Study on the Influence of Window Type on Natural Ventilation Effect Based on CFD Simulation

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Abstract. Good natural ventilation is one of the basic conditions for people to be able to work and live indoors. In this paper, wind velocity, wind velocity non-uniformity coefficient and air age are taken as the evaluation indexes of indoor ventilation condition. A simulation software Airpak is used to build room models with three window types (with the same ventilation area), namely, top-hung window, casement window and sliding window. The wind incidence angle was adjusted between 0°- 90°, and the indoor wind velocity and air age of the room were simulated when the casement window was opened at 90°, the sliding window was fully opened and the top-hung window was opened at 30°. The average wind velocity, wind velocity non-uniformity coefficient and air age of the room under each working condition were calculated and analyzed to evaluate the freshness and comfort of the indoor air, so as to provide guidance for the reasonable design of indoor layout.

1. Introduction

With the continuous improvement of human living standards, the Indoor Environmental Quality (IEQ) of buildings has also received more and more attention. Natural ventilation with Windows on the building facade can not only strengthen the air flow inside, improve the indoor air quality, but also do not need to consume additional energy. Therefore, it is of certain positive effect to China to achieve the goal of Peak Carbon Emission and Carbon Neutrality by selecting the appropriate ventilation window type according to local climatic conditions. The common ways of window opening are casement window[1] (Figure 1), sliding window[2] (Figure 2) and top-hung window[3] (Figure 3). Different window forms have a great influence on indoor air quality and are an important research subject of natural ventilation.

Figure 1 Casement window

Figure 2 Sliding window

Figure 3 top-hung window

At present, there are four methods to study natural ventilation of windows at home and abroad. One is to study natural ventilation by means of numerical simulation[4], the second is using the wind tunnel method[5], third, on-site measurement method, including CO_2 tracer gas method[6], in addition, Artificial Neural Network (ANN) prediction[7], which has emerged in recent years, also brings a new method for the study of indoor ventilation.

Wang et al[8] analyzed the effects of different window opening patterns on indoor natural ventilation by simulating and comparing indoor air flow, and then gave the optimal design of the best window opening pattern to provide a reference for improving indoor air quality. After studying under the same outdoor conditions, Li[9] found that the use of casement windows can appropriately increase the indoor air velocity, and the indoor air distribution is more uniform and comfortable with casement windows compared to top-hung windows. Hong Kong scholars[10] can quickly estimate the ventilation volume per hour by mathematical model simulation. They found that the air exchange rate of casement windows was 124% higher than that of sliding windows, and the air exchange rate of up-hung windows was 97% higher than

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that of sliding windows, so the priority of using window type from the perspective of reducing cooling energy consumption was casement windows > up-hung windows > sliding windows. Gao and Lee used air change per hour (ACH) as the evaluation index to evaluated the effect of open mode[11] and window type[12] on ventilation by field measurement, CFD simulation and ANN model analysis. The conclusion is that flat open window is the most suitable form of open window in subtropical climatic zone. Through full-scale model tests, Chu et al.[13] found the ventilation rate of buildings with internal partitions is lower than that of buildings without partitions at the wind direction of 0°-90°. When the wind incidence angle is between 22.5°-45°, the pressure difference between the inside and outside of the window dominates ventilation and the ventilation rate is linearly related to the incoming air velocity and the area of the window opening.

According to the research at home and abroad, the influence of window shape on indoor air distribution and ventilation effect is mainly focused on wind velocity and ventilation efficiency, but the assessment of air age is less. With the rapid development of computer technology, the numerical calculation method based on computational fluid dynamics becomes more and more mature. In this paper, a three-dimensional indoor space model is built by CFD simulation software Airpak, and flow field calculations are carried out for different inflow wind directions and different window types. After analyzing the indoor wind velocity and air age at different heights, the distribution rules are summarized to make reasonable arrangements in the indoor layout.

2. Influencing factors and evaluation method of ventilation effect of single-side window

2.1. Influence factors

The position of window opening, the size of ventilation area, the projection angle of incoming air direction and the angle of window opening all influence the natural ventilation of the window. This paper focuses on quantitative analysis of indoor flow field using single-side top-hung window, casement window, sliding window and other window types. Therefore, the window designed in this study is fixed and centered, with the same height of window sill and the same ventilation area.

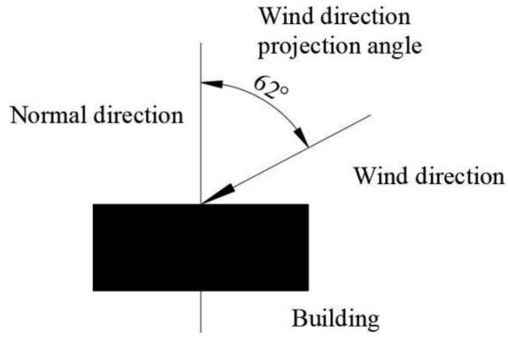

Figure 4 Schematic diagram of wind incidence angle

2.1.1 Wind incidence angle Wind incidence angle is the angle between the direction of outdoor wind and the normal line of the outer wall of the building (Figure 4), When the building is parallel to the direction of outdoor wind, the projection angle of the wind direction is 90°. When the building is perpendicular to the direction of outdoor wind, the angle of the wind direction is 0°[14].

2.1.2 Opening area The opening condition of the window can affect the ventilation rate. For the top-hung window and the casement window, under the same outdoor weather conditions, the larger the opening angle, the larger the air intake, the better the ventilation effect. The opening angle of the flat window is generally 0°-90° (Figure 6). For the sake of safety, the distance from the top-hung window to the outside is limited. Generally, the opening angle range is 0°-30° (Figure 5). For sliding windows, with the same lighting area, the open area is usually only half of the other two window types, but the open area can be fully ventilated without blocking the window (Figure 7). To facilitate comparison, the ventilation area of the three window types is fixed in this study, the opening angle of the top-hung window is fixed at 30°, the opening angle of the flat window is fixed at 90°, and the casement window is fully opened. In order to keep the ventilation area of the casement window consistent with the other two window types, the daylighting area of the casement window has been doubled.

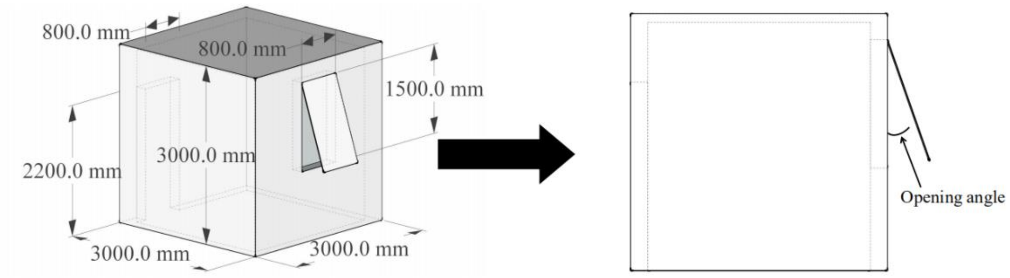

Figure 5 Opening angle of top-hung window

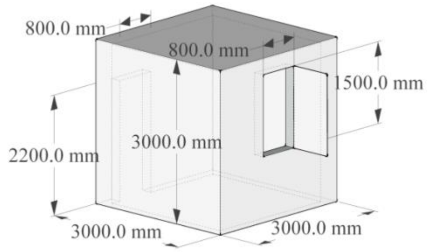

Figure 6 Opening angle of casement window

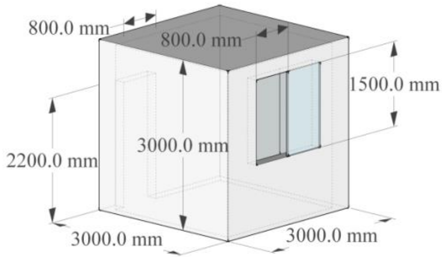

Figure 7 The sliding window is fully open

2.2. Evaluation method of indoor ventilation

2.2.1 Wind velocity evaluation method Indoor wind velocity affects the comfort of the internal environment. Excessive wind velocity will reduce the comfort of human body. Too much wind velocity will reduce human comfort, while too little will make the indoor temperature and humidity too high, making it difficult to discharge pollutants and affecting human health. Therefore, the analysis of wind velocity flow field is an important index for indoor ventilation evaluation.

2.2.2 Evaluation method of wind velocity non-uniformity coefficient The air flow condition inside the building has a great influence on the ventilation effect of the building. Uniform indoor wind velocity can improve the comfort of the human body. Therefore, the wind velocity non-uniformity coefficient is the main factor to measure the air flow in the building. In this paper, the post-processor is used to directly derive the average wind velocity $\overline{v}$ and the root mean square deviation of wind velocity σ_v in a certain height plane, and the wind velocity non-uniformity coefficient is obtained as follows:

$$K_v = \frac{\sigma_v}{\overline{v}} \quad (1)$$

Among them, Where: $\overline{v}$ is the average wind velocity, σ_v is the root mean square deviation of wind velocity, K_v is the non-uniformity coefficient of wind velocity.

The smaller the wind velocity non-uniformity coefficient K_v obtained from the above formula, the more uniform the air flow in the area, the higher the human comfort.

2.2.3 Evaluation method of air age Air Age refers to the time it takes for an air particle to reach a certain point from entering the room. The smaller the air age, the less pollution and the cleaner the air. As a quantitative indicator of indoor air freshness, air age can fully reflect the ventilation and ventilation effect of the room and the distribution of air in the room. It is an indicator that can reflect the ability of air flow to discharge pollutants, but the wind velocity can not reflect this change very well[15].

3. Modeling and Simulation

In this paper, AirPak software is used to establish a three-dimensional calculation domain, in which a 1:1 model of three different window types (Figure 5- Figure7) is built, with room size is 3000mm × 3000mm × 3000mm (long × wide × high). The window with opening dimension (i.e. the size of the ventilation surface) 1500mm × 800mm (high × wide) was mounted in centre of wall, the bottom of the window sill is 1200mm from the ground, and the wall thickness is 200mm. A door with height of 2200mm and a width of 800mm is set 300mm from the centre of the right wall. It is determined that the distance between left and right boundary of three-dimensional computational domain and room model is 3 times of the height of room model, the distance between the room boundary in windward direction and the entrance interface in computational domain is 3 times of the height of room model, and the distance between the room boundary in leeward direction and the boundary in computational domain is 6 times of the height of room model.

And the application of standard k- ε Turbulence model, the standard wall function method is adopted for the near wall, the simulated air flow is incompressible flow, the inlet interface is set as the velocity interface, the outlet boundary is set as the fully developed outlet boundary at the distance from the room outlet surface, the upwind direction (the wind incidence angle is 0 ° - 90 °), the wind velocity (the wind velocity of the outdoor flow is 5 m/s) and the local area type (urban areas with dense buildings) are set, Finally, unstructured grid is used in meshing modeling.

4. Comparison of simulation results

4.1. Wind velocity evaluation

With the inlet air velocity of 5m/s and the maximum opening of each window type (ventilation area being the same, the top-hung window is opened at 30°, the casement window is opened at 90° and the sliding window is fully opened), the wind field is simulated by changing the projection angle of the wind direction in turn between 0°,10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°, and then the average wind velocity is collected at 0.6m, 0.9m, 1.2m and 1.5m heights respectively and organized into a line diagram (Figure 8- Figure 11).

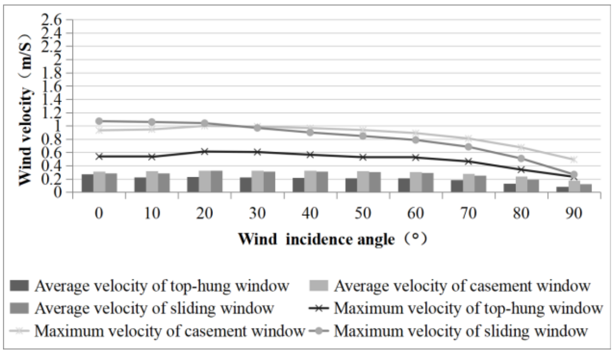

Figure 8 Average and maximum wind velocity at 0.6m height plane

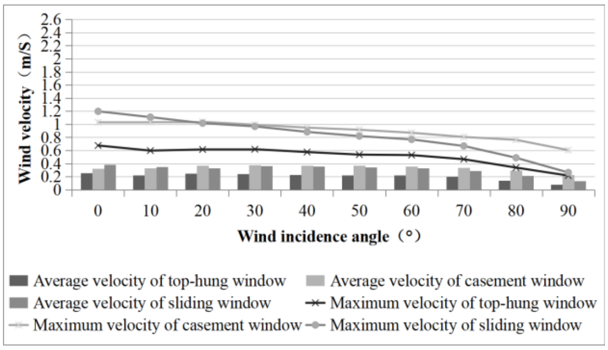

Figure 9 Average and maximum wind velocity at 0.9m height plane

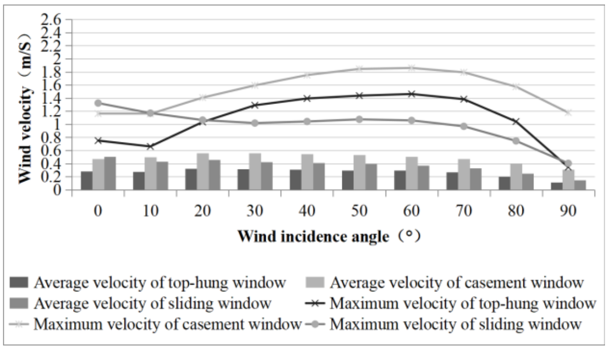

Figure 10 Average and maximum wind velocity at 1.2m height plane

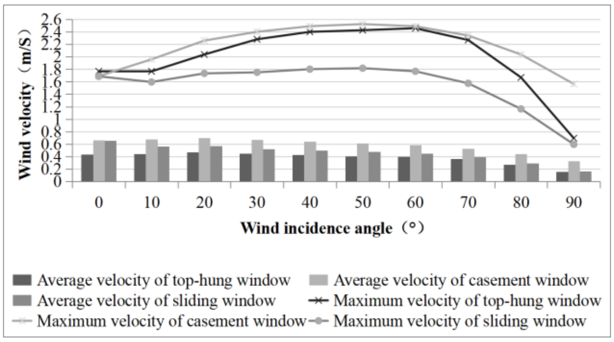

Figure 11 Average and maximum wind velocity at 1.5m height plane

From Figure 8 to Figure 11, it can be seen that the indoor average wind velocity and maximum wind velocity of casement windows are significantly higher than the other two window types. Under the same wind incidence angle, the average wind velocity and the maximum wind velocity in the plane have a trend of increasing from bottom to top, that is, the average wind velocity at 1.5m and the average wind velocity at 1.2m and the average wind velocity at 0.9m and the maximum wind velocity at 0.6m. Under the working conditions of the three window types, the average wind velocity and maximum wind velocity of the top-hung window increase most obviously with the increase of height. It can be seen that the top-hung window has the strongest function of guiding the air flow upward. When people sit and stand indoors, their head and neck are generally at a height of 0.8m-1m, so in order to ensure better ventilation in the space where people sit and stand, the installation position of windows can be appropriately lowered on the premise of ensuring safety (such as installing protective fence).

In general, under different wind incidence angles, the average indoor wind velocity of casement windows is almost the largest of the three window types; The indoor average wind velocity of the three types of windows has a trend of increasing first and then decreasing with the increase of the wind incidence angle, that is, when the wind incidence angle is greater than 60°, it becomes more and more unfavorable to ventilation. Therefore, the wall with windows should maintain an angle of more than 30° with the local high-frequency wind direction.

4.2. Evaluation of wind velocity non-uniformity coefficient

Based on the average wind velocity in the 3.1 wind velocity evaluation, the non-uniformity coefficient of wind velocity at the height of 0.6m, 0.9m, 1.2m and 1.5m is calculated and arranged as a line diagram (Figure 12-Figure 15)

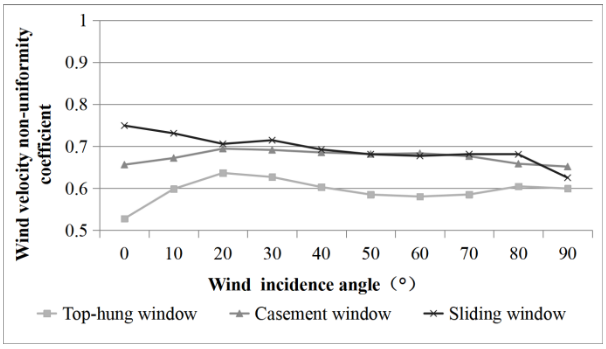

Figure 12 Wind velocity non-uniformity coefficient at 0.6m height plane

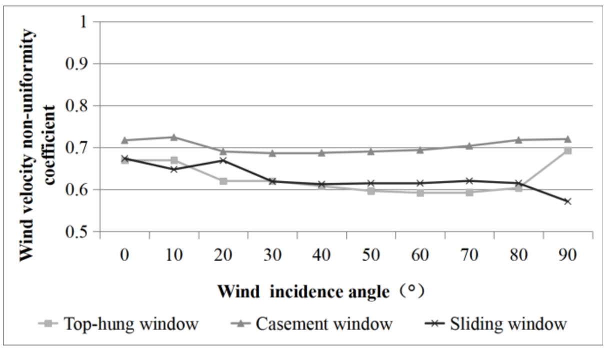

Figure 13 Wind velocity non-uniformity coefficient at 0.9m height plane

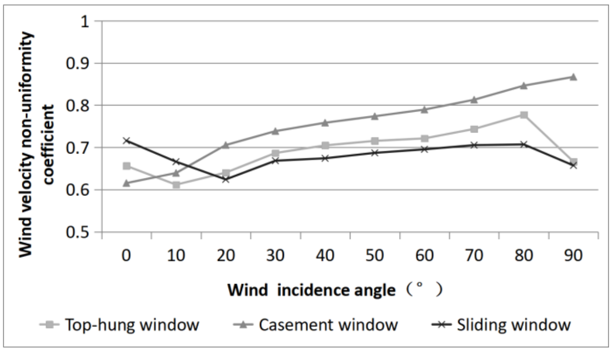

Figure 14 Wind velocity non-uniformity coefficient at 1.2m height plane

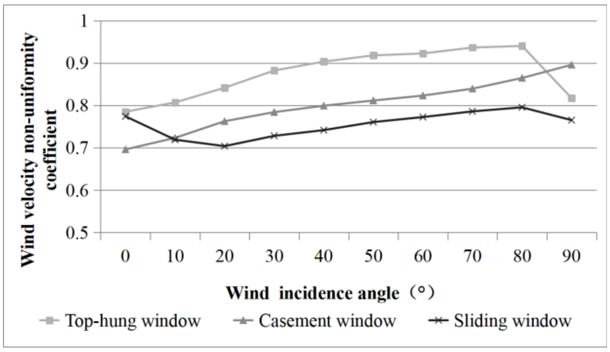

Figure 15 Wind velocity non-uniformity coefficient at 1.5m height plane

It can be seen from the above diagram that even if the wind incidence angle changes, the non-uniformity coefficient of wind velocity is relatively stable and the wind velocity is low in the plane below the windowsill (0.6m and 0.9m height) of the three window types. The coefficient of wind velocity non-uniformity above the windshield (at 1.2m and 1.5m heights) tends to increase with increasing projection angle of the wind direction until the wind direction is parallel to the windward side (Wind projection angle 90 °).

In the case of casement windows, because the open window sash can guide more air flow into the room, even when the wind incidence angle is 90 °, the wind velocity non-uniformity coefficient is still relatively stable (Figure 13) or increased (Figure 14 and Figure 15). In the case of sliding window and hanging window, when the wind incidence angle is greater than 80 °, the wind velocity non-uniformity coefficient has obvious changes.

4.3. Air Age Assessment

Based on the previous simulation, the distribution of air age can also be obtained. Since indoor people are usually in a sitting state, the maximum air age, minimum air age and average air age in the whole plane at the height of 0.9m (around head and neck) under three window types from the post-processor are derived, and sort out as shown in Figure 16.

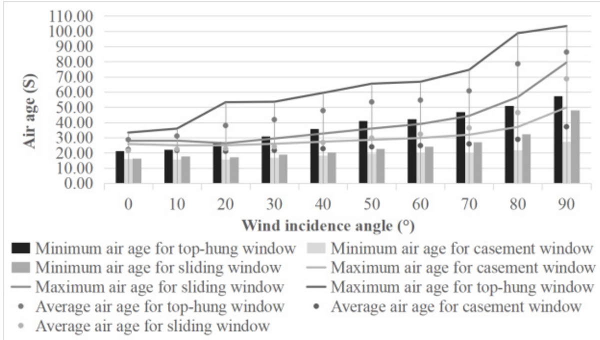

Figure 16 Air age statistics at 0.9m height for the three window types

In Figure 16, it can be seen that the air age at 0.9m height is less than 110s for all three window types, but the minimum, maximum and average air age of the top-hung window are the largest of the three window types, i.e. the air is the least fresh, which is consistent with the result shown in Figure 9, i.e. the wind velocity at 0.9m height is smaller in the room with the top-hung window.

5. Conclusion

1. At low indoor locations, such as 0.6m and 0.9m height, the indoor wind velocity is relatively stable under the three window types, and the maximum wind velocity slowly decreases, resulting in a weak sense of blowing. However, in the position above the window sill such as 1.2m and 1.5m height, the indoor wind velocity changes dramatically under the condition of the top-hung window, and the wind velocity non-uniformity increases, which has a great relationship with the strong ability of the top-hung window to guide the air flow upwards.

2. Under the three window types, the indoor maximum wind velocity and average wind velocity show a trend of first increasing and then decreasing with the increase of the wind incidence angle. Selecting the appropriate wind incidence angle (such as 30 ° - 60 °) according to the window type can help the indoor get better ventilation.

3. Considering the air age at the height of 0.9m, the indoor air using casement windows is the freshest, because when the casement window is opened at 90 °, the glass sash can guide more fresh air into the room.

4.When the wind incidence angle is 0 °, the indoor maximum wind intensity and wind velocity non-uniformity coefficient of the sliding window are greater, because the open window sash blocks part of the air flow from bypassing the building, but introduces it into the room, so the indoor wind velocity fluctuation is more obvious, and the wind velocity non-uniformity coefficient is greater.

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