Analysis on the Effect of Excessively Fast Urbanization on Urban Thermal Environment

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Abstract

As rapid urbanization has brought varied changes and even deterioration to urban climate in China, this paper, targeted at the construction land in a Chinese city, makes an investigation of the current situation and future planning of land use in the city. Focusing on the relationship between the degree of urban construction land expansion and the urban climate change, it summarizes the influence of urban expansion on urban climate, quantitatively summarizes how the degree of urban construction land expansion affects urban climate factors, such as air temperature, wind direction, wind speed, the balance of longwave and shortwave radiation, and the balance between sensible heat and latent heat fluxes. Based on the relationship between the degree of urban expansion and the urban climate change, the author puts forward suggestions on improving urban thermal environment. The research provides scientific theoretical basis for urban planning and design in the process of urbanization, and reference for the design of ventilation corridor in future urban planning.

Keywords: urbanization, construction land, urban thermal environment, temperature change, urban planning and design

1. INTRODUCTION

With the spread of urbanization across the globe, the size and population of cities are continuously growing in every corner of the world. However, urban climate factors, ranging from wind speed, air temperature, atmospheric pressure to humidity, have undergone tremendous changes due to the increase of greenhouse gas and pollutant discharge, the rapid growth of artificial energy consumption, the reduction of natural ground and green vegetation, and the surge in the number of urban buildings. All of these have led to the emergence of heat island phenomenon in urban areas (Fortelli et al., 2016; Gagliano et al., 2016). With the advent of drought, heavy rain, persistent high temperature, air pollution and other climate issues, it is of great urgency to protect urban ecology and improve the urban climate. (Hoyano, 2010)

Human activities and urban construction have had a tremendous impact on the climate characteristics of urban areas, creating unique urban climate characteristics in the context of global climate (Wilby and Perry, 2006). As the economy and living standards in China continue to improve, people will become increasingly eager to build environment-friendly and resource-saving cities, and the quantitative research on urban thermal environment is bound to become an objective requirement for China’s cities to enter an environment-friendly and resource-saving society (Theuray, 2006; Delmastro et al., 2015; Delmastro et al., 2016; Fichera et al., 2015; Fichera et al., 2016;). Based on the mesoscale meteorological simulation software combined with urban canopy model, the study on the relationship between urban development and urban climate environment provides new ideas and theoretical support for urban climate and urban planning and design (Luo et al., 2007). The expansion of the construction land will turn the original natural underlying surface into artificial underlying surface. The shift brings significant impact to the underlying surface’s abilities of receiving and reflecting solar radiation and achieving the energy balance, which, in turn, causes a certain influence on the climate environment in cities (Gasper et al., 2011; Roselli et al., 2016; Carotenut et al., 2016).

With the urban climate of City A as the research object, this paper studies the current situation of land use, the target land use in the 2020 urban master plan, and the expected urban land use in the long term, and selects 3
different cases to quantitatively summarize the influence of the degree of urban construction land expansion on urban climate factors, such as air temperature, wind direction, wind speed, the balance of longwave and shortwave radiation, and the balance between sensible heat and latent heat fluxes. The research provides theoretical basis for Chinese cities to solve the contradiction between urban development and the deterioration of urban climate and environment.

2. OVERVIEW OF THE DEVELOPMENT OF CITY A

2.1 The climate of City A

Located in the middle and lower reaches of the Yangtze River and the eastern part of Jianghan Plain, City A has a subtropical monsoon humid climate, which features hot summer, cold and wet winter, small daily temperature difference, adequate rainfall and abundant sunshine. The average annual temperature falls between 15.8°C and 17.5°C. The monthly mean temperature is the lowest in January, which is 3.0°C, and the highest in July, which is 29.3°C. Since it lies in a low-lying inland area far away from the ocean, City A has a hot urban climate. In summer, the temperature is generally above 37°C, with extreme high temperature reaching 42.2°C.

2.2 The current situation of City A’s thermal environment based on actual measurement

The test periods are the early morning, noon and night of July 22 and 23, 2012. The temperature data are collected by the test instrument embedded in a test vehicle, which drives at 25-30km/h from the starting point at Yezhihu Flyover along the test road sections to end point at the intersection of Hongshan Road and Tian’e Road. The temperature data are gathered on the early morning, noon and night of the two days.

An analysis is conducted to compare the temperature data gathered on July 22 and July 23 in the early morning (Figure 2). In this test period, the temperature in the urban center on July 22, a rest day, is slightly higher than that in the urban fringe; however, the temperature is basically the same from the urban fringe to the urban center in the same test period on July 23, which is a workday. On the early morning of the workday, there is little heat island effect; in the same period in the weekend, the heat island intensity reaches 1.0°C. The difference reveals that the artificial energy consumption is more obvious on the early morning of the rest day.

![Figure 1 Test roadmap](image)

![Figure 2 Comparison of the temperature trends of the rest day and the workday in the early morning](image)
Similarly, the temperature data gathered on the noon of July 22 and July 23 are also compared (Figure 3). The temperature difference between the urban center and the urban fringe is not obvious at noon, whether it is the rest day or the workday, indicating that the urban temperature in this test period mainly depends on solar radiation intensity. However, the apparent fluctuation in the temperature curves demonstrates the significant effect of urban artificial energy consumption on urban temperature.

![Figure 3](image3.png)

**Figure 3** Comparison of temperature trends of the rest day and workday at noon

The comparison between the temperature data gathered on the night of July 22 and July 23 is displayed in Figure 4. One of the curves records the temperature trend along the test route on the night of the rest day and the other records the temperature trend along the test route on the night of the workday. Both curves reflect obvious urban heat island effect, that is, the temperature gradually increases from the urban fringe to the urban center, and decreases from the urban center to the Donghu Lake area. The temperature curves are “high in the middle and low at both ends” and the heat island intensity reaches 2.0°C.

![Figure 4](image4.png)

**Figure 4** Comparison of temperature trends of the rest day and the workday at night

It can be seen from the above analysis that the heat island effect of City A mainly occurs at night, during which the heat island intensity reaches 2.0°C in the urban center and the urban fringe at the Yezhihu Flyover, while the effect is not obvious in the early morning and at noon. In the vicinity of lakes and open and wide areas, the temperature is usually low, making it difficult to produce urban heat island effect.

3. ANALYSIS OF SAMPLES FROM SPECIFIED AREAS IN CITY A

3.1 Comparison of diurnal temperature at sampling points A & B of each case

Two sampling point A & B are chosen for the three cases, which reflect different degrees of urban construction land expansion. Case 1 deals with the current situation of land use, Case 2, the target land use in the 2020 urban master plan, and Case 3, the expected urban land use when the construction land expands to the Outer Ring Road in the long term. The sampling point A is located at the intersection between the Jianshe Avenue and Hong Kong Road in District Q of the urban center, and the sampling point B is located at the government of District Q of the urban center. The diurnal temperatures at the two sampling points of Cases 1, 2 & 3 are compared and analyzed as below (Figures 5&6).

In Figure 6, the curves illustrate the diurnal temperature in each case at sampling point A, the intersection between Jianshe Avenue and Hong Kong Road. Based on the figure, it is discovered that:
(1) For each case, the temperature gradually falls from 0:00 to 5:00 in the early morning to the lowest point of the day at 25.0°C. There is only a slight difference in temperatures of the three cases. The trend has a lot to do with the heat preservation effect of the expanding urban construction land.

(2) In the figure, the temperature curves of the cases basically coincide with each other. The temperature difference is within 0.3°C. The warmest period of the day appears between 14:00 and 17:00 in the afternoon. At 15:00, the temperature peaks at 35.0°C. In this time period, the urban temperature is mainly affected by solar radiation intensity.

(3) After 19:00, the temperature curves of the cases begin to move away from each other. At 20:00, the temperatures at the sampling point of Cases 2 & 3, two expansion cases, surpass that of Case 1 by 0.5°C. From 20:00 to 20:00, the temperatures at the sampling point of all cases gradually converge. At 23:00, the temperature at the sampling point of Case 3, in which the urban construction land will expand to the Outer Ring Road in the long term, falls below that of the other two cases. At 24:00, however, the temperatures of all cases converge again.

Figure 5 The curves on the diurnal temperature at sampling point A (Q)

In Figure 7, the curves illustrate the diurnal temperature in each case at sampling point B, which is located at the government of District Q. The findings are as follows:

(1) The lowest temperature of the day appears at 5:00 in the early morning, which is 25.0°C at the height of 2m. From 6:00 in the early morning, the temperature begins to climb up. The period between 14:00 and 17:00 in the afternoon is the warmest of the day, during which the temperature reaches the peak point of 35.0°C at 15:00.

(2) From midnight to 5:00, Case 3, the long-term expansion case, has a slightly higher temperature than the other two cases. In the period between 6:00 and 18:00, the temperature curves of all cases basically coincide with each other.

(3) Starting from 19:00 in the evening, the temperatures at the sampling point of Cases 2&3, the two expansion cases, are significantly higher than the temperature at the sampling point of Case 1, the current situation case. The trend persists all the way to 20:00. From 19:00 to 20:00, the temperatures at the sampling point of Cases 2&3 exceed that of Case 1 by 0.5 to 1.0°C. The impact of urban land expansion on sampling point temperature begins to be felt in this period. The temperatures at the sampling point of all cases converge from 21:00 to 22:00 and move away from each other again at 24:00.
Figure 6: The curves on the diurnal temperature at sampling point B (Q)

Comparing the diurnal temperatures at the two sampling points, it is concluded that the degree of urban expansion has little influence on urban temperature in daytime, i.e. from 6:00 to 18:00. However, the influence begins to emerge after the sunset. The temperature at the sampling point rises with the degree of urban expansion. This trend continues till the hours before sunrise in the next morning.

Table 1: The differences between the average temperatures across the city of the cases at sampling point A

<table>
<thead>
<tr>
<th>Time</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 2-Case 1</th>
<th>Case 3-Case 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:00</td>
<td>24.75</td>
<td>24.66</td>
<td>24.48</td>
<td>-0.09</td>
<td>-0.27</td>
</tr>
<tr>
<td>15:00</td>
<td>34.15</td>
<td>34.05</td>
<td>33.98</td>
<td>-0.10</td>
<td>-0.17</td>
</tr>
<tr>
<td>20:00</td>
<td>29.7</td>
<td>30.11</td>
<td>30.44</td>
<td>0.41</td>
<td>0.74</td>
</tr>
<tr>
<td>24:00</td>
<td>27.29</td>
<td>27.27</td>
<td>27.72</td>
<td>-0.02</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Based on the average temperatures across the city at 5:00 in the early morning, 15:00 in the afternoon, 20:00 in the evening and 24:00 at midnight, the average temperature differences between the time points are obtained and displayed in Table 1. At 5:00 in the early morning, Case 3 is 0.27°C lower than Case 1 in terms of the average temperature across the city. 15:00 in the afternoon is the time point when all cases have the highest average diurnal temperatures with small average temperature differences between the time points. At 20:00, the cases boast the strongest island heat intensities. The average temperature of Case 2, which is about the target land use in the 2020 urban master plan, is 0.41°C higher than that of Case 1, the current situation case. If the construction land expands to the Outer Ring Road (Case 3), the average temperature across the city would be 0.72°C higher than that of Case 1. When it comes to 24:00 at midnight, the average temperatures across the city of Case 1 and Case 2 are basically the same. At this point, the target land use in the 2020 urban master plan has no impact on the average temperature of the city. However, Case 3 still exceeds Case 1 by 0.43°C in terms of average temperature, indicating that the expansion of construction land to the Outer Ring Road still affect the average temperature across the city but the effect would disappear within a few hours after midnight.

3.2 Comparison of diurnal heat island intensities at sampling points A & B of each case

Three sampling points are chosen for comparing the temperature differences. Specifically, sample point A is located at the intersection between the Jianshe Avenue and Hong Kong Road in District P of the urban center, the sampling point B is located at the government of District Q of the urban center, and another sampling point is located in rural areas. Figures 7 & 8 record the curve of heat island intensity of each case at sampling points A & B. The influence of urban construction land expansion on urban heat island intensity is discussed as follows:

(1) The heat island strength of each case at the two sampling points A & B remains at about 1.5°C from 0:00 to 4:00. After the sunrise, the heat island intensities of all cases start to fall and reach 0°C between 7:00 and 8:00. From 0:00 to 8:00, the heat island intensities at sampling points A & B of each case are consistent with each other, showing no impact from the expansion of urban construction land.
(2) After 8:00 in the morning, the heat island intensities of each case are negative at the two sampling points, which signifies the urban cold island effect. The urban heat island intensity turns negative because the urban temperature is lower than the temperature in surrounding villages. After the sunrise, the temperature of uncovered natural underlying surface in rural areas rises rapidly while the temperature in the city grows slowly. For all cases, the heat island intensities gradually turn positive at 13:00 at sampling point A, and at 15:00 at sampling point B. After the middle of the day, the urban heat island intensity begins to gradually increase.

(3) From 8:00 in the morning to 17:00 in the afternoon, the heat island intensity curves of the cases at the sampling points A & B converge at most points, and the difference is 0.5°C at the most.

(4) After 17:00 in the afternoon, the solar radiation intensity becomes very weak. At this time, the urban heat island intensity begins to rise rapidly. At around 20:00, the urban heat island intensities of each case at both the two sampling points reach the peak points. For sampling point A, the heat island intensity of Case 1 peaks at 2.5°C, and the heat island intensities of Cases 2 & 3 both peak at 4.0°C. For sampling point B, the heat island intensity of Case 1 peaks at 2.4°C, and the heat island intensities of Cases 2 & 3 both peak at 4.0°C. At 19:00, the heat island intensities of Case 3 at sampling points A&B are much lower than those of Case 2, while the two cases have basically the same temperatures at the two sampling points at the same time point.

According to the diurnal heat island intensities of each case at the two sampling points, the urban heat island intensities are negative, which signifies the urban cold island effect, for a period of time after 8:00 in the morning, and climb up after the middle of the day. From 18:00 to 22:00, the urban heat island intensities are the most obvious. For each case, the heat island intensities at both sampling points reach the peak values at around 20:00. This creates the false impression that the urban heat island intensities are falling. In Case 2, which is about the target land use in the 2020 urban master plan, and Case 3, which is about the expected urban land use when the construction plan expands to the Outer Ring Road in the long term, the heat island intensities at both of the two sampling points in urban center are 4.0°C, showing that there is a upper limit in the influence of the degree of urban expansion on urban heat island intensity.
3.3 Comparison between the diurnal variations of the average energy balance in the underlying surface change area of the cases

Figures 9, 10 & 11 are respectively the diurnal variation curves of the average energy balance in the underlying surface change area of Case 1, Case 2 and Case 3, in which H stands for sensible heat, LE stands for latent heat, G stands for surface heat flux, and Rn stands for net radiation quantity.

**Figure 9** Diurnal variation curves of average energy balance in the underlying surface change area of Case 1

**Figure 10** Diurnal variation curves of average energy balance in the underlying surface change area of Case 2

**Figure 11** Diurnal variation curves of average energy balance in the underlying surface change area of Case 3

Through the analysis of the changing patterns of the curves, it is concluded that, in all three cases, the net radiation Rn is slightly reduced with the urban expansion. The sensible heat gradually decreases with the further expansion of the city. The reason goes as follows: during urban expansion, the natural underlying surface develops into urban underlying surface; the buildings in the urban underlying surface shield the solar radiation,
leading to lower ground temperature throughout the city. Similarly, the amount of latent heat also shrinks with the further expansion of the city. This is mainly because of the reduction in water transpiration due to the increase in impermeable surface area in the city. Urban expansion also results in gradual increase in the surface heat flux for the ability to store heat is improved due to the expanding urban underlying surface in urban expansion. As the heat stored in the urban underlying surface increases, the cooling rate in the city is slowed down at night. That is why the urban temperature of Case 2 is higher than that of Case 1, and the urban temperature of Case 3 is higher than that of Cases 1 & 2 at 20:00 in the evening, and why the trend persists all the way to the midnight.

4. CONCLUSION

(1) The effect of urban expansion on urban temperature is evident from the evening to midnight. With the deepening of urban expansion, the urban temperature change area also increases. The effect of urban construction land expansion on urban temperature is obvious after sunset. At 20:00, the temperature in urban center rises dramatically with the increase in urban expansion. In Case 3, which talks about the expected urban land use when the construction plan expands to the Outer Ring Road in the long term, apparent temperature rise is seen in both the urban center and the urban fringe, particularly most of the northeastern area of the city.

(2) When the city expands to a certain extent, the heat island intensity at the urban center will not increase any more. There is an upper limit in the influence of the degree of urban expansion on urban heat island intensity. The limit is put at 4.0°C in this study. From midnight to sunset, the degree of urban expansion has no significant effect on the intensity of urban heat island. However, the effect is very prominent after sunset.

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REFERENCE


