RESEARCH ON THE IMPACT OF TRADITIONAL URBAN GEOMETRY ON OUTDOOR THERMAL ENVIRONMENT

Case Study of Neighbourhoods with Arcade Street in South China

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Abstract. With the deterioration of urban environment gradually in these decades, the demand for improving the outdoor thermal environment is increasing. The traditional architecture and urban planning contain abundant climate responding strategy, while current studies about it are still insufficient. Furthermore, many researches had profound results on how different urban design parameters would impact outdoor thermal comfort, but only a few of them could achieve an effective transformation into a practical scenario. Thus, this paper attempts to present the impact of different traditional urban form, which is extracted from different neighborhoods with arcade street in south China, on the outdoor thermal environment, through field measurements and climatic simulation with Envi-met. Moreover, these different complex urban forms were transferred into a simplified form with uniform character and simulating based on the same boundary condition. Comparing the SVF (Sky View Factor) and PET (Physiological Equivalent Temperature) of each point, the organic urban form would lead better thermal environment than others on the main road. On the other hand, the SVF of a point is not the only one aspect of its PET, which related with the form of urban geometry as well.

Keywords. Climate Responsive Urban Design; Traditional Arcade-Street Neighborhood; Urban Geometry; Outdoor Thermal Comfort.

1. Introduction

In these decades, the urban environment is deteriorating, even starting to jeopardize the public health (Change, 2015), due to dramatically increasing population and out-of-controlled expanding of urbanization. A strong relationship exists between urban morphology and urban environment (Golany, 1996). Additionally, many traditional settlements, which built over hundreds of years ago, so far coexisted in harmony with its local climate. In different climate zone the traditional architecture and urban presented diversity in form and scale, in which a lot of strategies to respond to local climate was contained as well (Piesik, 2017).
Thus, reintroducing the climate adaptation of these settlements and then finding guidelines for urban design could relieve the deterioration in the outdoor thermal environment.

2. Literature

With the help of computer-aided simulation technology (Tominaga and Stathopulos, 2013), the urban environment issue had been profoundly studied these years, and the main impact design parameters were defined, which could be categorized into aspect ratio, sky view factor, street orientation, neighborhood configuration and greening (Jamei et al., 2016, Chen and Ng, 2012).

Meanwhile, some research on climate adaptation of traditional settlements were conducted using the same numerical methodology, like the analysis on the street thermal stress of historical neighbourhood in Camagüey (Rodríguez Algeciras et al., 2016), the shading influence of urban layout and street canyon in Mediterranean (Andreou, 2014), the spatial scale study on historical arcade street in Guangzhou (Yin and Xiao, 2016), and aspect ratio and orientation of street canyon design effect on the microclimate in Thessaloniki (Chatzidimitriou and Yannis, 2017).

However, during the practice of urban design, the urban form would be decided by form lectotype rather than a single parameter, which itself could influence the thermal environment a lot (Sanaieian et al., 2014). On the other hand, most researchers were conducted to study the performance of archetype canyon, but in fact, the profile of a street could be more complex and adopt different shading strategy (Ali-Toudert and Mayer, 2007, Johansson, 2006).

This paper attempts to research the impact of traditional urban geometry with different characters on outdoor thermal comfort. Furthermore, by adapting lectotype strategy, the author also tries to transfer the different type of urban geometry into a simplified form. After comparing the impact of these form on the outdoor thermal environment, a guidance could be summarized out for urban design practice.

3. Survey on Traditional Neighborhood

3.1. CHARACTER OF GEOMETRY

A survey on the urban morphology of traditional neighborhood was conducted in south China. This district belongs to the hot and humid climate zone, where the radiation level and precipitation are quite high. As a response to local climate, a kind of special street canyon can be found in most traditional urban and distributed in many other cities in South China and Southeast Asia as well. The street, with a continuous colonnade in front of the ground floor, provides shading and protection for pedestrians. Most of these arcade streets were built at the beginning of the 20th century with the campaign of urban renovation and integrated with the local traditional neighborhood. Three districts with different urban form were surveyed, which were En Ning Road in Guangzhou (EN), Kai Yuan Road in Xiamen (KY), and Yong Tai Road in Shantou (YT). Their urban forms could be catalogized into fishbone, organic and net respectively. A continuous arcade street could be always
found on the main road (Figure 1).

3.2. SCALE OF NEIGHBOURHOOD

Regarding the scale of these settlements, the buildings in a traditional block are usually two to four stories with the height from 7m to 18m. In the main road, the width of streets ranges from 7m to 21m while the height-width ratio thus varies from 0.7 to 1.7, with the majority falls to around 1. In the minor road, the width of streets ranges from 4m to 6m while the height-width ratio thus varies from 1 to 4, with the majority falls to around 3. As for the scale of the arcade, the width is usually 3m to 6m, since the wider, the more expensive while the narrower, the more difficult for business operation and passengers transit. Usually, the first floor
will be 4.5m or 5m high. Thus, the aspect ratio for arcade varies from 0.7 to 1.3 (Yin and Xiao, 2016).

3.3. FIELD MEASUREMENTS IN DIFFERENT SITE

A series of field measurement was conducted in each site from 25th July 2017 to 6th August 2017. The recording time was from 8:00 to 20:00. Four detecting points were distributed in these areas, which were AW in the west of arcade, AE in the east of arcade, RM in the middle of the main road, and P in an E-W oriented alley. The height of each point was 1.5m. In addition, a small weather station was arranged on a roof (the height was 15m) without shading from other buildings. Meantime, major weather data were recorded including wind direction, wind speed, humidity, air temperature, black globe temperature and etc.

4. Applied Method

4.1. SOFTWARE OF CLIMATIC SIMULATION

To achieve comparison in different urban form, a climatic simulation software was adopted in this research. Considering the demand in urban design, Envi-met would be a better option for the designer (Huttner and Bruse, 2009), due to coupling wind and thermal environment together. With the site-specific climatic information, a reliable result could be achieved in Envi-met (Sharmin et al., 2017).

4.2. ASSESSMENT OF OUTDOOR THERMAL COMFORT

To compare weather data in different street canyons, Physiological Equivalent Temperature (PET) was adopted to assess the thermal environment. PET is a human thermal comfort index (Höppe, 1999), which is widely used in evaluating the outdoor thermal environment since it integrates various weather data and human activity factors (Ng and Cheng, 2012). With the useful calculation tool Rayman V1.2 (Matzarakis et al., 2007), PET could be calculated based on the simulation data directly. In this case, PET was calculated for a 35-year-old man, 1.70 m tall, 70 kg weight, with a metabolic rate of 86.21 W/m², and a clothing insulation of 0.3 m² K/W, which is nearly the same as the normal situation in summer of Guangzhou. Meanwhile, an indispensable parameter, the mean radiant temperature (T_mrt) of field measurements was calculated according to the following formula:

\[
T_{\text{mrt}} = \left[ (T_g + 273)^4 + \frac{1.10 \cdot 10^8 \cdot V^{0.6}}{(E \cdot D)^{0.4}} \cdot (T_g - T_a) \right]^{0.25} - 273 \quad (1)
\]

where T_mrt is mean radiant temperature (°C),
T_g is globe temperature (°C),
T_a is air temperature (°C),
V is air velocity (m/s),
D is globe diameter (m) (=0.038 m in this study),
E is emissivity (=0.95 for the black-coloured globe).
4.3. STEPS OF STUDY

4.3.1. Step 1: Climatic Modelling Validation

According to the above survey about different forms of the traditional neighborhood, three of them were chosen to conduct field measurement in a similar domain, which was Guangzhou, Xiamen, and Shantou. Their structures of neighborhood and aspect ratio of the road were similar. Validation experiments were conducted on each site and the boundary condition was set according to measurement (Table 1). The result of simulation was validated through comparing the correlation of air temperature and PET on each measured point.

<table>
<thead>
<tr>
<th>Table 1. Boundary Conditions for Each Model.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EN</strong></td>
</tr>
<tr>
<td>Location</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Date of Measurement</td>
</tr>
<tr>
<td>Simulation duration</td>
</tr>
<tr>
<td>Ta &amp; RH (simply forcing)</td>
</tr>
<tr>
<td>Spatial resolution</td>
</tr>
<tr>
<td>Wind speed (10m)</td>
</tr>
<tr>
<td>Wind direction</td>
</tr>
<tr>
<td>Specific Humidity in 2500 m</td>
</tr>
<tr>
<td>Initial Temperature Layer</td>
</tr>
<tr>
<td>Relative Humidity Layer</td>
</tr>
<tr>
<td>Heat transmission</td>
</tr>
<tr>
<td>Albedo</td>
</tr>
</tbody>
</table>

4.3.2. Step 2: Comparison of Validated Model

In the second step, the three-validated models were simulated in the same boundary condition to compare the impact of different urban geometry in an actual situation. The weather data recorded on 30.07.2017 in Guangzhou was adopted as the boundary condition for all simulation since it is the worst situation of them. The SVF and PET of each measured points, which are the same as it in step1, were
used for comparison in this part.

4.3.3. Step 3: Comparison of Simplified and Uniform Urban Geometry

In the last step, these three different urban forms were transferred into a corresponding uniform mode, which assumed urban canyons as having the same character with uniform building heights and plot sizes. In this design, the structure of neighborhoods is the same with each example. Arcade street was adopted as the form of the main road (N-S oriented), and the other scale was set the same as actual situation, which means, the height of buildings would be 15m, and the height of arcades would be set as 5m. The width of the main road was 15m, but the width of the alley was 5m. Thus, the aspect ratio in the road and arcade were 1, but in the alley was 3.

Then, these simplified models were conducted a simulation in the same boundary condition as it in step 2. Measured points (on 1.5m height) were arranged in the middle of the main road, both side of arcade street and one more in the alley (Figure 2). The result of simulation was compared with each measured point in hourly and average of PET, and SVF.

![Figure 2. Three Different Lectotypes of Urban Geometry.](image)

5. Result and Discussion

5.1. RESULT OF STEP 1

According to the comparisons of simulated Ta and PET with measured, whose data are extracted hourly. The correlation index of Ta in each point presents highly relationship mostly over 0.950, due to simply forcing on air temperature. In terms of PET, the range of correlation index are mostly between 0.800 to 0.930. Overall, the validated model could achieve relative accurate simulation in the hot and humid zone. In the next phase, weather data of Envi-met and settings of the model were used for all simulation (Table 2).
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Table 2. Correlation Index between Measured and Simulated Data.

<table>
<thead>
<tr>
<th>Point</th>
<th>Ta</th>
<th>PET</th>
<th>Ta</th>
<th>PET</th>
<th>Ta</th>
<th>PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>0.953</td>
<td>0.847</td>
<td>0.976</td>
<td>0.930</td>
<td>0.956</td>
<td>0.813</td>
</tr>
<tr>
<td>AW</td>
<td>0.985</td>
<td>0.751</td>
<td>0.964</td>
<td>0.895</td>
<td>0.945</td>
<td>0.915</td>
</tr>
<tr>
<td>RM</td>
<td>0.976</td>
<td>0.923</td>
<td>0.993</td>
<td>0.791</td>
<td>0.975</td>
<td>0.886</td>
</tr>
<tr>
<td>P</td>
<td>0.912</td>
<td>0.865</td>
<td>0.964</td>
<td>0.834</td>
<td>0.986</td>
<td>0.831</td>
</tr>
</tbody>
</table>

5.2. RESULT OF STEP 2

According to the result of the simulation, the street with arcade profile could be an effective buffer zone for pedestrians, whose average PET is only half of it on the main road. When comparing the relationship between SVF and PET in each location, the PET values for the arcade street are consistently lower than those for the main road, indicating a more comfortable thermal environment for pedestrians.
neighborhood (Figure 3), it can be discovered that, though the SVF in the arcade street of YT is the lowest in both two side, the PET is still higher than others. Furthermore, the point in KY-RM has the lowest SVF in middle of the main road, but the PET of it is the highest. Regarding the situation in the arcade of KY and EN, the PET of them is only 1/2 to 1/3 of itself point in the main road. The average PET of points in KY’s arcade street is always lower than EN and YT’s, which is only 36.5°C. The highest PET in the main street canyon belongs to KY, over 41°C. Regarding the point in the alley, YT-P has the best thermal environment of all, even though its SVF is not the smallest.

5.3. RESULT OF STEP 3

![Comparison of PET and SVF in Step 3](image-url)
Regarding the simplified situation (Figure 4), despite the SVF of points in arcade street and main road are the same with each other, the PET in the arcade and road are still different. The lowest PET is always found in KY, whose maximum PET of the point in east and west arcade is 40.1/41.5°C and the others are 41/42.5°C. However, the PET in the P point of KY is the highest over 37°C, and the others are only 36°C.

Above all, with an organic shape, the neighbourhood would have a better outdoor thermal environment. In contrast, the thermal environment in the secondary road would be damaged. That neighborhood with fishbone and net shape would form similar outdoor thermal environment.

6. Conclusions

According to the result of comparing experiments, the impact of different traditional urban form on the outdoor thermal environment is unequable. Generally, complex urban geometry can lead to the better thermal environment than it in uniform in the main street canyon. In this case, urban geometry in the organic form led a better thermal environment in the main street, while the thermal comfort was damaged in the alley. Furthermore, the arcade is an efficient buffer space for pedestrians, whose SVF was declined due to shading strategy design in street profile. However, the SVF of a point is not the only one aspect of its PET, which related with the form of urban geometry as well.

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References


Chatzidimitriou, A. and Yannas, S.: 2017, Street canyon design and improvement potential for urban open spaces; the influence of canyon aspect ratio and orientation on microclimate and outdoor comfort, Sustainable Cities and Society, 33, 85-101.

Chen, L. and Ng, E.: 2012, Outdoor thermal comfort and outdoor activities: A review of research in the past decade, Cities, 29(2), 118-125.
