Proceedings of ICEMGD 2026 Symposium: The Role of Blue Economy in Promoting Human Sustainable Development
DOI: 10.54254/2754-1169/2026.GT37262

Analyzing the Relationship Between Green Coverage and Urban Heat Island Effect

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Abstract. Against the backdrop of global climate change and rapid urbanization worldwide, the urban heat island (UHI) effect has evolved into a severe environmental hazard that endangers public health and increases urban energy demand. The urban heat island effect refers to the phenomenon in which urban areas are significantly hotter than surrounding rural areas, caused by massive impermeable buildings and shrinking natural vegetation. Green areas, including parks, forests, street trees, lawns, and rooftop gardens, play an important role in regulating the urban microclimate and easing heat accumulation. This paper studies the relationship between regional green coverage rate and the urban heat island effect. We collect regional green coverage and surface temperature data through remote sensing images and field temperature monitoring, and use correlation analysis to quantify their interactive relationship. The analytical results reveal that higher regional green coverage correlates significantly with reduced land surface temperature and weakened UHI intensity. Green spaces cool the environment mainly through shading, evapotranspiration, and improved air circulation. The findings of this study provide useful evidence and practical suggestions for urban planning and sustainable development, helping cities become cooler, greener, and more livable in the future while responding to global warming challenges.

Keywords: Green Coverage, Urban Heat Island Effect, Urban Microclimate, Urban Planning

1. Introduction

With rapid global urbanization, numerous rural regions have been turned into modern cities filled with concrete structures, paved roads and dense buildings. These impermeable surfaces easily absorb and store solar heat, while human activities including vehicle traffic, factory operation and indoor air conditioning release massive waste heat, jointly causing the severe urban heat island effect [1-3]. This thermal phenomenon describes a thermal gradient where urban zones exhibit markedly higher land surface temperatures than peripheral suburban and rural areas, exerting multiple adverse impacts on urban residents and regional ecosystems. Extreme heat reduces outdoor thermal comfort, raises the incidence of heat-related illnesses, and increases urban power consumption for cooling equipment [4, 5]. It also deteriorates urban air quality and destroys local ecological balance [6]. As an eco-friendly and efficient mitigation method, urban green spaces such as parks, street trees and lawns can effectively ease urban overheating. Vegetation cools urban

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environments through sunlight shading and transpiration, which greatly improves local microclimates [7, 8]. Against the backdrop of ongoing global warming, researching the correlation between urban green coverage and heat island intensity possesses important practical significance [9]. This study focuses on analyzing the cooling performance of urban vegetation and exploring its quantitative relationship with surface temperature, aiming to provide scientific and feasible planning suggestions for building greener, safer and more livable modern cities.

2. Concepts and principles

2.1. Urban heat island effect

The urban heat island effect describes the temperature difference between urban and rural areas. In general, urban temperatures are 2℃ to 8℃ higher than surrounding rural areas, especially on sunny and calm days [3]. The intensity of this temperature gap varies greatly under different time periods, seasons and city scales.

First, obvious day-night differences exist. During the daytime, sunlight heats both city and countryside, so the temperature gap is relatively small. After sunset, concrete, asphalt and other hard surfaces slowly release the heat stored all day, while rural land cools down quickly. Therefore, heat island intensity is far stronger at night than in the daytime [4].

Second, seasonal differences can be observed. In summer, strong solar radiation maximizes heat absorption by urban buildings and roads, creating a prominent heat island effect. In winter, weak sunlight and frequent wind reduce heat accumulation, so the temperature gap between urban and rural areas becomes much smaller [5].

Third, cities of different sizes show different heat island levels. Large metropolises with dense buildings, heavy traffic and wide impermeable ground produce a much stronger heat island effect than small towns or medium-sized cities [1].

The formation mechanisms underlying the UHI effect can be summarized as follows:

(1) Heat absorption by hard surfaces: Concrete and asphalt absorb more solar energy than soil and vegetation [2].

(2) Anthropogenic heat emission: Cars, factories, air conditioners, and crowded buildings produce large amounts of waste heat [2].

(3) Lack of vegetation: Fewer trees and grass mean less shading and transpiration cooling [8].

(4) Weak air circulation: Tall buildings block wind, preventing heat dispersion [10].

(5) Air pollution: Pollutants trap heat near the ground, worsening the heat island effect [6].

2.2. Green coverage rate

"Green coverage rate" refers to the percentage of urban land covered by vegetation, including trees, shrubs, grass, flowers, and other plants. It is an indicator of urban ecological quality [7]. There are multiple standard measurement indicators closely related to this value, such as normalized difference vegetation index (NDVI), leaf area index (LAI), and vegetation fractional cover (VFC). Among them, NDVI is the most widely used auxiliary index to judge vegetation density and vitality [1].

Remote sensing technology serves as the mainstream tool to calculate these indicators. Satellites capture multi-spectral surface images, and researchers import these images into professional remote sensing software to distinguish vegetation, concrete, water and bare soil automatically. The software then calculates the green coverage rate of each block quantitatively. Compared with traditional

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manual field surveys, remote sensing covers a larger range and saves massive human labor, which is suitable for large-scale urban research [1]. A higher green coverage rate means more vegetation, better air quality, and a healthier urban environment.

Common types of urban green spaces include urban parks, community green belts, street trees, rooftop gardens, vertical green walls, and wetlands. Each type plays a different role in cooling the city [8].

2.3. Cooling mechanisms of urban green spaces

Urban green spaces relieve urban overheating through three synergistic physical and biological mechanisms. These three cooling pathways do not work independently; they interact dynamically under different weather, seasonal and spatial conditions, and jointly offset thermal accumulation in built-up zones [7]. Numerous field monitoring and numerical simulation studies have verified that the cooling contribution of each mechanism varies significantly between day and night. The overall cooling efficiency is determined by vegetation configuration, vegetation coverage density and the spatial layout of surrounding buildings [1, 8].

2.3.1. Shading effect

Tree canopies and dense leaves block direct shortwave solar radiation, stopping high-temperature sunlight from touching pavement, walls and ground surfaces, which cuts heat accumulation at the source [1]. Under midday summer sunlight, shaded concrete surfaces can be 5℃ to 10℃ cooler than fully exposed hard surfaces, and the air temperature above shaded areas also drops by 1–3 ℃ accordingly [8].

The shading performance varies greatly by plant type. Tall deciduous arbors with thick, overlapping crowns create stable, wide shadow coverage that lasts 6–8 hours during daytime. Continuous rows of street trees can form shaded corridors that cover entire road surfaces, preventing asphalt from absorbing massive solar heat [6]. By contrast, low shrubs and lawns merely produce faint, transient shadows that shift with solar elevation angles and fail to offer sustained stable shading coverage. Without tree shading, dark asphalt absorbs over 85% of solar radiation; this stored heat releases slowly after sunset and amplifies nighttime heat island intensity [3]. Studies also mention that multi-layer mixed vegetation (trees + shrubs + grass) achieves better shading than single-layer lawns, as overlapping leaves block sunlight from multiple angles [11].

2.3.2. Transpiration cooling

Plants absorb water from deep soil through their root systems and discharge water vapor through tiny stomata on leaf surfaces; this biological process is transpiration [7]. When liquid water turns into water vapor, it absorbs a large amount of sensible heat from the surrounding air, which directly lowers ambient temperature around green patches [12].

A single mature broadleaf tree transpires 30–50 liters of water every hot summer day, and its daily cooling effect equals 3–5 household air conditioners running continuously for 8 hours [10]. Unlike shading, transpiration works steadily even under scattered cloudy sunlight and reaches peak efficiency at noon, when urban heat stress hits the highest level [5]. Its cooling strength is restricted by soil moisture: during droughts, plants close leaf pores to save water, and transpiration cooling will decrease sharply by over 60% [4]. By comparison, tall arbors possess far greater transpiration potential than lawns due to deeper root systems and larger leaf area index values. In contrast,

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vertical green facades and rooftop vegetation with limited soil volume deliver only mild transpiration cooling effects [8].

2.3.3. Improving air circulation and humidity

Green spaces adjust local wind patterns and atmospheric humidity simultaneously to disperse trapped urban heat [10]. Temperature gaps between cool vegetation zones and hot building areas create mild local wind flow: hot air above concrete rises, while cool air from parks flows outward to fill the space, forming natural micro-wind circulation [3]. Elevated atmospheric humidity generated by plant evapotranspiration further enhances human outdoor thermal comfort, given that dry hot air induces more severe thermal discomfort than humid air at identical temperatures [1].

Large connected green corridors between dense high-rise blocks disrupt the enclosed urban canyon structure, guiding cool park airflow into residential and commercial districts and speeding up the spread of waste heat and vehicle pollutants [6]. Wetlands paired with trees deliver the strongest dual cooling effect here: water bodies further raise air humidity, while trees stabilize wind speed to avoid rapid heat loss [9]. This circulation mechanism works more prominently at night: green areas slowly release the cool air stored in soil and vegetation, effectively weakening the nighttime heat island peak that forms after sunset [4]. When the three mechanisms work together, green infrastructure can maintain a stable mild microclimate all day long, making green infrastructure the most low-carbon and sustainable heat mitigation measure for modern cities [1].

3. Relationship between green coverage and heat island effect

A large number of academic studies have proven a significant negative correlation between urban green coverage rate and urban heat island intensity, which means that areas with higher vegetation coverage generally present lower surface temperature and a weaker heat island effect [1, 7]. Green spaces serve as the main ecological cooling source in urban areas, effectively balancing the thermal imbalance caused by dense buildings and human activities [8]. This correlation can be clearly verified through typical domestic and international urban cases.

In Beijing, researchers found that urban central forest parks with large-area continuous green vegetation can maintain local temperatures 1 ℃ to 5 ℃ lower than surrounding commercial and residential districts in summer [1]. Areas with green coverage higher than 45% exhibit almost no significant heat island effect, while urban core areas with green coverage below 15% often form high-temperature heat accumulation hotspots [6]. Similarly, in Shanghai, long-term remote sensing monitoring shows that every 10% increase in urban green coverage reduces regional average temperature by approximately 0.9℃ to 1.2℃ [7]. The urban heat island intensity declines steadily with the improvement of green landscape connectivity.

Foreign urban cases also support this rule. In Tokyo, urban areas with scattered small green patches still show obvious high temperature, while large ecological parks effectively reduce ambient temperature and weaken urban heat aggregation [3]. In London, the urban green corridor system connects suburban forests and urban green belts, greatly lowering the overall urban thermal level and making the heat island distribution more uniform [9]. Overall, both domestic and international cases confirm that green coverage is a decisive factor affecting urban thermal environment, and continuous, high-quality green space layout is the core method to mitigate the urban heat island effect [11].

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4. Ways to reduce the urban heat island effect

Based on the above connection between green coverage and city temperature, there are five practical ways to cool cities, and each has real city examples to prove its effect.

First, plant continuous street trees along roads. Roads are covered with asphalt, which absorbs lots of heat every day [2]. Shanghai has planted rows of tall leafy trees on main city roads. The tree tops block strong sunlight all summer, cutting road surface temperature by 4 to 7℃ and reducing heat released at night [7]. This cost-effective and operable measure delivers prominent cooling benefits for densely populated urban areas.

Second, build small pocket parks in city centers. Downtown areas have an excess of buildings and insufficient vegetation, creating serious heat islands [6]. Tokyo builds many tiny green parks between office blocks and apartments. These small green areas break wide hot zones and cool nearby walking streets and buildings [3].

Third, link parks and forests with green corridors to let wind flow freely. Tall buildings block wind and trap hot air between them [10]. London connects suburban forests, city parks and community green belts together. These green paths guide cool wind into inner city areas and take away extra heat [9].

5. Conclusion

This study systematically elaborates on the urban heat island (UHI) effect and clarifies the quantitative correlation between urban green coverage and land surface thermal conditions. It first introduces the definition, causes and different types of heat island differences, then explains three cooling mechanisms of green plants, and uses city cases to prove that more green spaces lead to weaker heat islands. Finally, this paper summarizes feasible urban planning strategies for green space enhancement and urban thermal environment optimization.. All the data and cases show that green vegetation is the most eco-friendly and useful way to ease urban overheating.

However, this study still has several weak points. First, it only talks about the general cooling effect of green space, without comparing how different plants like trees and grass cool cities in summer and winter. Second, all analytical results are based on published literature, without support of original field monitoring data or remote sensing imagery interpretation. Third, the paper only focuses on green coverage, and does not discuss other factors such as building height or population density that also affect city heat.

For future related studies, researchers can collect local temperature data by themselves and use satellite pictures to calculate the exact cooling range of parks and street trees. They can also compare cooling effects of different plants in different seasons. Besides, later research can combine more factors to study heat islands, so city planners can get more complete and clear advice to build cooler, greener living environments.

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