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The seasonal thermal environment in urban park and surrounding urban spaces: A case study in Xi’an, China

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ABSTRACT:

Urban parks are providing favorable conditions for sustainable urban planning, which is beneficial to the urban microclimate in different seasons. However, few studies have focused on the seasonal differences and comparisons between different urban spaces. In this research, air temperature, wind speed and wind direction of three seasons in the Xingqing Palace Park and its surrounding urban areas were measured in 2018. Through the analysis of air temperature, the actual seasonal thermal environment of park and surrounding urban spaces in different seasons is clarified. The temperature of high-rise building space and multi-story campus space in winter park is higher, but the temperature change of the multi-story residential building space is opposite to that of the park; the temperature difference between the inside and outside of the park is small and the fluctuation is diverse in spring; the internal temperature of park is slightly lower than the surrounding space in summer. In terms of application, surrounding urban spaces can be optimized in the future based on analysis results, so that the urban park can better exert its function by combining with the surrounding urban space, to mitigate the urban heat island (UHI) effect.

Introduction

With rapid growth of population and urban expansion, the urbanization process has led to significant modifications in the urban climate (Kalnay and Cai 2003). The most obvious feature is urban heat island (UHI), which is defined as the temperature difference measured in urban areas and surrounding rural areas (Oke 1982). As early as in 1978, this phenomenon was recognized in central business district and southern industrial district of Nagoya, Japan (Shionoya et al. 1978), which has continued to today. This phenomenon leads to the rise of temperature, which affects the outdoor thermal comfort of urban residents (Grimmond 2007).

Outdoor thermal comfort in urban area is known as an important contributor to the urban resident’s well-being. It is affected by many factors, especially urban green areas, which can be used to mitigate UHI. Urban green areas such as shrines and parks are cooler than surrounding city areas, so that climatic conditions of urban areas can be improved and environmental stress produced by heat islands can be reduced, based on these urban green areas (Shionoya et al. 1978). It can greatly improve the outdoor thermal environment, as well as mitigate UHI effect by reducing air temperature in summer (Yan et al. 2018). As an important part of urban green areas, urban parks play an active role in mitigating UHI effect and improving the thermal environment. Akbari.

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H. has found that an urban forest or park can ameliorate UHI and improve the climatic conditions of urban areas, by cooling air temperature in virtue of evapotranspiration and preventing incoming solar radiation from heating surfaces of surrounding buildings (Akbari 2002). Potchter et al. conducted a research on three different types of urban park with different greenbelt and forestland in summer in the Mediterranean city of Tel Aviv, Israel. The air temperature differences reached up to 3.51°C during the day between the built-up area and the urban park containing mature trees with a wide canopy (Potchter et al. 2006). Wong explored both the severity of UHI effect and cooling effect of green areas at the macro-level in Singapore, indicating a strong correlation between the temperature decrease and the appearance of urban parks in the city (Wong and Yu, 2005). Therefore, the urban park is an important factor to alleviate UHI effect and improve thermal environment.

However, the mitigation of UHI effect depends not only on the ecological effect of parks, but also on the diffusion of surrounding urban spaces. Howard first suggested considering the impact of urban form on microclimate (Howard 1833). In a study of Mohammad. T., the impact of different urban spatial forms, such as singular, linear and courtyard on microclimate with different comfort situations for pedestrians were demonstrated (Mohammad 2015). Steemers et al. proposed six archetypal generic urban forms for London, based on comparing the incident of solar radiation, built potential and daylight admission (Steemers et al. 1997). It is seen that the impact of urban space on the thermal environment cannot be ignored.

Similarly, in order to alleviate UHI, China’s urban green space construction has made great progress in the process of rapid urbanization (Song 2008). In China, most urban parks aim to meet the needs of urban beauty, so the construction of these parks lacks of the technical guidance for ecological function (Song and Binyi 2010). And accurate thermal comfort assessment is critical for the improvement of urban park and urban spaces (Chiru and Minghuang 2014). Therefore, it is necessary to understand the thermal environment difference between urban parks and surrounding urban space, so as to resolve environmental problems of urban sites and play the role of urban parks better.

Methodology

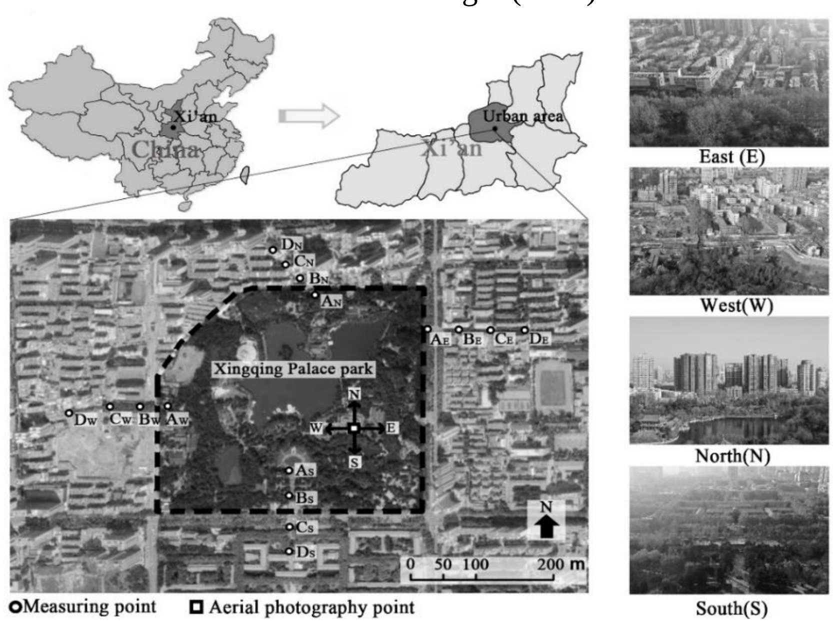
Study area

Xingqing Palace Park is the largest urban park in Xi'an, which covers an area of 520,000 square meters (including 100,000 square meters of water surface). The green area in the park is about 290,000 square meters, and the green coverage rate is up to 90% (according to Xi’an Xingqing Palace Park official website). The urban spatial forms around the park are different in spaces and functions. There are high-rise residential building spaces in the north, multi-story residential building spaces in the east, low-rise campus buildings in the south, and low-rise commercial building and multi-story residential building spaces as well as open spaces in the west (Figure 1).

Measurement

The hand-held mobile meteorological station is a portable meteorological observation instrument that is easy to carry, simple to operate, and integrates multiple meteorological elements (Figure 2). It can accurately measure five meteorological elements such as wind direction, wind speed, air pressure, air temperature and air humidity. On the top of the instrument, there are a wind vane measuring wind direction and a sensor recording wind speed. A temperature and humidity sensor in the small groove on the side of the instrument is used to record relevant values. Air temperature is the main analysis factor in this research. The measurement accuracy of instrument for air temperature is ± 0.2 °C.

According to the diversity of urban spatial forms around the park, field measurement has been carried out in this research. The measuring points are located in four directions of Xingqing Palace Park, with four measuring points in each side of the park. The distance between each measuring point is about 50 meters. A day of winter in 2017 (January 17, 2018), a day of spring (March 16, 2018) and a day of summer in 2018 (June 20, 2018) were selected for field measurement, which was conducted from 6 a.m. to 8 p.m. (9 p.m. in summer). The measurement was performed in four points per hour. Each measuring point in each direction was held for five minutes. And then, the instrument was moved to the next point at a constant speed. The measured environmental factors were recorded at the same height (1.5m).



a) Measuring point location b) Aerial photos of surrounding urban space

Figure 1. Location of Xingqing Palace Park and photos images around the park

Figure 2. Measuring point and measuring tools photos

In Figure 3, the Sky View Factor (SVF) images is listed as an auxiliary analysis of whether the measuring point is affected by the sun. In the SVF images, the visible sky range in the east and west of the park is smaller than that in the south and north of the park. One of the most visible image of the sky is the measuring point of the campus in the south, which makes the temperature affected by the sun. Moreover, the various urban parameters around each selected measuring point within 100 m are shown in Table 1.

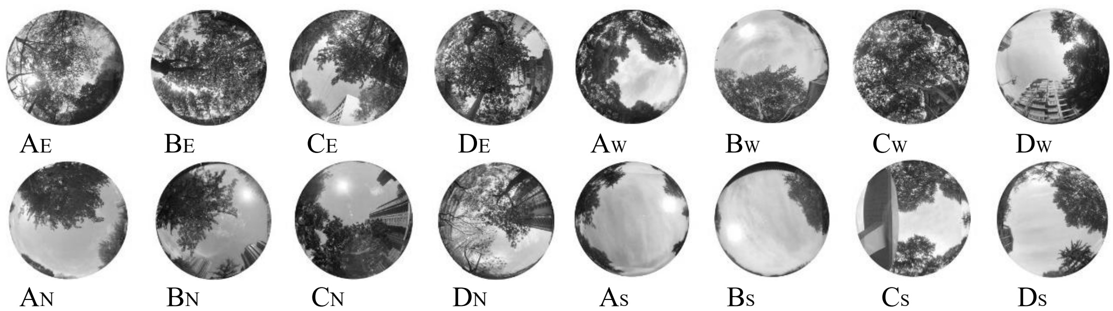


Figure 3. Sky View Factor (SVF) images of the measuring point (1.5m height)

Table 1. Detailed urban parameters within 100m around the measuring point

Direction	Measuring point	Centered on the measuring point, the radius of 100m				
		Building density	Average height of buildings(m)	Main building surface materials	Green coverage (%)	Road area ratio (%)
East	AE	0.14	18.64	Brick/Concrete	60.41	18.67
	BE	0.27	16.18	Brick/Concrete	14.74	7.96
	CE	0.26	15.92	Brick/Concrete	17.84	7.96
	DE	0.26	18.9	Brick/Concrete	22.99	7.96
West	AW	0.07	5.04	Brick	47.08	13.54
	BW	0.08	10.03	Brick	20.54	19.71
	CW	0.12	15.7	Brick/Concrete	13.37	5.73
	DW	0.22	10.82	Brick/Concrete	3.78	5.17
North	AN	0.23	15.08	Brick/Concrete	61.84	4.68
	BN	0.2	16.43	Brick/Concrete	44.62	10.76
	CN	0.15	64.76	Concrete	20.82	17.77

	DN	0.29	42.63	Concrete	9.5	10.82
South	AS	0.01	4	Brick	89.75	4.5
	BS	0.04	4	Brick	37.34	14.04
	CS	0.09	10.5	Brick	31.58	18.73
	DS	0.23	14	Brick	24.41	7.03

Source: The author organized factors according to Google Maps.

Data and analysis

Winter (January 17, 2018)

On the day of measurement, it was cloudy and foggy. The trend of air temperature changed in each measuring point of four directions can be seen from Figure 4.

In the east, the temperature at point AE is the lowest throughout the whole day. And the temperature at point BE is the highest between 11 a.m. and 5 p.m., which is up to 14.2°C at 3 p.m.. Although the SVF is high (Figure 3), the measuring points are affected by the midday sun. The same fluctuations are also visible at point Bw. All-day temperature changing trends of point CE and DE are similar. The maximum temperature difference between these two measuring points is 0.56°C (3 p.m.), and the minimum difference is only 0.03°C (10 a.m.). In addition, it can be seen from Table 1 that detailed urban parameters of the two measuring points are similar, which have an approximate impact on temperature. There is also a similar trend in the west. In the west, the temperature changes at four points before 11 a.m. are basically the same as the east. And the temperature at point AW in the park is also the lowest. The temperature trends of the other three points are similar to those in the east. But the maximum temperature at point BW (12.23°C) is lower than that of point BE (14.2°C). Although the SVF of point BW is lower (Figure 3), the green coverage is higher (Table 1). The results show that greening has a certain cooling effect on temperature. From the space of the low-rise and multi-story buildings in the east and west, the overall change is that the temperature of external park is higher than that in the internal.

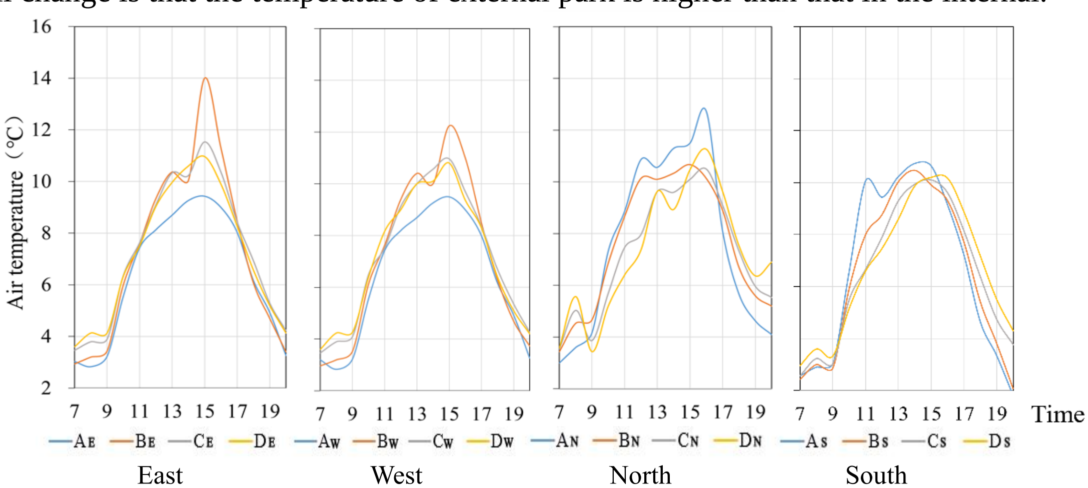


Figure 4. The temperature changes of measurement points in winter

But in the north and south, the temperature changing at the measuring points of the park is opposite to those outside the park. In the north, the building materials (Table 1) around point BN, CN and DN absorb heat during the day and release heat at night. In the south, the temperatures at point CS and DS are affected not only by the building materials, but also by trunks shadow. So, the temperature at these points are lower than other points in the park during the day. At noon, the overall temperature at point AN and AS are also higher than that of the other measured points. The highest temperature at point AS (10.74°C) is lower than that of point AN (12.73°C), because the green coverage at point AS is higher. The two points are both located on the open square inside the park. Although the green coverage rate is high, it is greatly affected by the sun.

In the surrounding urban spaces, the temperature at measuring point of the park is the lowest before sunrise and after sunset. Before 9 a.m., the temperature outside the park is higher than that inside the park. At noon, the temperature in the park is higher than that outside the park in the north and south spaces. After 5 p.m., the temperature in the park drops faster than that in the surrounding space. Although the trees are deciduous, with less shadow in winter, the shadow of trunks and branches still can affect the temperature inside and outside the park obviously. The temperature difference between the park and its surrounding area is beneficial to the local air circulation in Xi'an.

Spring (March 16, 2018)

On the day of measurement, it was sunny in the morning and became windy and cloudy in the afternoon. The changing trend of air temperature in four directions can be seen from Figure 5.

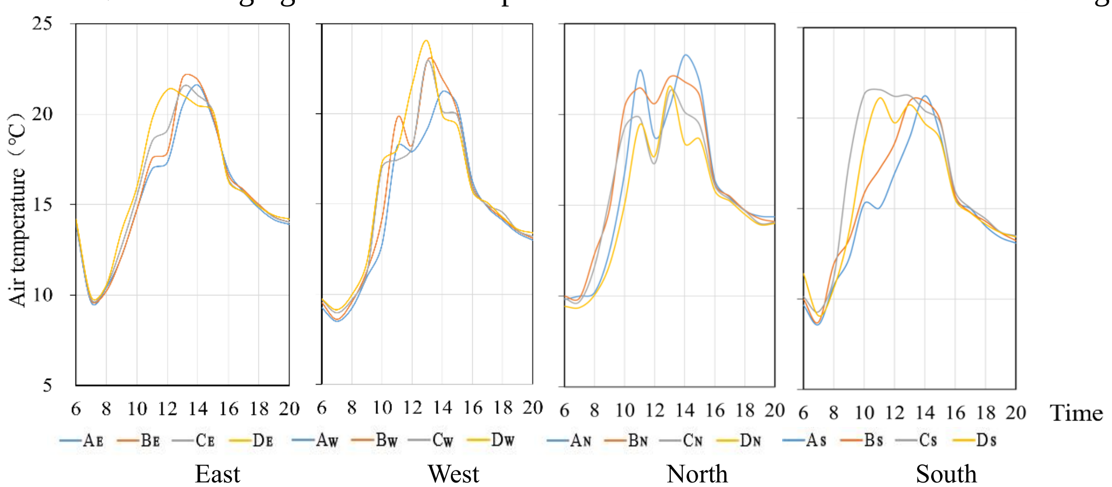


Figure 5. The temperature changes of measurement points in spring

In the east, from 8 a.m. to 1 p.m., the temperature at point AE near the park is the lowest. The changing trend at point BE and CE are similar. The maximum temperature difference between two points does not exceed 1°C. However, the temperature at point BE near the park is lower than that of point CE during this period. The SVF at point BE is higher than that of point CE (Figure 3), which can reduce the influence of sunlight. Temperature at point DE heats up fastest and may also be affected by the sun. After 2 p.m., point AE cools fastest, and the temperatures of other three points drop slightly slower due to the factors of surrounding buildings and roads (Table 1). In the west, the temperature at point AW is the lowest before 2 p.m.. The maximum difference is 4.87 °C, which appears at 1 p.m.. And then, the temperatures at point CW (from 22.93°C to 20.17°C) and DW (from 24.03°C to 19.93°C) drop quickly from 1 p.m. to 2 p.m., but the temperature at point BW falls (from 21.93°C to 20.17°C) slowly. Among them, SVF at point CW is higher (Figure 3) and the average building height at point DW is higher (Table 1), which can form shadows to block sunlight. These can have the temperature dropped. Although point BW has a high green coverage, its road area is also very large. It can be concluded that human factors play an important role in the temperature change, which suppresses the temperature reduction. After 3 p.m., the temperature changing trends at four points are similar.

While, in the north, the temperature at point DN is lowest, compared with most measurements, and the temperature fluctuation varies greatly. This is because the dominant wind direction on the day of measurement is northeast, which is very strong. Concomitantly, many high-rise residential buildings are in the north space. The wind speed direction are affected by the urban space, which has a significant impact on the temperature. Such effect can also be seen from the temperature fluctuations at four measuring points at 12 a.m.. In the south, temperatures at point AS and BS near the park rise slowly after 7 a.m., while it heats up quickly at point CS and DS. The temperature at point AS (21.26°C) and BS (21.02°C) reach the highest value at 2 p.m., while it is up to the highest value at point CS (21.12°C) and DS (21.14°C) at 11 a.m.. After 4 p.m., as the sun gradually set, the crowd activities decrease. Temperatures at point AN and AS in the park drop faster. But the temperatures at point CS and DS drop more slowly due to the influence of surrounding buildings and other factors. After 3 p.m., changing trends at four points are basically similar.

Due to the warm, windy and high wind speed in spring in Xi'an, measuring points are greatly affected by the urban space, with a great temperature fluctuation. Before sunrise and after sunset, the temperature changes in all direction are basically similar. In spring, the temperature changes inside and outside the park are affected by the urban climate. Consequently, the temperature fluctuates greatly in daytime and the temperature difference before and after sunrise is small.

Summer (June 20, 2018)

It was sunny on the day of measurement. The temperature changing trend in four directions can be seen from Figure 6.

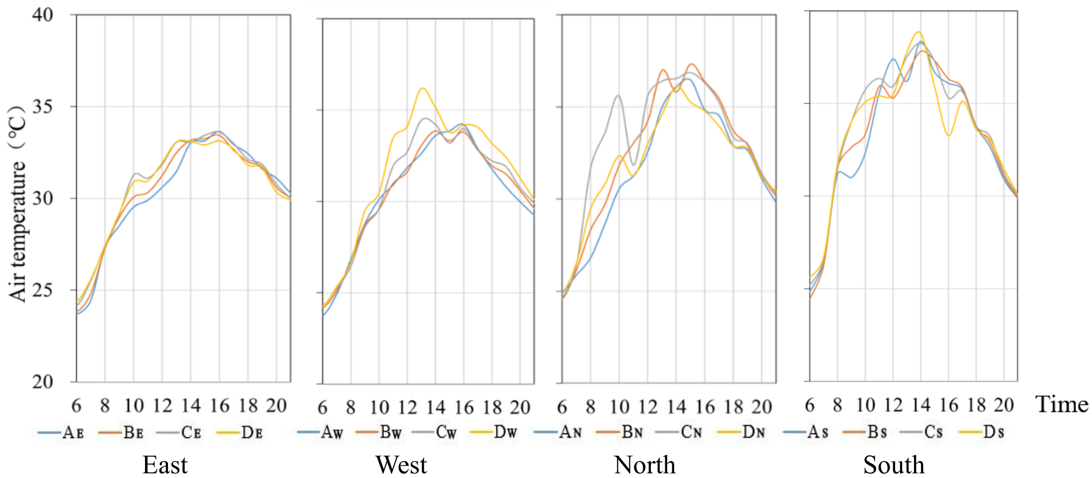


Figure 6. The temperature changes of measurement points in summer

In the east, the temperature at point AE is lowest before 3 p.m., and the temperature at point BE is higher than that at point AE. And then, the temperature changing trends at four sites are basically similar after 3 p.m., and the temperature differences between four measuring points do not exceed 1°C. The park inhibits the rate of temperature rise after sunrise. At 7 a.m., the maximum temperature difference between four measuring points is 0.12 °C. However, the maximum temperature difference between four measuring points is 1.34 °C at 12 a.m.. After 4 p.m., the temperature at point AE closest to the park declines slowly, which is due to leaves on the trees blocking the long-wave radiation from the ground, resulting in a slow temperature fall. The temperature at point BE, CE and DE are slightly higher during the day. The reason for that is three measuring points are located in the space of the multi-story building. Meanwhile, there are urban road areas which have an influence on the temperature (Table 1). However, all three measuring points have a certain green coverage (Table 1), which is conducive to the temperature fall. In the west, the temperature at point AW is the lowest in most measuring time, especially after 6 p.m., when the temperature drops from 31.78 °C to 29.24°C. It is the lowest value of four points at 9 p.m., followed by lower temperatures at point BW, CW and DW. Among them, temperature changes at point BW is close to that of point AW. But there is a big difference on the temperature changes between point BW and other two points (point CW and DW) from 10 a.m. to 2 p.m.. At 1 p.m., the temperature at point CW (34.44°C) and DW (36.18°C) reach the highest value, but it doesn't at point AW and BW. The temperature at point AW in the park drops fastest after 4 p.m..

But in the north and south, temperature fluctuations are more frequent, and overall temperature trends are higher, by comparison of temperature in the multi-story building spaces of the east and west. In the north, the temperature at point AN in the park is the lowest before 1 p.m. and after 6 p.m.. Point BN is close to the park, showing a slightly higher temperature, compared with temperature at point AN. As seen in Table 1, the detailed urban parameter of point BN is similar to that of point AN. Since point BN is located at the south gate of the park, with a higher building density and a lower green coverage, by reference to point AN. In addition, increased road area, as human factors, also has a considerable influence on temperature. The temperature at point CN and DN are variable, because the north space is mainly dominated by high-rise buildings in the upwind direction. In the south, although there is a high green coverage, the measuring points are located in open spaces with low SVF (Figure 3), thus leading to highest temperature risen by 0.48 °C in the north due to the influence of the sun. The maximum temperature difference between four measuring points at 8 a.m. is 4.89 °C. However, the maximum temperature difference between four measuring points at 10 a.m. is 5.37 °C. This is because point AS and BS are located in the park, which have a high green coverage, and is less affected by architectural factors. Temperature varies greatly at four points from 12 a.m. to 5 p.m.. This is because the four measuring points are located in the open spaces with less occlusion, so they are susceptible to wind and the sun. During the measurement, point BS and CS are close to the road, so the temperatures are higher in most time periods.

Before sunrise and after sunset, the temperature in the park is basically lower than that in the surrounding urban spaces. While, at noon, the temperature at some measuring points in the park is slightly higher than that in the surrounding spaces, which is due to the heat absorption and building cooling during the daytime. In summer, the temperature at the measuring point in the park or near the park is lower, which is partly the result of greenbelt. It plays a good role in inhibiting the temperature rise and rapid temperature fall after sunset.

Discussion

Urban parks have a cooling effect on urban space, contributes to reducing the urban heat island effects, improving air circulation and providing physical and mental pleasure for human activities. The results of the research indicated that the temperatures change inside and outside the park were different in different seasons, which are affected by surrounding environmental factors.

In winter daytime, the average temperature of multi-story building space around the park with a radius of 50 meters rises by 1.37 ℃. Accordingly, the average temperature of high-rise building space is up by 0.72℃. The average temperature difference of multi-story building space inside and outside the park is 0.2 °C at night, while the difference of high-rise building space around the park is 0.63 °C at night. It is indicated that the temperature of multi-story building space around the park drops faster than that of the high-rise building space after sunset, which is more conducive to the spread of the cooling effect in park. In spring, there is little difference in temperature between the inside and outside of the park before sunrise and after sunset. The temperature difference between the multi-story building space and park is 0.08°C, and that between the high-rise building space and park is 0.5°C. It is the evidence of better cooling effect of multi-story building space, which is superior to high-rise building space. In summer, the average temperature outside the park is 0.61°C higher than that inside the park, especially in the high-rise building space and in the space with city's main roads outside the park. The temperature difference between the two spaces and the park can be more than 1 °C. It can be seen that the two spaces have higher temperatures during the day, but the temperature difference inside and outside the park is 0.08°C, lower than that of the multi-story building space at night. Therefore, the cooling effect of these two spaces is similar to that of a multi-story building space. Based on the results measured in three seasons, the multi-story building space around the park is more conducive to temperature reduction.

However, there are some limitation in the result of field measurements. The weather conditions on the day of measurement, such as the wind speed and direction, will have an impact on temperature changes. In future research, the impact of weather conditions and surrounding environment on temperature changes will be further analyzed to make the results more accurate.

Conclusion

In this research, the weather conditions in 16 locations inside and close by a large scaled urban park are measured, and the measurement data are analyzed in order to investigate the effects from urban greening and urban building typology on urban micro-scaled climate. The actual data differences between the park and the surrounding urban spaces in different seasons were compared in this research, using field measurements. The temperature in the park during the daytime is higher than that in the surrounding urban spaces. The temperature differences between inside and outside of the park are greatly influenced by the type of surrounding building spaces, as well as in different seasons. On the whole, the multi-story building space with the tree-lined urban road has a more obvious cooling effect, which could be built around the park. Therefore, the space around the park should not be planned to build high-rise buildings and major urban roads with large traffic flows. Such space planning can better support the park's cooling effect and play a more effective role in improving the temperature change of local urban space. The three seasonal temperature relationships between the park and the surrounding urban spaces are different, which can be used as a basis for space planning to improve urban microclimate. This research laid a foundation for further research on the relationship between the surrounding urban space and the ecological effect of the park, and provided a reference for the urban park and the surrounding urban space planning.

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