Analysis of Natural Ventilation Design in Large Space of Railway Station

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Abstract. Generally, natural ventilation is a useful passive design method to improve thermal environment, especially in large space buildings. Taking Zhengzhou East Railway Station (Zhengzhou ERS) as an example, this paper discussed the natural ventilation of Zhengzhou ERS by comparing experimental test with simulation of Computational Fluid Dynamics (CFD), based on local climate characteristics. Then, combined with the Zhengzhou ERS model, optimized natural ventilation design was proposed by comparing the natural ventilation conditions of different types of roof forms. And some ideas and reference were provided to improve indoor thermal environment and passive energy-saving design for large-scale railway station buildings.

1. Introduction

Nowadays, high-speed railway has achieved world-renowned development in China, and promoted increasingly prominent for the national economy. At the same time, more and more attention has also been paid to the indoor comfort and energy efficient of railway station. And it gradually become the research focus to provide passengers with an internal environmental comfort, and reduce the energy consumption of large space buildings. Natural ventilation is an effective passive energy-saving design method for buildings, which have been studied by many experts and scholars in recent years. The location design of building vents has been researched by Ma Xiaoyu (2018) and others that has guiding significance for the layout of building ventilation structures and vents[1]; Jonas Allegrini, Aytaç Kubilay (2017) have conducted wind comfort studies on small train station shelters in Switzerland, performing computational fluid dynamics (CFD) simulations to predict local wind speeds in and around shelters[2]; The distribution of wind speed on the subway platform and the influence of wind speed on thermal comfort conditions have been studied by George Katavoutas (2016) et al[3]; Zhang Hui and Zhou Xuan (2016) have discussed the green and energy-saving design ideas from the aspects of natural ventilation, and combined numerical simulation and experimental tests to verify its effect[4]; Fu Weigang used computer software tools to optimize the natural ventilation of the elevated waiting floor[5]; Chen Xiaoyang and Zhong Dekun (2011) proposed the concept of passive energy-saving natural ventilation, which was divided into three types: natural ventilation type, passive pre-cooling type and passive pre-heating type[6].
This paper analyzed the internal environment of the Zhengzhou East Railway Station waiting room under the natural ventilation and constructed four different conditions for the natural ventilation problem to discuss the passive energy-saving measures in the waiting hall of Zhengzhou ERS.

2. Overview of Zhengzhou ERS
Zhengzhou ERS is located in Zhengdong New District, Zhengzhou City, Henan Province, China. which is one of the largest high-speed railway stations in Asia. Architectural design is fully considered tourists' entry, outbound, transfer, waiting and other activities, so that tourists can do the above activities more easily. The station building is arranged in 5 floors, 3 floors above ground and 2 floors underground. From top to bottom, it is divided into elevated entrance level, platform level, ground exit level, rail transit level and platform level. The area where passengers stay the longest is the waiting hall. As shown in Figure 1, each two inlets are symmetrically arranged relative to each other in the east-west direction, the rest seats are set between the same column inlets.

In this research, waiting hall model of Zhengzhou ERS was established by CFD. According to the simulation, building ventilation was analyzed by comparing simulation and experimental test data based on local climate, and Natural ventilation problems were discussed.

3. Analysis of the current situation of the waiting hall
The waiting hall of Zhengzhou ERS is located at the elevated entrance level which is one of the main areas for passenger activities with the combination of waiting, rest, eating, selling and entertainment. Its internal space is 421.45m long, 160.30m wide and 28.75m high and it is partially two floors and has centralized lighting on the roof. The 3D model of the waiting hall of ZER Station is shown in Figure 2. The long side direction of the model is approximated to east-west.

When having tested, the twelve measuring instruments were arranged on the horizontal interface 1.5m above the ground of the waiting hall. Therefore, the position selected when calculating by the CFD software needs to correspond to the same location. There are twelve test points from C1 to C12 as shown in Figure 3.
Figure 3. Waiting room model test points location

(a) Horizontal interface at a height of 1.5 m

(b) The vertical interface of the line where C2 and C11 are located

Figure 4. The calculation flow field of Waiting hall model

The simulated calculation flow field is shown in Figure 4. Due to its large-space, ventilation is difficult to achieve in the deep part of the building, resulting in the need of mechanical ventilation and air conditioning systems while increasing the energy consumption. Chen Xiaoyang has developed a way to set up ventilation shafts to solve such problems. The openable ventilation shafts can be used not only because of its chimney effect in summer, but also because of its greenhouse effect in winter which has more climate adaptability [7]. Natural ventilation can be achieved in the deep part of the waiting hall if we use of such measure which helps to adjust the microclimate inside the broad space, thereby reducing the energy consumption of the building.

This paper proposed to set the openable skylights on the roof of the waiting hall to achieve the effect of the ventilation shaft. Four different ventilation conditions were set, the position of the openable skylights is different for each condition, but the total area is exactly the same (Figure 4). After the simulation, the data of the indoor wind speed were compared and analyzed, the optimal working condition will be a guide to the optimised design of the waiting hall of Zhengzhou ERS.

(a) Condition          (b)  Condition 2        (c)Condition 3          (d )  Condition 4

Condition 1: Six skylights were arranged symmetrically in two rows in the lighting atrium;
Condition 2: Five skylights were staggered in two columns in the lighting atrium;
Condition 3: Three skylights were arranged in the middle of the lighting atrium;
Condition 4: Four skylights were arranged symmetrically in two rows in the lighting atrium.

Figure 5. The setting of the openable skylights working conditions in the lighting atrium
4. Analysis of different working conditions

4.1. Horizontal wind speed analysis

According to the simulation, wind vector cloud chart as shown in Figure 6. By having compared the average wind speeds of twelve measuring points (Figure 7), the ventilation characteristics of different conditions could be found.

![Wind vector cloud chart of each condition](image)

Figure 6. Wind vector cloud chart of each condition

Through the wind vector cloud chart of conditions it can be found that the attenuation range at the main vents in condition 1 was about 5 m larger than the initial model; expanded by about 10 m in condition 2; enlarged by about 7 m in condition 3; increased by about 10 m in condition 4. It shows that the change of the airflow flow field at the spatial level interface was the largest in conditions 2 and 4.

![Comparison of measured wind speed and simulated wind speed](image)

Figure 7. Comparison of measured wind speed and simulated wind speed

According to Figure 7, the test points with large difference between the measured and calculated values were C6, C7, C8 and C10. Among them, the measured data far exceeds the simulation data were C6, C7 and C8, while the simulation data far exceeds the measured data was C10. So, It was speculated that there might be new sources of wind at the C6, C7, and C8, while there might be obstructions at the C10. Data comparison of other test points, the error was within 0.2 m/s, It can be seen that the initial model reflects the actual situation of the waiting hall of Zhengzhou ERS.

Compared the wind speed value with the calculated value of the initial model in each condition, it can be found that 4 test point locations had higher wind speed values than the initial model in condition 1, and its natural ventilation attenuation range was farther. There were 6, 5, and 7 points where the natural ventilation attenuation range of measuring points have increased in conditions 2, 3 and 4 respectively. As could be seen the wind speed attenuation range of condition 4 was expanded more than that of condition 2. From what has been analyzed above, a conclusion may safely draw that arranging...
the openable sunroof in two columns symmetrically between the lighting atriums could maximize the attenuation of the wind speed at the horizontal interface.

4.2. Vertical wind speed analysis under different working conditions
Through the simulation, the wind vector cloud chart in the vertical interface of the east-west direction of the waiting hall can be gotten in Figure 8. The improved effect was shown when compared with the wind vector cloud chart of the Initial model.

![Figure 8. Wind speed vector cloud chart of natural ventilation in vertical interface](image)

It can be confirmed that the natural ventilation condition of condition 2 had the best chimney effect on the vertical interface by comparing the data of C2, C5, C8 and C11(Table 1).

| position | condition 1 | condition 2 | condition 3 | condition 4 |
|----------|-------------|-------------|-------------|-------------|
| C2       | 2           | 4           | 3           | 1           |
| C5       | 3           | 1           | 2           | 4           |
| C8       | 4           | 2           | 3           | 1           |
| C11      | 2           | 1           | 4           | 3           |
| Sorted average | 2.75 | 2 | 3 | 2.25 |

4.3. Comfort range analysis under different conditions
The most comfortable wind speed in the indoor waiting area is no more than 0.3m/s. refer to the comfort air conditioning room design parameters which were listed in BOOK11. As shown in Figure 7, by comparing the values of the four working conditions and the initial model, It can be seen that the simulated wind speed was relatively high at C1, C3, C10 and C12 because the test point located in front of the vents. Therefore, the wind speed at the position of the vents around the waiting hall is very fast, and it is not suitable as a long-term waiting area for passengers.

The other eight test points were in the central area of the waiting hall where the wind speed was small and not a windless area, suitable for passengers waiting for rest and it is marked with vertical lines as shown in Figure 9. The area with the best vertical ventilation can be determined by the further analysis through the vertical interface flow field in four working conditions (Figure 8) which is marked with horizontal straight line as shown in Figure 9. The most comfortable area is where the two areas are superimposed. The wind speed in the central area of the four working conditions were appropriate, so the rest seating area under any condition was suitable for passengers to stay for a long time.

![Figure 9. Rest seats setting area in waiting room](image)
5. Conclusion
The waiting hall in Zhengzhou ERS is one of the longest areas for passengers to stay, so it is necessary to provide a more comfortable indoor environment for passengers. For the ventilation problems, this paper proposed to solve by setting the openable skylight on the roof of the waiting hall. The working conditions of the windows were also studied to provide relevant data support for passive energy-saving design.

This paper discussed the way of natural ventilation passive energy-saving design and analyzed the natural ventilation flow field under four working conditions. The following four conclusions were drawn:

1) The openable skylights on the roof of the waiting hall could solve the natural ventilation problem inside the large space, and the updraft generated by the temperature stratification could provide a more comfortable indoor environment to passengers;

2) Condition 4 had the greatest influence on the internal environment of the waiting hall in the horizontal direction, and the range of attenuation of the natural air ventilation was most obvious. Condition 2 was slightly less than condition 4, and the wind speed attenuation range of condition 1 and condition 3 was improved. Among them, the condition 1 was reduced the most;

3) Condition 2 had the greatest impact on the internal environment of the waiting hall in the vertical direction, and the chimney effect of providing natural ventilation for the small space of the internal space was optimal;

4) The most suitable area for rest was in the intersection of horizontal and vertical lines, and the wind speed in this area was the best for human comfort. It can also be set in the horizontal and vertical lines.

The four working conditions were suitable for setting long-term stay area in the two, but condition 2 and 4 had the greatest effect on the improvement of the indoor environment of the waiting hall, which could provide passengers with a more comfortable internal environment.

Acknowledgments
This work was financially supported by National Natural Science Foundation of China (NO. 51508169).
This work was financially supported by 2017 science and technology project plan of the MHURC (No.2017-k1-009) fund.

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