Study on Street Space Microclimate Measurement and Improvement Strategy in Yangmeizhu Street in Beijing

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Abstract. The paper studied the quality of public space in Yangmeizhu Street in Beijing through thermal comfort evaluation from the perspective of human perception evaluation, and analyzed microclimate measured data and dynamic simulation to put forward suggestions for improving the old city environment. Firstly, the research used portable meteorological station to monitor the microclimate data all day. Secondly, based on verification and fitting of present monitoring data and model data, the research established microclimate dynamic model for Yangmeizhu street by using Envi-met software platform. The main model indexes included temperature, humidity, solar radiation, wind speed and wind direction. Then the research analyzed high aspect ratio, green coverage rate and pavement materials in Yangmeizhu Street, and analyzed synthetically the relation between microclimate and public space. The paper proposed possible factors to affect the microclimate in the old city public space and improvement strategies for microclimate.

1. Preface
Beijing Dashilan Yangmeizhu Street is located at southwest of Qianmen district with a total length of 496 meters, and called "Oblique Street" in Ming Dynasty because of inclined direction of street from northeast to southwest. Yangmeizhu Street used to be a cultural street. During the reign of Emperor Qianlong, Liang Shizheng and Shen Congwen, a modern writer, lived in this street. The back door of Qingyun building constructed by brick and on which have "Qingyun" stone plaque is still on street. Xicheng District Government renovated Yangmeizhu Street to vacate and return it to the owner in 2013. This is the first historic reservation project in Xicheng District and was fully invested by the government. The policy is voluntary for residents. Among 1700 residents, 529 households chose to move out and 1171 households chose to stay. Xicheng District puts forward the "translational pilot" for aboriginal people, implying that make a courtyard residence for the scattered residents and use the left places to build public kitchen, convenient food stations, public toilets and living facilities; besides, more than 20 courtyards are mainly introduced to the creative industry business. For now, Yangmeizhu Street is an important venue in Beijing International Design Week exhibition activities, and become an ancient city street loved by young people in combination with fashion and traditional culture, residential and creative industries.
The paper chose Yangmeizhu Street as the research object, through measurement and simulation of the street’s microclimate index, to evaluate the microclimate environment in the whole street, sum up direct and indirect relevance between landscape design methods and microclimate thermal comfort, analyse the main reason of microclimate differences considering the street landscape situation. At the same time, the paper used software simulation platform to quantify and analyse microclimate differences, aiming at putting forward some scientific suggestions and strategies for landscape reconstruction of the street space in ancient city.

2. Yangmeizhu Street Microclimate Index Measurement

Based on the microclimate measurement, the landscape space measurement and the software calculation methods, the research measured four points in Yangmeizhu Street. The measuring point 1 and 2 were seldom green, and the measuring points 3 and 4 were more green, and the measuring points were distributed as shown in Fig. 2. The research was carried out on September 8, 2017 and the weather was sunny with moderate wind. A set of instruments are placed at each measuring point. The microclimate index was measured during 9:00a.m.-16:00p.m.

The measuring instruments are American kestrel5400 portable weather station and TES1333R solar recorder. The instruments were placed on the bracket of 1.5 meters high. It is close to the height of head and neck of adult. The instruments were recorded automatically every 30s. The instruments recorded the temperature (°C, ±0.5°C, in -29°C and 70°C), the relative humidity (%，+ 2% in 10-90%), the wind speed (m/s, +3% in 0.6-40m/s) and the solar radiation (w/m2, + 10w/m2), including Wet Bulb Globe Temperature (WBGT) and the thermal comfort index. The street width and the surrounding building height were measured by Leica laser range finder and the aspect ratio of the street was calculated.

2.1 Analysis of Temperature and Relative Humidity Measured Data

Temperature and relative humidity of the four measuring points were the basic microclimate data and also the two key factors in evaluation of the thermal comfort. The data of temperature and relative humidity were analysed by means of average value, range and standard deviation. The average value of 20 minutes was taken for each measuring point, and the range and standard deviation were analysed by the average value of all day.
Table 1. The Measured Temperature Value Analysis (°C).

| Measuring point | Minimum value | Time for MIN | Maximum value | Time for MAX | D-value | Average value | Standard deviation | Variance |
|-----------------|--------------|--------------|---------------|--------------|---------|--------------|--------------------|---------|
| 1               | 26.40        | 9:20         | 36.40         | 14:41        | 10.00   | 30.90        | 2.42               | 5.87    |
| 2               | 27.70        | 9:10         | 38.60         | 13:23        | 10.90   | 34.00        | 2.45               | 6.01    |
| 3               | 30.00        | 9:00         | 38.30         | 11:29        | 8.30    | 34.72        | 1.36               | 1.85    |
| 4               | 27.60        | 9:00         | 38.80         | 13:00        | 11.20   | 33.56        | 2.37               | 5.63    |

Table 2. Analysis of Relative Humidity Value as Measured (%).

| Measuring point | Minimum value | Time for MIN | Maximum value | Time for MAX | D-value | Average value | Standard deviation | Variance |
|-----------------|--------------|--------------|---------------|--------------|---------|--------------|--------------------|---------|
| 1               | 44.30        | 14:46        | 68.50         | 9:21         | 24.20   | 55.00        | 6.81               | 46.37   |
| 2               | 36.20        | 13:24        | 74.80         | 9:00         | 38.60   | 46.55        | 7.27               | 52.79   |
| 3               | 38.60        | 12:25        | 56.80         | 9:02         | 18.20   | 44.82        | 3.73               | 13.88   |
| 4               | 38.20        | 13:00        | 64.90         | 9:00         | 26.70   | 48.58        | 6.72               | 45.09   |

Comparison of average value for temperature and humidity, the change trend of four points was roughly the same. The minimum temperature appeared at about 9a.m. with the highest value at about 13-14p.m.; and relative humidity minimum value appeared around 13-14p.m. with the highest value at about 9a.m.. The temperature and relative humidity showed anti-correlation. According to the average value of the whole measurement period of the four measuring points, it was found that the average temperature of the whole day followed the measuring point 3>2>4>1, and the average relative humidity followed 1>4>2>3. The standard deviation analysis showed the temperature and relative humidity fluctuations throughout the day, and the variation trend of temperature and relative humidity standard deviation of the four measuring points followed 2>1>4>3.

2.2 Analysis of Wind Speed Data as Measured

The measured wind speed was another important index in the microclimate data and the ventilation condition was closely related to the changes of temperature and relative humidity. The data analysis adopted the average value, range and standard deviation comparative analysis method. The average value of 20 minutes was taken for each measuring point, and the range and standard deviation were analysed by the average value of all day.
By calculating the average wind speed of 9:00a.m.-16:00p.m., it was found that the average wind speed of Point 2 was 0.39m/s, and the average wind speed of Point 3 was 0.13m/s, and Points 1 and 4 were in the middle. By calculating the standard deviation from 9:00a.m.-16:00p.m., it was found that the wind speed of measuring point 4 fluctuated greatly and the measuring point 3 was smaller.

2.3 Analysis of Solar Radiation Data as Measured

The measured solar radiation values at four measuring points were directly related to the variation of illumination in the whole day. Data analysis adopted the average value, range and standard deviation comparative analysis method. The average value of 20 minutes was taken for each measuring point, and the range and standard deviation were analysed by the average value of all day.
By calculating the average solar radiation of each measuring point at 9:00-16:00, it showed that the average solar radiation of four measuring points followed 4>2>3>1. The average solar radiation value of measuring point 1 was lower than other measured points mainly due to narrow street and higher building, so the larger shadow area within the street made smaller amount of radiation in all day. It was found that the standard deviation of measuring point 1 and 2 were smaller, indicating that the solar radiation fluctuation of these two measuring points were small.

3. Dynamic Microclimate Simulation in Yangmeizhu Street based on ENVI-MET

By using urban three-dimensional microclimate dynamic simulation software Envi-Met, CFD analysis grid was established according to information of the street space, and the model is modelled according to actual situation of underlying surface of the street space. The paper set up the building thermal construction according to the national standard and the wind environment according to the dominant wind direction and high frequency speed in Beijing in winter. PMV parameter set up speed 3km/h, 0.3clo of the clothing insulation coefficient in summer, 2.0clo in winter in reference to the universal Beijing City.

By using the measured data of the microclimate index above, the model was fit into the ENVI-MET software platform, and the dynamic model of microclimate environment was established in Yangmeizhu Street, which was modelled as the research area, and the grid and initial values were set up according to characteristics of ENVI-MET simulation. The length of the model roughness was 0.01, the grid resolution dx=2m, dy=2m, dz=1m (DX and Dy were the resolution of horizontal X and Y respectively, and DZ was the resolution of Z in the vertical direction). According to previous investigation and the measured data, people would do more activities during 13:00p.m.-15:00p.m. and the thermal environment changed prominently, so the time period was simulated and analysed. The initial simulation index and the street grid scale are shown in Table 5.

| Name          | Grid scale (m) | Initial temperature | Initial relative humidity | Initial wind speed | Initial wind director |
|---------------|----------------|---------------------|--------------------------|--------------------|-----------------------|
| Yangmeizhu Street | 248*48*23       | 33.3℃               | 48.7%                    | 0.29m/s            | 114°                  |

The paper used Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) to evaluate the simulation results, as shown in Equation (1) (2), in which Xobs was the measured value; Xmodel was the simulation value; n was the time.

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (X_{\text{obs.} \ i} - X_{\text{model.} \ i})^2}$$

$$\text{MAPE} = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{X_{\text{obs.} \ i} - X_{\text{model.} \ i}}{X_{\text{obs.} \ i}} \right|$$

Formula (1) Formula (2)

The error analysis of the measured values and simulated values at four measuring points in the study area showed that the RMSE value was between 0.29-0.71 and the MAPE was between 0.73%-1.76%. The smaller value of RMSE and MAPE was, the smaller error between the measured and the simulated would be. In the evaluation of ENVI-MET model, the RMSE value of temperature was between 1.31-1.63℃, and MAPE was less than 10%, indicating that the error between the measured value and the simulated value was small, and the model could predict the urban microclimate environment perfectly.

| Measuring points | RMSE | MAPE |
|------------------|------|------|
| 1                | 0.29 | 0.79 |
| 2                | 0.71 | 1.76 |
4. Calculation Method of Microclimate Thermal Comfort in Yangmeizhu Street

The calculation of microclimate thermal comfort in Yangmeizhu Street mainly analysed the physiological equivalent temperature (PET) and wet bulb globe temperature (WBGT) of the two thermal comfort indexes, in which WBGT was obtained in measurement and PET was obtained in RayMan software to calculate such microclimatic factors as temperature, relative humidity, wind speed and solar radiation. The calculation was carried out in Beijing with the longitude 116°25′29″ and latitude 39°54′20″. The clothing insulation coefficient in summer was set to 0.5clo, the activity quantity was 120W, the human body parameter was set as male standard, the height was 175cm, the weight was 75kg, the age was 35 years old, and the weather was clear and sunny in the course of measurement, so the cloud cover was set to 0.

As shown by the numerical variation trend of PET and WBGT, the general trend of the four measuring points was similar, but the occurrence time of peak value and valley value was different, which could comprehensively reflect the thermal comfort changes of the two indexes under the measured and simulated conditions. At measuring points 1, 2 and 4, PET peak value appeared at about 14:00p.m.-15:00p.m., respectively 30.75℃, 32.62℃, 32.09℃, and the peak of the measuring point 3 at about 10:40a.m. was 32.59℃; for measuring points 1, 2, 3 and 4, the PET valley value appeared during 9:00a.m.-10:00a.m., 23.46℃, 25.66℃, 28.78℃ and 26.01℃ respectively. The change trend of WBGT in all day showed that WBGT peak value at measuring points 1, 2, 3 and 4 appeared at about 12:00a.m.-14:00p.m., 29.53℃, 33.46℃, 32.18℃ and 31.56℃ respectively; the valley value of measuring points 1 and 4 appeared at about 9:00a.m.-9:20a.m., 23.96℃ and 27.99℃ respectively; for the measuring points 2 and 3 at 15: 40p.m.-16:00p.m., 28.24℃ and 27.74℃ respectively. In general, the thermal comfort value at the measuring point 1 was obviously lower than that at measuring points 2 and 3. The contrast of permutation of four measuring points between the morning and the afternoon was greater.

Table 1: Summary of PET and WBGT Values

| Point | PET (℃) | WBGT (℃) |
|-------|---------|----------|
| 1     | 32.09   | 26.01    |
| 2     | 32.62   | 28.78    |
| 3     | 30.75   | 23.46    |
| 4     | 32.59   | 25.66    |

On the basis of the above microclimate index distribution map and PET value analysis, PET value followed measuring point 3>4>2>1 in 9:00-10:00 a.m. and WBGT value followed measuring point 3>2>4>1. During 14:00p.m.-15:00p.m., PET value followed 2>4>3>1 and WBGT value followed 2>4>1>3. The PET value of measuring point 1 was the smallest in the morning and afternoon, 23.86℃ and 30.19℃ respectively, the corresponding thermal sensation was warmer, human thermal comfort was good and the comfortable space covered the entire street space mainly because the aspect ratio was relatively high; therefore, a large area of shadow was informed. The PET value and WBGT value of the measuring point 2 were in the middle stage in the morning while they were ranked on the top among 4 measurement points during 14:00p.m.-15:00p.m.. The PET value and WBGT value of the measuring point 3 were 30.07℃ high between 9:00a.m.-10:00a.m., the thermal comfort was poor, the PET value and WBGT value during 14:00p.m.-15:00p.m. were smaller, 30.44℃ and 28.08℃ respectively.
respectively. The comfort space was mainly in the south street primarily due to sunshine for a long time and more solar radiation in the northwest in the street space. As the southeast street received less solar radiation and was in a shadow for a long time, the PET value and WBGT value of the measuring point 4 were centred in the morning and afternoon, and the comfortable street area was located in the northwest and southeast because of trees like Malus micromalus, Magnolia denudata, Cerasus pseudocerasus and Toona sinensis which can effectively absorb solar radiation and increase the coverage of shadow.

Table 7. Thermal Comfort Value during Two Periods

| Measuring points | Morning (9:00-10:00) |  | Afternoon (14:00p.m.-15:00p.m.) |
|------------------|----------------------|------------------|---------------------------------|
|                  | PET                  | WBGT             | PET                             |
| 1                | 23.86                | 24.13            | 30.19                           |
| 2                | 26.24                | 29.88            | 32.47                           |
| 3                | 30.07                | 30.07            | 30.44                           |
| 4                | 26.83                | 28.76            | 31.99                           |
5. Quantitative Analysis of Relevance between Landscape Space and Microclimate Thermal Comfort in Yangmeizhu Street

In the research methods of thermal comfort, the indexes in microclimate environmental assessment were interrelated and independent, so it was difficult to evaluate the microclimate environment only by using an index. At the same time, the microclimate environment in the city was quite different from the climate. Its formation and change were directly related to the material environment and the function of space in the city. In addition to the climate index, it was related to human perception and metabolism. The evaluation of thermal comfort could provide more comprehensive and clear decision model for the study of complex microclimate environment in the city. For one thing, ENVI-MET software platform could obtain distribution map of thermal comfort index; for another thing, the model could build thermal comfort value at any point in public space. Comparative analysis can provide a better foundation for the design of public space. The simulation method of thermal comfort could be applied to the preliminary plan of renovation design and the evaluation of later plan in old city.

In this paper, on the basis of Yangmeizhu Street spatial scale and distribution of landscape elements, this paper chose the main landscape design sites to refine the thermal comfort value. At the same time, green coverage, street aspect ratio and underlying surface materials of the main sites were quantified and analysed. The paper made comparison research between the thermal comfort value and the street space and analysed reasons for differences.

First of all, the construction of public space in old city was greatly limited, but planting in any small spaces had very effectively improved the thermal comfort. Secondly, high aspect ratio in the environmental situation of old city streets was difficult to reform. In this sense, it was very important to arrange the only public space. Finally, the refinement design was the first principle to improve the microclimate environment of old city and create a liveable outdoor space. We should consider the arrangement of different periods and different functional requirements, and try to create a liveable living environment as much as possible in the complex microclimate environment.

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