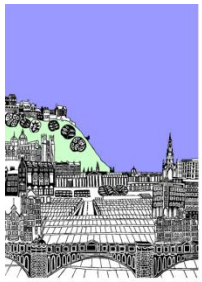

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Design to Thrive

Effects of the Building Typology on PET Value in Different Local Climate Zones: A Case Study in Beijing, China

Luyao Xiang[1], Chao Ren[1,2,3]

[1] School of Architecture, The Chinese University of Hong Kong, Hong Kong S.A.R., China, Room 505 An Integrated Teaching Building, The Chinese University of Hong Kong, Shatin, NT, Hong Kong;
[2] Institute of Future Cities, The Chinese University of Hong Kong, Hong Kong S.A.R., China, Room 406B Wong Foo Yuan Building, The Chinese University of Hong Kong, Shatin, NT, Hong Kong;
[3] Institute of Environment, Energy and Sustainability, The Chinese University of Hong Kong, Hong Kong S.A.R., China, Room 903 Yasumoto International Academic Park, The Chinese University of Hong Kong, Shatin, NT, Hong Kong

Abstract: Under the background of climate change, urban heat stress exacerbates with increasing level of urbanization (Rizwan et al., 2008). Local Climate Zones (LCZ) (Stewart and Oke, 2012) forms a systematic classification scheme that is commonly used nowadays for zoning and classifying the internal structure of urban areas. The world urban database and access portal tools (WUDAPT) (Mills et al., 2015) uses freely available Landsat imagery to create LCZ classification of cities. This study chose samples based on WUDAPT database of Beijing to explore whether different patterns and arrangement of buildings would influence the microclimate in a typical LCZ scale. Physiologically Equivalent Temperature (PET), as the most generally used indicator for thermal environment, will be used to assess the microclimate situation in the study. Result shows that within the same LCZ group, the microclimate situations vary with the building layout typology. To release the urban heat stress in summer, terrace and court typologies are the ideal choices for Beijing. On the contrary, semi-court and pavilion typology will cause extreme heat stress in summer.

Keywords: Beijing, LCZ, building layout typology, ENVI-met, PET, WUDAPT,

Introduction

The fact of climate change and extreme weather creates new demand for the building environment (Luber and McGeehin, 2008, Hallegatte, 2009). The Local Climate Zone (LCZ) system comprises 17 zone types at the local scale, each type contributes differently to the temperature increasing (Stewart and Oke, 2012). Its framework could be used to classify the aimed site into appropriate LCZs, and it could support the city planners, landscape designers, and global climate change investigators to make decisions. Using LCZ as the logical starting point, the World Urban Database and Access Portal Tools (WUDAPT) uses freely available Landsat imagery and LCZ classification framework to map the cities. It provides chance for the public to access to the city data. However, the LCZ types are characterized mainly by the parameters of land cover ratio, building height, construction material, street H/W and vegetation(Stewart and Oke, 2012). The building information about pattern typology and layout typology are not considered so far, but

these factors will influence the thermal microclimate as well (Middel et al., 2014). It could be understood that LCZ is proposed under a homogeneous environment context, but lack of those information will bring difficulties to the architects and planners when they are required to locate and design a specific block in a typical local climate zone site.

The effect of urban development on local thermal climate is widely documented in scientific literature (Grimmond, 2007, Steeneveld et al., 2011). Beijing, as the capital of China, after 3000 years of evolution, now, it is a typical mega city that holds 21.5 million population. Various kinds of building typologies emerged during the urbanization progress, especially in the downtown area with long history.

Therefore, this paper used downtown area in Beijing as the study case, and aimed to discuss the effects of building typology (pattern and layout) on the thermal microclimate. In this research, Beijing's WUDAPT image provided samples selection reference. In addition, the overall average physiological equivalent temperature (PET) was used to assess the thermal environment in one LCZ site. PET is a single index enables a layperson to assess the thermal component of climate on the basis of personal experience, so it will be easy for architects and planners to understand (Matzarakis and Amelung, 2008).

The research steps included: (1) Chose samples in LCZ1 and LCZ2. (2) Classified the samples into different groups according to their building patterns and layouts. (3) Conducted simulation in ENVI-met V4 and outputted the climate data: air temperature, relative humidity, globe temperature, wind speed, wind direction, and the solar radiation. (4) Used Bio-met to calculate PET value in each modeling grid, and outputted the final consequence.

Description of study area

Beijing urbanization history

Beijing is a political, cultural and international exchange center in China. It was built in 589 BC. Since 1953, Beijing's urban planning strategy was first proposed. There were four times of strategy adjustment, although each time a cycle was planned to inhibit the city expansion, Beijing still presents radical development mode now (Jing-qiu, 2001).

Historical documents shows that Beijing grew slowly during the period of 1932-1956, from 1956 to 1984, the speed was faster and the city began to expand along different directions. The rapid expansion began since 1984. Until the year of 1992, the construction of downtown area (Second and Third Ring Road) has been finished. During 1992 to 2000, the tendency of expansion eased, and the downtown area underwent second round of construction. After 2000, Beijing entered the period of fast urban expansion (HUANG Jie, 2014, Tian et al., 2011).

WUDAPT of Beijing

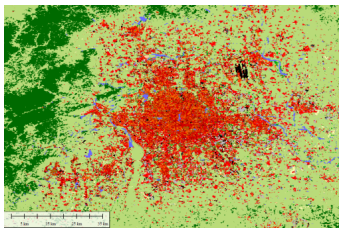

Figure 1 Beijing WUDAPT

The image of Beijing WUDAPT (Figure 1) in 2014 shows that LCZ1, LCZ2, LCZ3 mainly distributed in the center of Beijing, and the greening area mostly located out of the center. Combined with urbanization history of Beijing, the WUDAPT pattern fitted well with the construction tendency under different phases of development.

As the WUDAPT image shows the LCZ type classification clearly and accurately, it is easy for architects and planners to understand the building geometry characteristics in the samples without the complicated calculation. This paper uses WUDAPT of Beijing in 2014 as reference, chose research samples for discussion based on it.

Building typology in Beijing

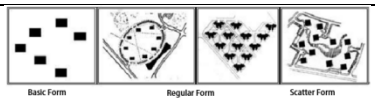

Figure 2 Pavilions Building Typology under Chinese Regulation

Figure 3 Courts Building Typology under Chinese Regulation

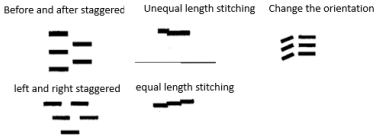

Figure 4 Terraces Building Typology under Chinese Regulation

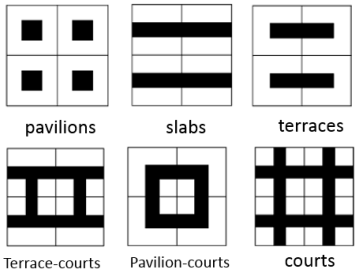

Figure 5 Western Building Typology

Building typology in this study and other documents refers to a set of buildings which have similarities in their form(Wood, 1968, Luperto et al., 2014). Normally, there are two dimensions of the word 'type'. The first is the common one to understand, the usage of buildings, such as office building, residence, shopping mall and so on. The second one, defines it with geometry, service life, materials and surrounding of buildings. The research discusses under the background of climate change, building parameters involves second definition of the word ' type' which have closer relationship with context (Middel et al., 2014, Salvati, 2015). So the building typology in this research is defined according to the second perspective, and involved geometry factors. Figure 5 shows the traditional building typology in western countries (Martin and March, 1972, Ratti et al., 2003). Figure 2-5 shows the specific building typologies which corresponding to Chinese Regulation (zhiqiang, 2010).

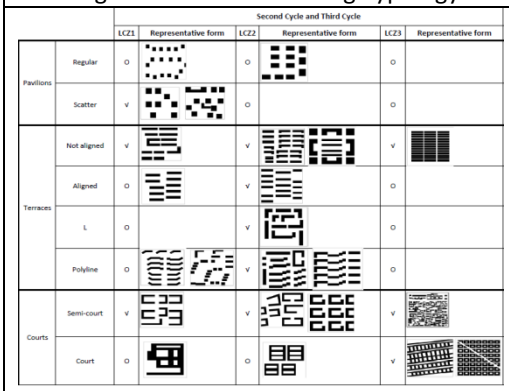

Figure 6 Beijing Building Typology

Based on the image of Beijing WUDAPT and the historical materials, this paper summarizes building types within the range of Second Ring Road and Third Ring Road. Figure 6 shows the result of summary. Beijing has its own characteristic of building typology: There are more pavilions types in LCZ 1 than LCZ 2, but LCZ 2 contains more types of terrace typology. Both LCZ 1 and LCZ 2 have unique types of courts.

Methods

Choose sample

The WUDAPT image gives clear description about the LCZ distribution over the whole city. Different colors of the pixel represents for different types of LCZ.

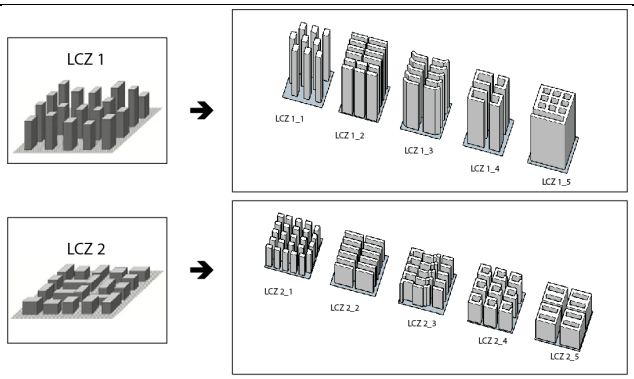

Figure 7 sub-classification of LCZ1 and LCZ2

According to the legend, LCZ types can be identified. Then, these two types are sub-classified based on the urban historical materials. 10 typical Beijing building typologies within Second and Third Ring Road are chosen in the simulation process. The samples cover the main kinds of typologies: Pavilions, Terraces and Courts. All the samples are 300m*300m in scale, which is a typical LCZ size.

Simulation in ENVI-met

ENVI-met, as an advanced simulation system that recreates the microclimatic dynamics of outdoor environment by addressing the interaction between climatic parameters, vegetation, surfaces, soil and the built environment. New features in ENVI-met V4 include simple forcing of air temperature and humidity in 2m level which needs simple input data, such as, initial temperature of atmosphere, specific humidity at model top and maximum and minimum values over a 24h cycle (Huttner and Bruse, 2009). This study used simple forcing mode and do not force any options during the simulation. Compared with other software, ENVI-met is particularly popular for its high temporal and spatial resolution, and it is based on the fundamental laws of fluid dynamics and thermodynamics, while other models are 3D radiation models (Ali-Toudert and Mayer, 2006).

Beijing typical summer weather is used to set up the configure document. The configuration is as below (SHI et al., 2012).

Setting		**Output**
Wind		Air temperature
Wind speed measured in 10m height (m/s)	5.5	Air humidity
Wind direction (deg)	150	Wind velocity
Roughness length at measurement site	0.1	radiant temperature
Temperature T		
Initial temperature of atmosphere (K)	299	
Humidity q		
Specific humidity at model top (2500m, g/kg)	7	
Relative humidity in 2m (%)	61	
Total Simulation Time (h)	5	

Form 1 ENVI-met configuration setting

The model resolution is 2m*2m, the base height is 0.75m on z axis direction. Version 250*250*30 is chosen when running the simulation.

Calculate the PET value

PET is defined as the air temperature that is required to reproduce in a standardized indoor setting and for a standardized person whose core and skin temperatures that are observed under the conditions being assessed. Normally, the calculation includes two steps:

1. Calculated the thermal conditions of the body with MEMI for a given combination of meteorological parameters.

2. Inserted the calculated values for mean skin temperature and core temperature into the model MEMI and solved the energy balance equation system for the air temperature T_a. This final T_a is equivalent to PET.

In this study, PET was calculated through BioMet 1.01. BioMet 1.01 is a post-processing tool to calculate human thermal comfort indices which includes PMV/PPD, PET and UTCI. It directly interacts with the ENVI-met and does calculation based on the simulation data output by ENVI-met. Basically, BioMet summarizes the impact of four variables on human thermal sensation: air temperature, radiative temperature, wind speed and humidity. The study used mean PET value (PET_{mean}) and the variation (MAX_{PET}-MIN_{PET}) to compare both the overall situation and variation of samples.

Result and discussion

PET_{mean}

Ten typical Beijing LCZ1 and LCZ2 samples were involved in this simulation, the image outputted by BioMet showed clearly the space distribution of PET. Extracting PET value from each grid at 1.95 height, then calculating their PET_{mean}, to evaluate the performance of the sample.

Referred to Figure 8, by comparing two groups of LCZ1 and LCZ2, the PET_{mean} of LCZ2 was significantly higher than LCZ1. This was mainly caused by the average height of LCZ1 larger than LCZ2, followed by it, the building shadow area was larger. Therefore, LCZ1 received less solar radiation during 10 a.m.-13 p.m., which could provide more comfortable thermal environment to human.

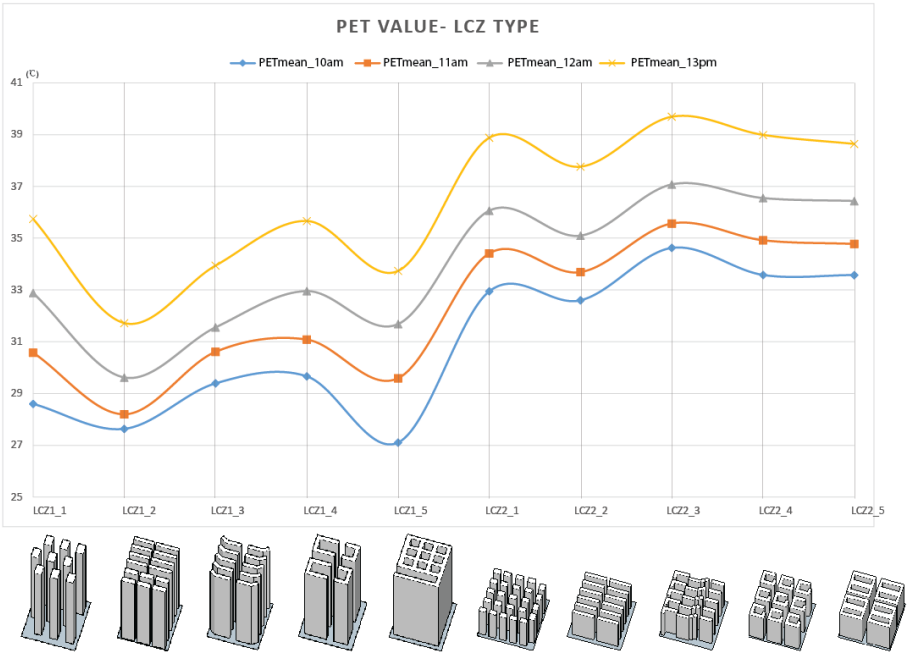

Figure 8 PET VALUE-LCZ TYPE

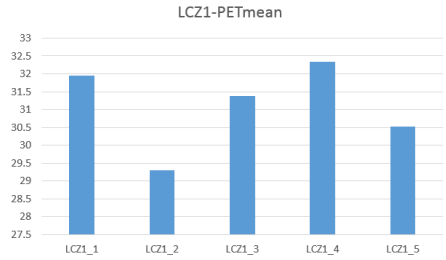

Figure 9 LCZ1-PETmean

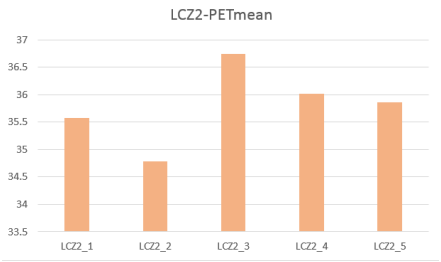

Figure 10 LCZ2-PETmean

Discussing within the same LCZ type, different building typologies' performance was different. In the group of LCZ1, the pavilion typology (LCZ1_2) has the lowest PET (29.0 ℃) during the simulation period. It means that people will only feel slightly warm by considering the influence of building layout typology that is terrace. While semi-court typology (LCZ1_4) has the highest PET (32.3 ℃), people will feel warmer in this sample. In addition, in the group of LCZ2, pavilion typology (LCZ2_2) also performs best with PET, whose value is 34.8℃. However, it is higher than the maximum value of LCZ1. At the same time, people in the polyline-terrace typology sample will feel the warmest.

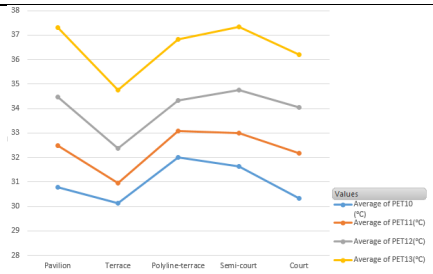

Figure 11 Different time PETmean

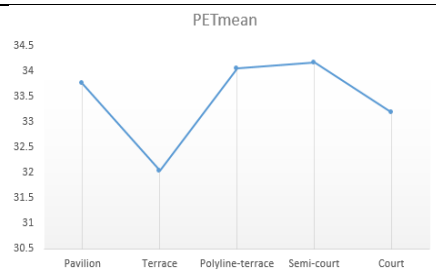

Figure 12 PETmean for different building typologies

Discussing within the same building layout typology, the terrace typology's performance is the best among all the typologies during the whole simulation period. On the other hand, the polyline-terrace, semi-court and pavilion typology have similar performance that PETmean is around 34℃.

It should be noticed that in the group of LCZ1 or LCZ2, semi-court typology has opening for better ventilation, while court typology is a closed building sample. However, the court typology's PETmean value is lower than semi-court typology. The reason for that is Beijing dry weather in summer and ventilation is less important than dryness in Beijing. While in humidity area, such as Hong Kong, Singapore, larger shading area still could help insulating solar radiation. That is why in Beijing, the court typology is a better choice than semi-court typology.

In summary, although LCZ classified different urban areas according to some geometry characteristics, the information it contains is not enough for architects and urban planners to design climatic response and sustainable buildings and cities. It could been seen from charts that even if in the same LCZ type, the effect of different building layout typologies is significance. The difference of microclimate between the best and worst samples is huge, under context of Beijing, terrace and court typologies are ideal solutions for LCZ1 and LCZ2 groups.

Variation of PET

Based on the result of PETmean, this part will focus on discuss the building layout typology which has influences on PET value. Through three statistics of 1. Maximum mean value of the simulation period, 2. Minimum mean value of the simulation period, 3. Variation (MAX-MIN) mean value of the simulation period, this part analyzes the extreme situation and how PET changes among all the samples.

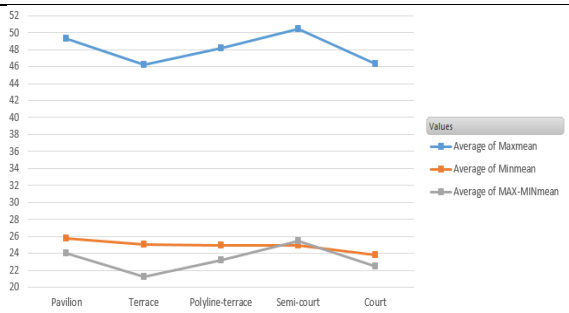

Figure 13 MAX-MINmean

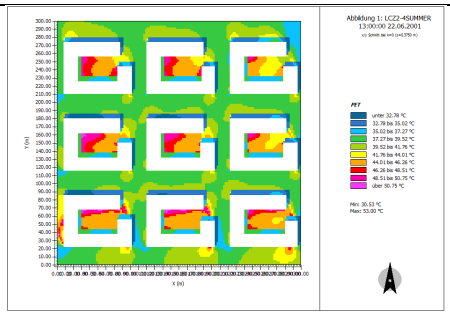

Figure 14 LCZ2-4 Summer 13.00 output

Figure 13 indicates that in terms of the minimum mean value of each sample, the PET value does not fluctuate a lot, while the maximum mean value is significantly different from each other. Terrace and court typology have lowest maximum mean PET value, conversely, semi-court typology has highest value which is over 50℃. People will feel extreme heat stress some places in these kinds of building samples. The pattern of MAX-MINmean is similar to the pattern of maximummean, the huge floating is accounted for the difference from highest PET value. For example, LCZ2_4 is a typical Beijing semi-court building layout typology. In the courts space, most of the space is with high PET values, while in the street space, the PET is significantly lower. Therefore, the huge variation does not mean the diversity of microclimate in this simulation, it could not provide comfortable thermal environment for different groups of people in high density area.

Conclusion and limitation

Climate change, urbanization are speeding up. The theory of urban planning should be modified response to this kind of change, otherwise, the city will undergo an unreasonable development, and become vulnerable in extreme weather. Under this context, Local Climate Zone is an infrastructure which could help architects and urban planners to understand better about how to design a climatic response block. So far, building height, building area cover, building density are included in LCZ classify criteria, these parameters will control the basic geometry characteristic of the samples. However, more parameters should be added into the system. This study firstly indicates Beijing, after a long time development, has its own classification building layout typologies. The general classification result does not proposed on the basis of Chinese building regulation and Beijing development history. The result from this study shows that, even within the same LCZ group, different build layout typologies will cause significant different microclimate situations. To release the urban heat stress in summer, terrace and court typologies are the ideal choices for Beijing, actually, courtyard is the traditional image of Beijing. On the contrary, semi-court and pavilion typology will cause extreme heat stress in summer. At the same

time, compared with the factor of ventilation, shading is more efficient in providing a thermal comfortable environment.

The study is only a start of completing the LCZ system, in order to make a better use for architects and urban planners to make decision. There are two limitations of this study. Firstly, only use Beijing summer for sample, while Beijing's winter is cold and dry, sometimes uncomfortable for human living. Therefore, for Beijing, the PET value in winter is also worthy to study. Secondly, simulation only last for five hours, which could not take the night situation into consideration. After one night, the situation will change as the building itself will release heat in evening.

Acknowledge

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