Overhead Space Layout Strategy of Enclosed Teaching Building Based on Wind Environment Performance Optimization

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Abstract. Based on the regional characteristics of Qingdao, this paper puts forward the evaluation standard of the courtyard wind environment, analyzes the influence of overhead space layout of teaching buildings on the courtyard wind environment, and puts forward the optimization design strategy to achieve the purpose of wind prevention in winter and ventilation in summer. Based on the case study, the standard model is established. Through the wind environment simulation experiment, the correlation law between overhead space layout form and the courtyard wind environment performance is analyzed, which provides methods and suggestions for overhead space design of enclosed teaching and research buildings in the Qingdao area.

Keywords: Enclosed teaching building; Outdoor wind environment; Overhead space; The courtyard

1 Introduction

Since the 21st century, Chinese university campus construction has entered a period of great development. In 2015, the state put forward the strategy of building "double first-class" universities, which provides another important opportunity for the development of university construction[1]. At present, teaching buildings in newly built universities in China often form a group of teaching buildings with inter-college combinations, and the common monomer forms are mainly determinant, L-shaped, U-shaped, enclosed, and so on [2]. Among them, the enclosed type also makes reasonable use of the unfavorable orientation and can create more indoor shared spaces and outdoor shared courtyards, which are widely used in the design of teaching and scientific research buildings.

At present, the relevant research on teaching buildings is mainly carried out from the aspects of spatial form, design strategy, and climate adaptability design. Some scholars divided the central teaching area space into centralized, linear, network, and comprehensive according to the organizational structure [3]. Some studies conducted regression analysis based on the correlation between campus spatial form and wind environment and proposed a wind-environment-oriented campus spatial form design method [4][5]. Others analyze the influence of factors such as building spacing, building orientation,

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and layout on the thermal environment of the teaching group [6]. Based on the above analysis, this paper establishes a standard model based on the case investigation data of the research object and uses computer simulation to explore the correlation between overhead space layout and the courtyard wind environment.

Qingdao is located in a hot summer and cold winter area, with a high frequency of wind in winter and summer [7], which makes it an important measure to improve the comfort level of the wind environment in the courtyard of the teaching building. Therefore, based on the demand for an outdoor wind environment under climatic conditions in Qingdao, this paper studies the correlation between overhead space layout and the courtyard wind environment, hoping to provide methods and suggestions for the early design stage of teaching and scientific research buildings.

2 Research Data and Setting of Simulation Conditions

2.1 Case study

The study selected more than 60 cases of domestic teaching and research buildings to investigate, analyzed, and summarized their layout. As shown in Figure 1, the common layout forms of teaching buildings have the following types: determinant, L-shaped, U-shaped, and enclosed type.

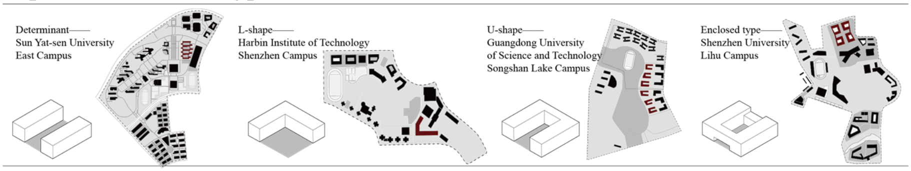

Fig. 1. Summary of layout types of teaching and research building.

To establish a typical experimental model, the grasshopper parametric platform was used to select 30 cases of enclosed teaching and research buildings in colleges built in the 21st century in China as research objects. Based on the survey data, the basic physical size information of the research object is determined (Figure 2).

2.2 Establishment of the basic information model

The establishment of the basic experimental model is shown in Figure 3. According to the form and size data of the enclosed teaching and research building shown in Table 1, the ideal model of the enclosed teaching and research building is established. And the paper takes the Guzhenkou Campus of the China University of Petroleum as an example to establish the surrounding site model (Figure 2). According to the spatial distribution of overhead, 16 groups of experimental models were designed (Figure 3). The selection of measuring points in the simulation is divided into three categories (Figure 2): yard corner points, points at the end of the axis, and uniform distribution of points.

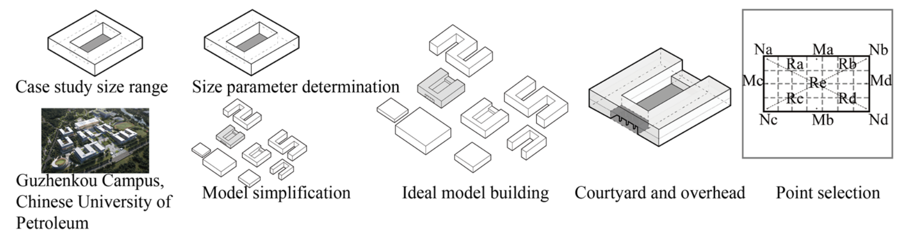

Fig. 2. The ideal model of enclosed teaching and research building.

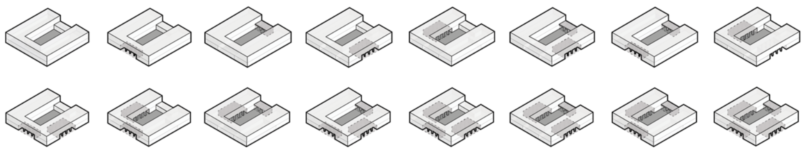

Fig. 3. 16 groups of experimental model design.

2.3 Computational domain and boundary condition setting

Qingdao is located in the south of Shandong Province, of which the dominant wind direction is obvious in winter and summer. According to relevant design specifications, the wind speed and direction are set as follows: the maximum frequency wind direction in summer is S, with a speed of 4.6 m/s; The maximum frequency wind direction in winter is N, with a speed of 6.6 m/s. Chang et al. [8] suggested that the size of the calculation domain is determined to be 690 m*930 m*190 m, and the mesh size is 139*176*38. K-ε turbulence model was adopted for simulation.

2.4 Wind environment assessment method

Comfort zone area ratio.

The comfort zone area ratio is the ratio of the comfort area of the courtyard to the courtyard area. The calculation formula is as follows: $S = \frac{S_C}{S_0} \times 100\%$.

S is the comfort zone area ratio, S_C is the comfort zone area, and S_0 is the total area of the courtyard. This paper mainly refers to Professor Li's doctoral thesis (Table 1), combined with the meteorological data query in the Qingdao area, setting the comfortable wind speed range in winter and summer as follows (Table 2).

Table 1. Evaluation criteria for wind speed influenced by temperature. (From a *Study on the influence of planning and design factors on cluster microclimate in hot and humid regions.*)

Evaluation range	Temperature range (°C)		
	<10	10~25	>25
Thermally uncomfortable breezy range (m/s)	-	-	<0.7
Human comfortable wind speed range (m/s)	<1.3	<1.5	0.7~1.7

Transition range (m/s)	1.3~2.0	1.5~2.3	1.7~2.9
Strong wind range (m/s)	>2.0	>2.3	>2.9

Table 2. Qingdao Meteorological Bureau official website meteorological data.

Season	Mean temperature	Mean wind speed	Comfortable wind speed range	Comfortable wind speed ratio range
Summer	Around 27°C	4.6 m/s	0.7~2.9 m/s	0.15~0.63
Winter	Around 3°C	6.6 m/s	0.5 ~2.0 m/s	0.08~0.30

Wind speed ratio.

The wind speed ratio is the ratio of the wind speed at the target location to the wind speed at the reference location [9]. Its calculation formula is $R_i = \frac{V_i}{V}$.

R_i is the wind speed ratio, V_i is the actual wind speed, and V is the initial incoming wind speed. Combined with the above comfortable wind speed range, it is determined that the summer wind speed ratio is between 0.15 and 0.63, and the winter wind speed ratio is between 0.08 and 0.30.

Wind velocity dispersion.

Wind velocity dispersion[10] can reflect the different degrees of wind velocity distribution in a block. Its calculation formula is $\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(v_i - v)^2}$.

σ is the wind velocity dispersion, v_i is the actual wind velocity, and v is the initial incoming wind velocity.

3 Research Results and Analysis

3.1 Analysis of simulation results under the influence of winter wind

Figure 4 shows the visualization results of winter wind environment simulation in 16 experimental models. The proportion of comfortable wind area and the data of 13 measuring points were counted, and the next step was analyzed.

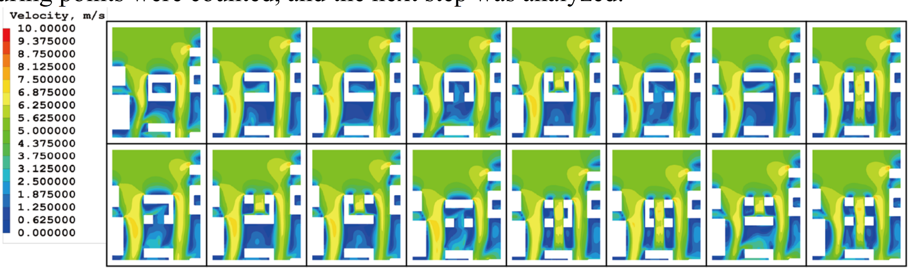

Fig. 4. Winter wind speed simulation.

Comfort of the courtyard wind.

As can be seen from Figure 5, under the influence of winter wind, the area proportion of the courtyard wind comfort zone varies greatly among different overhead space layout schemes. When there is an overhead opening in the north direction, the area proportion of the courtyard comfort zone decreases significantly. When there is no overhead opening in the north and there is an overhead opening in the south, the area of the comfort zone of the courtyard increases significantly. The inflection point of the comfort zone area ratio curve under the influence of winter wind appears in the above scheme.

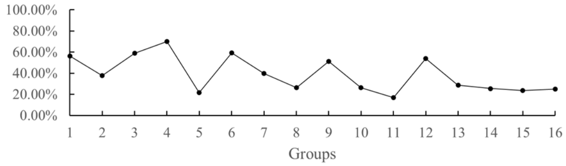

Fig. 5. Area proportion of comfort zone under the influence of winter wind.

Figure 6 shows the distribution range of wind comfort zone affected by winter wind. Due to the high average wind speed in Qingdao in winter, when there is an overhead opening in the north (Plans 5, 8, 10, 11, 13, 14, 15, 16), the wind speed in most areas in the middle of the courtyard is too high, and only a small amount of wind comfort zone is found in the edge area, and the overall wind environment of the courtyard is poor. When there is an overhead opening in the south, no overhead opening in the north (Groups 4, 6, 9, and 12), or no overhead opening (Group 1), the comfort zone area is relatively high except for a small part of the central area of the courtyard with excessive wind speed, and the wind environment is the best when there is only an overhead opening in the south. Groups 1, 3, 4, 6, 9, and 12 have a comfort zone area ratio of more than 50%, and Plan 4 has the highest comfort zone area ratio of 70%. The comfort zone area of the remaining schemes is below 40%, among which the comfort zone area of scheme 11 is the lowest, only 16.7%.

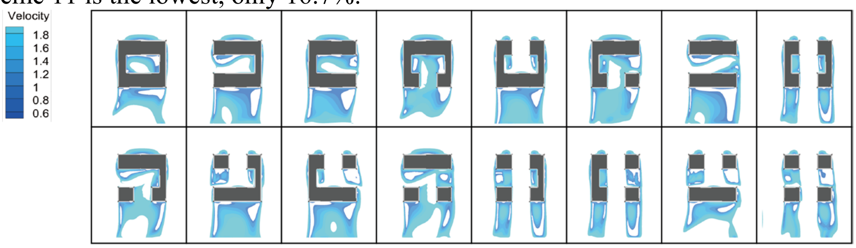

Fig. 6. Winter wind comfort range.

Relationship between overhead spatial distribution and wind speed ratio.

Figure 7 shows the wind speed ratio of each measurement point under the influence of winter wind, and the red dashed lines are the upper and lower thresholds of the wind speed ratio within the comfort range, respectively. When there are overhead openings in the north, the number of measuring points in the courtyard stroke velocity ratio is less than the threshold value, and the wind speed ratio of most measuring points is far more than the upper limit of the wind speed ratio of the comfort range. When there is no overhead opening in the north and there is an overhead opening in the south, the wind speed ratio of most of the measuring points is within the threshold value, and the wind environment is good. When the overhead space is located only on the east and west sides (Groups 2 and 3), there is the same result as above. When the east and west sides have overhead space to form through the wind corridor, the instability of the wind speed at the measuring points is enhanced, and the number of measuring points in the static wind area and the high wind speed area is increased. When there is no overhead space, the corner of the courtyard is easy to produce a quiet wind area, which is not conducive to air circulation.

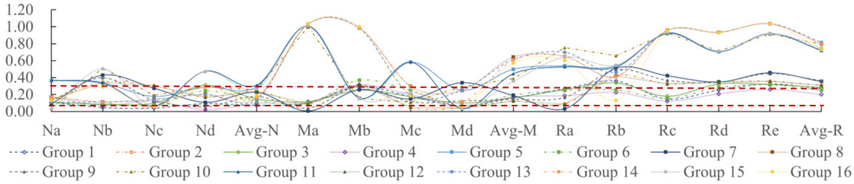

Fig. 7. Wind speed ratio under the influence of winter wind.

Relationship between overhead spatial distribution and wind velocity dispersion. As can be seen from Figure 8, when there is no overhead space or there is only one overhead space that is not in the north, the wind velocity dispersion of the three types of measurement points is small, and the overall wind environment of the courtyard tends to be stable. When there is overhead on the south side and no overhead on the north side, the wind environment is more stable. When there is overhead space on the north side, the dispersion of the courtyard wind environment is high, and the stability is poor. Moreover, the more overhead space is, the worse the stability of the overall courtyard wind environment is.

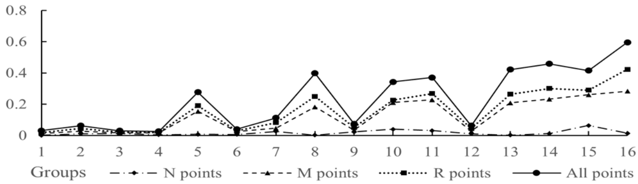

Fig. 8. Wind velocity dispersion at measuring points under the influence of winter wind.

3.2 Analysis of simulation results under the influence of summer monsoon

Figure 9 shows the distribution of the comfort zone of the summer monsoon environment in enclosed teaching buildings under the influence of 16 different overhead spatial distribution forms. The data from 13 points of each scheme were statistically analyzed and analyzed. (The summer data chart shows only the most important parts, and the conclusions are mostly written.)

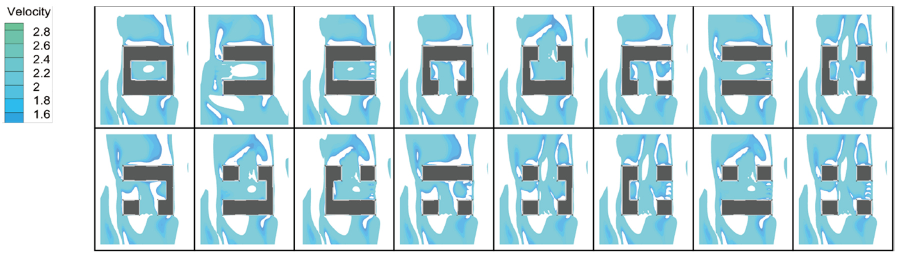

Fig. 9. Summer wind comfort range.

As shown in Figure 10, compared with winter, the average wind speed in summer is smaller (4.6 m/s, S), which made the comfort zone area of the courtyard wind in 16 schemes significantly increased, and the comfort zone area accounts for more than 60%. When there is no overhead space (Group 1), or there is overhead space in the south and no overhead space in the north (Groups 4, 6, 9, and 12), the comfort zone area in the courtyard is relatively small, basically about 70%. When there are elevated spaces in both the north and south directions (Groups 8, 13, 14, and 16) or the elevated spaces are located on both the east and west sides (Group 7), the comfort zone area of the courtyard accounts for about 80% due to good air circulation. When there is elevated space in the north and no elevated space in the south (Groups 5, 10, 11, and 15) or when the elevated space is in the east (Group 3), the comfort zone area of the courtyard occupies the largest proportion, all above 90%, and the overall wind environment of the courtyard are great.

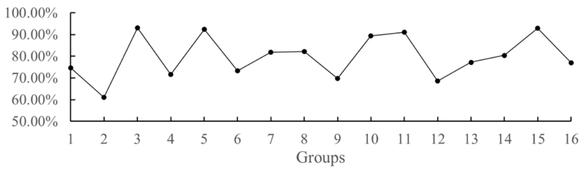

Fig. 10. Area proportion of comfort zone under the influence of summer monsoon.

Analysis of the wind speed at the measuring points shows that under the influence of the summer monsoon, the wind speed ratio at most of the 16 schemes is within the threshold. When there is an overhead space in the southbound (Groups 4, 6, 8, 9, 12, 13, 14, and 16), there are more measuring points in the static wind area and the local air circulation is poor, due to the high wind speed at the opening. When the overhead space is located on the west side (Group 2), the central area is prone to high wind speed, and the overall wind stability is poor. When there is no overhead or the overhead space is not in the southbound direction (Groups 1, 3, 5, 7, 10, 11, and 15), the wind speed at the measuring points is basically within the threshold value, and the wind speed dispersion is low, which shows that the courtyard wind environment is relatively good.

3.3 Brief summary

According to the above analysis, taking the enclosed experimental research building in the Qingdao area as the research object, under the influence of summer monsoon, the comfort zone of the courtyard wind environment accounted for more than 60%. However, under the influence of winter wind, only a few groups' comfort zone areas accounted for more than 50%. Therefore, compared with summer ventilation, the problem of winter windbreaks in Qingdao should be given priority. Based on the above analysis, the paper summarizes the following options (Table 3): The overall wind environment of the courtyard is more suitable when there is no overhead or no overhead in the winter wind direction, and there is overhead in the summer wind direction. The summer monsoon environment of the courtyard is the most suitable when the east side is overhead only. The winter wind environment of the courtyard is the most suitable only when there is overhead in the south direction.

Table 3. Scheme selection table.

Scheme selection	Winter	Summer	The overall wind environment is improved
preference	Group 1\3\4\6\9\12	Group 3\5\7\8\10\11\14\15	Group 1\3\4\6
selectable	Group 2\7	Group 1\4\6\9\12\13\16	Group 7\9\12
Not recommend	Group 5\8\10\11\13\14\15\16	Group 2	Group 2\5\8\10\11\13\14\15\16

4 Conclusions

Based on the investigation of enclosed teaching and research buildings built in colleges and universities since the 21st century, this paper establishes a typical model of enclosed teaching and research buildings, and analyzes the influence of different overhead space layout forms on the courtyard wind environment in Qingdao, so as to provide references for the performance of wind control environment in the early stage of scheme design. The conclusions are as follows:

(1) The overhead space distribution of enclosed teaching and research buildings is closely related to the comfort level of the courtyard wind environment, and the number of overhead spaces is not proportional to the quality of the courtyard wind environment.

(2) In the Qingdao area, when the incoming wind direction has no overhead and the opposite direction has overhead, the courtyard wind comfort zone occupies the largest area, the wind stability is strong, and the overall wind environment is the most comfortable. When the wind direction is overhead, the central area of the courtyard is prone to excessive wind speed and wind shadow area. The wind stability is poor, and the comfort level of the courtyard wind environment is low.

(3) Since the wind speed is generally high in winter and summer in the Qingdao area, and the summer ventilation and winter windbreak should be considered

comprehensively in the hot summer and cold winter areas, the overhead space should not be arranged in the north. When there is no overhead in the north and overhead in the south, the overall wind environment of the courtyard is generally more suitable. The overall wind environment of the courtyard is the best when there is only overhead on the east side, and the comfort zone of winter wind can reach 58.78% and that of summer wind can reach 93.09%.

But in real life, the courtyard wind environment of an enclosed teaching building is related to many factors, such as the patio length-width ratio, height-width ratio, and the size of the overhead space. To focus on the influence of overhead space distribution on the courtyard wind environment, the above-influencing factors are set as the same in this paper, which made the scope of application relatively limited. The paper has not conducted specific research on other influencing factors such as micro-topography and overhead space design, which will be the next research direction.

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