Parametric Study on the Comfort of Outdoor Wind Environment of Traditional Dwelling-----Taking Lius' courtyard in Kaifeng As an Example

Chunhang Liang¹, Lu Yu¹* and Xiaojun Liu²

¹School of Civil Engineering and Architecture, Henan University, Henan, 47500, China
²Kaifeng Meteorological Bureau, Henan, 47500, China
*Email: yulu917@henu.edu.cn

Abstract: In order to interpret the design wisdom of traditional dwellings in Kaifeng from a quantitative point of view, computational fluid dynamics technology is used to simulate the wind environment of traditional dwelling in Kaifeng in winter and summer. Parametric studies of three important architectural design elements on the traditional dwelling is quantitatively conducted. The quantitative design strategies for the traditional dwelling conforming to outdoor wind environment is obtained, which can be used to help local architects better understanding the traditional architectural wisdom and to guide design practice wisely in Kaifeng.

1. Research background

Traditional Chinese houses are the crystallization of Eastern culture and Chinese civilization. Traditional houses in various regions of China differ in construction due to differences in natural environment, social environment and building materials, forming a variety of architectural forms and distinctive construction techniques. As non-renewable cultural resources in Central China, traditional houses in Kaifeng reflect the cultural customs and aesthetic habits of the people in the region as well as its social, economic and cultural features and other regional characteristics and have great research significance.[1]

The research on traditional residential buildings has always been a hot topic in the field. There are hundreds of research papers on traditional residential buildings. While all-embracing in entry points, all studies have made plentiful achievements, ranging from the research on the protection of single traditional residential buildings to the research on the protection of traditional residential settlement space based on regional culture to the exploration of extracting ecological design strategies from traditional residential buildings and applying them to the design of modern green buildings. However, it must be pointed out that the climatic and environmental effects cannot be truly exerted if ecological climate design strategies of traditional buildings cannot be analyzed and used for reference rationally though traditional residential buildings have good climate adaptability and superiority in wind and heat environment, and that the application of right design strategies to wrong conditions may be counterproductive.[2]

Therefore, aiming at the Lius’ courtyard, a traditional residential building in Kaifeng, this paper conducted a parameter study on three important design elements of traditional residential buildings and a quantitative analysis on the outdoor wind environmental comfort of multi-step courtyard buildings under climate conditions of summer and winter respectively by technical means of CFD.
simulation, and obtained the quantitative design basis of multi-step courtyard buildings meeting the comfort level of human body to guide architects to correctly understand and reasonably apply the wisdom of traditional residential building design to the contemporary architectural practice in Kaifeng.

2. Research object and analysis of its regional climate characteristics

2.1 Research object
The Lius' courtyard (two parallel houses on the east side and the west side), a traditional residential building built in the sixth year of Emperor Guangxu in Qing Dynasty (1880 AD) and located in Liujia Hutong, Kaifeng, is a three-step courtyard with the typical quadrangle courtyard layout, covering an area of approximately 900 m². It is the most intact residential building in Kaifeng. The west courtyard of the Lius' courtyard is taken as the specific research object of this study, which faces south and includes the house facing north, the hallway, the stoep and the main building in sequence along the north-south longitudinal axis. With the layout of "front living room and back yard", the whole courtyard is in the axial symmetric form. [1](see Figures 1 and 2)

Figure 1. Plan of Liu's courtyard (drawn according to P34 of Henan Traditional Dwelling)

Figure 2. Section 1-1 of Liu's courtyard (according to P35 of Henan Traditional Dwelling)

2.2 Analysis of climate characteristics in Kaifeng
Kaifeng is located between 113°52"15" and 115°15"42" E and 34°11"45" and 35°01"20" N, the climate in which is temperate monsoon climate, belonging to the cold zone in China's architectural climate zoning. Its climate is mainly featured with four distinct seasons - cold and dry winter, dry and windy spring, high-temperature and rainy summer and crisp air in autumn. There are obvious seasonal changes in wind direction, with northwest wind prevailing in winter and southeast wind prevailing in...
summer. According to the annual meteorological data of Kaifeng (Table 1), the outdoor environment in Kaifeng is relatively comfortable in spring and autumn, and the uncomfortable wind environment may occur in strong winds in winter.

| Month    | Maximum average temperature (°C) | Minimum average temperature(°C) | Humidity(%) | Average wind speed(m/s) |
|----------|---------------------------------|---------------------------------|-------------|-------------------------|
| January  | 5.2                             | -3.5                            | 61          | 2.6                     |
| February | 8.8                             | -0.8                            | 60          | 2.8                     |
| March    | 14.4                            | 3.9                             | 61          | 3.3                     |
| April    | 21.6                            | 10.3                            | 62          | 3.2                     |
| May      | 26.9                            | 15.7                            | 65          | 3.0                     |
| June     | 31.3                            | 20.4                            | 65          | 3.0                     |
| July     | 31.5                            | 23.3                            | 78          | 2.4                     |
| August   | 30.4                            | 22.3                            | 80          | 2.2                     |
| September| 26.6                            | 17.1                            | 75          | 2.1                     |
| October  | 21.5                            | 10.9                            | 69          | 2.2                     |
| November | 13.9                            | 3.8                             | 66          | 2.5                     |
| December | 7.1                             | -1.9                            | 64          | 2.6                     |

3. Establishment of research process system
The research process system in this paper is mainly divided into data collection, model building, numerical simulation and data collection, data sorting and statistical analysis, and design guidance and control (see Figure 3).

First, we consulted the relevant literature and collected the surveying and mapping data of the Liu's courtyard; specified the wind environment comfort in the inner yard of and around the building as the research element according to current research achievements about the outdoor wind environment of residential buildings; and selected the variation of the surface width of the building based on influencing factors of the wind environment, the change in the height of the principal room, the hallway, the wing-room and the main building and the spatial scale between courtyard buildings as adjustable elements for research.
Second, the original numerical model was built based on the surveying and mapping data and the software Sketchup. Then, the standard k-ε turbulence model was used as the research model in this study due to its advantages of small calculation fluctuations and high accuracy in the numerical simulation of low-speed turbulence in the outdoor wind field and the inner yard [2]. In the initial simulation of the wind environment, the wind direction prevailing in summer in Kaifeng was set as the southeast wind at a speed of 5.5 m/s at a height of 10 m and that prevailing in winter was set as the northwest wind at a speed of 8.0 m/s at a height of 10m based on the meteorological values of Kaifeng over the years and the distribution pattern of the wind speed near the ground changing with height (i.e. the wind profile indicated in meteorology). Then, the numerical model was imported into the software PHOENICS for numerical simulation of the outdoor wind environment (see Figures 4).

![Figure 4. The wind field distribution at 1.5m height of courtyard in summer(L)and winter(R)(m/s)](image)

Third, the research data was collected. To observe the change in the environmental comfort in the three-step quadrangle courtyard of the Lius' courtyard, a data collection point was set up every 2 m along the north-south axis of the courtyard, totaling 12 points including 4 in the first-step yard, 4 in the second-step yard and 4 in the third-step yard. (See Figure 5.) Then, the wind environment of the courtyard was simulated under summer and winter conditions to obtain the wind speed value at each sample point. The average wind speed in the courtyard could be obtained through weighted averaging of numerical points in each courtyard.

![Figure 5. The distribution map of wind speed measuring points in courtyards](image)

Finally, this study showed based on the wind speed evaluation standard (Table2) proposed by the Japanese scholar Shuzo Murakami (1992) that the human body would feel relatively comfortable at the pedestrian level of 1.5 m and the wind speed between 1m/s and 4m/s and uncomfortable when the wind speed was lower than 1 m/s or higher than 4 m/s (the daily maximum instantaneous wind speed was greater than 10 m/s). Then, the collected data was sorted and analyzed statistically. Relative design guidance and control strategies were established based on the data results.
Table 2. Wind speed value (1.5m footbridge height) evaluation standard proposed by Shuzo Murakami (with maximum average or instantaneous wind speed for indicators)

| Uncomfortable wind speed value caused by weak wind | Comfortable wind speed value | Uncomfortable wind speed value caused by strong wind |
|--------------------------------------------------|----------------------------|-----------------------------------------------------|
| <1m/s (maximum average wind speed)                | 1m/s--4m/s (maximum average wind speed) | >4m/s (maximum average wind speed)                  |
|                                                  |                                  | >10m/s (maximum instantaneous wind speed)           |

4. Parameter study on influencing factors of wind environment

Important design elements including the surface width of the courtyard, the height of the building and the spatial scale between courtyard buildings were extracted to establish an experimental control group for further parameter research on influencing factors of the wind environment in order to further explore ecological climate design strategies of traditional courtyard buildings and their guiding value for contemporary green building design, thus providing architects with more specific quantitative design guidelines.

4.1 Comparison of average wind speed in the inner yard under the condition of different surface widths

To study the influence of the surface width of the inner yard on the wind environment, the building model with the surface width ranging from D, D+2m, D+4m, D+6m to D+8m (D refers to the surface width of a modern courtyard) was numerically simulated respectively under winter and summer conditions while other elements and the depth of the courtyard remained unchanged. Figures 6 shows the results of the parameter research. With the gradual increase of the surface width, the average wind speed in the first-step, second-step and third-step courtyards in summer and winter showed the same change trend, which first increased and then decreased and lied in the range of comfort of 1 m/s-4 m/s. According to further analysis, an obvious turning point of the wind speed from high to low could be seen when the surface width increased by 4 m and to about 10 m, which is beneficial to the improvement of the wind environment comfort in the courtyard from the perspective of ventilation in summer and wind protection in winter. Therefore, architects should pay attention that the design of the inner yard with the ratio of the surface width to the depth close to 1 is more conducive to creating good architectural environment and microclimate from the perspectives of yard space usage and wind environment in the process of introducing the traditional multi-step courtyard space design into the contemporary architectural practice in Kaifeng.
4.2 Comparison of average wind speed in the inner yard under the condition of different construction heights of the main building, the hallway, the wing-room and the principal room

Different construction heights of the main building, the hallway, the wing-room and the principal room will affect the wind environment in the first-step, second-step and third-step courtyards in winter and summer. Figures 7 shows the simulation results of their wind environment in winter and summer under the condition of different construction heights of the main building/hallway/principal room ranging from H, H+1m, H+2m, H+3m to H+4m. The simulation results indicated that the average wind speed in the first-step courtyard showed a downward trend in summer and remained basically unchanged in winter with the gradual increase of the construction height; the average wind speed in the second-step courtyard increased in summer and decreased in winter; and that in the third-step courtyard remained basically unchanged in summer and winter with the increase of the construction height. According to further analysis, as the construction height increased, the wind speed in the second- and third-step courtyards was within the range of human comfort of 1 m/s-4 m/s, while that in the first-step courtyard was obviously below the range of comfort when the construction height was about 10 m, i.e. the ratio of the construction height to the north-south depth of the courtyard was 1:1. Therefore, it is recommended that the height of the south-oriented building of a single courtyard should not be greater than its north-south depth from the perspective of wind environment comfort of a three-step courtyard.

4.3 Comparison of maximum wind speed in the area between courtyard buildings

With the development of modern cities, the overall scale of individual buildings has continued to expand, and correspondingly, modern green buildings no longer have the small-scale characteristics of
traditional buildings. Therefore, attention should be paid to the impact of scale expansion when the ecological climate design strategies of small-scale traditional buildings are applied to large-scale modern architecture. [2] The maximum wind speed in the area between courtyard buildings was analyzed based on the existing architectural scale of multi-step courtyards in this experiment, in which the distance between courtyard buildings was set as 1-5 times the east-west surface width x of the courtyard (see Figure 8). The simulation results (see Figure 9) showed that the wind speed in the area between courtyard buildings in summer at the pedestrian level of 1.5 m gradually increased with the expansion of the scale between courtyard buildings; when the overall scale was greater than 3 times the original scale, the maximum wind speed would exceed the wind environment comfort threshold; the maximum wind speed in the area between courtyard buildings in winter was much greater than the wind environment comfort threshold. Therefore, attention should be paid to handling the surrounding wind environment of the courtyard properly to reduce the impact of the wind on pedestrians in its surrounding environment when the architectural scale of traditional courtyards is expanded.

5. Conclusion
In this paper, the outdoor wind environment of the traditional multi-step courtyard building in Kaifeng was simulated under the climatic conditions of winter and summer based on computational fluid dynamics technology. A parameter study was conducted with three important design elements - variations of the surface width of the multi-step courtyard building, the change in the construction height of the principal room, the hallway, the wing-room and the main building and the spatial scale between courtyard buildings. The following conclusions are made: (1) In the spatial organization of multi-step courtyards, the form of a single multi-step courtyard with the ratio of the surface width to the depth close to 1 can meet the requirements for ventilation in summer and wind protection and warming in winter and meanwhile create a good comfortable wind environment; 2) More attention should be paid to the wind environment comfort in the first-step courtyard in summer when the construction height of multi-step courtyards is designed. It is recommended that the height of the south-oriented building of a single courtyard should not be greater than the north-south depth of the courtyard from the perspective of improving the wind environment comfort; 3) The spatial scale between courtyard buildings should not exceed 3 times the surface width scale of the existing courtyard building during the design of multi-step courtyard building organization; otherwise, the comfort of the surrounding wind environment will be reduced greatly. The research conclusions above can be used as a reference for architects when they draw on the traditional elements of multi-step courtyards in Kaifeng for design so that they can apply them to the practice of modern green buildings in the area in a reasonable way.

References
[1] Panpan, Huang. (2014) Study on the types and characteristics of the Traditional Dwellings in the east of Henan Province.D.Zhengzhou University.Zhengzhou,China.
[2] Yuan Shi. (2014) Parametric study on bioclimatic design strategies of traditional courtyard.J.Architectural Journal.2014(1):27-29
[3] Yuanding, Lu.(2004) Chinese Traditional Dwelling.South China University of Technology Press. Guang zhou,China.
[4] Manchang, Zuo(2007) Henan Traditional Dewelling.China Architecture&Building Press.Beijing,China.
[5] Qiuyue, Piao.(2017) Study on the comfort of outdoor environment into the courtyard of the Zhang’s Shuai FU.D.Shenyang Agricultural University.Shengyang,China.