UDC 711

Yuan Huang[1]*, Yanxiao Pan[1], Shuxian Chen[1], Jason Ching[2], Yu Xi[11]

[1]*Southwest Jiaotong University, Chengdu, 611756, China*
[2]*Institute for the Environment, University of North Carolina, Chapel Hill, NC, 27517, USA*
**e-mail of corresponding author: yuanhuang@home.swjtu.edu.cn*

A COMPARATIVE STUDY ON THERMAL ENVIRONMENTAL PERFORMANCE OF THE URBAN FORM PROTOTYPES BASED ON LOCAL CLIMATE ZONE (LCZ) SCHEME

Abstract: *The local climate zones (LCZ) classification was introduced by Stewart and Oke to standardize climatic observations. It aims at linking the different land cover patterns to their corresponding thermal properties directly from the perspective of urban geography. Yet the classification needs further development when it is applied into local urban form studies. The World Urban Database and Access Portal Tools (WUDAPT) strives to produce a global shared database capturing information on urban form and function for climate applications. Chengdu has been chosen as one of the testbeds around the world for WUDAPT level 1 and level 2 development. This article tries to develop the urban form typology study from the perspective of urban climatology, and to integrate the scheme of "local climate zones (LCZ)" landscape classification and "urban form typology". It takes Chengdu as the testbed in hot-summer and cold-winter area. Firstly, based on the survey of the actual urban form, it extracts and purifies the theoretical prototypes of LCZ1 ~ 6. Based on the numerical simulation model "ENVI-met", it compares the outdoor thermal performance of different LCZ theoretical prototypes in winter, it validates the applicability of LCZ theory in Chengdu and it has found that the result rules are basically consistent with the LCZ assumptions in the hot summer and cold winter areas. Finally, it proposes a research paradigm for the application of urban form typology to the further development of (LCZ) scheme.*
Keywords: *World Urban Database and Access Portal Tools (WUDAPT), local climate zones (LCZ), urban form typology, theoretical prototype, simulation and validation.*

1. Introduction

1.1. Research background

As a standardized classification for climate observations, local climate zones (hereinafter referred to as LCZ) approach aims at linking different land cover patterns to their corresponding thermal properties from the perspective of urban geography. LCZ approach classifies surface landscapes from the perspective of climatology based on land cover, land use functions, and urban spatial form. It "decodes" the principles of urban thermal climate through readable "form" languages, such as spatial scale (microscopic, local) and design elements (building height, low plants coverage rate) (Perera, Emmanuel, 2018), which has a great significance for the development of urban form typology study in the perspective of climatology.

However, the classification of LCZ is mainly based on land cover patterns, rather than form, structure and function. Therefore, although the description of the urban climate at the regional scale may be accurate, it is rather ambiguous for the description at the following scales below the block. When the classification is applied to the study of local urban form, it needs further development.

The World Urban Database and Access Portal Tools (hereinafter referred to as WUDAPT) aims at capturing the information of urban form and function from different levels for global climate research. LCZ approach is used as a core guiding framework for collecting urban form and climate data in the WUDAPT project. The data collection of the LCZ can be divided into three levels. At present, the method of obtaining the level 0 data is relatively mature. It is mainly linked to the satellite photos giving the description of the typical appearance of the city and the relevant value parameters. However, level 1 and level 2 data, the collection of urban form data from block to building scale requires enhancing data accuracy through increasing the extraction and description of building prototypes (Masson, Hidalgo & Amossé, 2015). Although the current urban form typology of level 1 and 2 data includes four categories, it is far from adequate for the form description at the block and building scales, which urgently require the support of urban form typology to provide more detailed information on urban form and function.

1.2. Research progress

In the development of LCZ researches, some scholars have attempted to take urban form into considerations and utilize urban form typology methods to develop LCZ localized applications. The research progress of the association of LCZ and urban form is as follows:

Middel, A. et al. have used *ENVI-met 3.1* to simulate the microclimate of five communities in Phoenix, Arizona with different forms (Perera, Emmanuel, 2015). The form classification followed the LCZ framework and subdivided the landscape. The study analyzed the temperature, ventilation, surface temperature and shadow at noon. The results showed that at the microscopic scale the influence of urban morphology on daytime temperature was greater than that of beautification landscape. At noon, dense urban morphology could create local cold island effect.

Ding Wowo team of Nanjing University (Wowo Ding, Youpei Hu, Pingping Dou, 2012; Hao Yang, 2015; Wei Liu, 2012) introduces the LCZ system into the study of the urban morphology with the starting point of the association research of urban morphology and the urban microclimate. They propose that the urban texture study should be divided into different scales and the morphological indicators' parameters should be used as the key connection points (Wowo Ding, 2018). At last, they studied the control and optimization strategies of urban form based on the form typology and indicators.

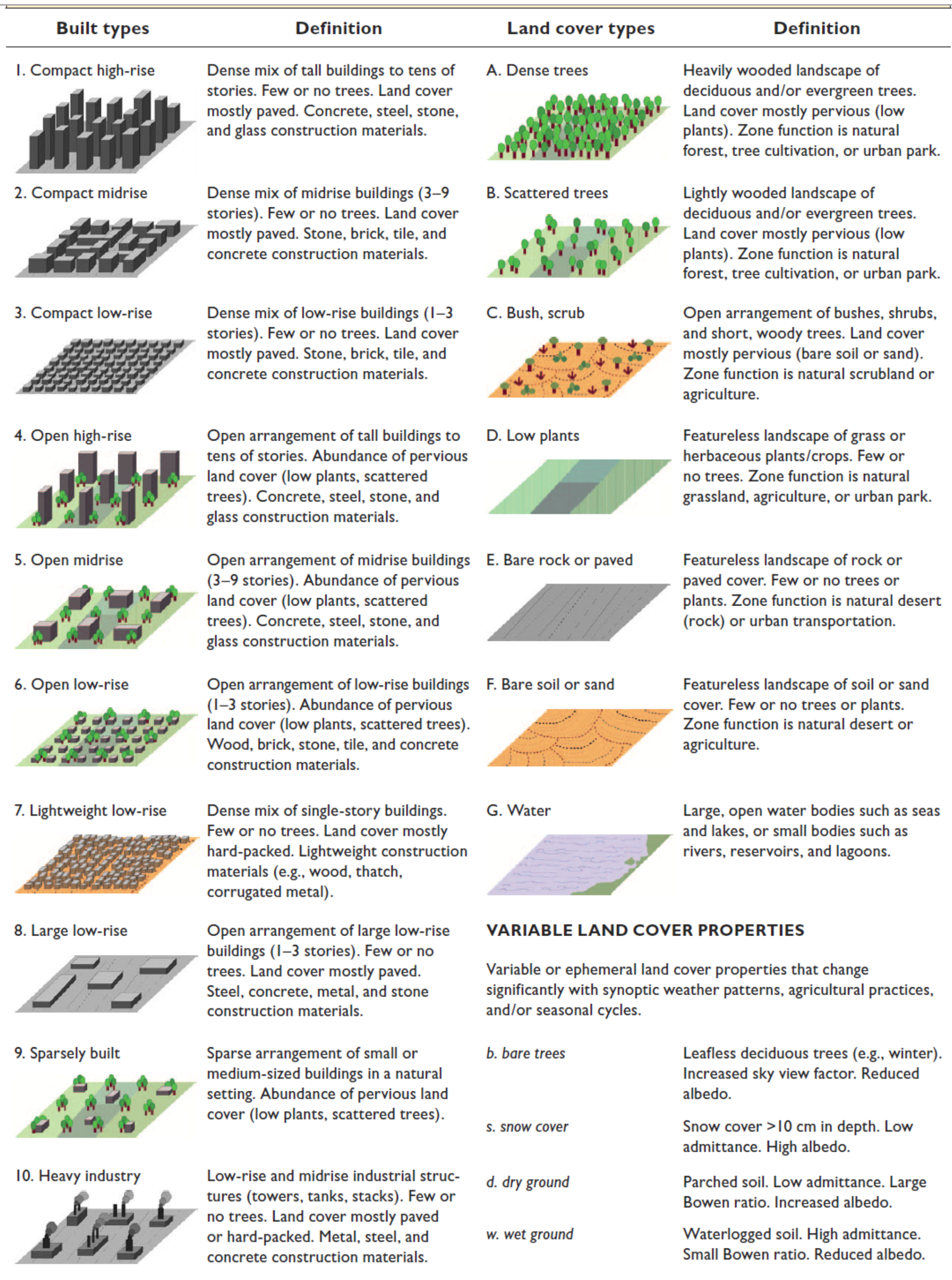
2. Methodology

As a classification system of surface landscape from the perspective of climatology, the LCZ can be divided into 17 types, including 10 built types and 7 land cover types. The 10 built types contain 6 basic built types. Each type of LCZ contains 10 indicators which are the most sensitive to the thermal environment, respectively representing urban form, surface coverage, building materials, and human activities (Stewart, Oke, 2012) (The detailed types description and indicators are shown in Tab.1,2).

Urban form typology is an important branch in the research of urban morphology. It is proposed in theory that type is the abstraction essence and structural principle of architecture (Fei Chen, Kai Gu, 2009). In the 1970s, the Urban Morphology and Land Use Research Centre founded by March and Martin at the University of Cambridge in the United Kingdom summarized the geometric features of modern cities and buildings by using European cities as models. Based on the geometric features, the basic archetypes of urban texture are presented (Tab.3) (Martin, March, 1972). They are synchronic variants of the development of urban form. They are characterized by complete blocks, small differences at the scale of building units, and a high degree of basic equality. Based on this model, the mathematical parametric model representation is completed. The model has been successfully associated with relevant indicators in the field of urban microenvironment research such as sky openness and roughness. The study of Ratti proves that generic built forms are made from simplified synthetic urban fabric. Under the same plot ratio, he proposed six archetypal forms linkage with several basic indicators (Tab.3) (Ratti, Raydan & Steemers, 2003). In the past thirty years, Martin's urban prototype forms have been widely used in various studies in the aspect of evaluating the environmental behaviour of urban form. The appeal of these common forms mainly comes from their simple and repeatable features, which eliminate the complexity of real city sites and allow more systematic comparative analysis of geometry and built forms (Ibid). However, these generic built forms also have great limitations in describing traditional form blocks with continuous interfaces. Their current applicability is mostly focused on the description of the pattern of array replication in a large number of modern urban forms.

Table 1

Abridged definitions for local climate zones (Source [8])



Built types	Definition	Land cover types	Definition
1. Compact high-rise	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.	A. Dense trees	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
2. Compact midrise	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	B. Scattered trees	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
3. Compact low-rise	Dense mix of low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	C. Bush, scrub	Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
4. Open high-rise	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	D. Low plants	Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
5. Open midrise	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	E. Bare rock or paved	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
6. Open low-rise	Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.	F. Bare soil or sand	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
7. Lightweight low-rise	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).	G. Water	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.
8. Large low-rise	Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.	**VARIABLE LAND COVER PROPERTIES** Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles.	
9. Sparsely built	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).	*b. bare trees* *s. snow cover*	Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo. Snow cover >10 cm in depth. Low admittance. High albedo.
10. Heavy industry	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.	*d. dry ground* *w. wet ground*	Parched soil. Low admittance. Large Bowen ratio. Increased albedo. Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo.

Table 2

Values of geometric and surface cover properties for local climate zones. All properties are unitless except height of roughness elements (m). (Source [8])

Local climate zone (LCZ)	Sky view factor[a]	Aspect ratio[b]	Building surface fraction[c]	Impervious surface fraction[d]	Pervious surface fraction[e]	Height of roughness elements[f]	Terrain roughness class[g]
LCZ 1 *Compact high-rise*	0.2–0.4	> 2	40–60	40–60	< 10	> 25	8
LCZ 2 *Compact midrise*	0.3–0.6	0.75–2	40–70	30–50	< 20	10–25	6–7
LCZ 3 *Compact low-rise*	0.2–0.6	0.75–1.5	40–70	20–50	< 30	3–10	6
LCZ 4 *Open high-rise*	0.5–0.7	0.75–1.25	20–40	30–40	30–40	>25	7–8
LCZ 5 *Open midrise*	0.5–0.8	0.3–0.75	20–40	30–50	20–40	10–25	5–6
LCZ 6 *Open low-rise*	0.6–0.9	0.3–0.75	20–40	20–50	30–60	3–10	5–6
LCZ 7 *Lightweight low-rise*	0.2–0.5	1–2	60–90	< 20	<30	2–4	4–5
LCZ 8 *Large low-rise*	>0.7	0.1–0.3	30–50	40–50	<20	3–10	5
LCZ 9 *Sparsely built*	> 0.8	0.1–0.25	10–20	< 20	60–80	3–10	5–6
LCZ 10 *Heavy industry*	0.6–0.9	0.2–0.5	20–30	20–40	40–50	5–15	5–6
LCZ A *Dense trees*	<0.4	>1	<10	<10	>90	3–30	8
LCZ B *Scattered trees*	0.5–0.8	0.25–0.75	<10	<10	>90	3–15	5–6
LCZ C *Bush, scrub*	0.7–0.9	0.25–1.0	<10	<10	>90	<2	4–5
LCZ D *Low plants*	>0.9	<0.1	<10	<10	>90	<1	3–4
LCZ E *Bare rock or paved*	>0.9	<0.1	<10	>90	<10	<0.25	1–2
LCZ F *Bare soil or sand*	>0.9	<0.1	<10	<10	>90	< 0.25	1–2
LCZ G *Water*	>0.9	<0.1	<10	<10	>90	–	1

[a] Ratio of the amount of sky hemisphere visible from ground level to that of an unobstructed hemisphere

[b] Mean height-to-width ratio of street canyons (LCZs 1–7), building spacing (LCZs 8–10), and tree spacing (LCZs A–G)

[c] Ratio of building plan area to total plan area (%)

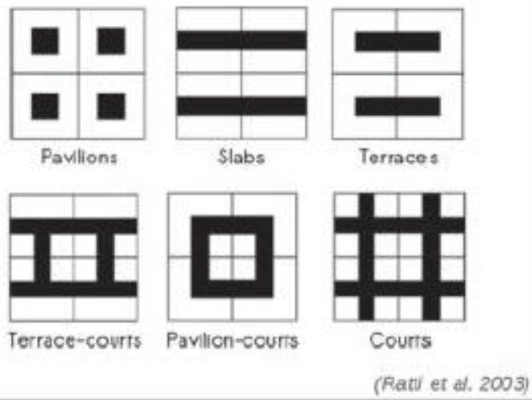
[d] Ratio of impervious plan area (paved, rock) to total plan area (%)

[e] Ratio of pervious plan area (bare soil, vegetation, water) to total plan area (%)

[f] Geometric average of building heights (LCZs 1–10) and tree/plant heights (LCZs A–F) (m)

[g] Davenport et al.'s (2000) classification of effective terrain roughness (z_0) for city and country landscapes. See Table 5 for class descriptions

Table 3
The basic prototypes of urban texture and relevant indicators (Source (Ratti, Raydan & Steemers, 2003)

SCALE	FORM PATTERN	RELATED INDICATORS
Generic built form		• plot ratio • site coverage • shape ratio (S/V) • total surface area • sky view factor (SVF)

As a surface landscape classification system, LCZ enriches urban form typology researches from the perspective of geography. However, the further development of LCZ requires the support of urban form typology and the implantation and supplementation of building prototypes and form function indicators, so as to enhance the description of the form and function. Thus, the research method of urban theory from the perspective of climatology can be further developed to guide climate-sensitive urban design. The research method framework is shown in Fig. 1.

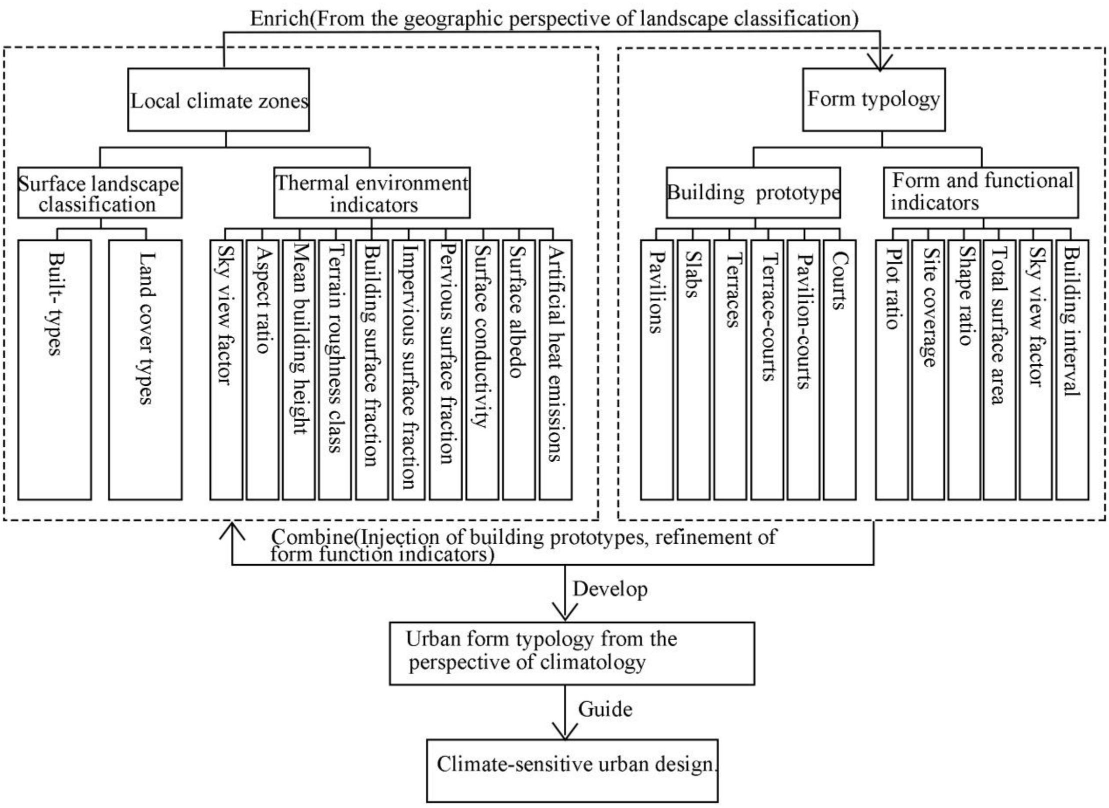


Figure 1. Research methodology framework (Source: The authors' drawing)

As a typical representative city in the hot summer and cold winter areas, Chengdu has been chosen as a testbed for collecting data at the scale from block to building in WUDAPT project. Therefore, based on the survey of real urban form in Chengdu and the combination of form typology, this article extracts the theoretical form prototypes of LCZ1~6 and LCZD, E, and assigns specific form parameters to construct theoretical cases. Through the simulation of the climate numerical simulation model *ENVI-met*, the local climate features of different LCZ types are compared and analyzed in order to serve as a study paradigm of theoretical cases, and the real cases are inspired to be guided by the simulation of theoretical cases in expectation.

3. Establishment of LCZ theoretical prototype cases studies

3.1. Theoretical form prototype

Based on the survey of real urban form in Chengdu, this article selects the theoretical prototypes of LCZ1~6 and LCZD, E. According to the combination of LCZ and urban form typology, tower-type building prototypes that are common in Chengdu are assigned in 500-by-500-meter blocks. In order to facilitate the comparison of the local climate features of different LCZ types, this article takes the indicators (Tab.2) of different LCZ types as a reference, and adopts the control variables method in the construction of the cases, in which the unified building interval and the plan view size are respectively controlled in the theoretical form prototypes of compact and open types to achieve unified building surface fraction, pervious and impervious surface fraction. The value selection of the terrain roughness class is based on the location of the block in the city. The form prototypes of the theoretical cases and relevant indicators are set in the following Tab.4,5.

3.2. Meteorological parameters

In the climate simulation of different LCZ types, the background meteorological parameter of Chengdu city on December 22 (winter solstice) was selected because the heat island intensity in winter is relatively large in theory. The weather on simulation day is sunny and cloudless. The prevailing wind direction is northeast with a wind speed of 1.0m/s. The minimum temperature is 2°C at 0:00pm, and maximum temperature is 12°C at 9:00am.

4. Result analysis

4.1. The comparative analysis of local climate features of LCZ theoretical cases

Based on the simulation, the article compares and analyzes the air temperature of different LCZ theoretical case types from the perspective of diurnal temperature per hour, diurnal temperture range and temperature at different times at the height of 1.5 meters. During the analysis we adopted a new framework for defining the heat island effect (UHI) magnitude in local climate zones. With this new framework, UHI magnitude is an LCZ temperature difference (e.g., ΔTLCZ 1 – LCZ D), not an “urban–rural” difference (ΔTu–r). LCZ differences are more conducive to analysis, and less prone to confusion, because they highlight the common surface and exposure characteristics of the compared field sites, and they invite physically based explanations of UHI magnitude[8]. Therefore, the article studies the relative differences of mean heat island intensity with the comparison between the respective value of different LCZ types and the mean value of all types (ΔTLCZ1-mean). This article divides the day as such: 7:00 to 18:00 – daytime, 19:00 to 0:00, 0:00 to 6:00 – nighttime.

4.1.1. The analysis of diurnal temperature per hour in different LCZ types

(1) The temperature peaks of different LCZ types

It can be seen from Fig.2 that the various LCZ types generally reach the highest peak in the mid-afternoon period (about 12:00 am to 15:00 am) and the lowest peak at midnight (about 0:00 pm to 3:00 pm). Among the highest peaks at 12:00 am, the maximum peak point is LCZE, which is 10.48°C; the minimum peak point is LCZ1, which is 9.43°C, it is 1.05°C lower than that of LCZE. At the lowest peaks at 0:00 pm, the maximum peak point is LCZ1, which is 5.58°C; the minimum peak point is LCZD, which is 3.04°C, it is 2.54°C lower than that of LCZ1. It can be seen that bare rock or paved zone (LCZE) are often the highest temperature areas in the city during the daytime. However, during the night, the low plants (LCZD) become the lowest temperature areas, and the temperatures of the built types LCZ1~6 are generally higher.

(2) The temperature change trends of different LCZ types

It can be seen from Fig.2 that the temperature rise and fall change trends of the land coverage types are more obvious than that of the built types. The LCZD and LCZE are relatively larger and higher in the magnitude and speed of temperature change, and LCZD, in particular, begins to cool down significantly after 16:00 by a large margin.

Table 4

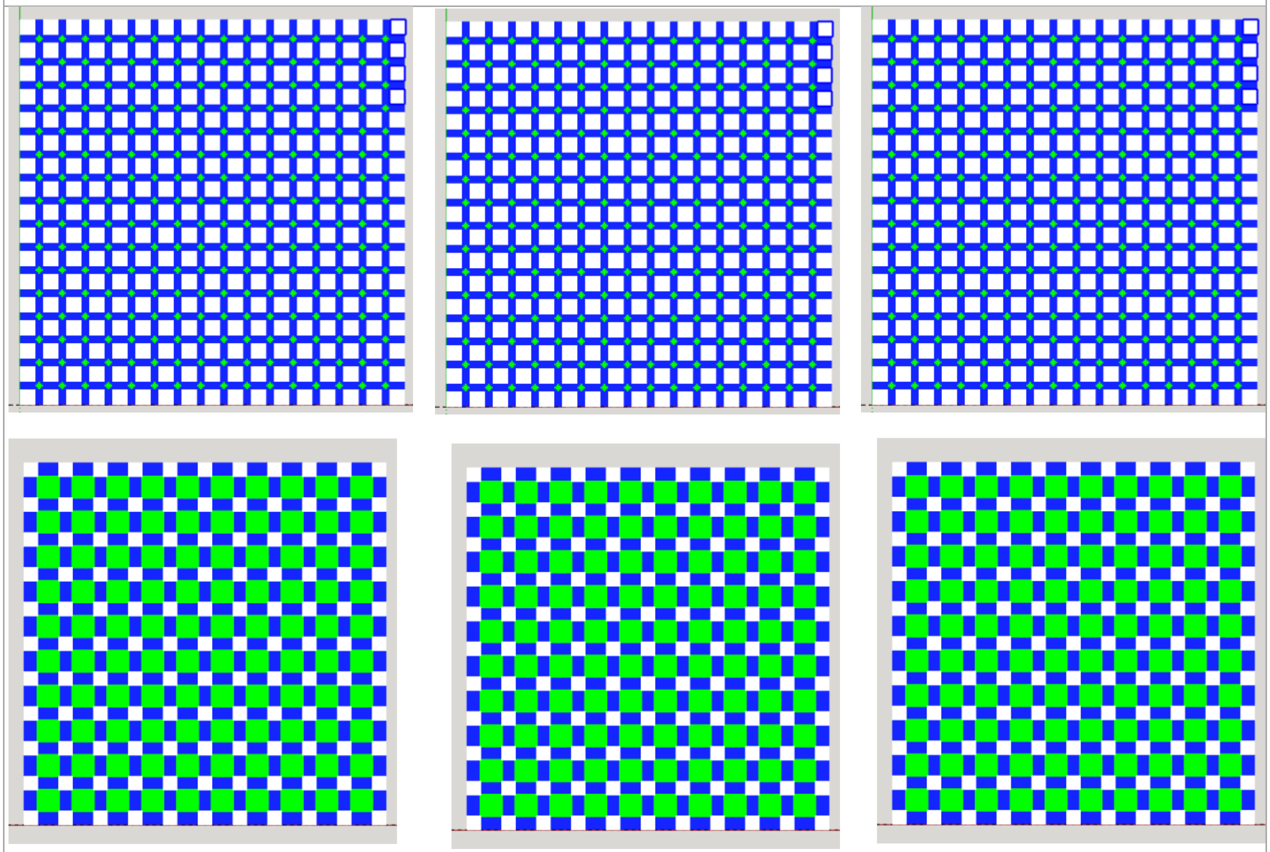
Values of thermal, radiative, and metabolic properties for local climate zones (Source: The authors' drawing)

LCZ	Plan view size (m)	Building interval (m)	Sky view factor	Space ratio of building interval	Building surface fraction	Impervious surface fraction	Pervious surface fraction	Height of roughness elements (m)	Terrain roughness class	Plot ratio
1	20×20	10	0.092	6	46	49	5	60	8	9.2
2	20×20	10	0.267	1.5	46	49	5	15	6、7	2.3
3	20×20	10	0.358	1	46	49	5	10	6	1.38
4	20×20	25	0.259	2.4	23	40	37	60	7、8	4.6
5	20×20	25	0.543	0.6	23	40	37	15	5、6	1.15
6	20×20	25	0.629	0.4	23	40	37	10	5、6	0.69
D	20×20		1						3、4	
E	20×20		1						1、2	

Annotation: The indicators of some theoretical case types are not in the threshold range of the LCZ theory (Tab.2) because the Height of roughness elements selection is relatively higher, thus, some SVF values are lower, some Space ratio of building interval values are higher, but still they belong to the LCZ types.

Table 5

Building prototypes of theoretical cases (Source: The authors' drawing)



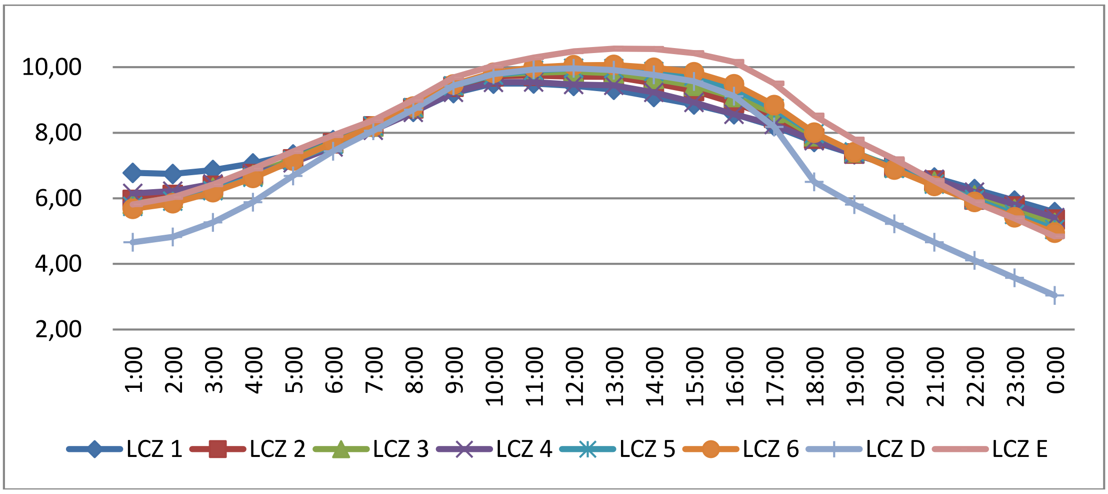


Figure 2: Comparison of diurnal air temperature per hour (°C) in winter
(Source: The authors' drawing)

4.1.2. The analysis of diurnal temperature range of different LCZ types

From Fig.3, it can be seen that the land cover types have relative larger diurnal temperature range than that of the built types. The maximum diurnal temperature range is LCZD, which is 6.93°C; the minimum is diurnal temperature variation LCZ1, which is 3.92°C. The difference between the two types is 3.01°C. That is because LCZD has relatively larger sky view factor and higher fraction of pervious surfaces, which significantly increases nighttime cooling, however, the building has a heat storage function and delays the release of heat.

In the comparison of diurnal temperature range of the built types, the open types are generally larger than that of the compact types, and the low types are generally larger than that of the high types. In the land cover types, the diurnal temperature range of the low plants is larger than that of the bare rock or paved zones. So it can be concluded that the diurnal temperature range in each class decreases with increasing impervious surface fraction and height/density of buildings [8], which is consistent with the LCZ theory.

In the built types, the diurnal temperature range of LCZ1~4 is significantly smaller than that of LCZ5,6, LCZ1 and LCZ4 are both significantly smaller than other types, showing that high-rise areas both have relatively small diurnal temperature range and large heat island intensity whether it belongs to compact or open types.

4.1.3 The analysis of temperature at different times in different LCZ types (relative heat island intensity)

(1) At 9:00 am

The maximum temperature difference of different LCZ types is 0.48°C between LCZ1 and LCZE. This indicates that the LCZE warms up rapidly, while the high-rise areas (LCZ1 and LCZ4) warm relatively slowly. That is because the heat absorption rates of LCZE are generally higher than that of the built types due to the specific materials. The temperature of the land cover types is generally higher than that of the built types (Fig.4).

(2)At 15:00 pm

Each type of LCZ generally begins to cool down at about 15:00, and different types gradually exhibit obvious temperature differences. The maximum temperature difference between different LCZ types is 1.57°C – between LCZE and LCZ1.

At this time, LCZ1~4 exhibits the cold island effect. The temperature of compact and high-rise types in LCZ1~4, which has larger heat island intensity and smaller diurnal temperature range, is lower than the temperature of LCZD. However, the LCZD and E which have smaller heat island and larger diurnal temperature range have higher temperature.

This may happen because in the afternoon the solar radiation is larger, the sun's height is reduced, and the shadows fraction is increased. As a result, some areas are shaded by the buildings, which reduce the effect of solar radiation which could promote the temperature rise to some extent, so the temperature is relatively lower (Fig.5).

(3) At 21:00 pm

The temperature of each built type is higher than the mean value, while the temperature of the low plants (LCZD) is lower than the mean value. The heat island effect begins to appear in the city. The maximum temperature difference between different LCZ types is 1.97°C – between LCZ1 and LCZD (Fig.6).

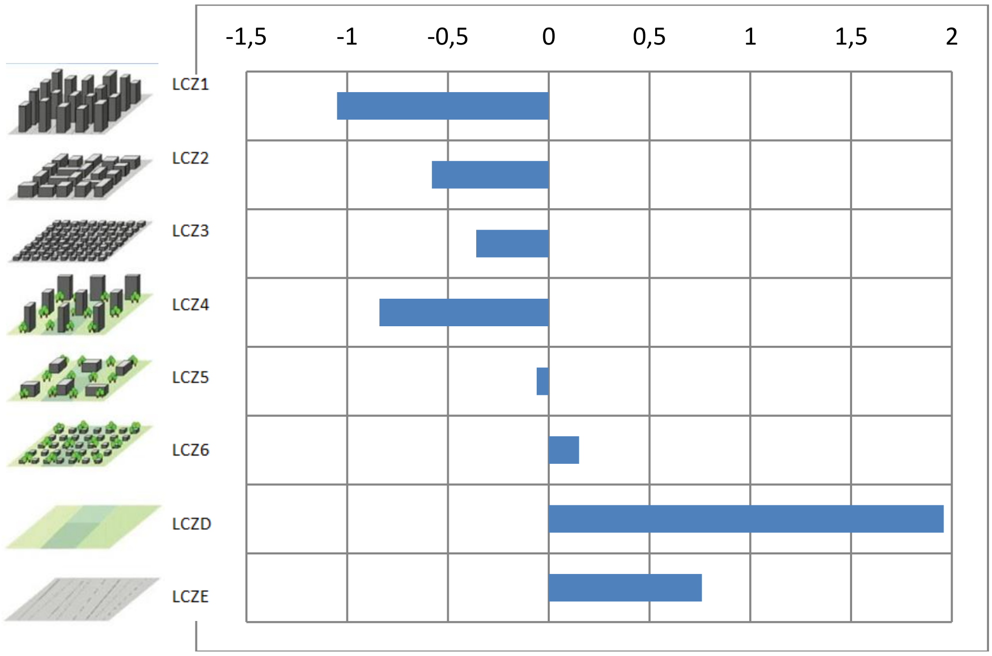


Figure 3: Departure from group mean diurnal temperature range (°C) in winter
(Source: The authors'drawing)

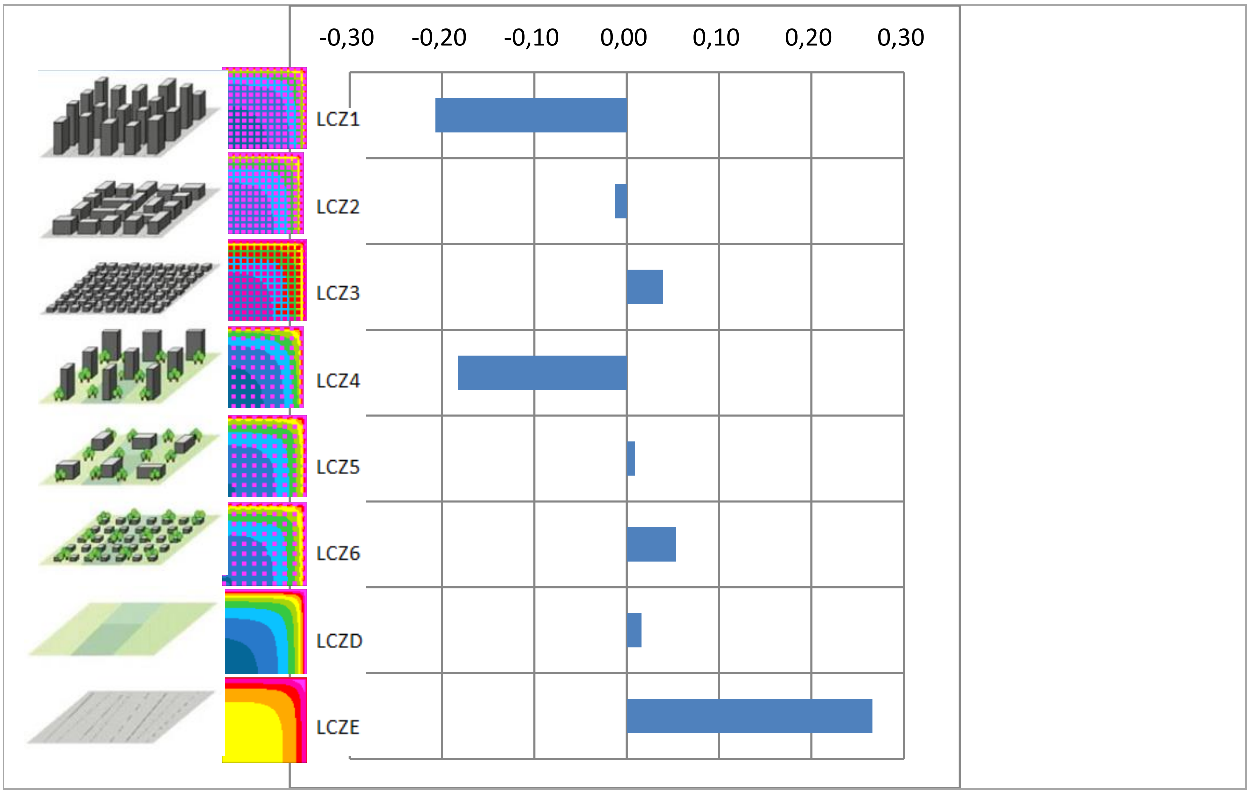


Figure 4: Departure from mean temperature (°C) at 9:00 am in winter
(Source: The authors' drawing)

below 8.90 °C 8.90 to 9.20 °C 9.20 to 9.50 °C 9.50 to 9.80 °C 9.80 to 10.10 °C

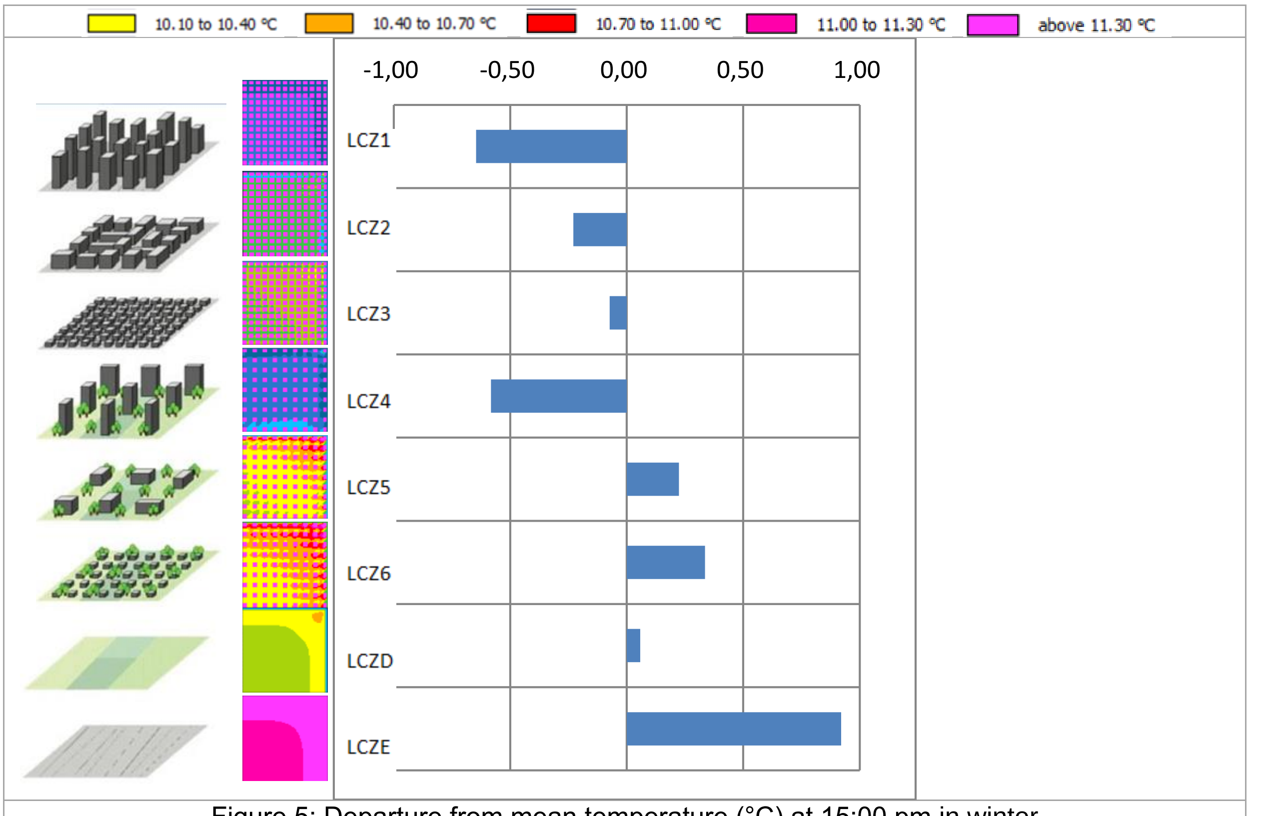


Figure 5: Departure from mean temperature (°C) at 15:00 pm in winter
(Source: The authors' drawing)

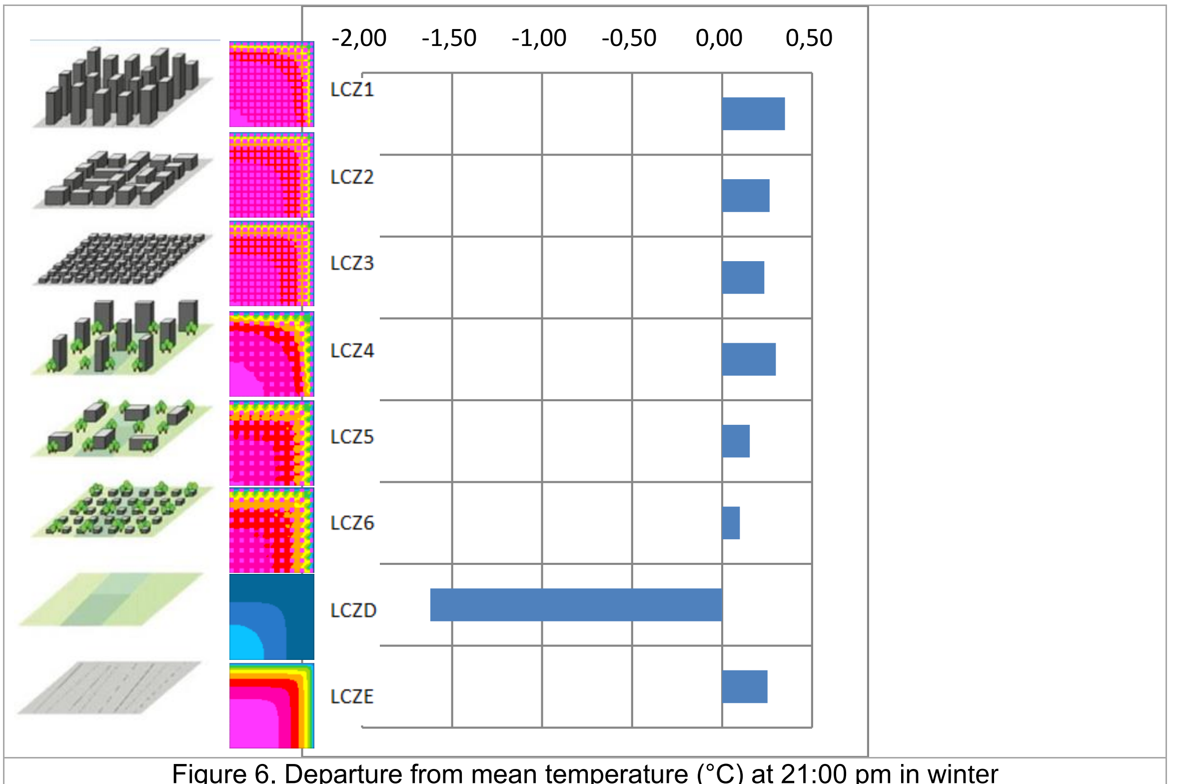


Figure 6. Departure from mean temperature (°C) at 21:00 pm in winter
(Source: Tha authors' drawing)

(4) At0:00pm

The maximum relative heat island intensity appears at 0:00 pm in the evening, which is 2.35°C difference between LCZ1 and LCZD, and a significant heat island effect is formed. Local climate features play a significant role at night.

The temperature of LCZ1~4 is 2.5°C higher than that of LCZD; the temperature of LCZ5,6 is 2°C higher than that of LCZD. It shows that the intensity of heat island in LCZ1~4 is relatively larger, which is consistent with the regularity of the obvious heat island effect that often appears in the central area of the city and the old town (Fig.7).

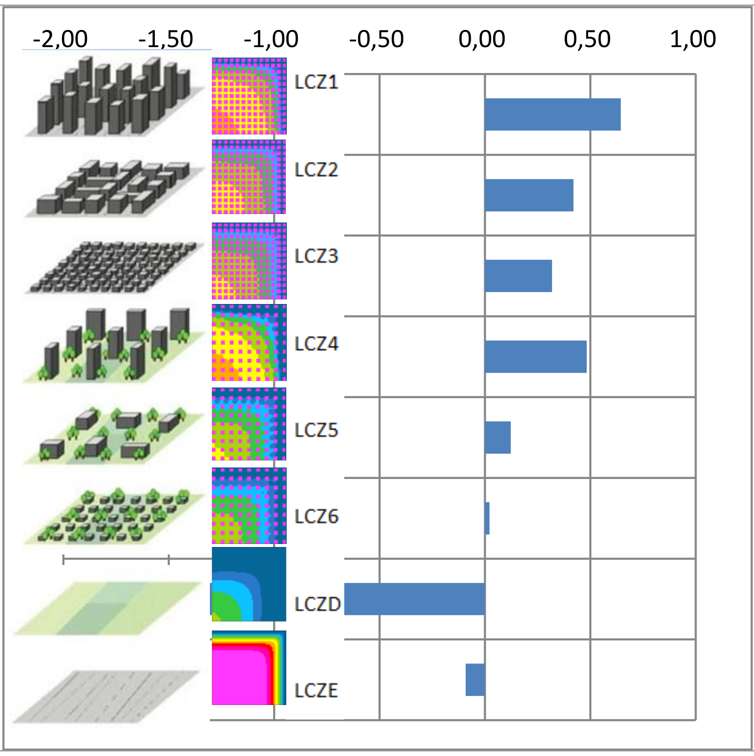
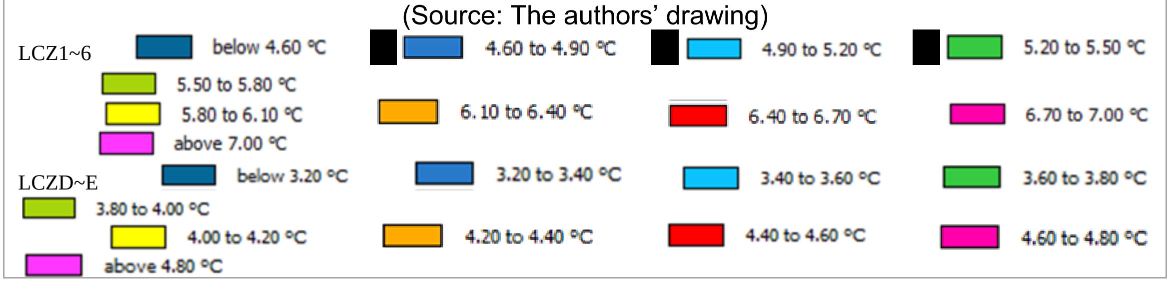


Figure 7: Departure from mean temperature (°C) at 0:00 pm in winter
(Source: The authors' drawing)



5. Discussion and Conclusion

In summary, the results of the simulation and validation of the LCZ theory which are extracted and implanted building prototypes in different types are basically consistent with the LCZ theoretical rules.

(1) Diurnal temperature change trend: In the morning, LCZE warms up rapidly, and the built types (LCZ1~6) warm up slowly. In the afternoon, the cooling rate of low plants (LCZD) accelerates, but the built types (LCZ1~6) cool down slowly.

(2) Diurnal temperature range: The diurnal temperature range of the land cover types is generally larger than that of the built types. The open types range is generally larger than the that of the compact types, and the low-rise types range is generally larger than that of the high-rise types.

(3) Cold island effect: In the afternoon the land cover types (LCZD and LCZE) have higher temperatures than the compact and high-rise types (LCZ1~4), and there appears cold island effect.

(4) Heat island effect: At night the temperature of the low plants (LCZD) is significantly lower than that of the built types (LCZ1~6). The heat island intensity of the built types (LCZ1~6) is greater than that of the land coverage types (LCZD, E), and the heat island effect appears.

In the above study, the comparative analysis of different LCZ types are basically consistent with the LCZ approach, which in theory verifies the scientificity and accuracy of LCZ theory, and validates the applicability of the LCZ theory in the development of localization in Chengdu. This study lays the foundation for the development of localization.

This article proposes a research paradigm for theoretical cases of urban form prototypes based on LCZ classification method. It is expected to guide the study of real form through the further exploration of theoretical form method and the construction of typical cases.

Moreover, it puts forward a research paradigm for the application of urban form typology in the further development of LCZ scheme. Based on the urban form typology, building prototypes in LCZ can be extracted and implanted to obtain more detailed information and enhance data accuracy, which can realize the development from level 0 to level 1, 2 in WUDAPT.

As a standard classification system of surface landscapes, LCZ scheme has developed the urban form typology from the perspective of climatology in terms of classification logic. Therefore, in this article, we can state that LCZ scheme should further use urban form typology method to promote the study of the relationship between urban climatology and urban morphology, to foster the cooperation between urban climatology and urban morphology, and thus to serve more effectively for urban climate-sensitive design and planning.

Acknowledgment

The authors would like to express gratitude to National Natural Science Foundation Project of China (approval number: 51508469) for supporting this study.

References

1. Perera N.G.R., Emmanuel R. A. (2018). “Local Climate Zone” based approach to urban planning in Colombo, Sri Lanka[J], Urban Climate, 23,188-203.
2. Masson V., Hidalgo J., Amossé A. et al. (2015). Urban Climate, Human behavior & Energy consumption: from LCZ mapping to simulation and urban planning (the MapUCE project)[C], ICUC9 - 9th International Conference on Urban Climate (jointly with 12th Symposium on the Urban Environment), Toulouse, France.
3. Perera N.G.R, Emmanuel R.A. (2015). “Local Climate Zone” based approach to urban planning in Colombo, Sri Lanka[C]. Icuc9 , International Conference on Urban Climate Jointly with, Symposium on the Urban Environment.
4. Wowo Ding, Youpei Hu, Pingping Dou (2012). Research on the Relationship between Urban Morphology and Urban Microclimate[J], Journal of architecture, 07, 16-21.
5. Hao Yang (2015). Research on the relationship between street corridor geography and urban planning indicators[D], Nanjing: Nanjing University.
6. Wei Liu (2012). The Method of Graphing in the Study of Urban Texture Morphology and Its Significance [J], Architect,01, 5-12.
7. Wowo Ding (2018). Coupling Mechanism and Control of Urban Morphology and Urban Microclimate [R], First International Symposium on Landscape Architecture and Microclimate, Shanghai, China, 01, 27-28.
8. Stewart I. D., Oke T. R. (2012). Local climate zones for urban temperature studies[J], Bulletin of the American Meteorological Society, 93(12): 1879-1900.
9. Fei Chen, Kai Gu (2009). Western Architecture Typology and Urban Morphology: Integration and Application[J], Architect,02,53-58.
10. Martin L., March L. (1972). Urban Space and Structures[M]. New York: Cambridge,.
11. Ratti C., Raydan D., Steemers K. (2003). Building form and environmental performance: archetypes, analysis and an arid climate[J]. Energy & Buildings, 35(1):49-59.