Analysis of the Effect of Urban Geometric Form Factors on Heat Islands in Guangzhou

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1. Introduction

Heat island is an extreme existence in the thermal environment of urban public space [1]. The high temperature for a long time will threaten the normal work and life of residents. The extreme thermal environment will increase the heat load of urban air conditioning, increase the building energy consumption, at the same time, the mechanical heat generated during air conditioning operation and the hot air discharged to the outdoor environment will further deteriorate the urban climate, increase the intensity of heat island effect, and form a bad cycle [2].

The research on the influencing factors of heat island effect at home and abroad mainly focuses on three aspects: the nature of underlying surface, artificial heat and urban geometric form factors. The study of underlying surface shows that there is a significant negative correlation between vegetation coverage, Normalized Difference Moisture Index (NDMI) and surface temperature [3]. Artificial heat related research shows that in some specific areas, due to the concentration of people or industry, the
heat is relatively concentrated, forming a heat island block [4]. In the past, there were more researches on the underlying surface and artificial heat factor, but less researches on the spatial geometric form factors. Oke [5] simulated the effect of sky field of view on urban heat island intensity. According to Yuan [6] in the high-density urban environment, increasing the building density and height can effectively alleviate the heat island effect. Yahia et al. [7] compared the air temperature and wind speed of the low-rise, middle-level and high-rise building areas, and concluded that compared with the high-rise building area, the space heat load pressure of the low-rise building area is greater. Some scholars believe that urban land expansion is an important reason for the rise of urban surface temperature and the intensification of urban heat island effect [8, 9]. According to the study of reclamation area and heat island effect in Shenzhen City, the expansion area of heat island is highly consistent with the increasing area of artificial reclamation from 1999 to 2009, which shows that the artificial reclamation project significantly enhances the urban heat island effect [10].

2. Research Purpose and Method
The purpose of this study is to compare the influence of urban spatial geometric factors on the intensity of heat island effect. Firstly, the intersection range of heat island is determined by the superposition of heat island map of Guangzhou over the years. Next, five different areas are selected in the intersection range of heat island over the years. In each area, four groups of measurement points and 20 comparison points are selected according to different street direction and sky view factor to measure the temperature. Under the condition of the same underlying surface factor and no significant difference in artificial heat factor, the temperature difference of different measuring points can reflect the influence of space geometry shape factor on heat island strength.

The measurement period is 14:00-16:00 from July to September 2018, and the measurement frequency is 10 min interval. The air temperature at 1.5m above the measuring point is used as the temperature data. The temperature and humidity measuring equipment is elitech RC-4HC (temperature and humidity recorder/manufacturer: Jingchuang), measuring range/accuracy/resolution - temperature: -40 ℃~85 ℃/± 0.5 ℃/0.1 ℃; humidity: 0-99% Rh/± 3% RH/0.1% RH. After the measurement, the data is converted into temperature chart data by using elitechlogwin RC-4H software.

Calculation of the sky view factor (SVF) of the measuring point: firstly, at the height of 1.5 m from the measuring point, the fish eye photos of the measuring point are taken horizontally with the micro distance fish eye lens with the viewing angle of 180°, and then the ratio of the visible area of the sky to the area of the hemispherical sky is calculated by Rayman software to obtain the sky view factor (SVF).

Calculation of the height width ratio of the measuring point: using the UT391 + handheld laser rangefinder (measuring range/accuracy/resolution: 60 m/± 2 mm/1 mm), measure the width W of the street where the measuring point is located and the height H of the surrounding buildings, and substitute it into the calculation formula of the height width ratio (H/W).

3. Selection and Measurement of Heat Island
Selection of measurement area: the data of heat island range is from Guangzhou urban heat island Monitoring Bulletin issued by Guangzhou Meteorological Bureau, and the distribution map of summer maximum temperature in Guangzhou in 2014, 2015, 2016 and 2017 bulletin is selected (figure 1). The areas with the intensity value of heat island over 1 ℃ in the four-year heat island map are selected as the high-intensity heat island areas, and the intersection blocks are selected by using Photoshop software to overlap the four-year high-intensity heat island areas, and these areas are taken as the intersection range of the four-year continuous heat island areas in Guangzhou in summer. Then, Tianhe, Yuexiu and Baiyun heat island blocks are selected from the summer heat island distribution intersection map of Guangzhou city. The cold island block of Haizhu District is selected from the summer heat island map of 2014, and finally a man-made reclamation area in Nansha District is selected.
Figure 1. Representative heat island distribution (℃) and intersection area of Guangzhou heat island in summer of 2014-2017.

Acquisition of field measurement data: the underlying surfaces in the intersection range of 4-year continuous heat island are mostly non permeable materials with high heat absorption rate and low heat capacity. Five different areas are selected in the intersection range of 4-year continuous heat island. Under the condition that the underlying surface factors are the same in each area and there is no significant difference in artificial heat factor, four groups measuring points and comparison points (20 in total) are selected to perform a temperature measurement according to different spatial form factors (street trend and sky view factor). Under the condition of the same underlying surface factor and no significant difference in artificial heat factor, the temperature difference of different measuring points can reflect the influence of space geometry form factor on heat island strength. Through field measurement and calculation, the comparison of geometric form factors of 20 measuring points in 5 areas of heat island intersection is shown in table 1.

Table 1. SVF, H/W and street trend of each measuring point.

| Fish eye photo | Location of selected points and SVF, H/W | Fish eye photo | Location of selected points and SVF, H/W |
|----------------|------------------------------------------|----------------|------------------------------------------|
|                 | Heat island observation in Tianhe District |                 |                                          |
| A1a             | A1a: SVF=0.435, H/W=2.4                 | A2a            | A2a: SVF=0.052, H/W=14.029               |
| A1b             | A1b: SVF=0.485, H/W=0.649               | A2b            |                                         |
|                 |                                         | A2b: SVF=0.032, H/W=7.689             |                                          |
| Region          | SVF  | H/W   | SVF  | H/W   |
|-----------------|------|-------|------|-------|
| **Heat island observation in Haizhu District** |      |       |      |       |
| B1a             | 0.317 | 1.467 | 0.159 | 2.343 |
| B1b             | 0.525 | 1.694 |      |       |
| B2a             |      |       | 0.384 | 1.694 |
| B2b             |      |       | 0.384 | 1.694 |
| **Heat island observation in Yuexiu District** |      |       |      |       |
| C1a             | 0.413 | 1.348 | 0.121 | 3.894 |
| C1b             | 0.496 | 1.410 | 0.291 | 1.944 |
| C2a             |      |       | 0.413 | 1.348 |
| C2b             |      |       | 0.413 | 1.348 |
| **Heat island observation in Baiyun District** |      |       |      |       |
| D1a             | 0.701 | 0.402 | 0.440 | 0.710 |
| D1b             | 0.714 | 0.384 |      |       |
| D2a             |      |       | 0.440 | 0.710 |
| D2b             |      |       | 0.440 | 0.710 |
| **Heat island observation in Nansha District** |      |       |      |       |
| E1a             | 0.998 | 0.000 | 0.401 | 2.374 |
| E1b             | 0.996 | 0.000 | 0.441 | 1.038 |
| E2a             |      |       | 0.401 | 2.374 |
| E2b             |      |       | 0.441 | 1.038 |

Through measurement and analysis, the temperature comparison of 20 measuring points in five regions at different times is shown in figure 2.
4. Data Analyses

Two dimensional geometric factor analysis [Street direction (defined by long axis)]: as can be seen in figure 2, the temperature of X1a is always higher than that of X1b (X represents each area A, B, C, d), X1x represents the part with larger sky view factor and smaller height width ratio in each area, X1a represents the measuring point in east-west street and close to the east-west street, while X1b represents the measuring point of the north-south street, it can be seen that the temperature of the east-west street and the street close to east-west will be higher than that of the north-south street in the area with large sky view factor and small height width ratio.

It can be found that in the area with smaller sky view factor and larger height width ratio, there is no significant difference between the temperature of X2a and X2b in Tianhe and Haizhu regions, in Yuexiu, the temperature of C2a is lower than that of C2b, and in Baiyun, the temperature of D2a is higher than that of D2b. This means that in the measurement period, in the area with small sky view factor and large height width ratio, the street direction has not much effect on the temperature.

Three-dimensional geometric factor analysis (H/W and SVF): as can be seen in figure 2, the temperature of measuring points X1a and X1b with larger sky view factor and smaller height width ratio is always higher than that of measuring points X2a and X2b with smaller sky view factor and larger height width ratio. It shows that without considering other factors, larger sky view factor and a smaller height width ratio mean less sky occlusion, which is more likely to lead to higher temperature, thus more likely to aggravate the heat island effect of the corresponding block.

Comparative analysis of reclamation area and non-reclamation area: Figure 2 shows that the temperature curve of points E1a and E1b in the reclamation area is always higher than that of points...
E2a and E2b in the non-reclamation area. It can be seen that the artificial reclamation will change the local microclimate and form a regional heat island in the reclamation area. When reclamation is further expanded, the scope of the heat island will also be expanded.

5. Conclusion

It is found that when the underlying surface factors are the same and the artificial heat factor have no significant difference, the heat island effect is related to the urban spatial geometric form factors.

(1) In the environment where there are no buildings on both sides of the street and the buildings are very dense, the influence of the street trend as a two-dimensional geometric factor on the temperature cannot be highlighted. The influence of street direction on air temperature only exists when there are moderate buildings on both sides of the street. In the sunny day in summer, the thermal environment of the north-south street is more pleasant, with the lowest temperature; while in the same region, the temperature of the east-west street is the highest, and the temperature of the northeast-southwest and southeast-northwest street is between the two. The heat island effect is more serious in the blocks with more east-west streets and less north-south streets.

(2) Three-dimensional geometric factor SVF and H/W reflect the sky openness of the street. Through the quantitative analysis of the sky view factor and air temperature, it is found that there is a strong positive correlation between the sky view factor and air temperature. The larger the sky view factor is, the smaller height width ratio is, the street bears more solar radiation, usually with higher temperature; on the contrary, the temperature is often lower.

(3) The temperature of artificial reclamation area is often higher than that of the surrounding non-reclamation area, which results in the heat island effect, which is more obvious in the newly built and non intensively developed reclamation area.

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References

[1] Jacobs 2009 Great Streets (China Architecture & Building Press).
[2] Shen S J 2003 Urban heat island and urban design Chinese and Overseas Architecture (5) 20-22.
[3] Wang G, Zhang Q P, Xiao R B, et al. 2017 Urban thermal island regulated by green spaces—A case study of Guangzhou Ecological Science. 36 (1) 170-176.
[4] Dhakal S and Hanaki K 2002 Improvement of urban thermal environment by managing heat discharge sources and surface modification in Tokyo Energy and Buildings 34 (1) 13-23.
[5] Oke T R, Shen X Y and Dai Z X 1983 Energy base of urban heat island Meteorological Science and Technology (06) 30-39.
[6] Yuan C 2010 Mitigating urban heat island effects of high density cities: A study at Hong Kong Architectural Journal (S1) 120-123.
[7] Yahia M W, Johansson E, et al. 2018 Effect of urban design on microclimate and thermal comfort outdoors in warm-humid Dar es Salaam Tanzania Int. J. Biometeorol. 62 373-385.
[8] Xiong Y, Huang S, Chen F, et al. 2012 The impacts of rapid urbanization on the thermal environment: A remote sensing study of Guangzhou, South China Remote Sensing 4 (7) 2033-2056.
[9] Mohan M and Kandya A 2015 Impact of urbanization and landuse/land- cover change on diurnal temperature range: A case study of tropical urban airshed of India using remote sensing data Science of the Total Environment 5 (06) 453-465.
[10] Chen W, Li L J, Li H Y, et al. 2013 Effect of artificial reclamation on urban heat island in Shekou peninsula, Shenzhen Ecology and Environmental Sciences 22 (1) 157-163.