Study on influencing factors and influencing strength of urban green space relieving heat island effect—taking Beijing as an example

Chao Jing¹, Shilong Li¹, Shuo Cao¹ and Xiaoyan Ma¹*

¹School of Landscape Architecture, Beijing University of Agriculture, Beijing, 102206, China

*Corresponding author’s e-mail: 19896602@bua.edu.cn

Abstract. With the acceleration of urbanization, the urban heat island effect has brought a significant impact on the urban environment, and the urban green space can effectively alleviate the heat island effect, but the specific influence intensity is yet to be further studied [1]. In this study, 65 urban green spaces of different sizes and different types within Fifth Ring Road of Beijing were selected through big data analysis to explore the effects of different influence factors such as area, perimeter, shape index and vegetation coverage on its internal temperature, and then the influence intensity of urban green space on heat island effect were studied and analyzed. The results show that: 1) when the green space area is 1-10 hectares, the average temperature inside the green space will decrease with the increase of the area, and the temperature will decrease by about 0.1 °C for each increase of 1 hectare; when the area is larger than 10 hectares, the average temperature inside the green space will basically not change; 2) the internal temperature of green space does not change with the perimeter and shape index of green space; 3) when the green space area is equal, the internal temperature of the green space will decrease about 0.158 °C when the vegetation coverage increases by 1% (i.e., there is a negative correlation between the green space vegetation coverage and the internal temperature).

1. Introduction

With the acceleration of urbanization and the continuous expansion of construction land area, the urban heat island effect has brought an important impact on the urban environment, and the research that urban green space can alleviate the urban heat island effect to a certain extent has reached a consensus[2]. However, the research on the influence intensity of green space on heat island effect is yet to be quantified. In the existing related studies, most of the simple experimental data unified linear fitting to explore the impact of a certain factor on green space, but this method can only draw qualitative conclusions. Therefore, this study adopted the control variable method while using this method, i.e., by setting up 15 green space control groups to carry on the experiment, under the condition of the same area in the green space control group, to explore the influence intensity of a certain factor on the heat island effect. These two methods complement each other, while improving the experimental methods; we can also draw accurate conclusions, which is more conducive to exploring the impact intensity of green space on urban heat island effect. This is the innovation point of this study and it is also expected to provide references for the construction of urban green space system [3].
2. Research methods and data sources

2.1. Research methods
In this study, in the context of big data analysis, a linear fit to the experimental data was made, combined with the control variable method, which were the two methods applied together to the study of the related influence factors and the influence intensity of the urban heat island effect. The results were linearly fitted by extracting the related information such as green space area, perimeter, shape index and average internal temperature, and the regression equation was established. Besides, the control group was set up for the sample green space with low credibility, i.e., the relationship between a certain influence factor and internal temperature was discussed under the condition that other influence factors were equal, so as to analyze the influence intensity of each influence factor on the heat island effect more directly.

2.2. Access to remote sensing image
In this study, we took the main urban area within the Fifth Ring Road of Beijing as the research area, taking the remote sensing image of landsat8 satellite on July 10, 2017 as the basic data, using the single window algorithm (MV method) proposed by Chinese scholar Qin Zhihao to invert the land surface temperature in the infrared band data of landsat8 satellite remote sensing image, and then obtained Figure 1. [4].

![Figure 1. Surface temperature inversion results of the study area](image)

The green space was selected on the basis of the surface inversion results of the study area. However, at this resolution, each pixel lattice in the Landsat8 satellite remote sensing image contained two or more kinds of environmental information of the underlying surface, which can easily affect the classification and selection of various types of green space in the urban underlying surface environment [5]. Therefore, in the following sample green space selection, the higher resolution GF-2 satellite image was used to continue the research.
2.3. Selection of sample green spaces

In order to avoid the inaccurate results caused by the small number of sample green space, single species and the interference of other cooling factors [6], the selection principles of sample green space in this study were presented as follows:
1) The number of selected samples of green space should be large, and the size should be different;
2) All types of green space were sampled;
3) A certain distance should be ensured between the sample green space to avoid mutual interference and similar research results;
4) Avoid the green space with water surface and reduce the influence of water body.

Under the guidance of the selection principle of sample green space, 65 green spaces of different types and sizes within Fifth Ring Road of Beijing were selected by using GF-2 satellite images, and then Figure 2 was obtained as the follow.

![Figure 2. Distribution of green spaces in the study](image)

2.4. Information extraction and grouping of green space

2.4.1. Information extraction. The average internal temperature, area, perimeter, and shape index of green space were analyzed. Among them, the average internal temperature was obtained from the surface temperature grid layer in the main urban area of Beijing, and the area and perimeter were derived directly by Arc GIS. The formula for calculating the shape index is as follows:

\[ D = \frac{0.25S}{\sqrt{A}} \]

In the formula, D is the shape index of the green space, S is the perimeter of the green space, and A is the area of the green space [7].

2.4.2. Grouping of green space. In this study, the control variable method was used to establish the sample green space control group. Among the 65 sample green spaces, 31 green spaces with an area difference of no more than 0.1 ha were selected and divided into 15 groups, i.e., it was considered that
the area of each of the 15 groups of green space was approximately equal, and in this case, the influence of other factors on the intensity of heat island effect was explored.

3. Analysis of influence factors and influence intensity

3.1. Correlation analysis of internal temperature and area of green space
In the WPS table, the area (unit: ha) and average internal temperature (unit: °C) of 65 sample green spaces were taken as horizontal and vertical coordinates respectively to form a scatter plot and draw a trend line to get Figure 3.

![Figure 3](image)

**Figure 3.** Linear regression chart of average internal temperature and area in green space

As shown in Figure 3, according to the distribution of each point in the scatter plot, we can see that the relationship between the internal temperature and the green area accorded with the characteristics of the logarithmic equation. The data were simulated to obtain the fitting equation $y = -0.964 \ln(x) + 42.396$ (represented by dashed lines in the figure). After calculation, it was found that the variance of the equation was 0.3506, indicating that the fitting result was relatively reliable and had reference significance. Through the analysis, it was found that for the green space area within 1-10 hectares, the internal temperature changed obviously with the increase of the area; but when the area is larger than 10 hectares, the internal temperature changed little and stabilizes in a certain range.

It can be seen that the internal temperature decreased gradually with the increase of the sample green space area, indicating that the increase of the green space area would play a certain role in the internal cooling, and the inflection point of the green space area affecting the internal temperature was about 10 hectares.

3.2. Correlation analysis of internal temperature and perimeter of green space
In the WPS table, the perimeter (unit: km) and average internal temperature (unit: °C) of 65 sample green spaces were taken as horizontal and vertical coordinates respectively to form a scatter plot and draw the trend line to get Figure 4.
Figure 4. Linear regression diagram of average internal temperature and perimeter in sample green space

As shown in Figure 4, the distribution of each point in the scatter plot was linearly fitted to obtain the logarithmic function $y = -1.165\ln(x) + 40.926$. Although the trend line showed that the internal temperature of the green space decreased with the increase of the perimeter, the variance was only 0.1902, which was less reliable and can’t be used as the basis for determining the relationship between the two.

In order to make the correlation analysis data of the internal temperature and perimeter of green space more accurate, this study also used another method—control variable method. From 65 samples of green space, 31 green spaces whose area difference was not more than 0.1ha were divided into 15 groups of data. Under the condition that the area of each group of green space was equal but the perimeter was different, the average internal temperature and perimeter of green space were linearly fitted again, and then Figure 5 was obtained as the follow.
As shown in Figure 5, a total of 15 groups of sample green space control groups were set up. According to the comparison of linear regression diagram, it was found that the average internal temperature of 7 groups of control green space increased with the increase of perimeter; the average internal temperature of 7 groups of control green space decreased with the increase of perimeter; and the temperature of the other 1 group increased with the increase of perimeter first, then decreased with the increase of perimeter. Therefore, with the increase of perimeter, the change of internal temperature was not fixed. Thus it can be seen that there was no significant relationship between the average internal temperature of the green space and the perimeter of the green space. To sum up, the conclusions reached in the two methods were relatively uniform—there was no linear relationship between the perimeter of the green patch and the average internal temperature within the green space (i.e., it was not affected by the change of the perimeter of green patch). Therefore, there was no obvious law between the perimeter of green space and the internal temperature of green space, and there was no significant relationship between the perimeter of green space and its average internal temperature.

3.3. Correlation analysis of internal temperature and shape index of green space

In the WPS table, the shape index and average internal temperature (unit: °C) of 65 sample green spaces were taken as horizontal and vertical coordinates respectively to form a scatter plot and draw the trend line to get Figure 6.
Figure 6. Linear regression diagram of average internal temperature and shape index of green space in sample green space

As shown in Figure 6, the shape index of the sample green space was concentrated in the range of 0.03-0.05, and the distribution of points was relatively random, and there was a big difference in the internal temperature of the green space with the same shape index. After the linear regression of the scatter plot, the obtained equation was \( y = 14.14x + 40.142 \), and its R\(^2\) value was only 0.0135, which had extremely low credibility and no statistical significance. Therefore, it can be seen from the first method that there was no significant correlation between the shape index of green space and the average internal temperature [8].

In order to improve the accuracy of the correlation analysis data, this study continued to use the control variable method to make a linear regression between the average internal temperature and the shape index for 15 groups of sample green space with the same area, and then obtained Figure 7.

Figure 7. Linear regression diagram of average internal temperature and shape index of 15 groups of green space with the same area
As shown in Figure 7, a total of 15 control groups of sample green space with the same area were set up. According to the linear regression diagram, it was found that the average internal temperature of 7 groups of control green space increased with the increase of shape index; the average internal temperature of 7 groups of control green space decreased with the increase of shape index; and the temperature of the other 1 group increased with the increase of shape index first, then decreased with the increase of shape index. Therefore, with the change of shape index, the change of internal temperature was not fixed. Thus it can be seen that there was no significant relationship between the average internal temperature of the green space and the shape index of the green space.

To sum up, in the two methods to explore the relationship between the shape index of green space and the average internal temperature green space under the same area, it was concluded that there was no linear relationship between the shape index of green patch and the average internal temperature of green space (i.e., the internal temperature was not affected by the change of the shape index of green patch).

3.4. Correlation analysis between internal temperature and vegetation coverage of green space
From the above, we had known that when the green space area was 1-10 ha, the internal temperature of the green space would decrease with the increase of the green space area. If the vegetation coverage of 65 sample green spaces were linearly fitted with the average internal temperature, it would inevitably lead to the inaccuracy of the experimental results. Therefore, this study used the control variable method, using the previous 15 groups of green space, in the case of equal area, to explore the relationship between temperature and vegetation coverage.

Firstly, according to the multi-scale separation method in eCognition, the sample green space was divided into three categories: vegetation, water body and impermeable water surface, and the screening was performed on this basis [9]. Among the 15 groups of green space control group: the temperature difference of green space between 1.68ha green space and 5.86ha green space was 0.01°C and 0.11°C respectively, and there was no significance for further research because the temperature difference was too small; the water surface area of Zhonghai Park in 5.315ha green space accounted for 11.3% of the total area, so the sample was deleted in order to eliminate the interference of water body. Therefore, the remaining 13 groups of green space in the control group were classified, and obtained Figure 8:
Figure 8. Classification chart of underlying surface types of green space in 13 control groups

On the basis of the classification results, the proportion of green space, water body and impermeable water surface was calculated. The proportion of water body area in green space was less than 3% of the total area, which had little effect on the average internal temperature of green space. Therefore, in the subsequent study of the influence of vegetation coverage on the internal temperature of green space, it could be regarded as vegetation [10] and added to the proportion of green space. Finally, the
proportion of vegetation in 13 groups of green space was linearly fitted with the internal temperature of green space, and Figure 9 is obtained.

As shown in Figure 9, in the 13 control groups of green space: in the case of the equal area of green space in the two groups, the internal temperature increased with increases in the green space vegetation coverage. In the other 11 groups of green space, the internal temperature of green space decreased with the increase of vegetation coverage. Therefore, vegetation coverage had a relatively uniform influence on the internal temperature (i.e., the internal temperature of green space showed a downward trend with the increase of coverage. It could be concluded that there was a significant negative correlation between vegetation coverage and internal temperature of green space. Meanwhile,
in the case of equal area of green space, the proportion of vegetation increased by 1%, the internal temperature of the green space would reduce about 0.158°C.

4. Conclusion
In this study, based on the big data analysis, 65 urban green spaces of different sizes, types and shapes were selected by using GF-2 satellite image and combined with the surface temperature inversion map. By using Arc GIs software to analyze and statistics the area, perimeter, shape index, average internal temperature and other related information of green space, 31 green spaces were selected, and 15 sample green space control groups were established. The control variable method was used to study the influence of other variables on the internal temperature of green space and its intensity on the basis of equal area. It was found that the perimeter and shape of green space had no obvious effect on alleviating the heat island effect, but the green space area had a certain influence on alleviating the heat island effect and there was a threshold. The influence intensity of vegetation coverage was the greatest, and the cooling effect was the most obvious. The main conclusions are as follows:
1) In the study of the influence of area on the internal temperature of green space, by linear fitting the area of 65 green spaces with their internal temperature, it was found that when the green space area was 1-10 hectares, the average temperature of green space decreased with the increase of area, and the temperature decreased by about 0.1°C for every 1 hectare increase. When the area was larger than 10 hectares, the average internal temperature of the green space fluctuated in a certain range. Therefore, there is a certain threshold for the intensity of green space area to alleviate the heat island effect, which can not be used alone to achieve the purpose of cooling;
2) In the study of the influence of the perimeter on the internal temperature of green space, through the linear fitting of the perimeter of 65 green space and its internal temperature, it was concluded that there was no obvious relationship between the perimeter of green space and the internal temperature of green space. Using the control variable method to continue the study, on the basis of equal area, observing the relationship between the perimeter and internal temperature of green space, it was still concluded that there was no obvious relationship between the perimeter and internal temperature of green space;
3) In the study of the influence of the shape index on the internal temperature of green space, the shape index of 65 green space was linearly fitted with its internal temperature, and it was concluded that there was no obvious relationship between the shape index and internal temperature of green space. Using the control variable method to continue the study, on the basis of equal area, observing the relationship between the shape index and internal temperature of green space, it was still concluded that there was no obvious relationship between the shape index and internal temperature of green space;
4) In the study of the influence of the vegetation coverage on the internal temperature of green space, the underlying surface types of 13 groups of green space in 15 control groups of green space were classified, and the proportion was linearly fitted with the internal temperature of green space by calculating the proportion of each classification. It was concluded that the vegetation coverage of green space had a high negative correlation with the internal temperature of green space. Besides, in the case of equal area of green space, the proportion of vegetation increased by 1%, the internal temperature of the green space would reduce about 0.158°C.

Therefore, in order to reduce the impact of heat island effect on cities, we should first ensure the coverage area of vegetation and appropriately increase the proportion of plant patches. In addition, because the influence of the area has a certain threshold, for urban green space planning, its area should be controlled within 10 hectares to ensure that it can maximize the mitigation effect on the heat island effect. Because the perimeter and shape index have no obvious effect on alleviating the heat island effect, the aesthetic value and design sense can be considered more for the shape and perimeter.

From the aspect of beauty and practical function, the green space is expected to be systematically planned to ensure that it can’t only effectively alleviate the urban heat island effect, but also provide users with a more comfortable and beautiful environment.
In addition, the number of control groups of green space in this study was only 15 groups, and the results will be more rigorous if more control groups are set up in the future; besides, limited by satellite resolution and other reasons, there is no related research on the effect of vegetation planting such as the proportion of shrub grass planting on the internal temperature of green space. As an important influencing factor to alleviate the heat island effect, vegetation patches should be studied in the future in order to provide more references for urban planning under the premise of alleviating the heat island effect.

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