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A NEW COMPARATIVE ANALYSIS OF LOCAL URBAN MORPHOLOGY BASED ON LOCAL CLIMATE ZONES: A STUDY USING MOBILE SURVEYS IN CHENGDU TESTBED

Abstract: *The local climate zones (LCZ) classification introduced by Stewart and Oke is to standardize climatic observations. It aims at linking different land cover types to corresponding thermal properties directly from the perspective of urban geography. Yet the classification needs further development when it is applied to local studies, especially to analysis of the urban morphology. The World Urban Database and Access Portal Tools (WUDAPT) is intended to produce a global shared database capturing information on urban form and function for climate applications. Chengdu was chosen as a testbed for WUDAPT level 1 and level 2 development. This study's purpose is to improve the local development and validate the applicability of the LCZ classification in Chengdu in hot summer and cold winter areas in China based on the urban morphological methods in architecture and urban design. A local urban morphological analysis template was developed, including qualitative characteristics and quantitative indicators. Field investigations on urban morphology and mobile surveys on air temperature have taken place 3 times since the summer of 2017 to gather the data about air temperature with surveyors going by vehicles and on foot. The result was in general accord with the LCZ theory. Moreover, it presented some interesting differences under the impact of local urban morphology.*
Keywords: *local urban morphological analysis template, local climate zones (LCZ), World Urban Database and Access Portal Tools (WUDAPT), mobile surveys.*

1. Introduction

Urban morphology has always been an important research topic in many disciplines such as urban geography, architecture, urban planning, and urban history. Urban morphology affects urban climate. Under the background of urban climate change, more and more urban climatologists begin to pay attention to the relationship between urban morphology and urban climate. The local climate zones (LCZ) classification was introduced by Stewart and Oke to standardize climatic observations and its aim is linking different land cover types to corresponding thermal properties directly from the perspective of urban geography (Stewart, 2012). Local climate zones are defined as regions with uniform surface cover, structure, material, and human activity that spans from hundreds of meters to several kilometers in horizontal scale, and a characteristic screen-height temperature regime over dry surfaces, during calm and clear nights. The local climate zone classification system has 17 basic types, including 10 built landscape types and 7 natural cover types. The classification framework has been applied to many cities in the world, such as Nagano (Japan), Vancouver (Canada) and Uppsala (Sweden) (Stewart, 2013), Nancy (France) (Leconte, 2014), Dublin (Ireland) (Alexander, 2014), Nagpur (India) (Kotharkar, 2018). However, few scholars have made the specific case verification in hot summer and cold winter areas in China. Besides, the classification needs further development when it is applied into local studies especially to analysis in the urban morphology.

The World Urban Database and Access Portal Tools (WUDAPT) aims to produce a global shared database capturing information on urban form and function for climate applications (Mills, 2015; Bechtel, 2015). Chengdu was chosen as a testbed for WUDAPT level 1 and level 2 development to make a sample survey of urban landscapes based on the LCZ map to provide more detailed information about urban form and function. During the rapid urbanization of the past, new open built-up regions with high-rise buildings and high-intensity business have been formed on the periphery of the traditional compact city centre with multi-storey buildings and medium-high density in Chengdu.

This study aims to improve the local development and validate the applicability of the LCZ classification in Chengdu (hot summer and cold winter area in China) based on the urban morphological methods in architecture and urban design.

2. Methodology

2.1. Study Areas

Chengdu is located in the middle of Sichuan Province, and the transition zone between the Northwest Plateau of Sichuan Province and the Sichuan basin, which is between 102°54' – 104°53' E and 30°05 ' – 31°26' N. According to Cobain's climate classification, it belongs to the subtropical monsoon humid climate with abundant heat, rich rainfall and four seasons. The annual average temperature is 16.7°C. According to the "thermal design code for civil building" (GB 50176-2016) of China, Chengdu is located in hot-summer and cold-winter climate zone. The climate is characterized by sultry heat in summer, humid cold in winter and less sunshine. Summer usually lasts from June to August with the monthly mean temperature of 23.8-25.4°C. Winter usually lasts from December to February with the monthly mean temperature of 5.6-7.9°C. The traditional central urban area and the southern new urban area were selected to map the local climate zones

2.2. LCZ map building method

For LCZ classification, Stewart and Oke put forward three steps: collecting site metadata, defining heat source area and selecting suitable LCZ area.

Data sources include Baidu map, street view and field research. ArcGIS was used to change the raster data of Baidu map to the DWG file of Autodesk AutoCAD. The height of building was determined with the street view and field surveys. Thus, the basic database of urban morphology was established in ArcGIS. Three indexes including building density, building average height and green coverage rate were selected to classify the local climatic zones preliminarily. Taking into account the need for follow-up mobile observations of thermal environment in typical samples, in order to minimize the impact of intensive traffic flow, road traffic analysis, was first performed on the survey area. The area was first divided with the main and minor roads. And then, using the block as the boundary, the average building height, building density of the block in ArcGIS, and the green coverage rate were manually calculated.

The second step was to understand the impact of the urban form on the local climate. According to WUDAPT protocol, we used free data and software to complete this step. Under the WUDAPT workflow, urban block data was used to create "training areas".

Finally, we compared the neighbourhood indicators with the LCZ reference indicators proposed by Stewart to preliminarily determine the types of local climate zones in each block, and construct a LCZ map of the study area. The mixed area and the open space to be built were retained.

2.3. Local urban morphological analysis template

Typical blocks were selected to conduct a sample survey to further analyze their morphological characteristics and thermal environment. The typical blocks selected have homogeneous form, the diameter of not less than 400 meters, or not less than 200 meters in special situation, less influence of traffic heat discharge, and convenience to make the mobile observations.

According to the local climate zone theory, each LCZ is associated with 10 indicators, but in fact, some indicators are difficult to obtain, such as the local-scale surface admittance, surface albedo, and anthropogenic heat output. At the same time, it is difficult to describe the actual morphological characteristics of the local climate zone completely by only calculating its morphological index while identifying the difference of the thermal environment of the local climate zone. We need to further develop the morphological analysis framework when we apply the local climate zone to the analysis of the local urban morphology. The framework of morphological analysis should include two parts: qualitative characteristics and quantitative indicators.

The qualitative characteristics include seven aspects: the city location, the surrounding area form, the building stereoscopic form, the block layout, the surface cover, the land use function and the anthropogenic heat fluxes (Table 1).

Table 1

Qualitative characteristics of morphological samples

Qualitative feature	Content
City location	Including the old city and the new city, the city centre and the periphery of the city. In Chengdu, urban centre means the densely-built areas inside the Third Ring Road, and the periphery of the city refers to urban areas outside the Third Ring Road separated by large-scale ecological green space.
Surrounding area form	Types of built form and natural cover around LCZ samples.
Block stereoscopic form	Changes in the height of the building and the openness of the street.
Block layout	Including singular blocks, linear blocks, courtyard blocks and mixed blocks.
Surface cover	Surface cover and vegetation condition.
Land use function	The main land use function of the district.
Anthropogenic heat fluxes	Air-conditioning use, traffic flow, heat removal from shops along the street, etc.

Quantitative calculation indicators include sky view factor (SVF), canyon aspect ratio (H/W), building surface fraction (BSF), impervious surface fraction (ISF), Pervious surface fraction (PFS), Mean building height (H) and Terrain roughness class (TRC). The calculation method of each indicator is shown in the table below (Zheng, 2017).

Table 2

Definition and calculation methods of urban morphology indicators

Indicator	Definition	Data Sources	Computational methods	Calculation Tools
SVF	Average SVF for non-building areas within the sample. The SVF is the SVF value (with an accuracy of 1m*1m) at a certain point in the non-building area of the sample, and *n* is the number of SVF points within the sample.	GIS data	$SVF=\frac{\sum_{i=1}^{n} SVF_i}{n}$	SkyHelios
H/W	The average aspect ratio of samples. It is the ratio of the average building height to the average street width in the sample. SW is the average street width.	GIS data	$H/W=\frac{H}{SW}$	ArcGIS
BSF	The proportion of land occupied by buildings in the sample. *n* is the number of buildings in the sample, S*i* is the building footprint, and S_*site* is the total footprint of the sample.	GIS data	$BSF=\frac{\sum_{i=1}^{n} S_i}{S_{-site}}$	ArcGIS
ISF	The impervious surface ratio in the sample.	Google earth	ISF=1-BSF-PSF	Artificial
PSF	Permeable surface ratio in the sample. S_*per* is the pervious area in the sample.	Google earth	$PSF=\frac{\sum S_{-per}}{S_{-site}}$	Artificial
H	The area-weighted building average height of the sample. *n* is the number of buildings in the sample, H_*i* is the height of the building, and S*i* is the building footprint.	GIS data	$H=\frac{\sum_{i=1}^{n} S_i H_i}{\sum_{i=1}^{n} S_i}$	ArcGIS
TRC	Davenport terrain roughness class	According to the Davenport classification		

2.4. Mobile survey

Fixed observations and mobile surveys are the two main methods of urban climate ground observations. Fixed observations can obtain stable and reliable observation data, but only one meteorological datum from one observation site can be obtained each time. Under the condition of limited observation sites, it is difficult to obtain meteorological data in a large spatial range of the city at the same time. The mobile observation compensates effectively for this shortcoming. With the combination of current high-sensitivity temperature and humidity sensors that can continuously collect meteorological data and GPS trajectories, it is possible to obtain high spatial resolution along the design path with the help of mobile tools using limited instrumentation equipment. Weather data have important advantages for studying the local climate differences of different local-scale urban morphotypes on a large scale. The mobile survey method has been widely used in urban climate studies in Singapore (Priyadarsini, 2008), Malaysia (Qaid, 2016), Hungary (Unger, 2001), and Japan (Yokoyama, 2017). Therefore, the mobile survey method was chosen to get the air temperature conditions at screen height (1.5 m) of typical blocks of different LCZ types.

The instruments used in the mobile observation experiment mainly include 3 automatic temperature and humidity recorders and a GPS device. The parameters of instruments used for mobile observation are shown in Table 3. The automatic temperature and humidity recorder was placed in the shutter box to block the radiation and facilitate ventilation. Two temperature and humidity recorders were used to record the temperature and humidity parameters of the mobile observation route. One was fixed on the roof of the car to collect observation data route (Fig. 1), and the other was used to collect temperature data while travelling on foot in the inconvenient for car area. Another temperature and humidity recorder was used for fixed observation. The temperature and humidity recorder and GPS recording time interval were set to 5s for making correspondence of climate data and trajectory later. All temperature and humidity instruments were located 1.5 meters above the ground.

Table 3

Equipment for the mobile survey

Instrument	Manufacturer/ Model	Basic function/Accuracy
Temperature and humidity automatic recorder		
	Shenzhen Huatu S100-TH++	Basic function: recording climate data such as air temperature and humidity on the mobile observation route. Accuracy: Temperature measurement range is -20 ~ 70°C, accuracy ± 0.2°C; Humidity measurement range is 0 ~ 100% RH, accuracy is ± 2%.
GPS		
	Garmin eTrex201x	Basic functions: recording latitude and longitude, altitude reading and vehicle speed information of each track point according to the movement observation route. Accuracy: Positioning accuracy (SBAS) is 1-3 meters, time accuracy is 1s.

An effective mobile observation route was designed to cover most typical neighbourhoods. The route should be simple and conducive to traffic. Mobile observations had been conducted three times. The specific mobile observation time and weather conditions are shown in the following table (Table 4). The wind direction and wind speed date were received from Chengdu Weather Network data on the day of observation. The wind speed is the average wind speed during the observation period, and the wind direction is the prevailing wind direction during the observation period. The cloud amount is estimated according to the actual situation during the observation period. Each mobile observation required about 2.5 to 3 hours, with weather conditions of clear, partly cloudy sky and low wind speed. These meteorological conditions were similar during the previous day.

Figure 1. Instrument device for vehicle-mounted mobile survey

Table 4

Mobile survey time and weather

date	route	time	Cloud amount	wind direction	Wind speed
06/09/2017	Route1	19:26-21:46	3	N	0.6m/s
03/02/2018	Route2	19:30-22:42	4	NE	0.6m/s
06/03/2018	Route 2	19:32-22:35	4	NE	1m/s

The fixed observation site was located at the top of the school's teaching building, with no shelter around it, so it could well reflect the background meteorological changes. Considering the evolution of air temperature occurring in the mesoscale during the mobile observation process, simultaneity correction of the mobile observation data was performed based on the observation data from the fixed reference site.

2.5. UHI Calculation

The intensity of the urban heat island (UHI) in the local climate zone means the temperature difference between different LCZ types ($T_{LCZ\,X-Y}$). Stewart recommended the low vegetation (LCZ D) as a reference to calculate the UHI of different LCZs. In the actual observation of this study, the sparse tree type (LCZ B) with similar vegetation types on the mobile observation route was selected as the reference, with the surface coverage of mainly lawn and low-density forests. The UHI of each LCZ, written as $UHI_{LCZ\,X}$, is defined as

$$UHI_{LCZ\,X} = T_{LCZ\,X} - T_{LCZ\,B}$$

$T_{LCZ\,X}$ represents the average temperature of the LCZ X, and $T_{LCZ\,B}$ represents the average temperature of the LCZB.

3. Results analysis

3.1. The LCZ map

The result shows that LCZ2 and LCZ4 are the predominant classifications in this area, followed by LCZ5 and LCZ1, which are also significant. The number of LCZ3 is relatively small and there is only one LCZ6 (Fig. 2). This is related to the high cost of land development in the central urban area. The area also contains two city parks which are LCZBs. It can be seen from the map that there are more mixed forms in the old urban blocks within the three ring roads. The main manifestations have two forms: one is the combination of multi-storey buildings and high-rise buildings; the second is the mixture of large green spaces, squares, multi-storey buildings and high-rise buildings. The southern new urban area is relatively more homogeneous, but there exists some undeveloped construction land.

In the mobile observations of different seasons, 25 morphological samples were selected, including 24 built landscape types and 1 natural coverage type. The built types consist of 3 LCZ1, 6 LCZ2, 3 LCZ3, 8 LCZ4 and 4 LCZ5.

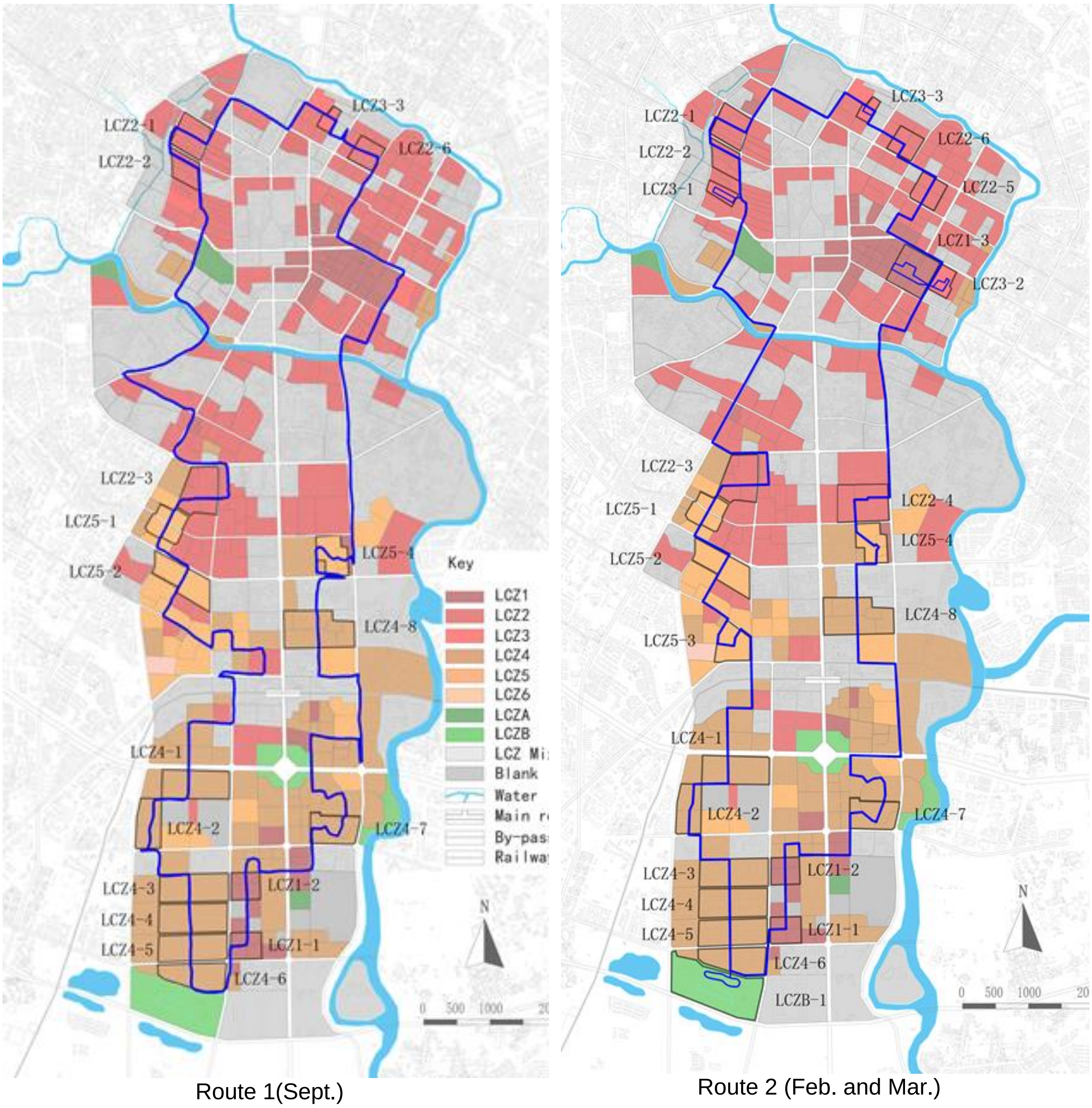


Figure 2. LCZ map and the mobile survey route

3.2. Morphological characteristics of typical blocks

Figures 3-8 show airborne views, street views and indicators in the range of different LCZs.

LCZ1 is the lowest and that of the LCZ4 is the highest; the street height width ratio of the LCZ1 is the highest and that of the LCZ5 is the lowest; the building density of the compact type is obviously higher than that of the open building, and its permeable rate is far lower than that of the open high-rise building.

3.3. Mobile surveys outcome

Figure 9 shows the temperature distribution of mobile survey routes of the three times. The average temperature of typical samples is presented in Figures 10-12. All the temperature data were indicated for one and the same moment. The relative UHI intensity of different LCZ types in different months is shown in Figure 13.

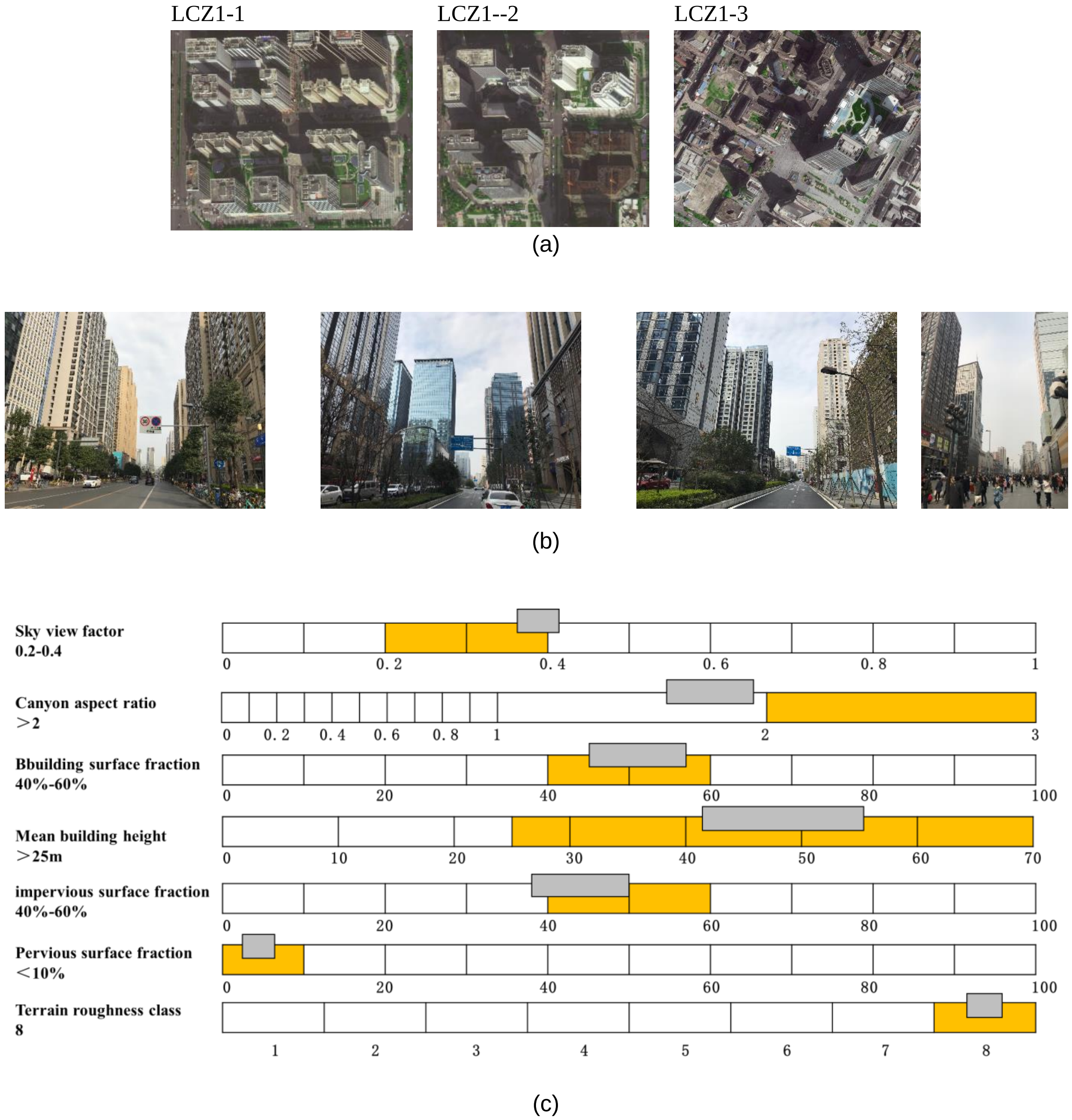
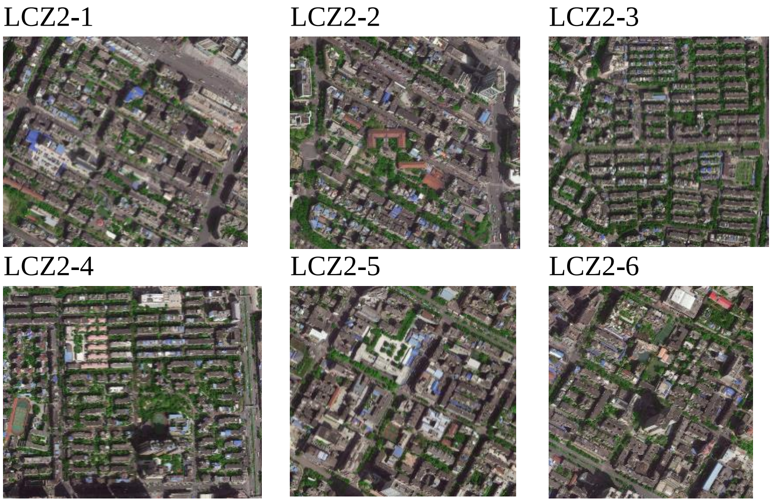


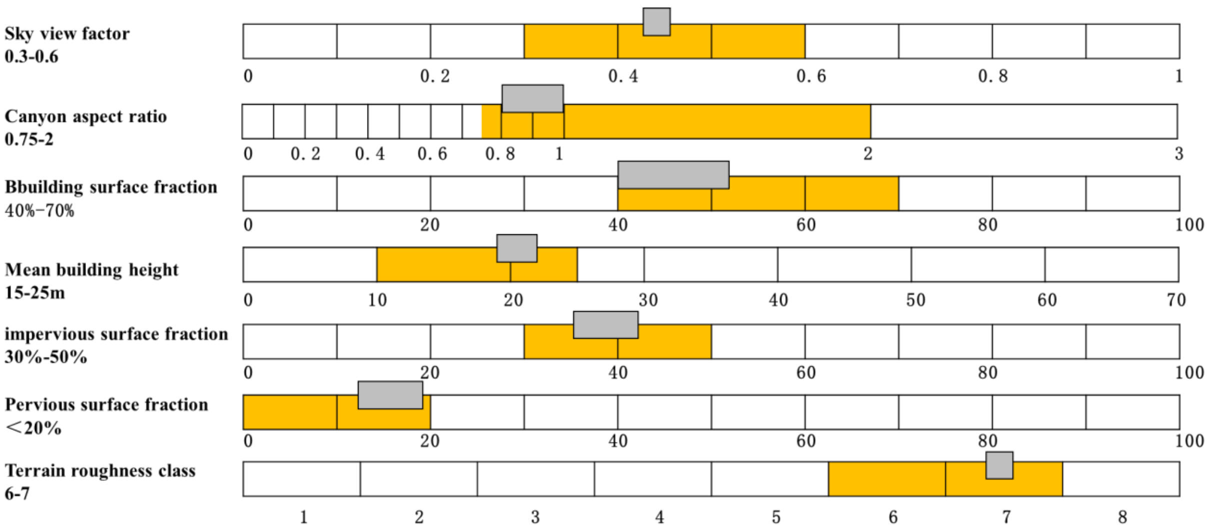
Figure 3. (a) Airborne view of LCZ1, (b) Street view in LCZ1, (c) Indicators range for LCZ1

The results show that the thermal difference exists between samples of the same LCZ and different LCZ types. For LCZ1, the temperature on the periphery of the city is significantly lower than the temperature at the centre of the city. For LCZ3, the temperature at LCZ3-3 is always lower than LCZ3-1 and LCZ3-2. LCZ4, LCZ4-1 and LCZ4-8 often have higher temperature anomalies, while LCZ4-6 and LCZ4-7 often appear as “cold spots”. According to the UHI results, it is higher in March. In general, LCZ1, LCZ2, and LCZ3 located in the centre of the city have higher UHI. The UHI of LCZ4 located at the periphery of the city is the lowest, followed by that of LCZ1 located at the periphery of the city and LCZ5 near the centre of the city. Among them, the difference in the UHI of LCZ1s in different locations is significant, and the UHI of LCZ1 located in the centre of the city is considerably higher than of that located at the periphery of the city.



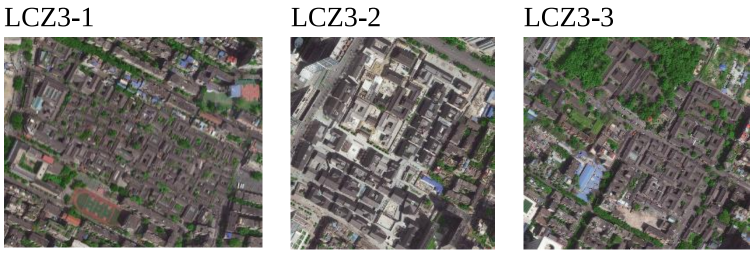
(a)

(b)



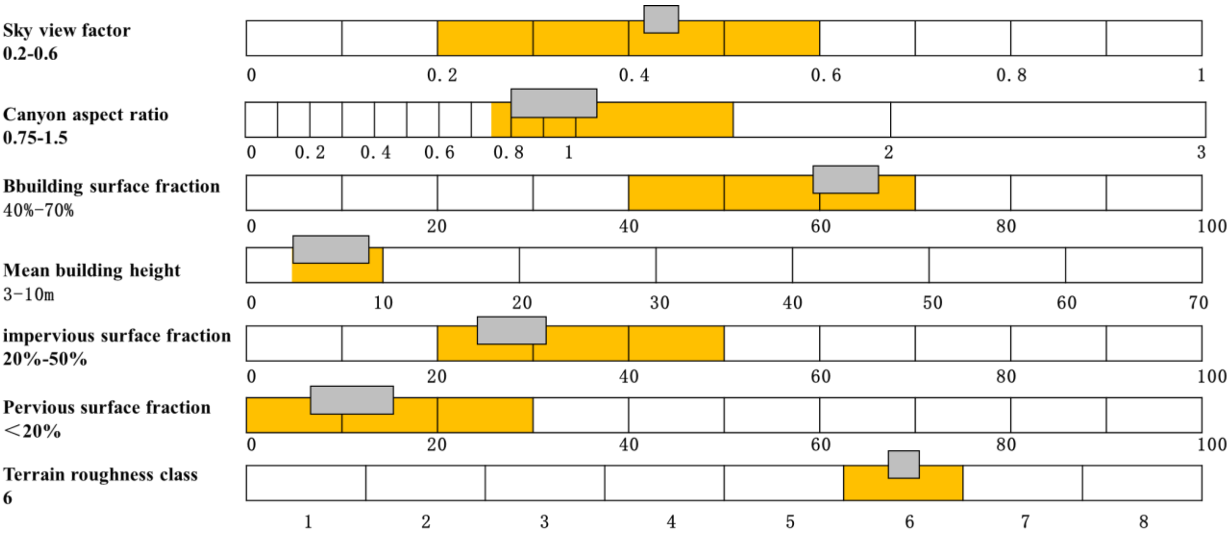
(c)

Figure 4. (a)Airborne view of LCZ2.(b) Stre et view in LCZ2.(c) Indicators range for LCZ 2



(a)

(b)

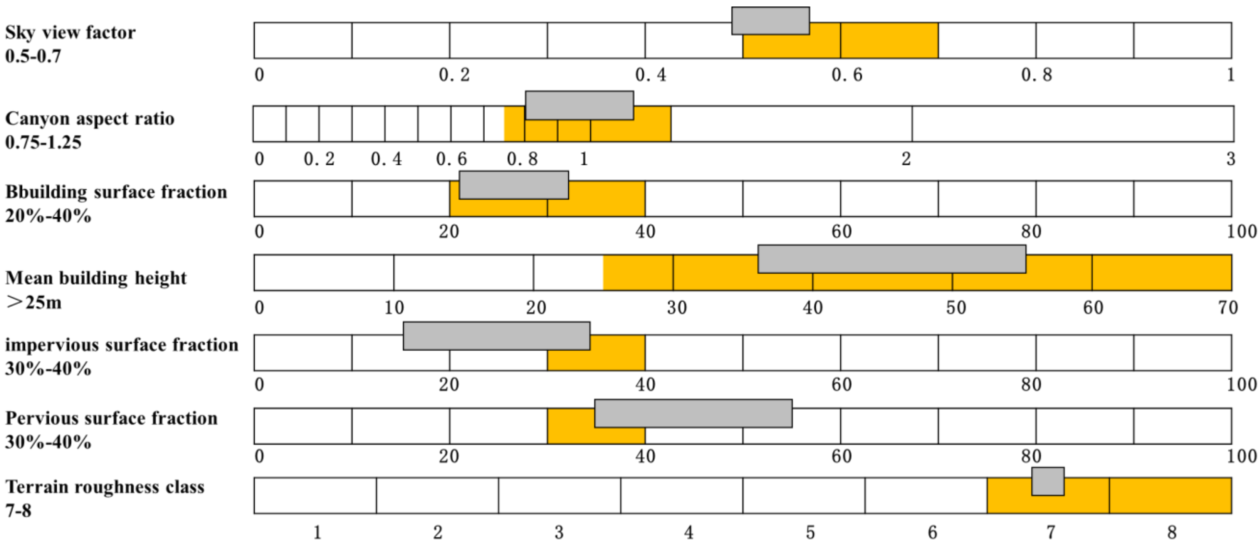


(c)

Figure 5. (a)Airborne view of LCZ3.(b) Street view in LCZ3.(c) Indicators range for LCZ 3

(a)

(b)

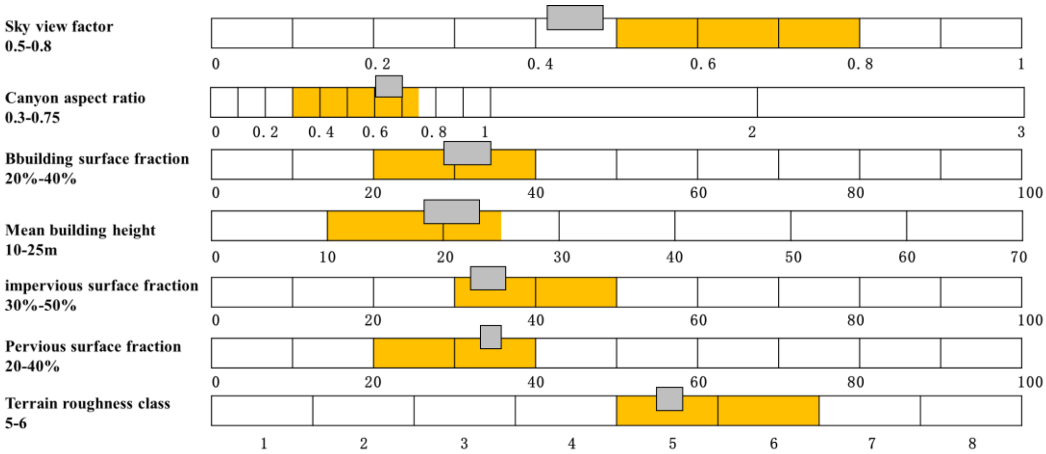


(c)

Figure 6. (a)Airborne view of LCZ4.(b) Street view in LCZ4.(c) Indicators range for LCZ 4

(a)

(b)



(c)

Figure 7. (a)Airborne view of LCZ5.(b) Street view in LCZ5.(c) Indicators range for LCZ 5

Figure 8. Airborne view and street view in LCZB

Quantitative indicators of the selected blocks are basically consistent with the reference indicators provided by Stewart and Oke, but there are also some differences. For example, LCZ1 has lower aspect ratio, LCZ4 has higher permeability and lower impermeability. For the single indicator, the SVF of the

20:40 of Sept. 06 | 21:00 of Feb. 03 | 21:00 of Mar. 06

Figure 9. Temperature distribution of mobile survey routes

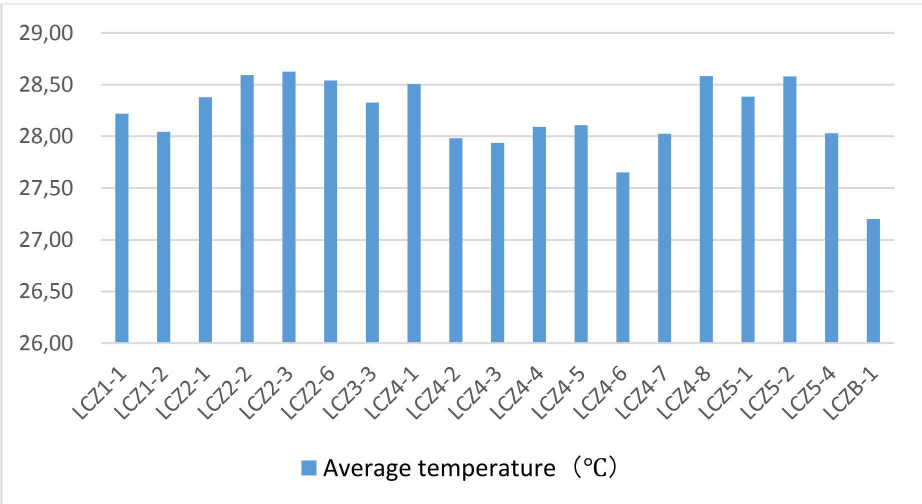


Figure 10. Average temperature of typical samples at 20:40 of Sept. 06

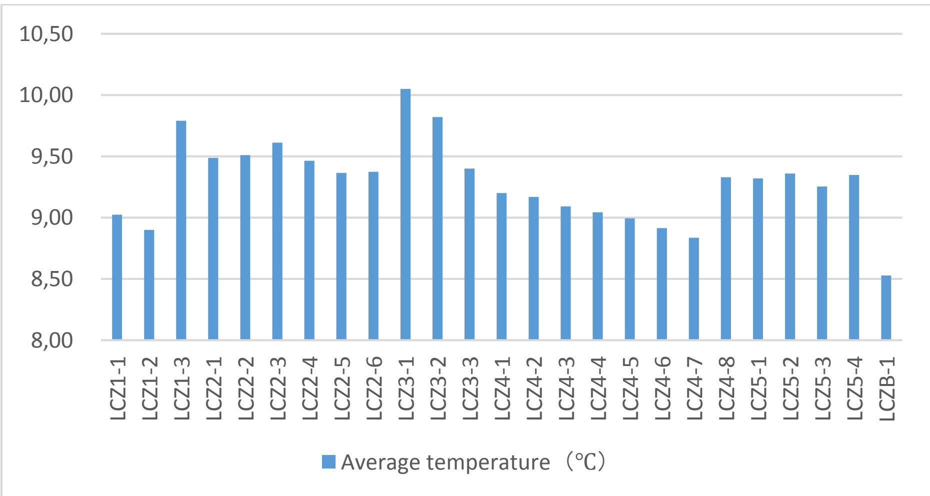


Figure 11. Average temperature of typical samples at 21:00 of Feb. 03

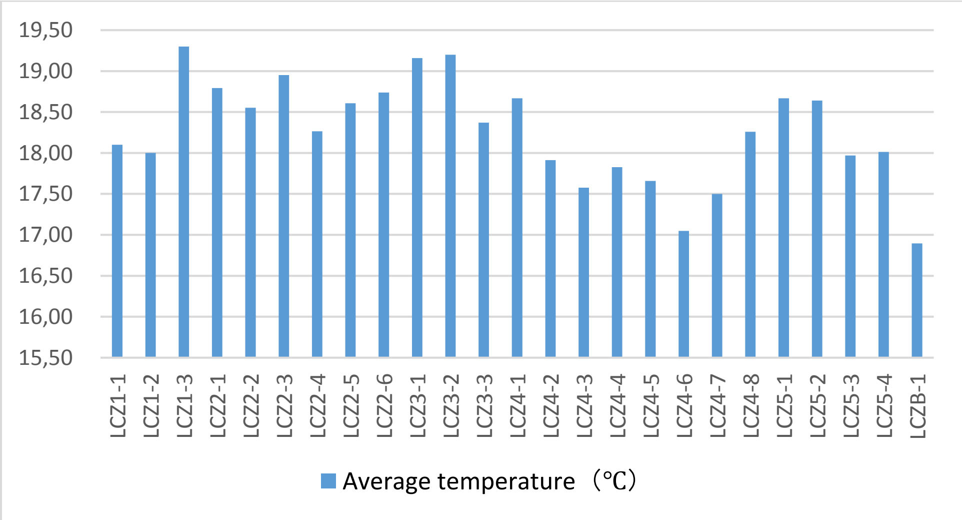


Figure12. Average temperature of typical samples at 21:00 of Mar. 06

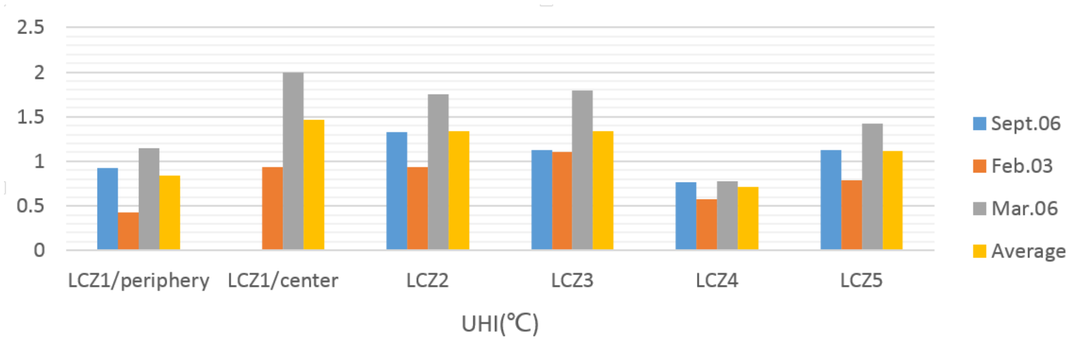


Figure 13. UHI of different LCZs at night of different months

4. Disscusion and Conclusion

The results analysis shows that, in addition to the morphological indicators, the qualitative characteristics of the morphological features, including urban location, surrounding area morphology, land use function, and anthropogenic heat fluxes, have important influence on the thermal environment. Urban areas at the periphery of the city beyond the Third Ring Road with large-scale ecological green spaces have better ventilation and heat dissipation conditions, compared with the densely-built areas in the city centre within the Third Ring Road, which is conducive to reducing the heat island effect. The form of the surrounding area affects the thermal environment at a relatively small scale, showing that when the surrounding area is compact, it is beneficial to the heating, and it has obvious cooling effect when the surrounding area is open or is situated near large parks and rivers. The impact of land use function is more complex. Under the combined effects of urban form, greening level, and anthropogenic heat fluxes, it is used as land for warming or cooling. The anthropogenic heat fluxes happen due to the effect of increasing the temperature of traffic heat and crowds. It has a strong warming effect close to the main traffic roads in the city, and the air temperature is usually higher in areas where commercial activities abound.

This study aims to improve the local development and validate the applicability of the LCZ classification using mobile surveys based on the urban morphological methods in architecture and urban design. The result was in general accord with the LCZ theory. Moreover, it presented some interesting differences under the impact of local urban morphology. The template of local morphological analysis based on the meteorological metadata development showed important value to make more effective analysis.

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