Influence of a railway station and the Yangtze River on the local urban thermal environment of a subtropical city

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ABSTRACT
Urbanization causes various climate-related environmental problems, such as the urban heat island phenomenon and extreme weather. As such, the outdoor thermal environment is worsening in cities, and researchers are increasingly concerned with mitigation measures. Here, we investigated the influence of a major railway station and the Yangtze River on the local thermal environment in a city with a subtropical climate. Field measurements were performed in Wuhan, China, from 21 July 2017 to 25 July 2017. The cooling effect of the Yangtze River modulated the surrounding urban environment substantially at night, especially in areas closer to the river border. During the afternoon, areas farther from the railway station experienced higher temperatures, that meant railway station showed a cooling effect. By contrast, at night, the temperature exhibited a decreasing trend with increasing distance, that meant railway station showed heat island effect. Moreover, there was a significant relationship between the percentage of the man-made area (versus natural area) and air temperature at night, where temperature increased with an increasing percentage of man-made area. The cooling effect of the Yangtze River and Wuchang railway station could be taken into account to mitigate the urban thermal environment in Wuhan in the summer.

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1. Introduction
In recent years, urbanization has caused various climate-related environmental problems, such as the urban heat island (UHI) phenomenon and extreme weather. As such, the outdoor thermal environment is worsening in cities (Grimmond 2007; Li and Bou-Zeid 2013). Improving natural factors (eg green spaces and water) in cities has become the main method of alleviating UHIs, and many studies have assessed the influences of natural factors on the outdoor thermal environment of cities (Bowler et al. 2010; Ghosh and Das 2018; Giridharan et al. 2008; Park et al. 2012; Wang et al. 2018). For instance, Uchida et al. (Uchida et al. 2009) carried out measurements in the summers of 2007 and 2008 in and around a biotope to clarify the thermal effects of a biotope containing a pond and green space. Furthermore, a questionnaire survey was conducted at the measurement site to assess the principal drivers affecting human thermal comfort. Meanwhile, regression analyses by Buyantuyev et al. (Buyantuyev and Wu 2010) confirmed the important role of vegetation during the day in explaining the spatiotemporal variation of surface temperatures. In addition, Steeneveld et al. (Steeneveld et al. 2014) studied the influence of open water surfaces in mitigating the maximum UHI intensity and found that water bodies increased, rather than decreased, the 95th percentile of the daily maximum UHI. Moreover, Yan et al. (Yan, Wu, and Dong 2018) performed a field measurement to study the influence of a large urban park on the local urban thermal environment and found that the park had a cooling effect on the urban environments adjacent to the park, which extended approximately 1.4 km from the park boundary. Rivers with meandering paths generally have positive impacts on urban thermal environments (Evans and Schiller 1996; Fukagawa et al. 2006; Gospodini 2001; Hagerman 2007; Hathaway and Sharples 2012). However, interestingly, Moyer and Hawkins (Moyer and Hawkins 2017) studied the effects of a river on the heat island of Harrisburg, Pennsylvania, USA, and found that the Susquehanna River increased the UHI due to warmer water temperatures at night and its positive effect on local humidity.

Meanwhile, man-made factors (eg paved areas, buildings, etc.), which occupy a large proportion of the area of modern cities, have also been the focus of UHI research (Heusinger and Weber 2015; Shojaei et al. 2017; Xu et al. 2018; Yang et al. 2018). For example, Kubota et al. (Kubota et al. 2008) carried out wind tunnel experiments to study the relationship between building density and pedestrian-level wind velocity and presented the results of wind tunnel tests on 22 residential neighbourhoods selected from actual Japanese cities. They found a strong relationship between the gross building coverage ratio and mean wind velocity ratio, and proposed a method for the development of guidelines to realize acceptable wind environments in residential...
neighbourhoods based on the gross building coverage ratio. In addition, Yokobori and Ohta (Yokobori and Ohta 2009) studied the effects of land cover on ambient air temperature and found that the development of an intra-UHI was related to land-cover features, where the causal factors that enhanced intra-UHIs differed between day and night. Meanwhile, Xuan et al. (Xuan et al. 2016) studied climatically adapted building arrangements to maximize the outdoor thermal acceptability at different latitudes and analyzed the optimal building distance-to-building height ratio from the perspectives of urban ventilation and sun-shading in Sendai, Japan, and Guangzhou, China. Their results showed that the distributions of wind velocity around buildings became polarized as building distance decreased and the proportion of low wind velocity increased, which was the main cause of poor ventilation and thermal discomfort, while significant cooling effects of building shade were observed in closely packed arrangements. Furthermore, Yan et al. (Yan et al. 2014) studied the effect of land-cover composition on intra-urban air temperature and found that 80% of the temperature variation could be explained by a combination of the proportion of building area and proportion of paved area at a 200-m scale on winter nights. Among five land-cover types, the percentage of building area was the most important factor in increasing local air temperature. As large stand-alone buildings, railway stations, especially large stations located in city centres, have a substantial influence on urban thermal environments. Several studies have assessed the indoor human comfort and CFD of railway stations (Deb and Ramachandraiah 2010; Li et al. 2009; Liu et al. 2016, 2015; Nakamura et al. 2011; Yu et al. 2017), but there has been little research on the outdoor thermal environment of railway stations (Li and Liu 2016).

Large railway stations represent centres of urban transportation and railway stations located in city centres have a substantial effect on anthropogenic heat due to passengers, traffic, and the use of air conditioning. Moreover, railway stations in China operate continually, thereby exerting a significant impact on the surrounding urban thermal environment. In particular, the Wuchang Railway Station (Wuhan, China) shares not only the general characteristics of Chinese railway stations, but is also located only 3.0 km from the Yangtze River. Therefore, the surrounding thermal environment is likely affected not only by the anthropogenic heat generated by the railway station, but also by the Yangtze River, representing the influence of complex interactions between both natural and anthropogenic factors on the thermal environment.

In the present study, we assessed the effects of both the Yangtze River and the Wuchang Railway Station on the thermal environment of the surrounding area to assess the importance of various natural and anthropogenic factors influencing the thermal environment in the study area. To achieve this, we performed continuous measurements of the thermal environment in the study area.

2. Study site and measurements

2.1. Study area

Wuhan is the capital of Hubei Province, central China, and is a strategic pivotal city within the region. Wuhan occupies a land area of 8,494.41 km², 888 km² of which is built-up. In 2013, the population of Wuhan was 10.22 million. Wuhan experiences a humid subtropical climate with abundant rainfall and four distinct seasons. Summer lasts almost 135 days, while spring and autumn together total of 120 days. Wuhan has a reputation for its harsh climate, with very humid summers (Wu et al. 2014).

Wuhan is the core city of the National Central City and the Yangtze River Economic Belt. Because of its key role in domestic transportation, it is known as the “thoroughfare to nine provinces”. Wuhan is served by three major railway stations: the Hankou Railway Station, the Wuchang Railway Station, and the Wuhan Railway Station. The Wuchang Railway Station is located on the east side of Zhongshan Road in Wuchang District, and is the largest transportation centre in Wuhan, with daily traffic of 77,000 passengers and 20,000 packages in 2000, and a record of 80,000 passengers per day during the Chunyun period in 2008 (Li, 2010).

This study was conducted around the Wuchang Railway Station in central Wuhan. This study area was bordered by the Yangtze River to the west and residential areas on the other sides. The area experiences intense vehicular traffic and severe anthropogenic heat generation. Thus, there is a substantial UHI phenomenon.

The measurement points were divided into two groups according to their distance from the Yangtze River and the Wuchang Railway Station. Group one was located perpendicular to the Yangtze River, connecting the tunnels between the Yangtze River and the Wuchang Railway Station. Meanwhile, group two included two circles centred around the Wuchang Railway Station. In group one, eight measurement sites (N1–N8) were chosen to investigate the influence of the Yangtze River on the area surrounding the Wuchang Railway Station. In group two, six measurement sites the first circle (C1–C6) and eight in the second circle (H1–H9, N4–N8) were chosen to study the influence of the Wuchang Railway Station on the surrounding area (Figure 1).

2.2. Field measurements

2.2.1. Measurement and computation of landscape parameters

Urban features influence the behaviour of weather variables. Numerous landscape parameters have been
developed to assess and quantify the effects of urban environment characteristics on air temperature. In this study, two categories of landscape parameters, spatial location, and land-cover features were selected to measure the environmental characteristics of the study site. The spatial location of each measurement point was determined as the distance from the Yangtze River and the Wuchang Railway Station. Meanwhile, land-cover features included the percentage of building cover, percentage of paved cover, percentage of green cover, and percentage of water cover.

Aerial photographs (Google Earth Maps 2017) were used to acquire the land-cover features of each measurement site. According to several previous studies, urban air temperature is mainly affected by the surrounding surface cover within a few hundred meters (Costa, Labaki, and Araújo 2007; Yan et al. 2014; Yokobori and Ohta 2009), and from 20 m to 300 m, a buffer zone in 150 m radius results better correlation coefficients in the summer (Yan et al. 2014). Thus, a buffer zone with a 150-m radius around each point was used to calculate the proportions of vegetated and impervious area in this study. Using a similar method as Krüger and Givoni (Krüger and Givoni 2007), the percentage of impervious surface and vegetation cover around each measurement point was calculated using AutoCAD (Autodesk, Mill Valley, CA, USA) by drawing the corresponding areas on the aerial photograph. The detailed statistics of these landscape parameters are listed in Tables 1 and 2.

Figure 2 shows the percentage of all land-cover types around all measurement points. More vegetation and water bodies often have a positive impact on the
Table 1. Description of the measurement sites.

| Site number | Distance from the Yangtze River (km) | Distance from the Wuchang Railway Station (km) | Percent building cover (%) | Percent paved cover (%) | Percent green cover (%) | Percent water cover (%) | Sky View Factor (SVF) | SVF photos of measuring points | Environmental photos of measuring points |
|-------------|--------------------------------------|-----------------------------------------------|----------------------------|------------------------|------------------------|------------------------|------------------------|-------------------------------------|---------------------------------------------|
| N1          | 0.04                                 | 2.60                                          | 14.9                       | 27.1                   | 25                     | 33                     | 0.81                   | ![Image](SVF_photo_N1.jpg) | ![Image](Env_photo_N1.jpg) |
| N2          | 0.70                                 | 1.90                                          | 35.9                       | 44.4                   | 19.7                   | 0                      | 0.37                   | ![Image](SVF_photo_N2.jpg) | ![Image](Env_photo_N2.jpg) |
| N3          | 1.10                                 | 1.50                                          | 38.6                       | 35.6                   | 25.8                   | 0                      | 0.83                   | ![Image](SVF_photo_N3.jpg) | ![Image](Env_photo_N3.jpg) |
| N4          | 1.90                                 | 0.87                                          | 43.2                       | 45.5                   | 11.3                   | 0                      | 0.89                   | ![Image](SVF_photo_N4.jpg) | ![Image](Env_photo_N4.jpg) |
| N5          | 2.60                                 | 0.34                                          | 21.1                       | 75.2                   | 3.7                    | 0                      | 0.72                   | ![Image](SVF_photo_N5.jpg) | ![Image](Env_photo_N5.jpg) |
| N6          | 2.90                                 | 0.20                                          | 26.7                       | 55.9                   | 17.4                   | 0                      | 0.78                   | ![Image](SVF_photo_N6.jpg) | ![Image](Env_photo_N6.jpg) |
| N7          | 3.10                                 | 0.22                                          | 23.1                       | 62.1                   | 14.8                   | 0                      | 0.87                   | ![Image](SVF_photo_N7.jpg) | ![Image](Env_photo_N7.jpg) |
| N8          | 3.30                                 | 0.38                                          | 27.6                       | 50.6                   | 21.8                   | 0                      | 0.22                   | ![Image](SVF_photo_N8.jpg) | ![Image](Env_photo_N8.jpg) |
| C1          | –                                    | 0.02                                          | 48.1                       | 30.8                   | 21.1                   | 0                      | 0.11                   | ![Image](SVF_photo_C1.jpg) | ![Image](Env_photo_C1.jpg) |
| C2          | –                                    | 0.11                                          | 30.1                       | 51.2                   | 18.7                   | 0                      | 0.66                   | ![Image](SVF_photo_C2.jpg) | ![Image](Env_photo_C2.jpg) |
Table 1. (Continued).

| Site number | Distance from the Yangtze River (km) | Distance from the Wuchang Railway Station (km) | Percent building cover (%) | Percent paved cover (%) | Percent green cover (%) | Percent water cover (%) | Sky View Factor (SVF) | SVF photos of measuring points | Environmental photos of measuring points |
|-------------|--------------------------------------|-----------------------------------------------|-----------------------------|------------------------|-------------------------|-------------------------|----------------------|---------------------------------|------------------------------------------|
| C3          | 0.11                                 | 0                                             | 25.2                        | 62.9                   | 11.9                    | 0                       | 0.78                 | ![SVF photo](image1) | ![Environmental photo](image2) |
| C4          | 0.32                                 | 0.32                                          | 24.6                        | 60.8                   | 14.6                    | 0                       | 0.99                 | ![SVF photo](image3) | ![Environmental photo](image4) |
| C5          | 0.10                                 | 0.10                                          | 20.2                        | 58.6                   | 21.2                    | 0                       | 0.99                 | ![SVF photo](image5) | ![Environmental photo](image6) |
| C6          | 0.08                                 | 0.08                                          | 10.2                        | 68                     | 21.8                    | 0                       | 0.96                 | ![SVF photo](image7) | ![Environmental photo](image8) |
| H1          | 0.28                                 | 0.28                                          | 28.8                        | 35.6                   | 26.6                    | 9                       | 0.83                 | ![SVF photo](image9) | ![Environmental photo](image10) |
| H2          | 0.37                                 | 0.37                                          | 16.4                        | 36                     | 19.6                    | 28                      | 0.93                 | ![SVF photo](image11) | ![Environmental photo](image12) |
| H3          | 0.44                                 | 0.44                                          | 32.2                        | 33.5                   | 34.3                    | 0                       | 0.77                 | ![SVF photo](image13) | ![Environmental photo](image14) |
| H4          | 0.67                                 | 0.67                                          | 29.8                        | 62.1                   | 8.1                     | 0                       | 0.71                 | ![SVF photo](image15) | ![Environmental photo](image16) |
| H5          | 0.44                                 | 0.44                                          | 24.7                        | 60.2                   | 15.1                    | 0                       | 0.58                 | ![SVF photo](image17) | ![Environmental photo](image18) |
| H6          | 0.37                                 | 0.37                                          | 22.9                        | 60.6                   | 16.5                    | 0                       | 0.97                 | ![SVF photo](image19) | ![Environmental photo](image20) |

(Continued)
Table 1. (Continued).

| Site number | Distance from the Yangtze River (km) | Distance from the Wuchang Railway Station (km) | Percent building cover (%) | Percent paved cover (%) | Percent green cover (%) | Percent water cover (%) | Sky View Factor (SVF) | SVF photos of measuring points | Environmental photos of measuring points |
|-------------|-------------------------------------|-----------------------------------------------|----------------------------|-------------------------|-------------------------|------------------------|------------------------|---------------------------------|---------------------------------------------|
| H7          | –                                   | 0.89                                          | 20.7                       | 53.3                    | 26                      | 0                      | 0.71                   | ![Image1]                         | ![Image2]                                   |
| H8          | –                                   | 0.76                                          | 21.5                       | 22.2                    | 56.3                    | 0                      | 0.67                   | ![Image3]                         | ![Image4]                                   |
| H9          | –                                   | 0.80                                          | 33                         | 33                      | 34                      | 0                      | 0.90                   | ![Image5]                         | ![Image6]                                   |

Table 2. Environmental description of the measurement sites.

| Site number | Shading information | Surface information |
|-------------|---------------------|---------------------|
| N1          | No shade            | Brick paved         |
| N2          | High density building area | Granite hard paving |
| N3          | A small amount of the shade | Concrete pavement |
| N4          | A small amount of the shade | Granite hard paving |
| N5          | No shade            | Concrete pavement   |
| N6          | No shade            | Concrete pavement   |
| N7          | Thin shade          | Granite hard paving |
| N8          | Thin shade          | Concrete pavement   |
| C1          | No shade            | Concrete pavement   |
| C2          | No shade            | Granite hard paving |
| C3          | No shade            | Granite hard paving |
| C4          | No shade            | Brick paved         |
| C5          | Thin shade          | Grass               |
| C6          | No shade            | Grass               |
| H1          | No shade            | Concrete pavement   |
| H2          | Thin shade          | Granite hard paving |
| H3          | No shade            | Concrete pavement   |
| H4          | No shade            | Concrete pavement   |
| H5          | No shade            | Concrete pavement   |
| H6          | Dense shade         | Concrete pavement   |
| H7          | Dense shade         | Concrete pavement   |
| H8          | Thin shade          | Granite hard paving |
| H9          | Thin shade          | Granite hard paving |

thermal environment, while the increase of building coverage and pavement coverage often has a negative impact on the thermal environment. The measured zone is between the Yangtze River and Wuchang Railway Station, and the distances of measured points to large-scale water bodies and high-energy buildings are also important. Man-made areas included built-up and paved areas, while natural areas included green space and water. The maximum percentage of the man-made area appeared at N5 (96.3%), at a large intersection near the Wuchang Railway Station, while the minimum value appeared at N1 (42%), located beside the Yangtze River. The average percentage of man-made and natural areas was about 76% and 24%, respectively, and over half of the measurement points contained less than 20% natural area. As such, man-made areas accounted for a high percentage of the study site, and the underlying urban surface was expected to have a substantial impact on the local thermal environment.

2.2.2. Measurement schedule and instruments

At the train station, measurements were started on 21 July 2017 and ran until 25 July 2017. HOBO sensors (UX100-003; Onset Computer Corporation; MA, USA) were installed 1.5 m above ground level with a protective cover against radiation to obtain and record the air temperature and relative humidity. TSI sensors (TSI 9565-P; TSI Inc.; MN, USA) were used to measure and record wind speed. In addition, portable weather monitoring stations were set up for long-term measurement. Table 3 lists the detailed information on the instruments used in this research.

3. Results and discussion

3.1. Measurement results

3.1.1. Measurement point data

Figure 3 shows the air temperature and relative humidity at each measuring point and the Wuhan meteorological station. The Wuhan meteorological station is an automatic monitoring station located in the suburbs of Wuhan, about 25 km from the Wuchang Railway Station. The data from this station are mainly used for weather forecasting. In this study, we used the data to calculate the UHI intensity near the Wuchang Railway Station. The average air temperature of the Wuhan meteorological station (32°C) was far lower than the range observed in the study area (35°C–36°C), revealing a clear UHI phenomenon in the study area. Among the measurement points, the air temperatures at N1, N2, and N3, located near the Yangtze River, were markedly lower than those at the other measurement...
points, suggesting that the Yangtze River had a modulating influence on the UHI intensity at the study site; however, this influence was limited by the distance from the river border.

Moreover, the average relative humidity of the meteorological station was 70%, while the relative humidity of the study site generally ranged from 50% to 60%. In addition, the relative humidity of N1 was much higher than that of the other stations.

### 3.1.2. UHI intensity around the Wuchang Railway Station

Figure 3 displays a comparison of the air temperature around the Wuchang Railway Station and at the

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**Table 3.** Range and accuracy of the measurement devices.

| Instrument  | Parameter    | Range         | Accuracy   | Frequency (min⁻¹) |
|-------------|--------------|---------------|------------|-------------------|
| HOBO sensor | Air temperature | −20–70°C    | ±0.2°C     | 5 (AO)            |
|             | Relative humidity | 15–95%     | ±3.5%      | 5 (AO)            |
| TSI sensor  | Wind speed    | 0–30 m/s     | ±0.015 m/s | 30 (AO)           |

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**Figure 2.** Percentage of land-cover types at each measurement point.

**Figure 3.** Air temperature and relative humidity at each measurement point in the study site and at the Wuhan meteorological station.
Wuhan meteorological station. The average temperature of point C2, C5, and C6, located near the railway station, was used to represent the temperature of the Wuchang Railway Station. The two sites showed similar daily trends in temperature, where the highest temperature at the railway station area appeared at 16:00, while the highest temperature at the meteorological station appeared at 17:00, with a 1-h deviation (Figure 4). Meanwhile, the lowest temperatures at the railway station and weather station were observed at 05:00 and 06:00, respectively, also showing a 1-h deviation. The average UHI intensity based on a comparison of the two sites was about 4°C (maximum: 6°C, minimum: 1.5°C). These results revealed a clear UHI phenomenon in the area surrounding the railway station.

3.2. Distance as a factor of thermal effect

3.2.1. Relationship between temperature and distance from the railway station border

Figure 5 shows the relationship between the distance from the railway station border and temperature for all measurement points. There was a low correlation between distance and temperature during the day, and a clearer correlation between sunset (20:00; $R^2 = 0.191$) and sunrise (04:00; $R^2 = 0.147$), where the best correlation appeared at midnight ($R^2 = 0.762$). Over the entire study area, the temperature at the measurement points decreased with increasing distance from the railway station border. At midnight, for each 1-km increment in distance from the railway station border, the temperature decreased about 0.8°C. The points farthest from the railway station were located near the Yangtze River, where a cooling effect was expected.

3.2.2. Relationship between air temperature and distance from the river border

The Yangtze River had a substantial cooling effect on the surrounding urban environment at night (Figure 6), with high correlations between the distance from the river border and air temperature at points N1–N8 (20:00: $R^2 = 0.672$; 24:00: $R^2 = 0.930$; 04:00: $R^2 = 0.496$). At midnight (24:00), for each 1-km increment in distance from the river border, the temperature increased about 0.61°C. By contrast, during the day, the correlation between the distance from the river border and air temperature at points N1–N8 was weak, likely due to strong solar radiation and anthropogenic heat generation.

3.2.3. Relationship between air temperature and distance from the railway station border at measurement points near the railway station

Figure 7 displays the relationship between the distance to the station border and air temperature at different times for measurement points within 1.0 km of the station, which showed a positive correlation at 15:00 ($R^2 = 0.595$) and 16:00 ($R^2 = 0.287$). Overall, the highest outdoor temperatures were observed during the afternoon, resulting in the generation of anthropogenic heat by an air conditioning of residential units, shopping malls, and vehicles to improve comfort. Meanwhile, the Wuchang Railway Station operates at a full load of 24 h in the day; therefore, anthropogenic heat generated by the railway station remained relatively stable. Thus, artificial heat generated during the afternoon had a substantial influence, resulting in higher temperatures farther from the railway station.

By contrast, at night, temperature exhibited a decreasing trend with increasing distance from the railway station, and the distance from the railway station border was somewhat correlated with air temperature at night (20:00:...
For instance, the temperature decreased by about 0.07°C, 0.09°C, 0.13°C, 0.04°C, and 0.04°C at the respective times with 0.1-km increments in the distance from the railway station border.

### 3.3. Land cover as a factor of thermal effect

#### 3.3.1. Relationship between temperature and the percentage of paved area

For all land-cover types, the paved area accounted for the largest proportion of area (maximum: 75.2%, average: 48.9%) (Figure 2, Table 1). There was no significant relationship between the percentage of paved area and air temperature during the day; however, at night, air temperature showed a slight correlation with the percentage of the paved area (20:00: $R^2 = 0.277$; 24:00: $R^2 = 0.296$; 04:00: $R^2 = 0.385$) (Figure 8). For instance, just before dawn (04:00), the air temperature increased about 0.15°C for each 10% increment in the percentage of the paved area.

Interestingly, a negative correlation was observed at 08:00. There were several explanations for this trend. Measurement points with high percentages of the paved area were mostly located in the square and were located some distance from the road. As such, these points were affected less by anthropogenic heat during
the morning rush hour, while points closer to the road were more affected. In addition, at this time, solar radiation had yet to reach a maximum; therefore, the temperature decreased with an increasing percentage of the paved area.

### 3.3.2. Relationship between the percentage of man-made area and air temperature

Figure 9 displays the relationship between the percentage of the man-made area and air temperature at different times on July 22–23, 2017. There was a nonsignificant relationship between the percentage of paved area and air temperature, and a significant correlation at night (20:00: $R^2 = 0.303$; 24:00: $R^2 = 0.210$; 04:00: $R^2 = 0.470$). For instance, just before dawn (04:00), the air temperature increased about 0.16°C for each 10% increment in the percentage of man-made area.

### 3.3.3. Relationship between the percentage of natural area and air temperature

Figure 10 displays the relationship between the percentage of natural area and air temperature at
different times on July 22–23, 2017. The temperature exhibited a decreasing trend as the percentage of the natural area increased at most times. Meanwhile, there was a significant relationship between the percentage of natural area and air temperature at night (20:00: $R^2 = 0.299$; 23:00: $R^2 = 0.363$; 24:00: $R^2 = 0.222$; 02:00: $R^2 = 0.267$; 04:00: $R^2 = 0.402$), where the temperature...
decreased by 0.16°C, 0.33°C, 0.20°C, 0.15°C, and 0.17°C for these respective times as the percentage of natural area increased by 10%.

4. Conclusions

We analyzed the influences of the Wuchang Railway Station and Yangtze River on the local urban thermal environment in Wuhan, China, a subtropical city, based on field measurements. We reached the following conclusions from the results.

(1) There was a 1-h deviation between the highest air temperature at the Wuchang Railway Station and Wuhan Weather Station, with a substantial UHI intensity around the railway station (maximum UHI intensity = 6°C). Overall, the air temperature near the Yangtze River was lower than that at other measurement points, and the lowest air temperature within the study site (31.3°C) appeared near the Yangtze River.

(2) The cooling effect of the Yangtze River affected the surrounding urban environment substantially at
night. At midnight, for each 1-km increment in the distance from the river border, the temperature increased about 0.61°C. During the day, the correlation between the distance from the river border and air temperature was weak due to strong solar radiation and anthropogenic heat generation.

(3) In the afternoon, higher temperatures were observed with increasing distance from the railway station, likely due to the greater influence of anthropogenic heat from residents, shopping malls, and vehicles, that meant railway station showed a cooling effect during the afternoon. By contrast, at night, there was a negative correlation between the distance from the railway station border and air temperature, that meant railway station showed heat island effect.

(4) There was a nonsignificant relationship between the percentage of the man-made area and air temperature during the day, but a significant correlation at night. Temperature exhibited a decreasing trend as the percentage of the man-made area increased.
natural area increased most of the time, although this trend was most evident at night.

The cooling effect of the Yangtze River and Wuhanchang railway station could be taken into account to mitigate the urban thermal environment in Wuhan in the summer. And the land cover also could play an important role.

**Disclosure statement**

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