitioners can co-create holistic solutions that maximize the utility of urban green spaces.

Ultimately, fostering collaboration among stakeholders across disciplines will be critical in unlocking the full potential of UGSs as a cornerstone of sustainable and climate-resilient urban development. Through coordinated action and informed planning, cities can transform their landscapes into adaptive environments that serve both people and the planet.