ANNUAL HEAT ISLAND MAGNITUDE OF DIFFERENT URBAN FORM TYPES BASED ON MOBILE SURVEYS

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ABSTRACT

Local Climate Zones (LCZs), from the perspective of urban form typology, interprets the principles of urban thermal climate, which can realize the standardized comparison of the thermal environment differences between any urban form types, and promote the study of urban heat island. This paper introduces the LCZ and adopts mobile survey to collect morphological data and thermal environment data for 18 months in the urban-rural junction area of Southwest Jiaotong University, Pidu District, Chengdu. This study's purpose is to discusses the relationship between different urban form types, morphological indicators and heat island magnitude, and finally verify the rationality and effectiveness of the application of LCZ in the urban-rural junction area, which is beneficial to provide new directions for the exploration of sustainable urban form at block scale.
Keywords: urban form,Local Climate Zones,urban-rural junction,mobile survey,heat island magnitude.

INTRODUCTION

Rapid pace of urbanization is leading to the intensification of urban heat island, and sustainable urban development is a priority. In recent years, research on urban sustainable form development has attracted much attention, and exploring the relationship between urban form and urban heat island has become a research hot spot, which has greatly promoted the research on heat island. Local Climate Zones（LCZs）(Stewart& Oke,2012) uses urban morphological language to explain the principles of urban thermal climate and divides urban form and surface landscape into 17 types. This classification scheme breaks the traditional definition of heat island intensity for the temperature difference between urban and rural areas, and achieves a standardized comparison of thermal environment differences between any morphological types within the city, that is, "local heat island magnitude". Since LCZs was put forward in 2012, it has carried out studies on the differences between different types of urban heat islands and the influencing factors of urban heat island in more than 130 cities and regions(Stewart et al., 2014; Alexander & Mills, 2014; Leconte et al., 2015;Chen&Huang,2019). However, related researches mostly take small and medium-sized cities as the research object, the studies on the comparison of diverse samples in local areas of cities are relatively limited. Especially in China, there are few studies on the observation of thermal climate features in the urban-rural junction area where large-scale built-up areas and natural areas are highly intertwined.

BACKGROUND

Mobile survey can use limited instruments to capture high-coverage urban form information and environmental temperature in the study area in a short time, becoming one of the most classic

methods of data collection. Bicycle survey can capture more information about urban form that are not available in open urban data, and obtain detailed information on air temperature fields in areas where cars cannot pass (Lehnert et al., 2018). It is a new and more promising method for data collection at block scale. Long-term mobile surveys will cost a lot of manpower and material resources, but the changes in the built form(Kotharkar et al., 2019), seasonality of plants (Yang et al., 2018) and human activities (Stewart et al., 2014) have a comprehensive effect on the urban heat island, which will cause fluctuations in the annual urban heat island effect. Long-term research is particularly necessary.

This study trys to apply LCZs to the urban-rural junction area of the Southwest Jiaotong University in the Pidu District, Chengdu and aims to test its rationality and applicability. Bicycle surveys are used in urban-rural junction with station surveys to collect urban form information and long-term night heat island observations to study the annual change characteristics of the heat island effect, considering the impact of built form, plants, human activities and other factors on the urban heat island.

METHODOLOGY

1.Sample selection and survey route

The area of Southwest Jiaotong University, Pidu District, Chengdu, where compact mid-rise built area and natural area are highly intertwined, is more suitable for bicycle surveys to collect urban spatial patterns and thermal environment data on the mobile survey scale.

This paper use the photos and videos taken by mobile survey and combine with the urban open data to calculate the sky view factor (SVF) and other morphological indicators in the study area, and then classify the LCZ types of different samples. Finally, 11 LCZ samples in the area were selected for long-term temperature observations, including 6 purely built samples, 1 built-natural sample, 3 natural samples, and 1 sample of LCZ type changed from built to natural coverage due to human activities (Figure 1).

LCZ *Sample name*	*Satellite Map*	*LCZ* *Sample name*	*Satellite Map*	*LCZ* *Sample name*	*Satellite Map*	*LCZ* *Sample name*	*Satellite Map*
$LCZ2_E$ *Linwan Village*		*LCZ5* *TangRong Yuan*		*LCZ5* *Southern District Dormitory*		*$LCZB_G$* *Xipu Lake*	
LCZ4 *Jinyuan*		*LCZ5* *Xihui Jinyuan*		*LCZ9** *Datian Road Farmhouse*		*LCZD* *Datian Road Farmland*	

LCZ4 Jinyuan Phase II		LCZ5 North District Dormitory		LCZB Southern District Park	

Figure 1 This is a table that introduces the LCZ type of selected samples.

The observation route is a single line, from south to north, from the compact built area (Linwan Village) through the center of all the research samples and avoid the route being too long to the natural area (Datian Road farmland/farmhouse). The length of the whole route is 12km(Figure 2), and it takes about 80-90 minutes for a bicycle survey. At the starting point of the observation, the rider uses the Bluetooth connection to start the automatic temperature and humidity measuring instrument about 1.5m from the ground, and the GPS logger on the chest, then rides according to the pre-routed route.At the same time,the fixed stations also start data collection. In order to accurately carry out the simultaneous correction of the data of various samples , 5 fixed stations were set in the built and natural samples (Figure 2).

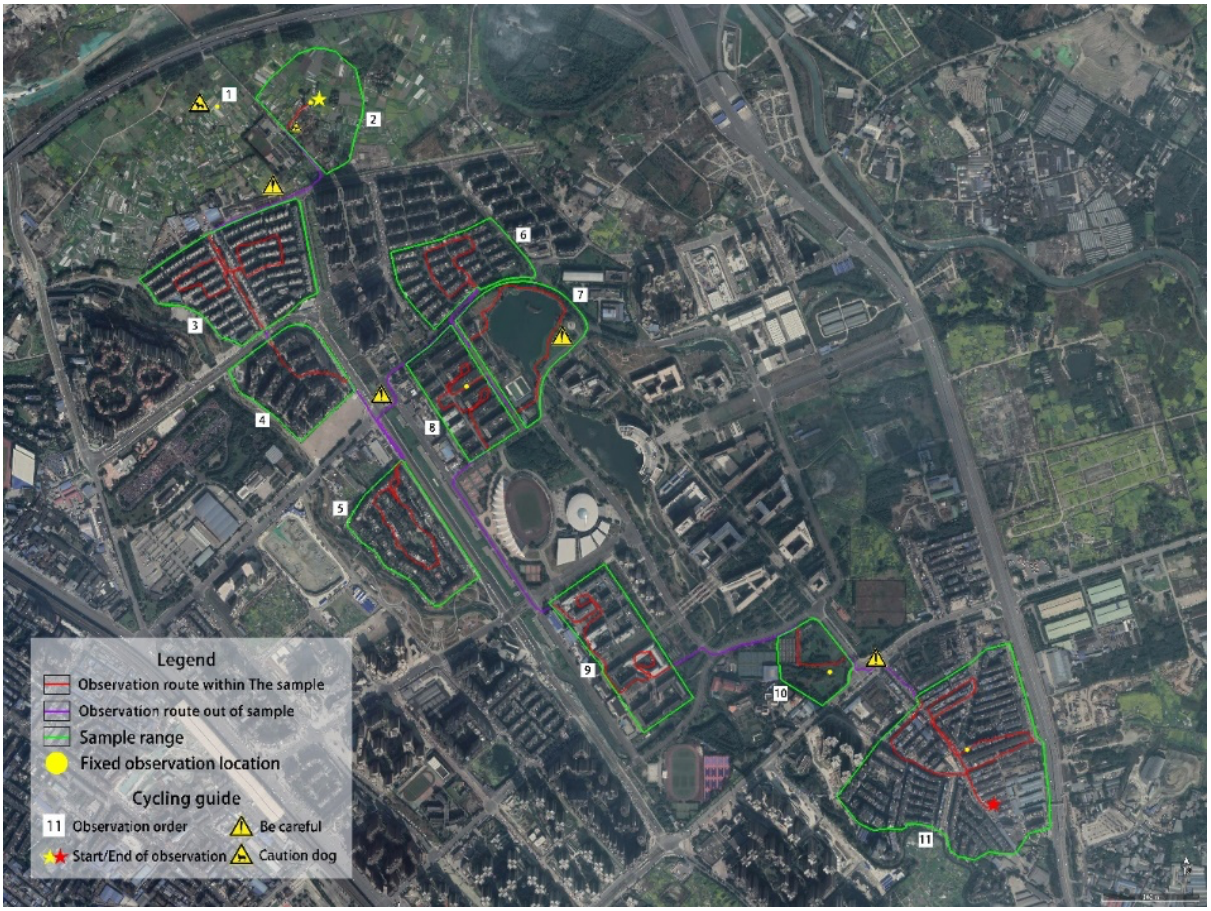

Figure 2. Observation samples and route map

2.Typical observation days

From August 2018 to January 2020, the team carried out 34 mobile survey experiments, covering the four seasons. The weather factor(ω_W) (Stewart et al., 2014) evaluation method was used to

quantify the weather conditions on the day of observation, and the day with $\theta_W \geq 0.8$ and without precipitation before 24h was regarded as the ideal observation day. In total, 19 days are selected.

3.Heat island magnitude solution

The LCZD in the study area are affected by human activities (surface coverage, man-made heat removal), its type changed throughout the year.Therefore, the more stable sample LCZ5 (North District Dormitory) with fixed station is used as a basic case to calculate the local heat island magnitude. The magnitude is defined as the temperature difference between other LCZ types[i] and LCZ5 (North District Dormitory),which is $\Delta T_{LCZX} - \Delta T_{LCZ5\ (\text{North District Dormitory})}$,or $\Delta T_{LCZX-LCZ5}$.

FINDINGS

1.Morphological characteristics of different samples

Based on the sample form data obtained by the mobile survey, morphological indicators of 11 LCZ samples are as follows(Figure 3), where θ_{sky}, θ_v and θ_b are the key indicators that affect the heat island(Kotharkar et al., 2019). In all samples, natural samples have a larger θ_{sky} than built samples, but the θ_{sky} of LCZB is close to built type due to trees. The law of θ_v is: compact built type ($LCZ2_E$) <open built type (LCZ4/5) <sparsely built type (LCZ9)<natural type ($LCZD/B/B_G$). In the built samples, the law of θ_b is: compact built($LCZ2_E$)>open built(LCZ4/5)>sparsely built (LCZ9). The characteristic parameter values of LCZ4 and LCZ5 are similar, and the characteristics of LCZ9 is close to the natural sample.

LCZ Type	*Sample name*	*Characteristic Parameters*[a]				
		θ_b *(%)*	θ_H *(m)*	θ_{sky}	θ_v *(%)*	θ_i *(%)*
LCZ 2_E	*Linwan Village*	*41*	*17*	*0.63*	*6.6* [b]	*52.4* [b]
LCZ 4	*Jinyuan*	*30.1*	*33*	*0.55*	*31.5*	*37.7*
	Jinyuan Phase II	*27.4*	*33*	*0.59*	*34.0*	*38.6*
LCZ 5	*Xihui Jinyuan*	*28.7*	*25*	*0.53*	*27.4*	*43.9*
	TangRong Yuan	*27.7*	*17*	*0.68*	*35.5*	*36.8*
	North District Dormitory	*27.0*	*17*	*0.64*	*39.4*	*33.6*
	Southern District Dormitory	*26.7*	*17*	*0.66*	*28.4*	*44.7*
LCZ 9/LCZ D_E*/LCZ* C_{DW}*/ LCZ* C_{WE}*/LCZ* D_{CE}*	*Datian Road Farmhouse*	*10.0*	*4*	*0.86*	*84.6*	*6.5*
LCZ B	*Southern District Park*	*0.8*	*3*	*0.63*	*94.5*	*4.7*
LCZ B_G	*Xipu Lake*	*8.9*	*3*	*0.83* [b]	*84.6* [b]	*6.5*
LCZ D/LCZ D_C*/LCZ* C_D*	*Datian Road Farmland*	*0*	*<1*	*1.00*	*96.5*	*3.5*

[a] θ_b is the building surface fraction, θ_H is the height of roughness elements, θ_{sky} is the sky view factor, θ_v is the pervious surface fraction, θ_i is the impervious surface fraction;[b]Exceeds the threshold of the corresponding LCZ category indicator; * Mean

the type corresponding to the sample at the beginning of the observation, and then its type changes due to building demolition or seasonal vegetation replacement.

Figure 3 This is a table that shows morphological indicators of selected LCZ samples.

2.Sample types and heat island magnitude

Based on the observation results of 19 ideal observation days, the project team analysised the night heat island magnitude boxplot of each LCZ (Figure 4). Linwan Village ($LCZ2_E$) is the sample with the largest heat island magnitude relative to the North District dormitory (LCZ5), with a median value of 1.0K, and the samples with the smallest heat island magnitude are Datian Road Farmland and Datian Road Farmhouse, they are -2.7K,-2.2K.

The interquartile range in the boxplots show that the annual heat island magnitude fluctuations of natural coverage samples (LCZB/$LCZB_G$ and Datian Road Farmland/Datian Road Farmhouse) are relatively large, which are 0.98, 0.49, 1.68, 1.34, it is related to the seasonal changes of plants and the annual changes of human activities (mainly surface coverage). However, compared with LCZB, $LCZB_G$ has a smaller fluctuation range. Because the $LCZB_G$ contains a large amount of water, the specific heat capacity of the water is large, so the temperature of the lake surface changes slowly, and the temperature of the adjacent air also changes slowly. The fluctuation of the heat island magnitude of the built samples ($LCZ2_E$/LCZ4/LCZ5) is basically smaller than that of the natural samples, which are all less than 0.9. $LCZ2_E$ is a compact midrise commercial and residential mixed zone, and the fluctuations of the heat island are mostly unstable due to human activities and unstable artificial heat removal. LCZ4 and LCZ5 are mostly residential areas with lush plants, so heat island changes are mostly related to seasonal changes of plants.

3.Morphological indicator and heat island magnitude

The magnitude of 7 types of local heat islands with different surface morphological characteristics are very different. The heat island magnitude of the built samples (except for Datian Road Farmhouse) are larger than the natural samples. Because the Ψ_{sky} of natural samples are larger than the built samples, the built samples are covered by more sky, making it difficult for heat radiation to dissipate heat to the sky. In addition, Ψ_v for the natural samples are much larger than the built-up samples, and more permeable ground helps to reduce the heat island effect. It can be speculated that increasing both Ψ_{sky} and Ψ_v has the potential to reduce the magnitude of the heat island.

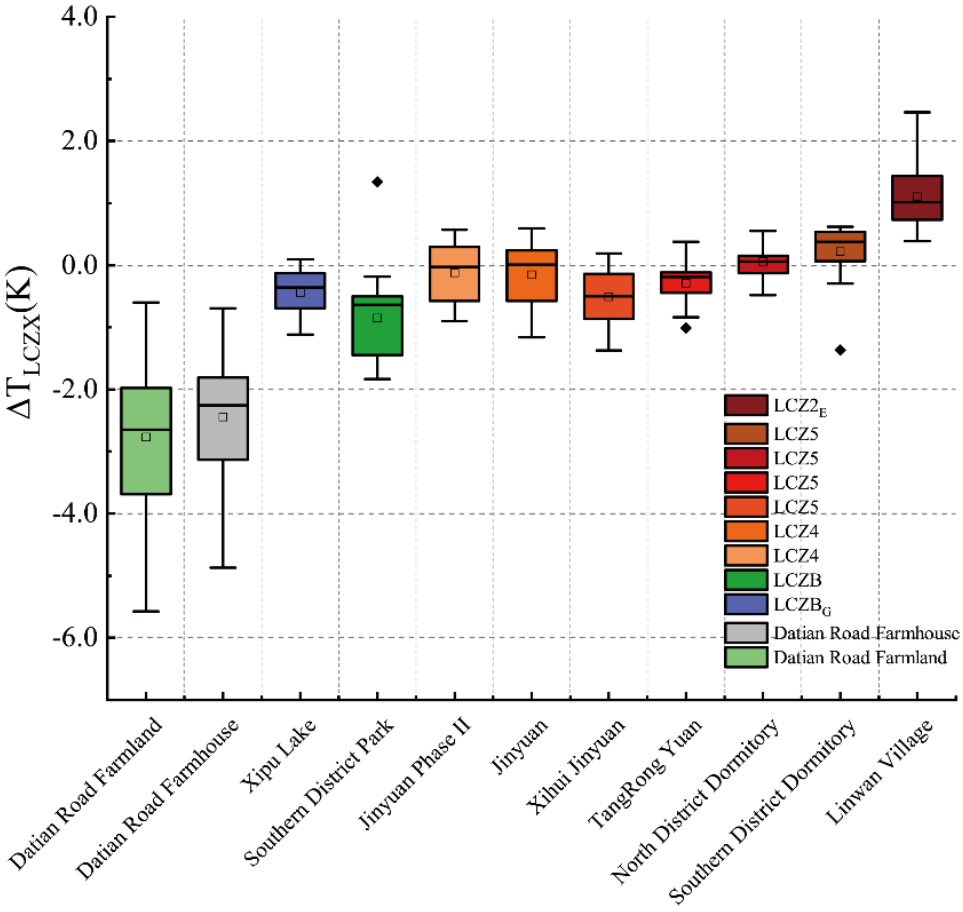

Figure 4. Box plots of heat island magnitude of selected zones

Among the built samples, compact type ($LCZ2_E$) is hotter than open type (LCZ4/5) and sparsely type (LCZ9), because the λ_b of the compact sample is higher, and there is more permeable ground and tree planting, transpiration and daytime shading helps to slow down the heat island effect at night. It can be speculated that the sample λ_b is positively correlated with the local heat island magnitude, and λ_v is negatively correlated with the local heat island magnitude. The open type samples of LCZ4 and LCZ5, which have closely λ_b. The Z_H of LCZ4 is slightly larger than that of LCZ5, but the heat island magnitude of LCZ4 and LCZ5 is not much different, and the regularity of the gap is not obvious. Therefore, The significant impact of Z_H on urban heat island has not been captured in this experiment. In addition, the annual heat island magnitude of Datian Road Farmland and Datian Road Farmhouse is similar, which is related to the close morphological characteristics of the two(Stewart& Oke,2012).

CONCLUSIONS

This paper has selected the urban-rural junction area where the compact midrise area and the natural area are highly coupled and intertwined, which is very suitable for the study of the local climate characteristics of different built forms and naturally covered land surface. This study has initially verified the rationality and application of LCZ in the urban-rural junction area and has promoted the research of the built form impact on the thermal environment in the urban-rural junction.

LCZs is used to interpret the principles of thermal climate from the perspective of urban form classification, and to explore the magnitude difference of local heat island between different urban form types.At the same time, through the quantification of indicators for different urban form types, the law of morphological indicators and heat island magnitude are further discussed.This law can provide a reference for the regulation and design of urban form, and has a positive significance for the exploration of sustainable urban block form.

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[i] Local temperature after the simultaneous correction of the observation data of LCZ sample