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Measuring Ground-Level Urban Temperature: A Case Study of Suzhou, China

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Abstract

Ground-level temperature has an impact on human activities. As pedestrians involve physical movements at a walking speed, they are likely to seek out better walking environments. Ground-level temperature is a core to the walking environment in extreme weather conditions. This research addresses following research questions: what are the key to ground-level temperature in a highly urbanised area? What public facilities can decrease the ground-level temperature? The result shows that natural grass contributes to higher temperature in daytime and lower temperature after sunset. Shadings are very effective in decreasing ground-level temperature. Effects of water bodies in a city are unclear in mitigating warmer weather at a micro level.

Keywords: Ground-Level Temperature, Paving, Shading, Suzhou, Urban Heat Island Effect

1. Introduction

Ground-level temperature has an impact on human activities. As pedestrians involve physical movements at a walking speed, they are likely to seek out better walking environments. Temperature is one of the key elements for human activities. As global warming is threatening the earth, one evident concern is how to manage hot weather in summer, particularly in urban areas. An urbanisation rate reached at 52.1% worldwide in 2011; this rate is expected to increase up to 85.9% by 2050[24]. As manifested by urban heat island effects, temperature in cities is becoming a crucial issue in a city. Especially ground-level temperature, being warmer by the urban heat island (UHI) effect, is important to create better environments for human activities. UHI effects emphasise the temperature difference between urban areas and rural areas[12]. Highly urbanised areas tend to be warmer than the surroundings. However, research about the temperature within the highly urbanised area has not been addressed in detail despite extensive scholarly attention to the UHI effects. This research is, therefore, to focus on following research questions: what are the key to ground-level temperature in a highly urbanised area? What public facilities can decrease the ground-level temperature? The answers to these questions can help creating temperature-sensitive cities that encourage walking and outdoor human activities that are the core to liveability within the city where most people live. This research pays attention to one Chinese city, Suzhou that is experiencing rapid urbanisation, with a special focus on paving, shading and water bodies.

1.1 What Factors Make the Urban Heat Island Effects?

UHI effects are a well-known environmental outcome of urbanisation. Since Luke Howard, a British scientist, first found warm temperature in London in the 1810s[17], scholarly efforts have been paid to investigate UHI effects. UHI effects mean higher temperature in cities than rural surroundings due to heat generated by built materials and urban activities. The UHI effect is globally observed[14]. The temperature gap between urban areas and rural areas ranges 10 to 15°C in daytime[1]. Temperature continues hot even at night in a highly urbanised surface[7]. Heat is stored during the daytime and the urban materials radiate the accumulated heat at night.

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A wide range of interrelated factors are associated with high urban temperature. Firstly, the construction of cities has destroyed urban vegetation[12,15]. Natural plants provide shade, increase evapotranspiration and reduce run-off of rain water. However, urban development is a process of land use conversion from natural land to an impervious surface. The impervious hard surface cover radiates heat, increasing urban temperature[20]. New construction of buildings, roads and other infrastructure alters flows of evapotranspiration, energy, water and wind.

Second, materials of the surface affect urban temperature as they are the key to albedo, thermal emittance[21], and heat capacity. Albedo means solar reflectance calculated by the percentage of solar energy reflected by a surface. The material and the colour of the surface affect albedo. For instance, concrete and asphalt have low albedo; much heat remains on the surface, causing high surface temperature[6]. Building materials, such as steel and bricks, have higher heat capacities than rural materials, such as natural soil and sand. With regard to colours of the material, it is known that dark surfaces such as asphalt roads absorb more sunlight that light-coloured surfaces[2]. [5]Claimed that metropolitan areas can absorb and store heat twice more than rural surroundings during the daytime.

Third, urban geometry is one of the causes for UHI effects. Urban geometry refers to the dimensions and layouts of buildings in a city. High-density buildings can store heat and change wind at a micro level[19,25].

Fourth, anthropogenic heat (or heat generated by human activities) also matters for urban temperature. Anthropogenic heat is primarily from fossil fuel combustion. The source of anthropogenic heat includes power plants, vehicles, and air-conditioners[6,18]. High density cities tend to have high anthropogenic heat due to massive energy consumption for cooling in summer and heating in winter[23]. Human activities result in emissions of heat, carbon dioxide and pollutants, too. These emissions are one of the causes for the microclimate change[1].

Fifth, natural weather plays a fundamental role in urban temperature. Wind and cloud are the two main elements for urban temperature[3]. UHI effects are more obvious in less windy weather, with a clear sky without cloud. Wind can blow away heat; cloud can block solar heat to reach to urban surfaces[16].

Six, some studies have paid attention to effects of water on temperature. However, the result is controversial. For instance, Steeneveld et al[22]. Have argued that urban water bodies have a limited influence on the urban microclimate. There is a cooling down effect especially when the temperature of surface water is relatively warm such as at night in summer. Hathway and Sharples[9] observed that rivers could decrease urban temperature up to 1.5°C in day time in spring.

Seventh, the topography and the geographic location of the city affect urban temperature. For instance, mountains create wind and the hilly sections provide cool weather at high altitudes[32].

The literature has shown that multiple factors are involved in the UHI effect as discussed. A number of studies have shown a trend in temperature across the city and the surrounding rural areas[1]. However, the literature has little attention to key factors to urban temperature on the street within cities. What factors are critical to urban street temperature within highly urbanised areas at a micro scale? This question is crucial in helping design temperature-sensitive cities. Temperature on the streets affects pedestrian behaviours such as walking, recreating, and shopping. The primary objective of this research is to investigate street-level temperature in a city. To provide implications for urban design, this research pays attention mainly to physical, tangible elements. From the findings in the literature, three key elements that can be possibly designed and managed were specified: surface materials (paving), shelters (shading), and water bodies. Suzhou, one of the fast urbanising Chinese cities, is used as a case study for this research.

2. Suzhou, a Fast Urbanising, Water Abundant Chinese city

This chapter outlines the case study area, Suzhou. It has experienced fast urbanisation that affects urban temperature. Also, there are a number of water resources that could be an important element for urban temperature.

2.1 Urbanisation in Suzhou

Suzhou is located in the centre of the Yangtze River Delta. Over the last three decades, Suzhou has experienced rapid urbanisation[8]. As can be seen in Figure 1, land cover changed dramatically between 1986 and 2005. Buildings were mainly located in traditional urban centres in 1986 when urbanisation was at the very initial stage, but farmland disappeared due to massive construction as can be seen in 2005. Growth in hard surfaces would be one of the causes for UHI effects in Suzhou.

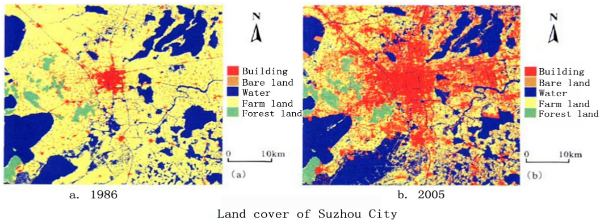

Figure 1. Land cover changes in Suzhou, 1986 – 2005. *Source*: Xu et al[30].

Urbanisation in Suzhou started with the Chinese nationwide reform and open policy in 1978. The urbanisation rate of Suzhou was less than 17% before 1978. However, it increased to 24.9 % in 1990[26]. In the period of the early stage of urban expansion in Suzhou (1979 – 1990), urban development and economic growth relied upon Township and Village Enterprises (TVEs)[11,28,29]. In the 1990s, TVEs have disappeared due to inefficient labour-intensiveness, vague property rights, backward technology and poor productivity [31].Suzhou urbanisation entered into the second stage when the Chinese government focused on the construction of development zones in Suzhou. At the 14th National Congress of the Chinese Communist Party in 1992, two nation-level development zones were confirmed in Suzhou: High-tech Industrial Zone (or Suzhou New District) and Suzhou-Singapore collaborated industrial zone (or Suzhou Industrial Park)[8].As a result, Suzhou has transformed into a highly urbanised, globalised area. In 2000the urbanisation rate reached at 42.9% in Suzhou[26]. The trend in urbanisation has continued to the extent that the urbanisation rate reached at 72.3% in 2013.

In accordance with rapid urbanisation, built-up areas have been increasingly growing. The built-up area was 55 km^2 in 1978; increased to 130 km^2 in 1996; 336 km^2 in 2011; and even 437 km^2 in 2012.[1] Over the one year, more than 100$km^2$of land was converted to impervious land in Suzhou[27].

2.1.1 *A Water Abundant City*

Suzhou is located at the downstream of the Yangtze River and the eastern side of the Tai Lake. Including these two water bodies, there are more than 20 thousand canals and 300 lakes in Suzhou [4,10]. The water area is 3609.4km^2, accounting for 43% of the total Suzhou land area. These lakes used to provide fresh water for agriculture, but their use is changing to provide recreational functions for residents. The size of the Dushu Lake, where this research has conducted, is 11.5km^2.

2.2 Research Design

Three factors: paving materials, shading, and water bodies

As discussed, this research has relied upon three factors to analyse urban temperature at a ground level. At the same whole day from midnight to midnight (24 hours), temperature was recorded by professional thermometers in different places. The measurements have been completed in both a sunny day and raining day. As UHI effects are more critical in summer, temperature observation has been recorded in summer, June – July, 2014. All the thermometers were placed at a level of 1.5m to reflect how pedestrians feel, as shown in Figure 2. Also, the temperature was compared with temperature information from the local meteorological centre.

First, thermometers were placed on different paving materials. They were natural grass, concrete floors, and concrete floors along the traffic road. Second, to measure the shading effect, thermometers were placed under trees, pavilion, and shaded bus station (plastic cover). Here, the control variable was the temperature on the impervious street without any shading. Third, to analyse the effect of water bodies, thermometers were placed along the different size water bodies, i.e., the Dushu Lake, a small canal and an artificial fountain.

2.2.1 *Description on the Thermometer and the Process of Temperature Recordings*

Professional temperature measuring devices were used for this research. The whole set of devices includes temperature loggers, a base station with coupler and a computer software to transit the log data to a computer. Temperature was measured and the data were recorded by

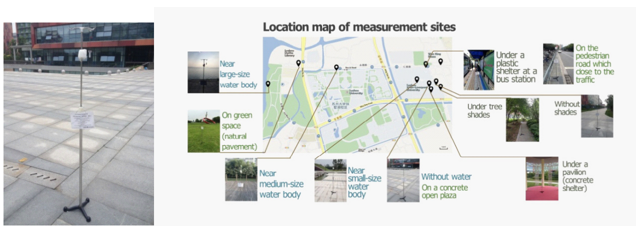

Figure 2. A temperature logger and a location map.

1 Here the built-up area excludes roads and urban parks.

2 The Tai Lake is the second largest lake in china, providing fresh water resource for Suzhou.

HOBO Pendant Temperature loggers [Model: UA-001-64] produced by Onset Computer Corporation. Each temperature logger has a sensor to measure temperature and a memory chip with approximately 64kb storage space that enables to record over 52,000 temperature data. The measurement range of each device is from -20°C to 70°C with an accuracy of ±0.47°C at 25°C. The loggers are water-proof. The temperature was measured at every 5 minutes.

2.3 Results of Temperature Measurements

2.3.1 Paving Effects

The trend in temperature was similar in sunny and rainy days. The ground-level temperature was stable in the early morning and began to rise after 7:00am.Since the noon, the temperature had increased significantly as a typical summer day. It reached record highs in the afternoon about 4.00 pm. Then, the temperature dropped gradually (Figure 3 and Figure 4).

The temperature on the natural grass tended to be the highest in the daytime especially in sunny weather

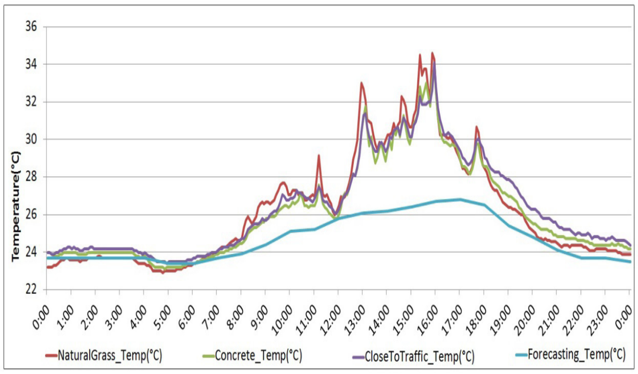

Figure 3. Temperature on different paving materials in a sunny day.

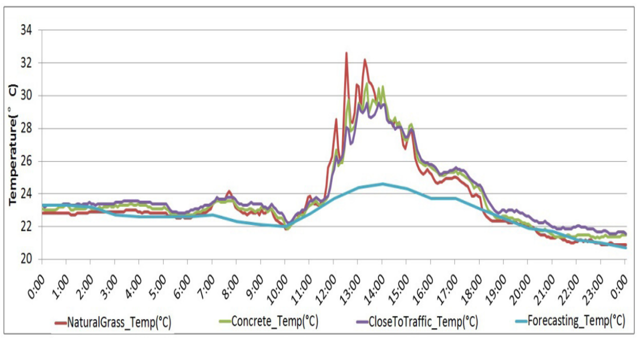

Figure 4. Temperature on different paving materials in a rainy day.

(Figure 3). The natural grass had even higher temperature than the concrete surface by 2.2°C. This may be related with very low albedo levels of grasses[13]. However, the temperature on the grass tuned into the lowest after sunset. Natural grasses were the lowest in temperature for the longest period of time over a day. On a raining day, there were a few hours for the temperature on natural grass to reach the highest. As long as grasses were not under direct sunshine, e.g., rainy or cloudy weather and after sunset, urban parks provide cooler environments. Grasses radiate heat immediately when heat from the sun acted upon. In the same way, grasses do not store heat for a long time, so natural grasses were the lowest in temperature at night.

The close-to-traffic concrete paving showed the highest in temperature both before 7.00am and after 4.00pm. Motorised vehicles produce warm greenhouse gasses that could affect ground level temperature. The temperature gap between the concrete surface away from motorised vehicles and close-to-traffic concrete paving was 0.897°C on a sunny day, representing emissions from vehicles could increase the temperature by almost 1°C.

One obvious result was that there was a significant difference between the weather information from the local meteorological centre. In most cases, the temperature information from the meteorological centre was lower than measured temperature. The temperature gap reached at 8.2°C. The weather forecast and/or announced information may provide underestimated temperature information because the temperature might not be observed within a city where most people act.

From this observation, paving could affect the urban temperature at a ground level, but the influence was not as evident as shading to be discussed in the next section.

2.3.1.1 Shading Effects

Shading has a more direct impact on ground-level temperature. The temperature on the open plaza without any shading was approximately 4°C higher than that in the shade of concrete pavilion, approximately 5°C higher than that in the shade of plastic cover at the bus station and more than 7°C higher than that in the shade of tree tunnels (Figure 5 and Figure 6). This result was from the temperature record at 11:00am in a sunny day. The temperature under the tree shade was always the lowest among all the different types of shadings. Trees were more effective than artificially built structure. So, they provide cooler walking environments for pedestrians.

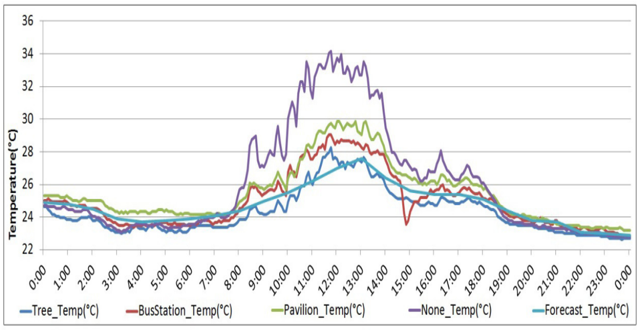

Figure 5. emperature under different shadings in a sunny day.

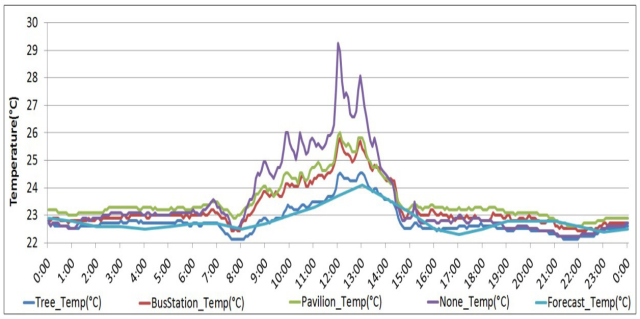

Figure 6. Temperature under different shadings in a rainy day.

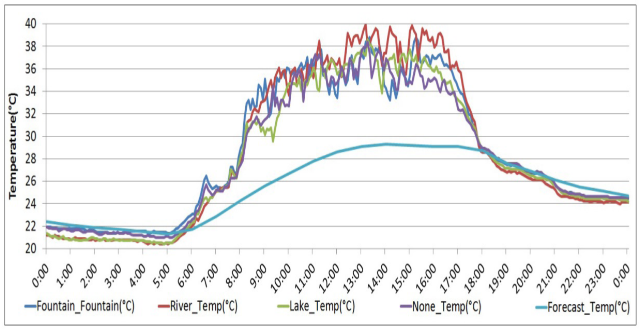

Figure 7. Temperature with proximity to different types of water bodies in a sunny day.

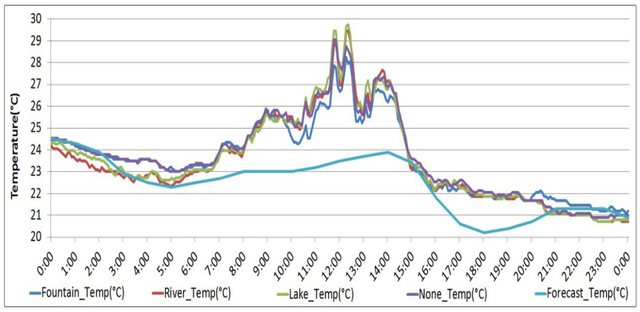

Figure 8. Temperature with proximity to different types of water bodies in a rainy day.

Obviously other types of shading structure provide lower temperature during the daytime. However, temperature during the night time under built structure was higher than the temperature in the open plaza. Built structure absorbs heat and radiates it during the night time. When shading is unnecessary at night, the temperature is even higher than the places under no shading. Nevertheless, man-made shadings can contribute to creating pedestrian-friendly environments as human activities are likely to take place in the day time.

2.3.1.2 Water Effects

Water effects on the ground level temperature are unclear from the data (Figure 7 and Figure 8). There was no clear trend in changes in temperature in accordance with proximity to water bodies. The temperature near lakes and large water bodies was not always cooler than places without water, which was different from common perceptions. Large lakes, such as the Dushu Lake, may radiate and absorb heat concurrently while they create wind. All these impacts may not directly affect the ground level temperature. The presence of lakes may affect climate at larger scales, but that impact is out of the scope of this research. The manifest result is the temperature gap between the measured temperature and announced temperature. The recorded temperatures fluctuated frequently due to micro-level climates, but the graph of the temperature from the meteorological centre was relatively flat.

Fountains are also unclear in ground level temperature. People may feel cooler because of water from the fountain and canals, but does not affect temperature directly.

2.4 Implications and Conclusion

This research measured ground-level temperature in Suzhou in relation to paving, shading and water bodies. In contrast to common perception that natural grass is helpful in mitigating urban heat island effects, the research outcome shows that natural grass is hotter than hard surface such as concrete and paved roads alongside the traffic lanes in day time due to low albedo. However, along with sunset, natural grass immediately turns into the coolest place. The temperature on the natural grass after sunset was lower than other paved roads by a maximum of 3°C. Heat is unlikely to be stored on the natural grass; heat is quickly released from the natural grass. Therefore, in summer, the hottest season, parks on natural grass are helpful for outdoor activities after sunset due to low temperature. So, in a park, trees and other facilities that can provide shading are encouraged for daytime activity; lights are encouraged in the evening.

Secondly, natural trees are the most effective in mitigating hot temperature on the street. Trees can decrease the temperature up to 7 °C. Leaves block heat from the sun directly and radiate the heat to the air due to low albedo. Connected tree tunnels can decrease temperature significantly and may be able to encourage pedestrians to walk under the tree shades. So, planting trees in public plazas and between main nodes within walking distance will benefit pedestrians and facilitate their walking. In the same way, built facilities such as plastic and concrete shelters provide cool temperature environments although their effects are less significant than natural trees. This can provide design implications in public space particularly for warm cities such as cities with tropical weather or in the period of summer seasons. Semi-opened public space covered by artificial shelter can benefit from sunlight and block direct sunshine and heat. For instance, as seen in Figure 9, outdoor cafes covered by shelters can decrease temperature encouraging outdoor activities. Temperature can be also managed by planting natural grass under the shelter. As the canopy blocks direct sunshine, natural grass can contribute to the reduction of ground-level temperature.

Fountains on the street may get people to feel cool psychologically, but indeed the effect on the temperature is minimal as long as people are not wet. The announced temperature is not reliable especially on the street where sun is directly shining. This research has focused on measuring temperature at a ground level. How the temperature affects human behaviour on the street could be a next step for further research.

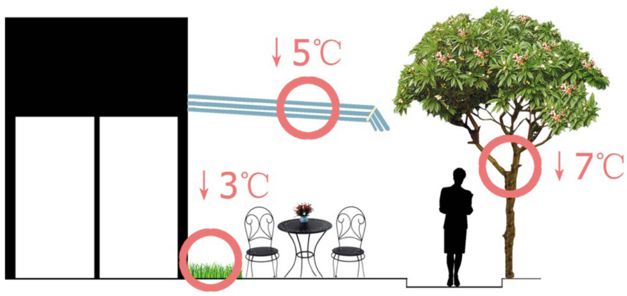

Figure 9. Exemplary street design with public facilities to decrease ground-level temperature.

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