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Research Paper

The form of street spatial layout based on a wind environmental perspective

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ABSTRACT

With China's rapid urbanization, the construction of central areas in city with numerous buildings and dense population has greatly changed the microclimate. Different street spatial layouts change the internal wind environment, which affect the pedestrian comfort. Computational fluid dynamics (CFD) models are used to study the correlation between the three-main street spatial layout factors, which are near-line rate, street interface density and street aspect ratio, under the simulation of relevant weather conditions. Firstly, the wind speed within the street change with the increase of the near-line rate like a parabola trend, and the wind speed reaches its peak about at a near-line rate of 70%. In that case, it’s conducive to ventilation. Secondly, with the reduction of street interface density the variation of the wind speed of each measuring point in the streets is getting bigger and bigger, and the pedestrian walking in them will feel the change of wind speed which makes the comfort of pedestrian decrease. Thirdly, the average wind speed in urban streets is inversely proportional to the street aspect ratio. These conclusions will provide an important reference and evaluation basis for urban designers at the beginning of design and effectively avoid future wind environment problems.

1. Introduction

With the rapid progress of urbanization in China, China's urban construction is in a period of continuous changes. The construction of urban central area gradually steps into a high-speed development period. The new central area with Buildings, densely populated cities began to enter people's daily lives, and greatly changed the city micro-climate. Wind is an important factor in urban microclimate(Stathopoulo,2007). The high-rise buildings in the city's new central area will directly affect the movement of the canopy in the city (Iamtrakul,2012). It exacerbates the airflow movement near the ground, causing the formation of the underflow, the upper flow, the angle flow and so on, and may cause the local airflow to accelerate, and the formation of a certain vortex area, static wind area or blast area, thus affect people's comfort, health and travel safety (Uehara,2012).

In the past, urban planners and architects were more focused on the form and function, while ignoring the design of the outdoor wind environment, resulting in a lot of potential wind damage, such as the canyon effect, quiet wind area, wake area, wind tunnel effect, and

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directly affect the urban climate (Ying,2014). The new urban area in the hot summer and cold winter area needs the wind environment related planning strategy. Professor Jiang (2006) of Tsinghua University in 2006, pointed out in the “China Green Building Report" that the hot summer and cold winter areas of energy-saving measures focus on the shade and ventilation in summer, and the use of natural ventilation in spring and autumn. For hot summer and cold winter areas, the design strategy should consider the huge climate differences between the two quarters.

Physical indicators of the five indicators are ventilation, lighting, temperature, humidity and radiation. And among them, the volumes and shapes of buildings, and the scatter and undulation of buildings of, and the spatial layout of streets and the external environment directly impact on the speed and direction of air flow (The Chinese University of Hong Kong,2009) (Peng,2005). Moreover, the wind environment can be evaluated on different scales of urban spatial layout categories. In the general planning and architectural design, the content of urban space layout can be divided into three categories from large to small scale: urban space planning, building layout, single building spacing relationship. Prof.Chen (2004), editor-in-chief of Building and Environment, wrote in 2004 that "wind environmental assessment is an effective evaluation tool for different scale design work, such as urban spatial planning, building complexing, etc."

Jacobs (2006) said: “When we think of a city, the first thing that comes to mind is the streets. There are angry cities on the streets and the streets are boring.” We can see the importance of streets to the city. Due to the nature of the commercial use of commercial pedestrian streets, the number of pedestrians in commercial pedestrian streets is becoming more important. The wind environment is critical to pedestrian comfort in pedestrian streets. The appropriate wind speed will significantly increase pedestrian walking comfort and will attract more pedestrians into the street space and enhance the vitality of the city's pedestrian streets.

In the field of urban design, there are three main elements related to the layout of the street space: near-line rate, street interface density, and street aspect ratio. At present, the study of the rate of near-line rate is mainly focuses on the concept of near-line rate determination, and the application of near-line rate in practical design projects. For example, Wang (2013) put forward the design of the street interface density and the design process of the urban space and the street interface density; Zhou (2016) through studying the use of the status quo of "near-line rate" indicators and found its meaning and there are a variety of inconsistent statements in the algorithm, and then proposed to limit the scope of the application of the rate. And the study of the street interface density is very few, only Shi (2005), Shen (2007) define its concept. Street aspect ratio has attracted the attention of researchers early, research areas are about the architectural environment psychology, such as Luhara Yoshinobu wrote in the "external space design" that "the distance between the adjacent building and building height D: H is an important factor in determining the spatial scale. D: H = 1 for the boundary, building height and spacing between a certain are known, with the D: H bigger than 1 increasing, then form the sense of remote, with D: H smaller than 1 decreasing, then form the sense of tight, when D: H> 4, the impact between each other has been weak.

In general, the current research on the spatial layout elements of walking streets is still at the concept level, and the individual analysis and evaluation of this factor has not yet combined these factors with the evaluation of the architectural wind environment. Therefore, the research results cannot meet the complexity and diversity of street space layout in urban design.

This paper will compare the wind velocity ratio of walking streets at pedestrian height when the related factors are changing and conclude that under the premise of not affecting the continuity of urban streets, the relation between the wind environment in the urban pedestrian street and the near-line rate, street interface density, street aspect ratio. This will provide an important reference and evaluation basis for urban designers at the beginning of the design to effectively avoid wind problems such as airborne pollutants in the streets that may occur, and to take measures from the perspective of planning and design to optimize the program

2. Research method and simulation model

2.1 The establishment of the original layout

Through the study of the author's area, the statistics show that the building blocks along the street width, the street height， and the street width of the highest frequency.

Brown (2001) wrote in his book that the buildings which have the same width with the depth increasing and the geometric changing, the wind speed and flow field in the construction of the wind are basically not affected by the form. Therefore, this paper only considers the statistics of the highest frequency of the architectural form, so that there is a certain general applicability.

Claus (2010) pointed that the numerical simulation software Phoenics was developed based on Reynolds' time-averaged equations. The required conditions were

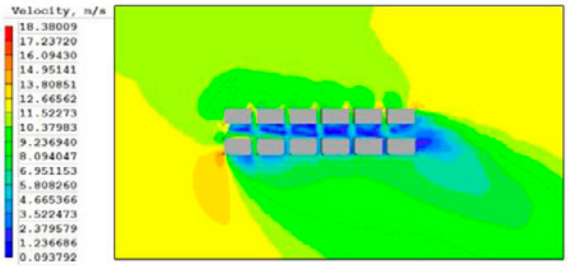

Fig. 1. The original layout.

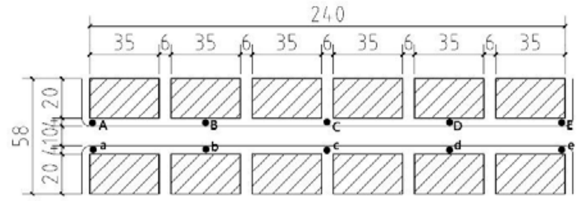

Fig. 2. Velocity vector field of original layout.

calculated using the software's own automatic selection function. The initial wind setting is as follows: Due to surface friction, the wind speed near the surface decreases with the height of the ground. Only at a distance of 300-500 m above the ground, the wind speed is not affected by the ground surface, and it can flow freely under the influence of the atmospheric gradient. Therefore, the variation of wind speed at the incoming surface is expressed as an exponential rate:

$$U(z)=UG\times(z/zG)\alpha \qquad [1]$$

$U(z)$ is the average wind speed at any altitude z, UG is the average wind speed at the standard altitude zG, and exponent α is a parameter describing the ground roughness. The standard height zG is set to 400 m in the simulation, and the average wind speed UG is 13 m/s at this height and α is 0.25. The turbulence intensity is assumed to be 12% above the ground of 52 m

When the direction of the traffic corridor in the complex is the same as the wind direction, the wind speed in the traffic trunk road will be increased and the wind speed of the traffic trunk road will be small when the direction of the main road is perpendicular to the wind direction. In addition, and when the angle between the direction of the main road and the wind direction is 45 degrees, the wind speed in building group is more uniform. This shows that when the direction of the street and the direction of the wind are vertical or same, the impact of wind speed is obvious. And in both cases, the study of public building layout impact on wind speed slightly. However, when the angle between the direction of the street and the wind direction is 45 degrees, the wind speed is stable and the direction of this factor has little effect on the wind speed of the street. Therefore, in this case, it is more suitable to study the morphological factors of the street corridor. And to make the simulation

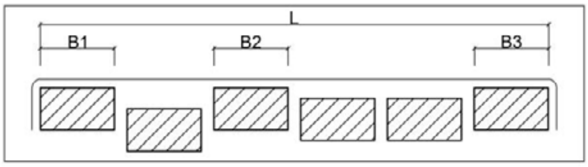

Fig. 3. The illustration of near-line rate.

results more intuitive, this paper chooses the Hangzhou winter wind speed 10m/s to simulate.

The provisions of article 3 of the Technical Provisions on Building Spacing and Departure Management stipulates that the spacing between non-residential buildings shall be less than the height of the building at the height of the building, in addition to the following provisions, in addition to the following provisions: Times, not less than six meters; vertical arrangement, the spacing of not less than nine meters, gable spacing should not be less than 6 meters. According to the above provisions, the model spacing in this model is greater than or equal to six meters.

The green building design standard stipulates that the building coverage area is less than 3% of the total calculation area; the target building is the center, and the radius is within the range of 5H. The calculation above the building is larger than 3H, and H is the height of the building. Therefore, the simulation area is 1200m * 600m * 100m.

The following original model was established according to the above and the original simulated image was obtained. To make the simulation results more inclined, we do not consider the impact of the surrounding environment. And we selected ABCDE five points at the north side of the sidewalk, and abcde five points at the south side of the sidewalk as measure points as **Fig. 1** suggests. Then the wind environment simulation was carried out and we get the velocity vector field of original layout as **Fig. 2** suggests.

2.2 The correlation between the near-line rate and the street wind environment

To cope with the low level of the sense of closure in the street interface and the incomplete status quo of urban form, establish a more complete urban form and restore urban street enclosures, the Shanghai urban planning department create a new regional street mandatory rate for the sake of standardizing the near-line rate. In the urban plots that on both sides of specific street, the ratio between the length of the street wall and the length of the building control line is known as the near-line rate, that is: street wall length ÷ building control line length × 100% as **Fig. 3** suggests.

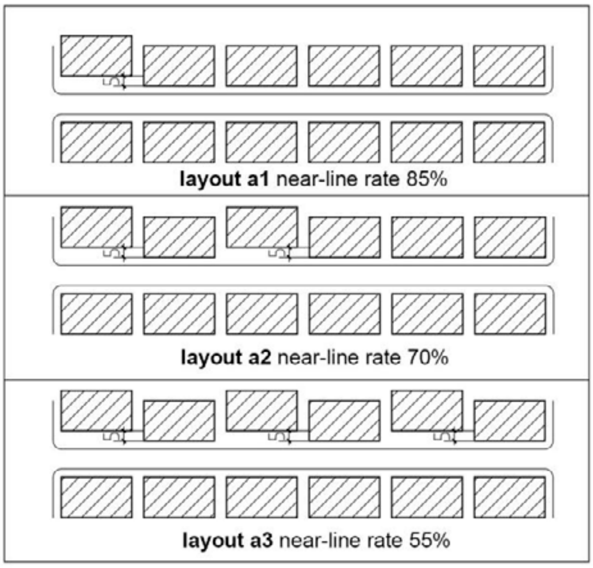

Fig. 4. The layout types of different near-line rate.

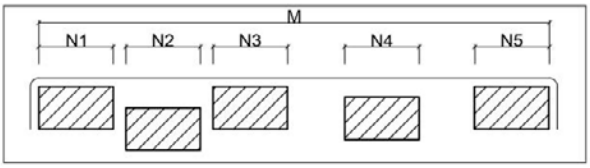

Fig. 5. The illustration of street interface density.

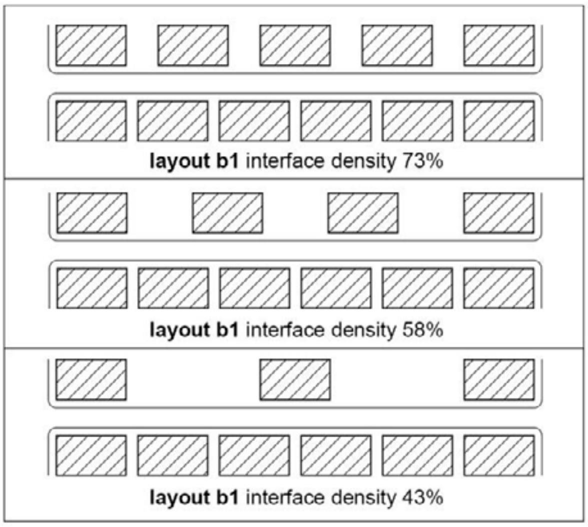

Fig. 6. The layout types of different street interface density.

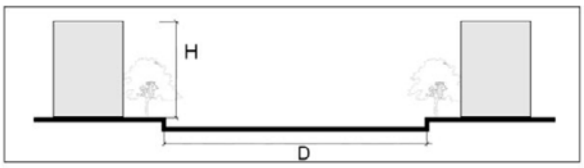

Fig. 7. The illustration of street aspect ratio.

A total of four different near-line rates were selected for this set of simulation experiments, that is 100% (original layout), 85% (layout a1), 70% (layout a2), and 55% (layout a3). The building retreat distance is 5m, and the following simulation results are obtained as **Fig. 4** suggests.

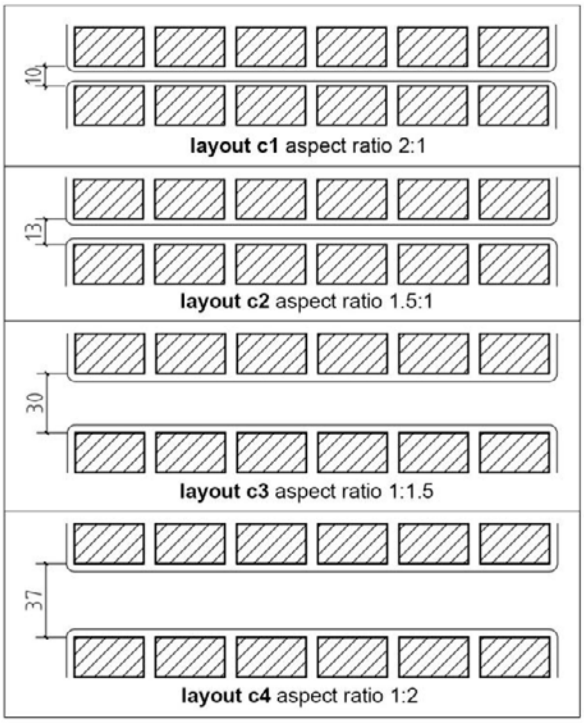

Fig. 8. The layout types of different street aspect ratio.

2.3 The correlation between the street interface density and the street wind environment

The degree of encirclement of the street interface can be measured by the existing "interface density": the interface density is the ratio of the width of the street projection plane to the length of the street as **Fig. 5** suggests. The interface density is clearly dependent on the amount of the building surrounding the street and is further linked to the building density.

The following model was established according to the above. We reduce the number of buildings at leeward side to achieve the purpose of reducing the street interface density. The street interface density values are 87.5% (original layout), 73% (layout b1), 58% (layout b2), and 43% (layout b3), respectively as **Fig. 6** suggests.

2.4 The correlation between the street aspect ratio and the street wind environment

Street aspect ratio is that the width of the street which is to D, the height of the building on both sides of the street which is set to H, the ratio between the two H: D as **Fig. 7** suggests. Through the comparison of the ratio of building height and space width (H: D) and visual analysis on both sides of the traditional street, it can be seen that different ratios can cause different psychological reactions.

Aihara (1985) pointed out that in general, the street aspect ratio between 1.5:1 ~ 1:2 is relatively pleasant; commercial street can be moderately compact, narrow

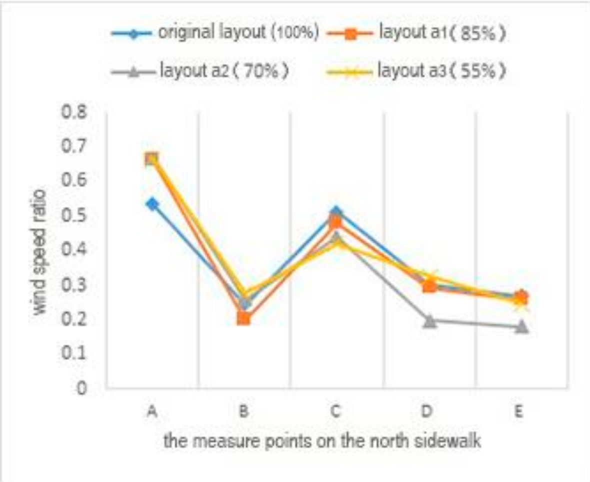

Fig. 9. The wind velocity ratio of the measure points on the north sidewalk.

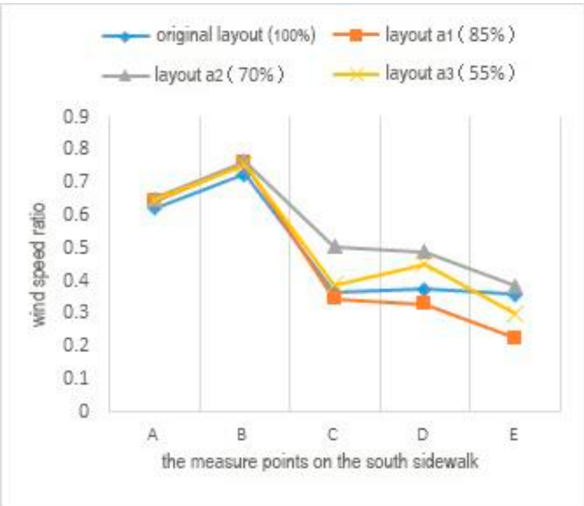

Fig. 10. The wind velocity ratio of the measure points on the south sidewalk.

commercial street aspect ratio can reach 3:1; both sides of the traffic streets and integrated street can be appropriately open, aspect ratio can be controlled between 1:1 ~ 1:2.

Therefore, we established five models, corresponding to the aspect ratio of 2:1(layout c1), 1.5:1(layout c2), 1:1 (original model), 1:1.5(layout c3), 1:2(layout c4) five

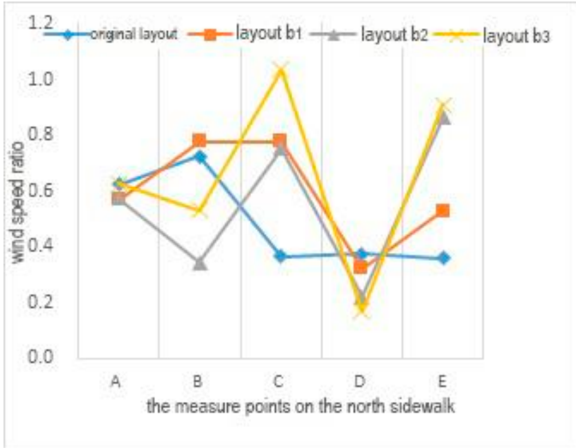

Fig. 12. The wind velocity ratio of the measure points on the north sidewalk.

cases as **Fig. 8** suggests.

3. Analysis of the results of the simulation

3.1 Analysis of near-line rates simulation results

It can be seen from the simulation results (**Fig. 9, Fig. 10 and Fig. 11**) that the wind speed of measure point a and measure point b changes shows no remarkable change. measure point a and measure point b are on the south side of the sidewalk, generally located in the outlet non-wind area. And the wind speed of each point is higher than that of other simulation conditions under the simulation condition of 70% of the layout a2, so it can be deduced that the wind speed of the city streets is relatively high when the near-line rate is 70%, which is favorable for ventilation and air quality update.

Based on the simulation data of the two groups of measure points on the south sidewalk and the north sidewalk, it can be seen that the variation range of each measure point is not obvious when the near-line rate is changing, and the wind speed of each measuring point is shows stable variations, which shows that in other conditions are stable under the premise of the change in the near-line rate will not cause changes in the wind environment within the street, and the reason that

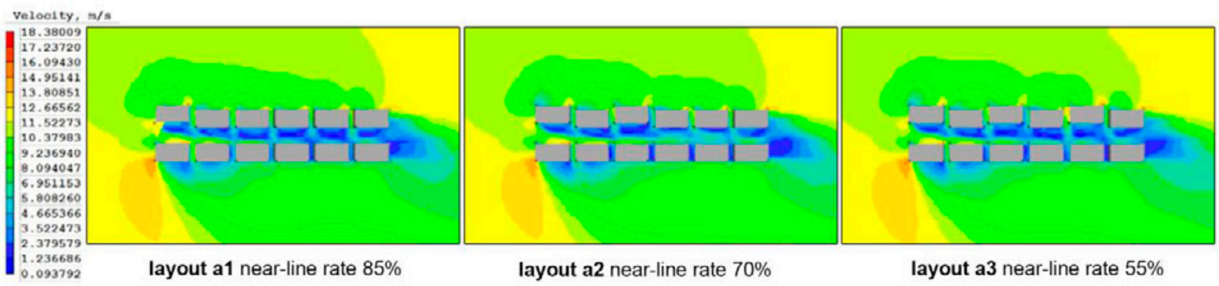

Fig. 11. Graphical simulation results of different near-line rates.

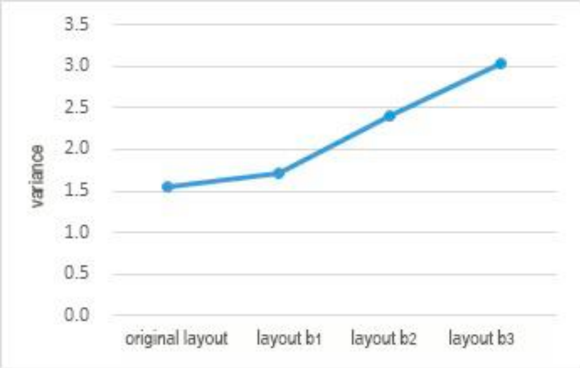

Fig. 14. The data volatility of interface density simulation results.

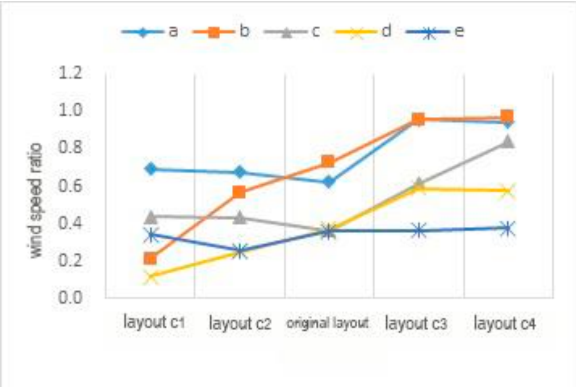

Fig. 15. The wind velocity ratio of the measure points on the south sidewalk.

environment is mainly that the location is different.

3.2 Analysis of street interface density simulation results

It can be seen from the simulation results (**Fig. 12 and Fig. 13**) that under the wind environment simulation conditions of the original layout (street interface density is 87.5%), variation range of each measure point in the urban street is the least. And under the wind environment simulation conditions of the layout b3 (street interface density is 43%), variation range of each measure point in the urban street is the most.

To make the simulation test data more intuitive and accurate, we made an analysis of variance about the wind speed at each measure points, and the line pattern of the fluctuation range of the wind speed fluctuation in different layouts is obtained. As shown in the **Fig. 14**, when the street interface density is decreasing, the variation range of each measure point in the urban street is increasing. So that pedestrians walking in the streets feel a strong wind speed changes, resulting in greatly reduced its comfort.

3.3 Analysis of street aspect ratio simulation results

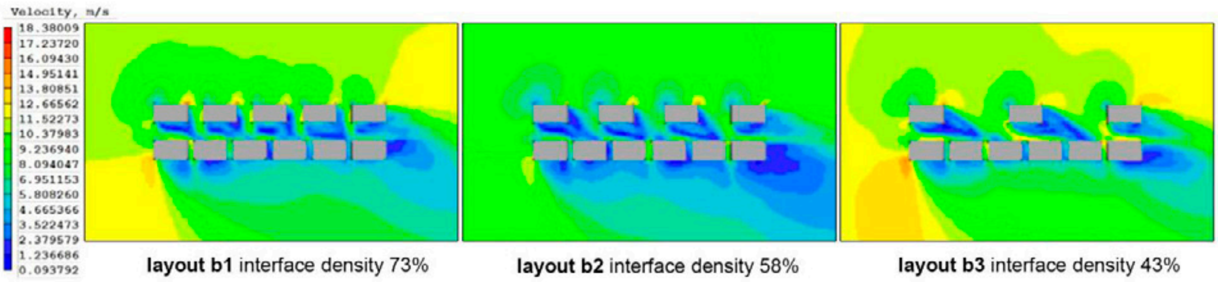

Fig. 13. Graphical simulation results of different interface densities.

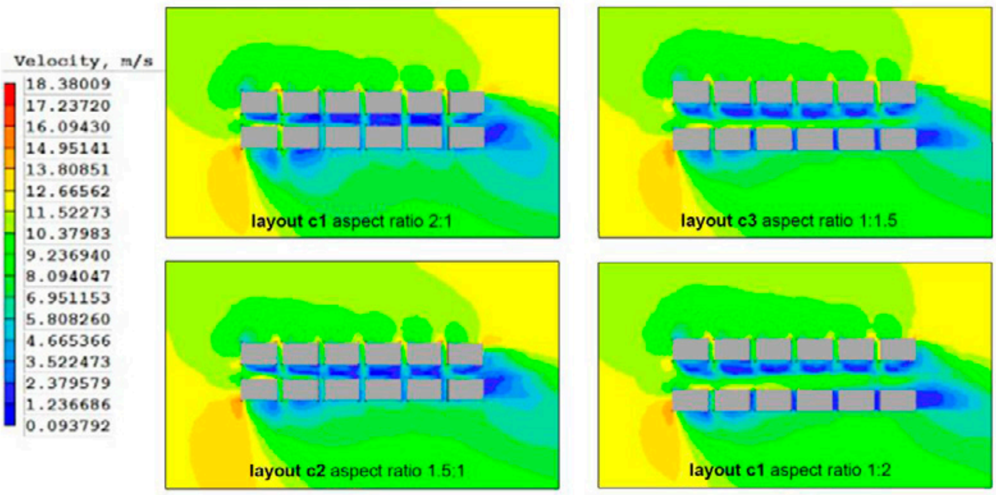

Fig. 16. Graphical simulation results of different aspect ratios.

different locations within the street have different wind

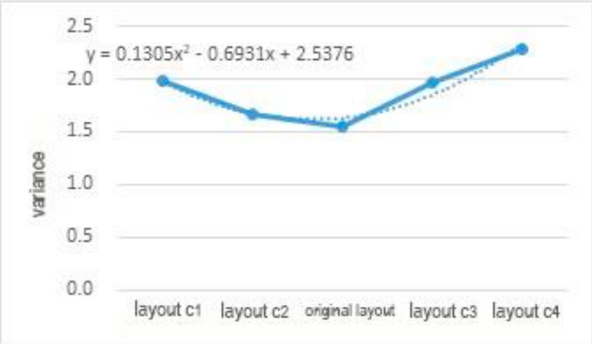

Fig. 17. The data volatility of aspect ratio simulation results.

It can be seen from the simulation results (**Fig. 15** and **Fig. 16**), with the reduction of the street aspect ratio, the wind speed of each measuring point in the street is gradually increased. Through this trend, it can be boldly deduced that there is inverse proportional relationship between wind speed and the street aspect ratio. Therefore, we ought to consciously control the street aspect ratio, try to avoid the wind speed within the city streets is too large or too small.

To make the simulation test data more intuitive and accurate, we made an analysis of variance about the wind speed at each measure points, trying to link it with the street aspect ratio, and the line pattern of the fluctuation range of the wind speed fluctuation in different street aspect ratio layouts is obtained as shown in the **Fig. 17**. By calculating the distribution of scatter, and then set up curve fit, we can get the curve between the street aspect ratio(x) and the variation range of each measure point (y).

$$y=0.1305x^2-0.6931x+2.5376 \qquad [2]$$

The curve shows that the y value decreases with the increase of the x value. When x = 2.6, the y value reaches a minimum of 1.62. Then, as the x value continues to increase, the y value increases slowly. Therefore, it can be deduced that when the street aspect ratio is close to 1: 1, the wind environment in the street is the smallest and the most stable, and the pedestrian can provide a more comfortable external space environment.

4. Conclusions

In this paper, we change the value of the near-line rate, the street interface density and the street aspect ratio by the computer simulation method and make the comparative analysis of the simulated wind environment and obtain the correlation between the three-main street spatial layout factors and the street wind environment. Specific conclusions are as follows:

1) Taken the three-main street spatial layout factors together, when the size of the factor changes, the corresponding wind speed changes can illustrate that the influence of the interface density on the street wind environment is most obvious.

2) When the near-line rate is 70%, the urban street wind speed is large, and it is conducive to ventilation and air quality update.

3) Under the premise that the other conditions are stable, the change of the street near-line rate does not cause the change of the wind environment in the street. The reason of the difference in the wind environment in the different places in the street is mainly the location.

4) As the street interface density decreases, the volatility of the various points in the city streets is increasing, which makes pedestrians walking in the streets feel a strong wind speed change, resulting in a significant decline in comfort.

5) With the reduction of the aspect ratio of the street, the wind speed of each measuring point in the street also gradually increases, which is roughly inversely proportional.

6) When the aspect ratio is close to 1: 1, the variation of the wind environment in the street is the smallest and most stable, and the pedestrian is provided with a more comfortable external space environment.

The above conclusions will provide an important reference and evaluation basis for the urban designers at the beginning of the design, and effectively avoid the possible wind environment problems in the future. Compared with the existing research, the uniqueness of this paper is:

1) Reveals the relationship between the three-main street spatial layout factors and the street wind environment.

2) In the conclusion of the experiment, we get the concrete value of near-line rate corresponding to the optimum wind environment.

5. Limitation and future study

Although we have researched the correlation between wind environment and spatial layout, there still be lack of the research of other fields about the spatial layout. For instance, the volume rate, the landscape and so on. The results of the study highlight the need for future research to broaden the scope of the special layout and then get a more comprehensive guidance in the spatial layout planning.

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