Impact of Green Space Layout Patterns in Pocket Parks on Thermal Comfort

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Abstract Pocket parks play a positive role in enhancing the urban thermal environment and human thermal comfort. Existing research mostly emphasizes green space area, vegetation types, and the overall cooling effects of urban parks. However, investigations into the relationship between the internal green space layout pattern within pocket parks and their impact on thermal comfort remain limited. To systematically clarify the relationship between green space layout patterns and human thermal comfort, this study focused on pocket parks within the high-density urban environment of Beijing. The ENVI-met microclimate model was employed to simulate seven distinct green space layout patterns, using a permeable brick paving scenario without green space as the control. The physiological equivalent temperature (PET) was employed to assess human thermal comfort across various scenarios. The findings showed the impact of green space fragmentation degree, shape complexity, and green belt orientation on thermal comfort. It was observed that the average temperature reduction among the seven green space layout patterns was relatively small overall. Altering the green space layout alone proved insufficient to significantly decrease the overall air temperature. In contrast, PET exhibited greater sensitivity to changes in green space layout, particularly indicating a more pronounced improvement in thermal comfort at 07:00 and 18:00. Further analysis indicated that increased fragmentation, edge density, and shape complexity did not necessarily enhance thermal comfort. Instead, the continuity of green spaces, the presence of tree canopy shading, and the organization of ventilation pathways were more critical factors in improving PET. This study offers valuable insights for optimizing the green space layout of pocket parks in Beijing and informs the design of climate-adaptive strategies in high-density urban environments.

Keywords Pocket park, Green space layout pattern, Thermal comfort, Physiological equivalent temperature (PET), ENVI-met
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The ongoing expansion of urban construction land has resulted in a growing proportion of impermeable surfaces[1], thereby modifying the processes of solar radiation absorption, storage, and release by these surfaces. This alteration influences local atmospheric circulation, exacerbates the urban heat island effect, and leads to elevated urban temperatures[2-3]. These changes give rise to numerous challenges, including reduced urban thermal comfort, increased energy consumption, higher risks of air pollution, and adverse impacts on residents' health[4].

In response to the challenges posed by increasing urban temperatures, urban green spaces are widely recognized as an important strategy for mitigating heat in urban environments[5]. These green spaces can greatly reduce ambient temperatures through processes such as vegetation transpiration and shading, which decrease solar radiation[6]. However, in densely built-up areas, opportunities for creating or significantly expanding green spaces are limited[7]. Pocket parks, characterized by their small size, low construction costs, and flexible design, have emerged as an important supplement of enhancing the urban thermal environment[8]. The cooling effect of pocket parks is closely associated with their size; however, this relationship is not strictly linear but involves a specific area threshold and range of efficiency. Previous studies have shown that pocket green spaces exceeding 0.17 hm^2 can generate a noticeable local cooling effect[9], whereas the threshold for higher cooling efficiency in urban parks across various climate zones is mostly concentrated in 0.5–0.8 hm^2[10-11].

The layout pattern of green spaces is an important factor influencing the thermal environment of pocket parks, primarily characterized by the geometric shape, arrangement pattern, and spatial network of these green areas[12]. Previous research has shown that the layout pattern of green spaces significantly impacts their cooling effects. Nevertheless, the majority of existing studies have concentrated on urban green space systems[13] and large-scale urban parks[14]. Investigations into the regulatory role of internal green space layouts within small-scale pocket parks on the thermal environment, as well as the quantification of their morphological characteristics, remain comparatively limited[15-16]. The layout pattern of green spaces can be quantitatively expressed using landscape indicators, whereby the spatial distribution characteristics of green space patches are converted into comparable geometric and topological parameters[17]. In studies of the thermal environment, commonly employed landscape indicators include the landscape shape index (LSI), which quantifies the complexity of patch shapes, as well as patch density (PD) and edge density (ED), which measure the degree of fragmentation of green spaces[18]. However, discrepancies remain in the literature regarding the effects of PD and ED on the cooling capacity of green spaces[19]. Some studies indicate that increased PD and ED enhance the contact surface between green spaces and their surrounding environments, thereby improving the cooling effect[19-20]. Other research has highlighted that excessively fragmented boundaries may weaken the core cold zone within green spaces, rendering them more susceptible to heat intrusion from adjacent high-temperature built environments and consequently reducing their cooling potential[21]. This discrepancy in findings can be attributed to the challenges faced by empirical studies—often relying on remote sensing inversion or field observations—in effectively controlling confounding variables such as background climate, real-time wind speed, land use, and the three-dimensional urban morphology of surrounding areas. To address these limitations, the present study employs numerical simulation methods to isolate and examine the independent effects of green space layout on the thermal

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environment and human thermal comfort within pocket parks, while maintaining consistent control over other influencing factors.

To date, various simulation software have been developed for simulating outdoor thermal environments, including OpenFOAM[22], ANSYS Fluent[23], and ENVI-met[24]. Among these, ENVI-met was developed by Bruse and Fleer[25]. It is a three-dimensional microclimate simulation tool grounded in computational fluid dynamics (CFD) and thermodynamic principles. ENVI-met is capable of simulating energy exchange processes among buildings, vegetation, soil, and the atmosphere, and it can output key microclimatic variables such as air temperature (TA), relative humidity (RH), wind velocity (WVEL), mean radiant temperature (MRT), and solar radiation. Compared to other simulation tools, ENVI-met is particularly well-suited for small-scale urban environment studies, including neighborhoods, parks, and open spaces, and it has been widely employed in urban microclimate and thermal comfort analyses. In addition, the rise in urban temperatures obviously influences residents' outdoor activity experiences and their thermal comfort levels. To provide a more comprehensive assessment of the impact of green space layout within pocket parks on the human thermal environment, the physiological equivalent temperature (PET) was selected as the index for evaluating thermal comfort. PET, introduced by Hoppe based on the Munich Energy Balance Model for Individuals (MEMI), is defined as the air temperature (TA) at which the human body's heat exchange is in equilibrium with equivalent skin and core temperatures[26]. Previous research has demonstrated that PET has been extensively utilized in studies of thermal comfort across various urban spatial patterns, climate zones, and outdoor environments. It is frequently employed to compare the effectiveness of green space layouts, architectural patterns, and microclimate regulation strategies in enhancing human thermal comfort[27–29].

This study is grounded in extensive pocket park construction practices in Beijing. Data indicate that, as of August 2024, the city had established over 610 pocket parks[30]. Meanwhile, Beijing's relevant planning documents project that by 2030, the total number of parks of all types will exceed 1,200, increasing to 1,300 by 2035[31-32]. Given the current severe climate challenges and the large demand for park development, it is imperative to address the following questions prior to the construction of new pocket parks: Are there significant differences in the effects of various green space layout patterns on thermal comfort? Which green space layout yields the most pronounced improvement in PET? Does the shape of green space influence thermal comfort?

1 Research methods

1.1 Research objects

This study adopted Shuangyushu Park in Haidian District and its surrounding built environment as the realistic background for the ideal model (Fig.1). The area is situated within a typical high-density built-up zone, characterized by residential buildings, urban roads, pedestrian spaces, and hard pavements, thereby exemplifying the spatial attributes of pocket parks in central Beijing. Key elements of the built environment, including surrounding building heights, road widths, and pavement materials, were identified and treated as fixed background conditions. Furthermore, when determining the ideal model scale, this study comprehensively considered existing research on the area threshold for the cooling effect of pocket parks, as well as the construction size requirements in the *Pocket Park Construction Guidelines* (*Trial*) issued by the General Office of the Ministry of Housing and Urban-Rural Development of China (Table 1). Consequently, medium-sized pocket parks were selected as the focus of this research. This scale combination effectively represents the types of pocket parks commonly found in high-density urban areas and demonstrates significant cooling potential.

1.2 Construction of theoretical model for green space layout pattern

Based on the above physical model foundation, a theoretical model measuring 150 m× 150 m was developed using the SPACES module of ENVI-met, with a pocket park located at the center of the model. The park area for each scenario was fixed at 5,000 m^2, and the green space ratio was maintained at 50%. This study constructed a total of seven green space layout scenarios (Fig.2), which are described as follows: Layout 1–centralized layout; Layout 2–four-patch clustered layout; Layout 3–sixteen-patch highly dispersed layout; Layout 4–U-shaped enclosed layout; Layout 5–square-ring enclosed layout; Layout 6–north–south strip layout; and Layout 7–east–west strip layout. To ensure comparability among scenarios, the tree height was standardized at 10 m, the crown diameter at 5 m, and the grassland height at 10 cm for model construction. Based on these parameters, this study maintained constant parkland area, green space area, and surrounding built environmental conditions, while solely modifying the internal green space layout pattern to assess the impact of different layout patterns on thermal comfort.

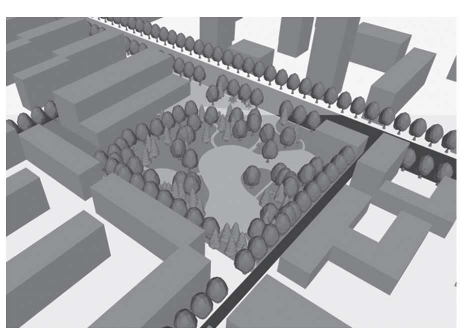


Fig.1 Model of Shuangyushu pocket park

This study concentrated on the relative differences among various green space layout scenarios rather than the absolute restoration of the thermal environment at a single real site. Accordingly, while maintaining consistency in meteorological conditions, building background, surface materials, and green space area, the non-landscaped permeable brick paving scenario was used as the control group (Fig.2). Each green space layout scenario was then compared to this control. The range of TA and PET values was calculated across different scenarios to assess the relative improvement effects of various layout patterns on human thermal comfort.

1.3 Numerical simulation and analysis

1.3.1 ENVI-met settings. To ensure that the simulation day accurately represents the high-temperature thermal pressure characteristic of summer, June 22, 2025, was selected as the simulation date for the theoretical model of a typical sunny and hot day. The simulation period spanned from 07:00 to 18:00, totaling 11 h. This study utilized ERA5-Land reanalysis data to provide the boundary meteorological conditions for the ENVI-met simulation. Apart from the meteorological boundary conditions, parameters related to soil, building materials, surface pavement, and vegetation were held constant across all scenarios. Additionally, atmospheric pressure, cloud cover, and particulate matter parameters were set to the default values provided by ENVI-met.

1.3.2 Simulated data analysis. The simulation results for seven different layouts were analyzed at three distinct time points: 7:00, 14:00, and 18:00. These time points correspond to the morning warming phase, the afternoon peak temperature period, and the evening residual heat release stage, respectively[33]. At 7:00, the study area was in the initial warming phase, characterized by weak solar radiation and an underdeveloped shading effect from vegetation. By 14:00, solar radiation intensity was relatively high, and the cooling effects of vegetation through shading and evapotranspiration were most pronounced. At 18:00, although solar radiation had substantially weakened, heat stored in surrounding buildings, roads, and hard pavements persisted, maintaining considerable pressure on the urban thermal environment. Therefore, these three time points effectively characterize the variations in thermal comfort improvement across different stages.

The cooling intensity of each scenario was evaluated by examining both the average cooling effect and the maximum cooling effect. The average cooling effect was defined as the difference in mean temperature at a height of 1.5 m between each green space scenario and the control scenario. The maximum cooling effect was determined as the difference between the lowest temperature recorded at 1.5 m within the scenario and the temperature at the same height in the control scenario, which was covered with permeable bricks.

1.4 Quantification of green space layout through landscape indicators

The green spaces in the scenario were quantified using three landscape indicators: patch density (PD), edge density (ED), and landscape shape index (LSI). PD and ED serve as key indicators for assessing the fragmentation of green spaces. Specifically, PD is defined as the number of green space patches per unit area of the landscape, whereas ED denotes the total edge length per unit area (Table 2). The LSI, developed by McGarigal and Marks (1995) based on the habitat diversity index introduced by Patton (1975), describes the complexity and compactness of patch shapes. This index is considered a significant factor influencing the park cool island (PCI) effect. Lower LSI values correspond to more compact, concentrated shapes, while higher values indicate more complex patch shapes (Table 2).

1.5 Assessment of human thermal comfort

PET was employed as the experimental indicator to assess thermal comfort in each simulation scenario. This indicator can be computed using the Biomet post-processing tool within ENVI-met by inputting relevant human parameters (such as age, gender, height, weight, static clothing insulation value, and total metabolic rate) and integrating these with simulated meteorological output values (including TA, RH, WVEL and MRT)[34]. This approach facilitates a comprehensive evaluation of the effectiveness of adaptation measures.

To accurately assess human thermal perception within various green space layout patterns, PET values can be categorized into nine distinct levels. Each level corresponds to a specific thermal sensation, ranging from “very cold” to “very hot”, as well as an associated physiological stress level, spanning from “extreme cold stress” to “extreme heat stress”. The Mayer research team conducted surveys to establish PET value intervals linked to different thermal sensations and physiological stress responses corresponding to MEMI[35] (Table 3). This PET classification framework has subsequently been applied to assessments in other cities located within the temperate continental climate zone of China[36].

2 Results and analysis

2.1 Differences in average TA and PET improvement caused by different green space layouts

From the perspective of TA indicators (Fig.3), all seven green space layouts exhibited a certain cooling effect compared to the control group. At 7:00, 14:00, and 18:00, the average TAs for each layout were reduced by approximately 0.09–0.11 °C, 0.02–0.03 °C, and 0.04–0.06 °C, respectively, relative to the control group. These findings suggest that green space layout exerts a limited regulatory influence on overall TA. Regarding extreme values, the maximum TA recorded for each layout during the three time periods were slightly lower than those observed in the control group. Specifically, at 7:00, maximum TAs decreased from 27.23 °C in the control group to a range of 27.12–27.14 °C; at 14:00, from 39.04 °C to approximately 39.01 °C; and at 18:00, from 37.28 °C to 37.25–37.26 °C. Similarly, minimum TAs exhibited slight reductions at 07:00 and 18:00.

Compared to the TA indicator, as illustrated in Figs.4–5, the PET showed greater sensitivity to variations in green space layout. At 7:00, the PET in the control group was 36.27 °C, whereas the PET values for the various green space layouts ranged from 33.24 °C to 34.40 °C, reflecting an improvement of 1.9–3.1 °C. Notably, Layout 1 and Layout 6 exhibited the greatest improvements, each approaching a 3.0 °C reduction. At 14:00, the PET of the control group reached 58.48 °C, while the PET values for the different layouts ranged between 58.17 °C and 58.20 °C, corresponding to an improvement of only 0.28–0.31 °C. This finding suggests that during the afternoon period characterized by high temperatures and intense solar radiation, the mitigating effects of the green space layouts on overall PET were limited. At 18:00, the control group’s PET was 48.81 °C, whereas the layouts yielded PET values between 45.16 °C and 46.48 °C, indicating improvements ranging from 2.32 °C to 3.64 °C. Among these, Layout 1 achieved the greatest reduction of 3.64 °C, with Layout 3 and Layout 7 also demonstrating notable improvements of 3.53 °C and 3.43 °C, respectively.

Under varying green space layout patterns, temperature variations were minimal, whereas PET exhibited significant differences. This phenomenon can be attributed to the consistent surrounding built environment, including uniform building height, road conditions, surface materials, and meteorological boundary conditions, which collectively establish a stable baseline thermal environment. Within this controlled context, differences in average, maximum, and minimum TAs across different layout patterns were relatively small, suggesting that building shading and the prevailing high-temperature background partially diminish the influence of green space layout on TA. In

Table 1 Classification of pocket park sizes and proportion of green space

Size	Area	Proportion of green space
Small-sized pocket park	400–2,000 m^2	> 35%
Medium-sized pocket park	>2,000–5,000 m^2	⩾ 50%
Large-sized pocket park	>5,000–10,000 m^2	⩾ 65%

Table 2 Description and formulas of PD, ED and LSI

Name	Definition	Calculation formula	Unit
PD	Number of green space patches per unit area	$PD=(n/A)\times10^4$ n represents the number of green space patches, and A denotes the total area of the scenario (m^2).	number/hm^2
ED	Total edge length per unit area	$ED=(\sum_{i=1}^{n} e_i/A)\times10{,}000$ e_i represents the total edge length of green spaces (m), and A denotes the total area of the scenario (m^2).	m/hm^2
LSI	Complexity of the patch’s overall shape (when the patch is a perfect circle, LSI=1; higher LSI values indicate increasingly irregular and elongated patch shapes)	$LSI=P_t/2\sqrt{\pi X A}$ P_t represents the total perimeter, and A denotes the total area.	–

contrast, PET, as a comprehensive thermal comfort indicator, is influenced by multiple factors such as TA, WVEL, RH, and MRT. Consequently, PET is more responsive to variations in tree canopy shading, solar radiation exposure, and human thermal perception. Therefore, despite limited TA fluctuations, distinct green space layouts can still produce notable differences in PET.

2.2 Impact of PD and ED on thermal comfort

Layouts 1-3 of green space exhibited varying PD and ED. As the number of patches increased from 1 to 16, PD rose from 2 to 32 patches/hm^2, while ED increased from 400 to 1,600 m/hm^2 (Table 4). These three layouts represent a gradient from low to high fragmentation, providing a framework to analyze the impact of green space PD and ED on thermal comfort.

From the perspective of TA (Fig.3), changes in local minimum TA were relatively small, suggesting that PD and ED exert limited influence on extreme TA values. In contrast, the magnitude of improvement in PET was more pronounced. As illustrated by the bar chart depicting PET improvement amplitudes (Fig.6), Layout 1 exhibited improvements of 2.97 °C, 0.28 °C, and 3.64 °C at 7:00, 14:00, and 18:00, respectively, demonstrating the most favorable overall performance. Layout 2 showed improvements of 2.23 °C, 0.30 °C, and 2.96 °C at the corresponding time periods, indicating a comparatively weaker effect. Layout 3 recorded improvements of 2.50 °C, 0.31 °C, and 3.53 °C, which were slightly higher than those of Layout 2 but remained slightly lower than Layout 1 overall. These findings suggest that simply increasing PD and ED does not necessarily result in a continuous enhancement of thermal comfort. Furthermore, the influence of PD and ED on thermal comfort appears to be more closely associated with factors such as shading, radiation exposure, and alterations in human thermal perception, rather than a significant reduction in TA (Fig.7).

2.3 Effects of green space LSI on thermal comfort

To analyze the impact of green space LSI on thermal comfort, this study selected Layouts 1, 4, and 5 for comparative analysis. All three layouts consisted of continuous green patches with identical PD but varied in morphological complexity (Table 5).

Compared to the control group, an increase in LSI did not correspond to a greater enhancement in thermal comfort. The PET improvement magnitudes for Layout 1 at 7:00, 14:00, and 18:00 were 2.97 °C, 0.28 °C, and 3.64 °C, respectively, demonstrating the best overall performance. In contrast, Layout 4 exhibited improvements of 2.38 °C, 0.29 °C, and 2.32 °C, while Layout 5 showed improvements of 1.87 °C, 0.28 °C, and 2.41 °C at the same time points. These results indicate that although Layout 4 and Layout 5 had higher LSI values than Layout 1, their PET improvement effects were comparatively weaker, particularly at 18:00, where the difference was more pronounced (Fig.8).

Existing studies indicate that the LSI can characterize the shape complexity of green spaces and may affect their cold island effect[37-38]. However, some research has demonstrated that the impact of shape complexity on cooling effects is not consistently positive. For example, certain studies have found that as the shape complexity of green spaces increases, their cooling distance may decrease. Additionally, morphological indicators of green spaces may exhibit varied or even contradictory effects at different scales and in different spatial backgrounds[39-40].

The research demonstrated that in small-scale pocket parks, U-shaped and square-enclosed layout with higher LSI did not yield superior improvements in PET. This outcome is attributed to the fact that, although the enclosed green spaces increased boundary length, the hard surfaces within these areas remained exposed to intense solar radiation. Additionally, the enclosed configurations impeded local air circulation, resulting in heat retention within the space. Conversely, Layout 1, despite having the lowest LSI, exhibited greater spatial continuity of green space and more continuous tree-canopy shading, facilitating the formation of stable shaded areas and a cooling core (Fig.9).

3 Effect of green space layout orientation on thermal comfort

Both Layout 6 and Layout 7 consisted of four strip-shaped green spaces. The number of patches and the total area of the green spaces remained constant; the primary difference lay in the orientation of the green belts. As illustrated by the WVEL distribution map (Fig.10), Layout 6 established a relatively continuous north-south ventilation corridor through the center of the park, exhibiting a coherent WVEL pattern. This suggests that, under the prevailing wind conditions considered in this study, a north-south oriented green belt is more conducive to forming smooth airflow channels, thereby mitigating heat retention in the park's central area. Conversely, the east-west oriented green belt in Layout 7 altered the airflow organization to some extent. The continuity of WVEL in the park's center was comparatively weaker, with zones of higher WVEL concentrated near building edges and localized openings. These findings indicate that the ventilation enhancement effect of Layout 7 on the central space is less pronounced than that observed in Layout 6.

From the perspective of thermal comfort,

Table 3 PET intervals corresponding to different levels of thermal sensation and physiological stress

PET//℃	Thermal sensation	Physiological stress
<4	Very cold	Extreme cold stress
4–8	Cold	Strong cold stress
8–13	Cool	Moderate cold stress
13–18	Slightly cool	Slight cold stress
18–23	Neutral	No thermal stress
23–29	Slightly warm	Slight heat stress
29–35	Warm	Moderate heat stress
35–41	Hot	Strong heat stress
>41	Very hot	Extreme heat stress

Table 4 PD and ED in Layouts 1–3

Name	Layout 1	Layout 2	Layout 3
PD	2	8	32
ED	400	800	1,600

Table 5 PD and LSI of Layouts 1, 4, and 5

Name	Layout 1	Layout 4	Layout 5
PD	2	2	2
LSI	1	1.76	2.08

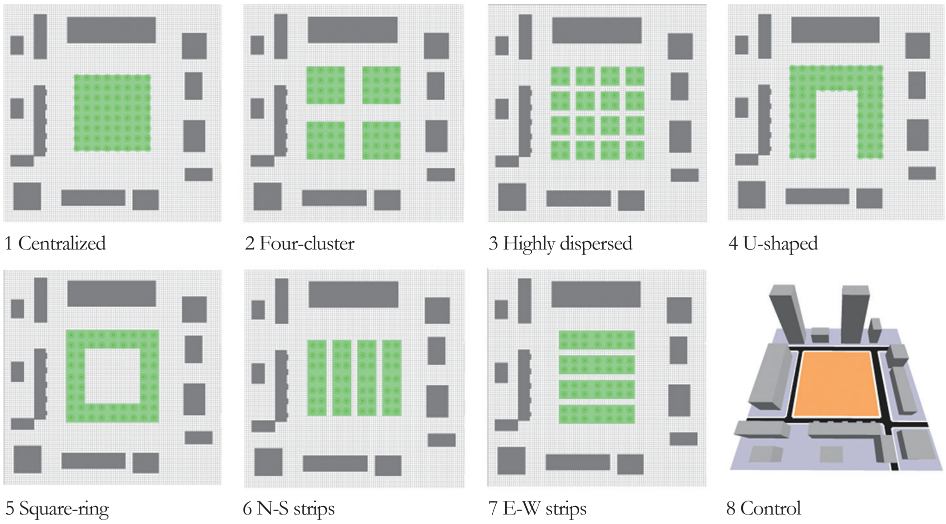


Fig.2 Green space layout of theoretical model and the control model

both Layout 6 and Layout 7 demonstrated significant improvements at 07:00 and 18:00 compared to the control group, with PET reductions relative to the control ranged from 2.48 °C to 3.43 °C. Furthermore, the north-south orientation exhibited greater improvements than the east-west orientation, consistent with the characteristic of the north-south green belt forming a continuous ventilation channel in the WVEL map. This finding suggests that enhanced airflow, combined with tree canopy shading, can effectively reduce the human perception of heat exposure. However, at 14:00, the improvements in PET for both Layout 6 and Layout 7 were modest and identical, at 0.29 °C. This indicates that under conditions of strong solar radiation and high afternoon temperatures, the influence

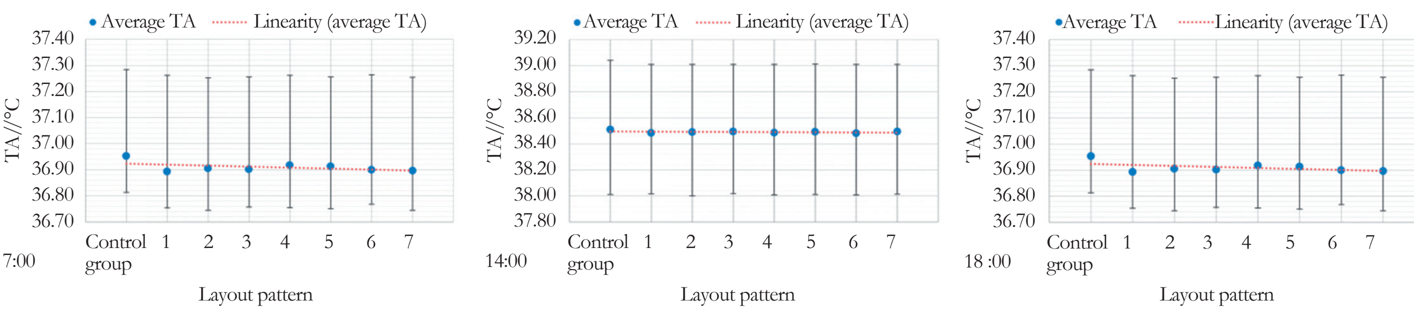


Fig.3 Range and average value of TA changes at 7:00, 14:00, and 18:00

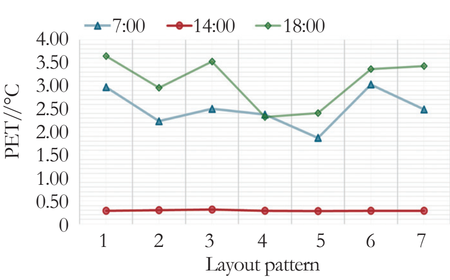


Fig.4 Differences in PET between different layout patterns and the control group

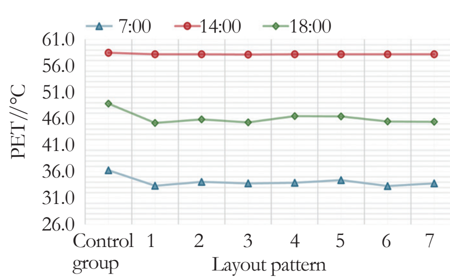


Fig.5 Average PET values of the seven layout patterns at 7:00, 14:00, and 18:00

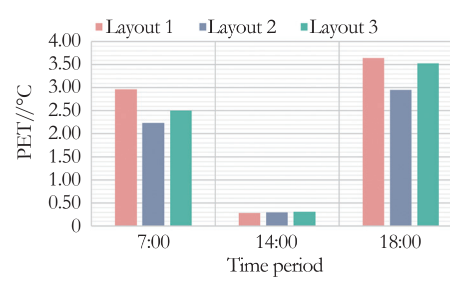


Fig.6 Difference in PET between Layouts 1–3 and the control group

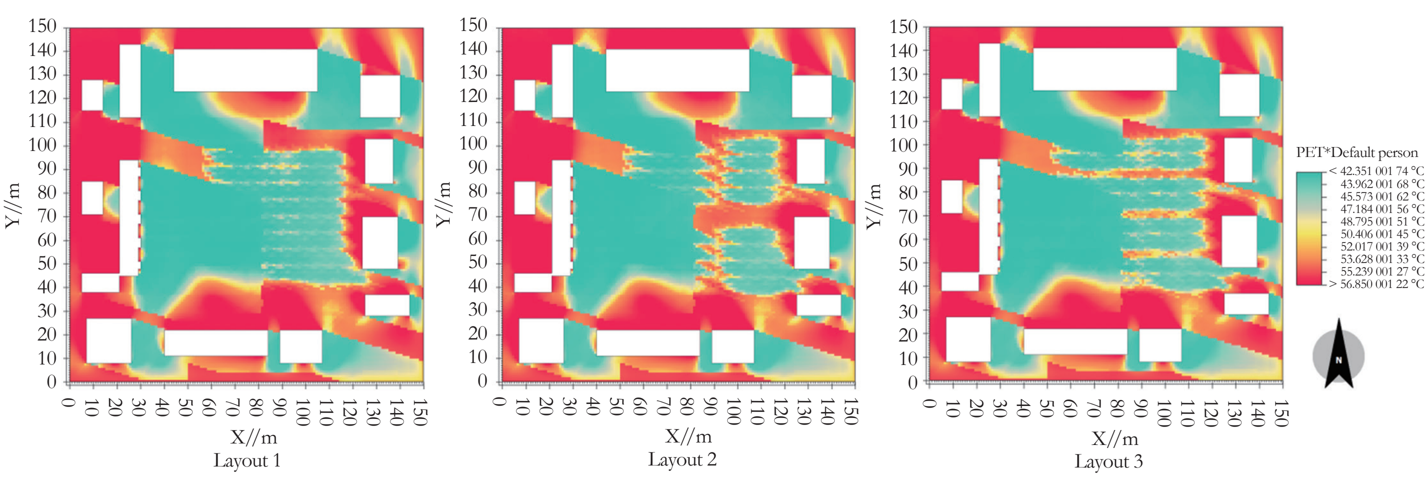


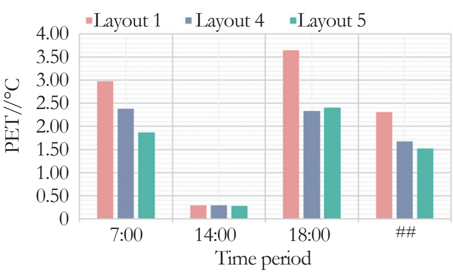
Fig.7 Simulated PET spatial distribution of Layouts 1–3 at 18:00

of green space orientation on overall PET is diminished.

4 Conclusions

In response to the construction requirements of numerous pocket parks in Beijing, this study developed an idealized model using ENVI-met. By maintaining consistent park area, green space area, vegetation parameters, surrounding built environment, and meteorological conditions, the study compared the effects of seven distinct green space layout patterns on TA and PET thermal comfort. The findings indicated that variations in green space layout patterns had a generally small impact on average TA. Specifically, the average TA reductions observed at 7:00, 14:00, and 18:00 were marginal across all layouts, suggesting that altering green space layout alone is insufficient to significantly decrease overall TA. Conversely, PET demonstrated greater sensitivity to changes in green space layout patterns, with notable improvements in thermal comfort observed at 7:00 and 18:00. These results imply that green space layout primarily enhances human thermal comfort by providing shading, reducing radiation exposure, and improving ventilation.

From the perspective of specific spatial configurations, Layout 1 (the centralized layout) and Layout 6 (the north–south strip layout) demonstrated relatively superior overall performance. Layout 1 facilitated the formation of continuous shading and a stable cooling core, whereas Layout 6 established a relatively continuous ventilation corridor along the central axis of the park. Layout 3 (the sixteen-patch highly dispersed layout) and Layout 7 (the east–west strip layout) exhibited moderate performance. Layout 2 (the four-patch clustered layout) ranked in the middle, while Layout 4 (the U-shaped enclosed layout) and Layout 5



Note: ##.Average improvement over the three time periods.

Fig.8 Differences in PET between Layouts 1, 4, and 5 and the control group

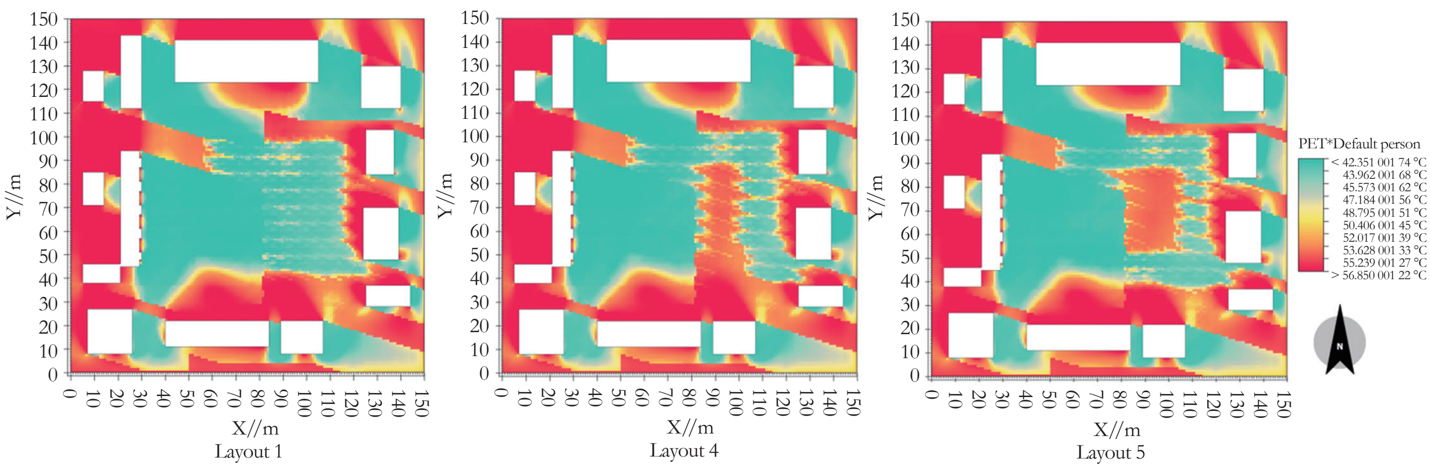


Fig.9 PET spatial distribution of Layouts 1, 4, and 5 at 18:00

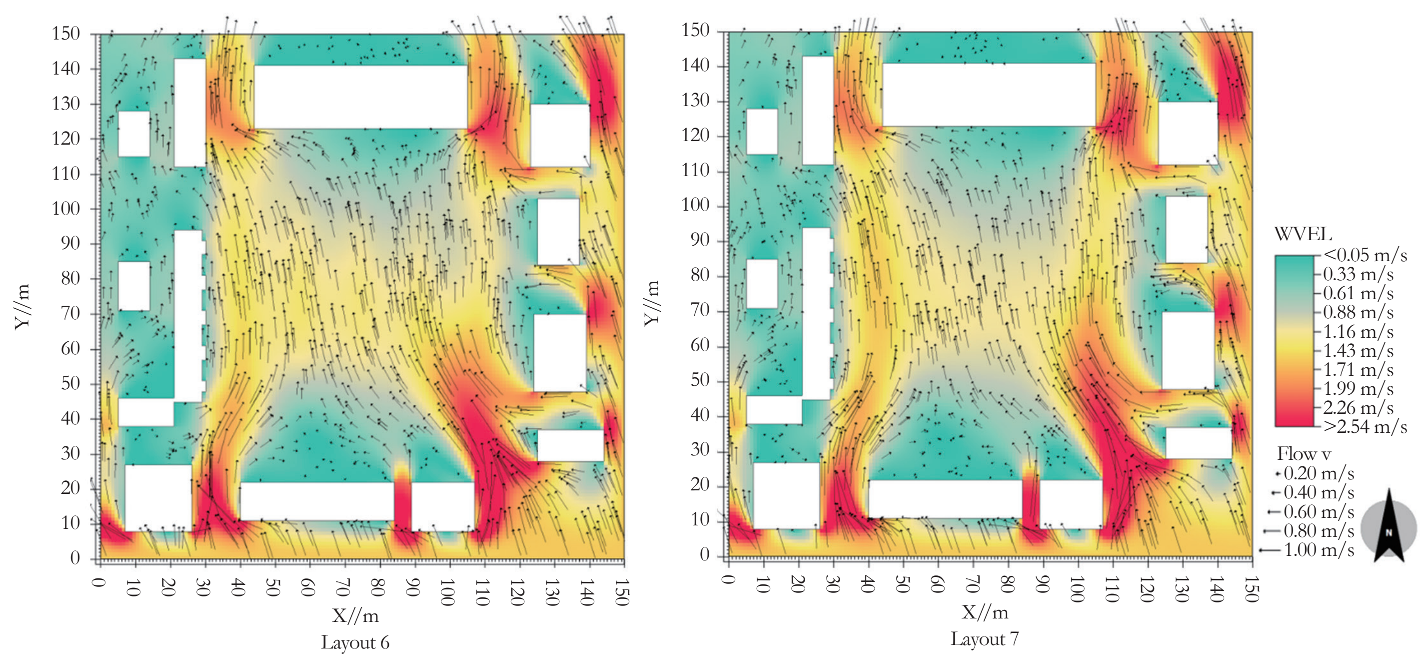


Fig.10 WVEL distribution in Layout 6 and Layout 7

(the square-ring enclosed layout) performed comparatively poorly. Further analysis of PD, ED and LSI suggests that higher values of PD, ED, and shape complexity do not necessarily correspond to improved thermal comfort. For small-scale pocket parks, optimizing green space layout should prioritize the continuity of green spaces, shading coverage provided by tree canopies, the organization of ventilation pathways, and the enhancement of thermal comfort in primary activity areas, rather than focusing solely on patch fragmentation, boundary complexity, or enclosure forms.

This study, motivated by the anticipated large-scale construction demand for pocket parks in Beijing, aims to inform the optimization of green space layouts in high-density urban areas. The findings indicate that, under constraints of limited land availability, green space design should prioritize the continuity of shading, ventilation pathways, and enhancement of thermal comfort in primary activity zones, rather than merely focusing on diverse patterns or complex boundaries. Simulation results demonstrate that a centralized layout is more effective in establishing a stable cooling core. Additionally, a north–south strip layout better facilitates ventilation pathways aligned with the prevailing wind direction observed in this study. Highly fragmented or enclosed layouts do not significantly improve the PET.

Therefore, when constructing or renovating pocket parks in Beijing, priority should be given to using green space cores with strong continuity, and strip-shaped green spaces ought to be strategically arranged in accordance with road orientations, building shadows, prevailing wind directions, and areas of human activity to enhance the thermal comfort of these limited green spaces. It is important to note that the recommendations presented in this study are primarily focused on thermal comfort. In practical design applications, other factors such as functional organization, landscape experience, plant adaptability, construction costs, and maintenance requirements must also be thoroughly considered. Future research should incorporate a greater number of actual pocket park cases and empirical data from Beijing to further validate the applicability of various green space layout patterns within real urban environments.

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connectivity system of green spaces has been optimized by opening previously closed entrances and exits, thereby integrating walking, cycling, and public transportation. These measures reduce residents' access costs to parks and comprehensively enhance the accessibility and utilization efficiency of green spaces[6].

5 Conclusions

Urban park green spaces constitute public welfare infrastructure that optimizes the living environment, enhances ecological structure, and promotes human well-being. In the context of the high-quality development phase of urbanization, the construction of urban green spaces should move away from extensive and fragmented development models. Instead, it should adhere to development principles emphasizing equity and inclusiveness, ecological priority, high efficiency and intensification, as well as systematic coordination[7]. By balancing the layout of green spaces across the region, establishing an interconnected ecological network, revitalizing existing green resources, and enhancing planning and regulatory mechanisms, efforts will focus on advancing the transformation of green space development from mere expansion in scale to improvements in quality, from localized embellishment to comprehensive coverage, and from singular landscapes to diverse and composite environments. It is essential to continuously optimize the structure of green spaces, address deficiencies in green space facilities across both new and old urban areas as well as among diverse social groups, and develop urban green spaces that are ecologically sustainable, inclusive in service provision, and efficient in operation and maintenance. Such efforts will facilitate the construction of park cities, promote harmonious coexistence between humans and nature, and achieve high-quality, coordinated development of urban ecology, society, and public well-being.

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