*Research Paper*

# Cooling Effects of Urban Blue-Green Spaces

## A Cross-Climate Review

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### Abstract

*Nature-based solutions have been widely recognized in alleviating urban heat island. Nevertheless, the cooling potential and cooling quality of urban blue-green space are different due to different climatic conditions. This part of the research has not been deeply explored. In this research, the difference of climatic zones is brought into the literature analysis by bibliometrics. Climate can be divided into five categories according to Koppen climate classification: equatorial(A type), arid(B type), warm temperate(C type), snow(D type), and polar(E type) climates. Research and sort out the literature of urban blue-green space to alleviate urban heat island from 1989 to 2025. Carry out bibliometrics review further. Citespace was used to visualize knowledge graphs of research characteristics, hotspots, and trend frontiers, to identify research progress, and future trends. Systematically investigate the impacts of urban blue-green spaces on the heat island effect under different climatic conditions, as well as the differences in cooling intensity, efficiency thresholds, and their associated influencing factors. Research findings indicate that blue-green spaces in most A type experience year-round cooling effects, while C type demonstrate distinct seasonal variations in cooling effects across blue-green spaces. In D type, blue-green spaces show summer cooling and slight winter warming. The cooling intensity of blue-green spaces follows the pattern of A>C>D climatic zone. The cooling efficiency threshold shows the pattern of C and D＞A climatic zone. However, studies on B type remains limited, and their patterns require further verification. Influenced by unique climatic conditions and evapotranspiration, arid areas are significantly affected by air humidity and diurnal radiation variations. Compared to high-humidity arid regions, low-humidity arid areas demonstrate stronger short-term cooling intensity per unit of blue-green space. Based on the above findings, the adaptive planning strategy is put forward according to the cooling characteristics of blue-green space in different climatic zones. It aims to enrich the planning objectives and management strategies of urban heat island adaptation and mitigation. So that nature-based solutions can exert the greatest effect in different climatic zones and urban areas.*

### Keywords

*Climate change, Blue-green space, Urban heat island, Bibliometrics*

## 1. Introduction

In recent years, the urban heat island effect (UHI) has intensified with urban expansion, exacerbating global warming. Nature-based solutions are increasingly becoming crucial measures to mitigate urban overheating. Numerous studies demonstrate that blue-green spaces outperform cooling materials and green roofs in cost-effectiveness, environmental friendliness, and political acceptability (Byrne and Jinjun , 2009; Carvalho et al., 2017).Vegetation cools by transpiration and shade(Dar et al., 2021). However, water has a significant cooling capacity because of its high specific heat capacity(Wang, Zhan and Ouyang, 2019).The cooling intensity follows a pattern: blue-green spaces> blue spaces> green spaces. Divergent spatial configurations may produce varying cooling effects. Areas with high-density, high-intensity development cannot substantially expand blue-green spaces. Therefore, rational planning of blue-green space patterns becomes particularly crucial for these regions.

Past studies have shown that there are climatic zone differences between cooling intensity and cooling potential in urban blue-green space. The cooling range of blue-green spaces during spring daytime in Nanjing, China is 0.2 ° C(Yao et al., 2023), sometimes reaching 11.18 ° C(Lin et al., 2023).The temperature drop in Nanjing during autumn is 0.0 ℃(Yao et al., 2023) . Erzurum, Türkiye, experienced 0.02 ℃ heating in winter(Dursun and Yavaş, 2024). Similarly, there are climate background differences in the cooling efficiency threshold (TVoE) between water bodies and green spaces. Research has shown that the TVoE of water bodies in Copenhagen, Denmark is 0.69 ha. The TVoE of green spaces is 1.12 ha (Yang et al., 2020).Le found that green space TVoE in tropical cities (Hanoi) was 1 hectare(Le, Cao and Tran, 2019). Yang found that TVoE of Copenhagen's green spaces is 0.69 hectares. TVoE is highly correlated with the local climate background(Yang et al., 2020).Therefore, the conclusions of subtropical region research can’t be directly applied. Therefore, it is very important to clarify the difference and mechanism of urban blue-green spatial form on UHI in different climate zones. Can deepen the scientific understanding of UHI and global climate change.

A bibliometric review was conducted on the mitigation of urban blue-green space induced urban heat island (UHI) from 1989 to 2025. Utilize Citespace to conduct knowledge graph visualization research on research features, hotspots, and trend frontiers. Further incorporate climate zone differences into literature analysis and classify and summarize them. Evaluate the differences in cooling intensity, cooling efficiency threshold, and influencing factors between blue-green spaces in different climate zones. Intended to ensure the application of nature based solutions tailored to local conditions, achieving a transition from theoretical validation to refined urban management.

## 2. Methodology

### 2.1. Scope

Firstly, the scope of literature search review from 1989 to 2025 was determined. The Netherlands and other countries began to formulate the earliest national climate change strategies in 1989 under the background of global warming. 1989 is called the "first year of policy" for global climate governance. Up to now, the research on urban thermal environment can be divided into three stages. In the first stage, from 1989 to 2003, people's understanding of urban thermal environment focused on two research clusters: urban thermal identification and impact assessment and thermal health and adaptation. It was not until the extreme high temperature event in Europe in 2003 that the research entered the second stage from 2003 to 2015. The research on urban thermal environment has evolved into three clusters,

namely, heat island and microclimate, climate-related health impacts and solutions, and temperature changes driven by urbanization(Emmanuel and Fernand, 2007; Hunter et al., 2015).The third stage of climate research began after the Paris Climate Agreement in 2015.The number of research clusters has been expanded to four, adding strategies and technologies for urban heat reduction.

The international bibliographic database of the core collection of Web of Science from 1989 to 2025 was searched. Literature quantitative review on mitigation of UHI in urban blue-green space is made. The search is based on the following standard: (1) Area; (2) Blue-green space; (3) Function. Complete search queries for each search term category are shown in Table 1. A total of 5024 related studies were obtained after streamlining the literature topics. Exclusion standards include: health, medical care, energy and other unrelated fields, unable to obtain full-text literature, repeated publication of literature. 4693 articles were excluded after checking the literature. Inclusion criteria include: urban heat-related research, involving blue-green space, and research carried out in urban planning and other related fields. Finally, a total of 331 articles were selected for analysis.

| Search term category | Term |
|---|---|
| Area | Urban, city, neighborhood , cities, union |
| Blue-green spaces | blue-green area,blue-green, blue infrastructure, green infrastructure, blue space, green space, urban lake, forest, park, green vegetation, urban river, surface water, water area, water body |
| Function | Cool, adapt, mitigate, cooling effect, cool island, heat island, UHI mitigation, heat mitigation, heat adaptation |

**Table 1. Structure of the search query used for literature analysis. Source: Author's compilation**

## 2.2. Bibliometric analysis and co-occurrence analysis

CiteSpace is one of the primary tools for scientific visualization and analysis(Chen, Dubin and Kim, 2014).The screened literature was imported into CiteSpace 6.3.1 for bibliometric analysis. Identify the core research content of the research field, analyze the annual trend of publication volume and citations, and conduct collaborative network analysis on the country. Finally, keyword co-occurrence and clustering, as well as highlighting hot words analysis, are conducted to identify hotspots and trends. To further investigate the specific methods and conclusions of each research topic, the literature will be classified into five climate zones, and expert inductive analysis methods will be used to capture the details of relevant research (Figure 1).The climate classification employs the internationally recognized Köppen climate classification system, which categorizes regions into five major types based on temperature and precipitation patterns: equatorial(A type), arid(B type), warm temperate(C type),snow(D type), and polar(E type), as illustrated in Table 2. Research inductive analysis is carried out according to the following ideas: (1) The overall characteristics of the research, the change of the published quantity, and the source area of the literature; (2) The research hotspots, trends and achievements in different climatic zones are summarized; (3) Clarify the differences in cooling intensity, cooling efficiency threshold, and influencing factors among different climate zones, and summarize the adaptive rules.

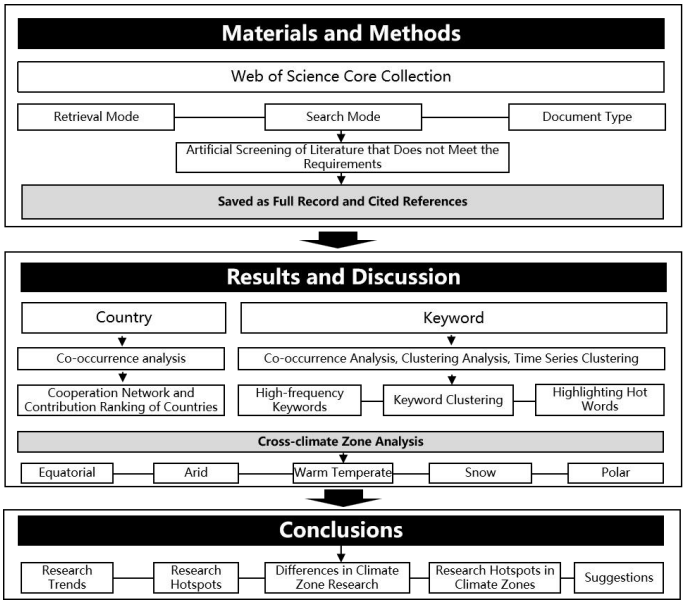



**Figure 1. Research framework.Source: Author's own illustration.**

| | Climate type | Climate type classification criteria |
|---|---|---|
| A | Equatorial | The average temperature of all months is higher than 18°C and the precipitation is abundant. |
| B | Arid | Precipitation is less than evaporation, including desert and grassland climates. |
| C | Warm temperate | The coldest month has an average temperature between-3°C and 18°C, and the four seasons are distinct. |
| D | Snow | The coldest month has an average temperature below -3℃. The warmest month has an average temperature above 10℃. |
| E | Polar | The average temperature of all months is below 10°C, and it is cold all year round. |

**Table 2. Köppen climate classification and classification criteria. Source: (Kottek et al., 2006)**

## 3. Discussion

### 3.1. Research overall feature analysis

（1）Annual publication volume and citation trend analysis

After literature screening, the earliest literature that meets the search requirements was published in 1998. In the first stage from 1998 to 2003, research focused more on urban thermal identification and thermal environment status, and there was only one relevant literature on the cooling effect of urban blue-green spaces. In the second critical stage of climate research from 2003 to 2015, the understanding and cognition of urban form on urban thermal environment gradually increased(Emmanuel and Fernand, 2007; Hunter et al., 2015). There are a total of 24 articles related to blue-green space, with 408 citations. After the 2015 Paris Climate Agreement, entering the third phase, the number of published papers on the cooling effect of urban blue-green spaces has increased year by year, and the mitigation of urban overheating has gradually evolved into a separate research cluster(Li and Wang, 2021; Wang, 2021). At this stage, the number of articles published increased to 320, with 7511 citations and an average of 23.47 citations per article(Figure 2). The total number of citations has been increasing year by year. This indicates that the research achievements in this field have been increasingly recognized and referenced

by scholars at this stage, and their influence continues to expand. The research field has entered an active period.

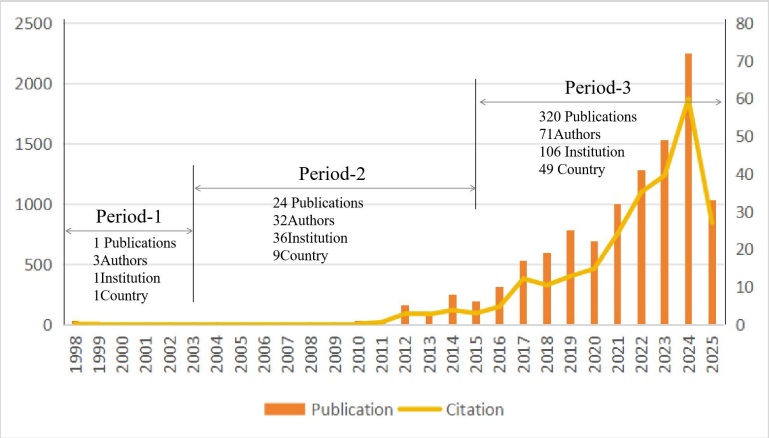



**Figure 2. Trends in annual publications and citation counts of research on cooling in urban blue-green spaces. Source: Author's own illustration.**

（2） National contribution and collaborative network analysis

By leveraging CiteSpace6.3.1 to analyze national contribution networks, we can gain a more comprehensive understanding of global patterns in academic collaboration and research dissemination. Figure 3 shows the top ten countries in publishing volume, with China, the United States, Britain, Germany, Japan and other countries as the largest number. The proportion of publications in China is 69.18%, with 229 articles. The United States accounts for 12.99%, with a total of 43 articles. China is in a stage of rapid urbanization, and changes in land use patterns are affecting urban surface temperature, leading to prominent issues. In Japan, understanding the development of national urban heat islands is beneficial for rational planning of urban density to control and regulate urban sprawl. The United States, the United Kingdom, and Singapore are mainly related to research on climate change and heat related health impacts.Germany, South Korea and other regions pay more attention to urban biometeorology and climatology, cooling of green plants, and cooling of green infrastructure. Different countries have unique climate background and social needs. There is a preference for research according to local conditions.




| Nation | Number of Published Papers | Proportion |
|---|---|---|
| CHINA | 229 | 69% |
| USA | 43 | 13% |
| ENGLAND | 20 | 6% |
| GERMANY | 15 | 4% |
| JAPAN | 13 | 4% |
| INDIA | 11 | 3% |
| SINGAPORE | 9 | 3% |
| SOUTH KOREA | 8 | 2% |
| DENMARK | 8 | 2% |
| AUSTRALIA | 7 | 2% |

**Figure 3. Top 10 countries with national cooperation networks and centrality. Source: Author's own illustration.**

（3） Research hotspot and research trend analysis

This study makes a cluster analysis of the high-frequency keywords in the literature. The outstanding emerging topics in the research field are further identified, as shown in Figure 4. In keyword clustering analysis, there are 10 categories. It reflects many research directions and categories. The current research mainly focuses on urban parks and different urban functional areas. Emphasis is placed on the cooling effect of blue-green space at the level of urban morphology. As well as research on blue-green infrastructure, green roofs, cooling materials.

By analyzing the emerging topics, 15 popular keywords were identified in two different periods. During 2011-2016, prominent terms included 'vegetation', 'intensity', 'landscape pattern', 'energy', 'configuration', and 'model'. During 2016-2023, the research focus changed to 'green space', 'remote sensing', 'design', 'dynamics', 'trees', 'indicators', and 'form'. The first stage emphasizes the mitigation of high temperature by shading with green vegetation, cooling materials and saving energy. Second stage began to explore how urban green space and spatial form affect UHI. Meanwhile, remote sensing has become the main research tool. Thermal infrared radiation transmission method has been widely used to identify urban LST and its changes. (Zhu *et al.*, 2025).

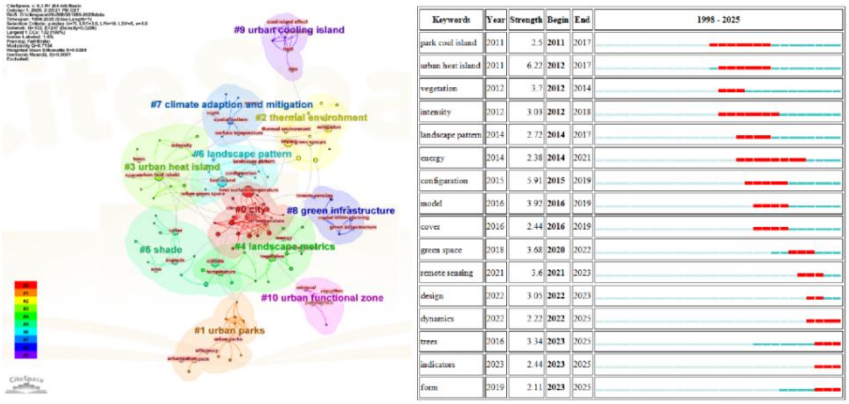



**Figure 4. Cluster analysis of keywords and analysis of emerging topics in research fields. Source: Author's own illustration.**

## 3.2. Characteristics and hotspot analysis of different climatic zones

The research history and present situation of natural-based solutions to alleviate UHI are understood through bibliometric analysis. However, the climate has regional differences. The literature is further divided into different climatic zones. To carry out the analysis of climate difference. Observing the research hotspots, characteristics and future development trends in different climate zones. Comprehensive understanding of the global warming background, the problems faced by different climate zones, and research strategies. 46 review literatures were excluded from 331 literatures. Class C research accounts for 66%. The proportion of Class D is 21%, Class A is 9%, and Class B is 4%.

Class A main research areas are Indonesia, India and Brazil. The areas usually face rapid urbanization, high population density and hot and humid climate. The main research goal is to alleviate UHI in urban blue-green space and provide comfortable climate environment. Research focuses on quantifying the cooling effect of blue-green space, efficient cooling strategy.

Class B main research areas are Saudi Arabia and Phoenix, Arizona, USA. Research in arid areas is constrained by the scarcity of water resources, which is different from that in other climate areas. It pays more attention to how the spatial structure affects the function of blue-green space to alleviate urban

high temperature. Energy balance perspective often appears in the research. The physical mechanism of urban heat is deeply discussed.

Class C main research areas are East Asia and Europe. Its published amount is far more than that of other climate zones. They pay more attention to small-scale parks, living quarters and urban streets. Improvement of human settlement environment and life experience of urban residents are the focus of research. Besides, it also includes urbanization and the cooling phenomenon of blue-green space. As well as the influence of landscape pattern on the cooling effect and the simulation prediction and evaluation of the future.

Class D main research areas are northeast cities in China and high-latitude cities such as Gothenburg, Sweden. Research has typical multi-season characteristics. The difference of temperature regulation function in blue-green space in different seasons is emphasized. The cold season in the frigid zone accounts for a long time in a year. Studying only the cooling effect of blue-green space in hot season is not enough to cover and alleviate the demand of UHI in the study area. The multi-year urban heat island evolution and the inter-annual difference of blue-green space cooling effect are also discussed.

### 3.3. The difference of cooling intensity

Blue-green space of Class A generally shows strong cooling intensity. The related research in Bangkok shows that the maximum intensity of urban cold island can reach 4.83 °C and Kolkata 8.07 C(Li et al., 2022).Blue-green space in Gopalpur, Rajasthan, India can be cooled by 4 ~ 6 ℃ compared with the adjacent hot spots(Mitra et al., 2025).In the average cooling value, the average cooling range of the blue-green space in Manila, Philippines is 3. 1℃. The high temperature and high humidity environment will hinder the evapotranspiration rate of plants and water when the air humidity is high. The average cooling intensity within 3ha in summer in Hainan is-0.7 C (Zhou et al., 2023).

Cooling intensity of Class B blue-green space is greatly influenced by air humidity(Middel et al., 2012). For instance, there are great differences in cooling intensity between Cairo and Giza provinces in Egypt, such as agricultural areas (3.3 °C), parks (4.4 °C) and rivers (12.2 °C) (Abd-Elmabod et al., 2024). Moreover, water resources and green space are scarce in arid climate areas. Thus, the optimal spatial layout of green space to achieve efficient cooling potential is the focus of research. A study in Phoenix, Arizona shows that adding new green space can reduce the LST by about 1 ~ 2 C. Decentralized mode can produce greater regional cooling. Other studies have pointed out that the increase of vegetation coverage will also lead to the increase of municipal water consumption, which contradicts the long-term sustainability goal(Chao Fan., Soe W. Myint., and Baojuan Zheng., 2015).Therefore, the related research in arid areas still needs further discussion.

Class C cooling intensity is obviously affected by seasons. The daytime temperature drop in Tokyo, Japan is about 2 ~ 1.2 ℃ in summer(Sugawara et al., 2016).The difference between the blue-green space in Paraná state in southern Brazil and other regions is about 2.0 °C(Créso, Conor and Patricia, 2019). Average cooling range of Fuzhou throughout the year is 0.81℃, 1.67℃, 0.63℃ and-0.13℃ (Yao et al., 2022). Some areas, there is a warming phenomenon in winter. Studies in coastal cities in Italy show that water bodies get cold in summer and may get warm in different streets in winter.

Seasonal differences in the climate zone of Class D frigid zone are more obvious. Cooling intensity of Tianjin waterfront compound greening in summer is 2.2 ~ 0.6 C. Average summer cooling in Beijing is 1.1℃. In Copenhagen, the research shows that the ΔLST in summer is always positive, while in spring and

autumn, especially in winter, some blue-green spaces are negative (Yang et al., 2020). On the other hand, the average cooling intensity in erzurum is 5.0℃ in summer and -0.02℃ in winter, which also shows a warming phenomenon(Dursun and Yavaş, 2024).

Research show that Class A climate zone has a strong cooling effect due to persistent vegetation and high evapotranspiration. With the latitude rising and the climate getting colder, the cooling intensity gradually weakens. Average cooling intensity of blue-green space presents the pattern of A> C > D (Table 3). The cooling intensity in class B climate zone is greatly influenced by air humidity and other related factors.

### 3.4. Cooling efficiency threshold and cooling distance difference

Analysis from the perspective of threshold. According to the study of Class A climate zone, the TVoE of Hanoi greenland is 1 ha(Le, Cao and Tran, 2019). TVoE is 0. 37 ha in Dhaka, 0. 77 ha in Kolkata and 0. 42 ha in Bangkok. TVoE in Hong Kong, Jakarta, Mumbai and Singapore is about 0.6-0.62ha(Yu et al., 2019). . Class B has little research on threshold. With class C temperate climate, the TVoE area of Fuzhou is 4.55ha. In Shanghai, the absolute threshold of cooling efficiency is 4.0ha. Serbian threshold is about 3ha. Taipei 3ha(Jaganmohan et al., 2016). For Class D climate zone, the absolute threshold of cooling efficiency of blue-green space in Beijing is 5.9 ha. TVoE of Copenhagen water body is 1.12 hectares. A-class climate zone's blue-green space can reach the threshold of refrigeration efficiency through a smaller area than other climate zones. Overall, it presents the pattern of D, C > A (Table 3). It is not absolute, however, the efficiency threshold has a complicated relationship with the climate and environment. Research laws of cooling efficiency and TVoE in urban blue-green space still need to be fully studied.

Analysis from the angle of cooling distance. For Class A climate zone, Aman Gupta and other scholars have studied that the cooling distance of the blue-green space in Kolkata is about 250m(Gupta and De, 2025). Bangkok is 300 m, Calcutta is 420 m. In Pune, India, the research reached 350 m. In class B climate research, the maximum cooling distance in Phoenix Arizona is about 200m(Chao Fan., Soe W. Myint., and Baojuan Zheng., 2015). Egypt's cairo province is about 240m(Abd-Elmabod et al., 2024). For class C climate research, the cooling distance of water and vegetation in Shenzhen is about 200 m and 100m respectively 100 m (Wu et al., 2020). Wind direction is considered in the study of Tokyo, Japan. The cooling air in the park depends on the downwind side, and the cooling distance is 450 m greater than 65 m on the upwind side(Sugawara et al., 2016).Among the Class D climate studies, the cooling distance in a study in Beijing can reach 550 m(Khan and Li, 2024).The average cooling distance of lake greening space in Copenhagen is 150 m(Yang et al., 2024). Overall, compared with other climate zones, Class A has a larger cooling distance in a certain area of blue-green space. The pattern of D and C < A is presented (Table 3). But the cooling distance may be more influenced by the external environment such as wind direction, and it still needs further exploration.

| Type | Characteristics | Cooling intensity | TVoE | Cooling distance |
|---|---|---|---|---|
| A | High temperature mitigation strategy | Average cooling 2 ℃ ~10℃ | Average 0~1ha | Average 200m~400m |
| B | How to cool down efficiently | Cooling effect is affected by humidity | Less research | Average 100m~300m |
| C | Microclimate and Residents' Comfort | Average cooling 2℃~8℃ | Average 0~6ha | Average 100m~200m |
| D | Difference between day and night and seasonal cooling | Average cooling 1 ℃ ~3; Partial warming in winter | Average 1~6ha | Average 100m~200m |

**Table 3. Structure of the search query used for literature analysis. Source: Author's compilation**

### 3.5. Planning strategy of climate adaptability

The results show that cooling effect of blue-green space is different in climate zone. Compared with the blue space, the cooling effect of green space is more obvious in different climate zones. Perhaps the reason is that there are differences in soil and plant habits caused by climate in different regions. Specific scientific's principle still needs further study. Blue-green space in Class A climate zone has the characteristics of high cooling intensity, long cooling distance and low TVoE. As the air humidity is high, these advantages will be obviously weakened. The layout planning of small area, multiple distribution and ensuring urban ventilation can maximize the cooling effect of blue-green space. Increasing greenland and briefly creating arid landscape can not completely alleviate UHI in B climate zone. The increase in green spaces in desert cities will lead to an increase in water resource consumption. Optimizing vegetation spatial patterns and adopting water-saving shrubs and fog collection systems can be considered as alternative strategies to regulate the local climate. Based on its distinct seasonal differences, the C climate zone can optimize the coupling of seasonal vegetation configuration and tiered blue space management. D cold zone cities focus on winter high albedo surface and evergreen tree species configuration, achieving precise optimization of blue-green space scale and spatial layout, and improving resource utilization efficiency.

## 4. Conclusion

Research systematically discusses the climate zone dependence and temporal and spatial differences of the cooling effect in blue-green space. However, the research still has limitations. Literature data only comes from the core collection of Web of Science, and doesn't cover other achievements such as conference papers and monographs. These may lead to the omission of relevant results. Bibliometric methods can not reveal the specific conclusions or quality of research findings in depth. Subsequent verification should be combined with content analysis. Research reveals the differences of temperature regulation and change characteristics in blue-green space in different climatic zones. Further reveal its changing law. The research is helpful for urban managers to understand the regional and seasonal differences of cooling effect in blue-green space. The management policies for UHI mitigation in different regions will be further formulated or adjusted. Strategies to alleviate UHI by developing green space and water areas according to local conditions. The purpose of this research is to deepen the understanding of urban climate and provide insights for feasible climate adaptation planning policies.

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