Indoor Thermal Comfort Analysis of a Green Building in East China during Summer Time

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Abstract. For buildings with large open areas inside, air distribution is the key to influence the ventilation and cooling effect during summer time. The design of their air-conditioning systems is different from traditional buildings, which must pay attention to the influence of chimney effect. This study adopted numerical simulation methods to analyze the indoor thermal environment of a building with a large atrium in summer. It is found that the transparent envelopes of the atrium and the location of the air inlet and outlet in the building have a great influence on the indoor temperature, and were the main reasons why the indoor thermal comfort could not meet the requirements.

Keywords: Green building, transparent envelope, numerical simulation, air distribution

1 Introduction

With the exacerbation of global climate change and energy crisis, green buildings are gradually becoming the mainstream trend in the construction industry. Green buildings aim to improve energy efficiency, reduce environmental impact, and enhance indoor environmental comfort. However, in practical applications, the problem of high room temperatures in green buildings still exists, which affects the quality of life for occupants.

Extensive research has been conducted both domestically and internationally to investigate the phenomenon of elevated room temperatures. For instance, During the hot season, a significant amount of solar radiation enters the interior of a museum in Gansu province through skylights, leading to excessive heat buildup inside the building [1]. Mohammed et al. [2] proposed that in hot climatic conditions, transparent building envelopes are the primary source of indoor solar heat gain.

In a large spatial building where office areas are connected to a central atrium, the average temperature in the office area exceeds 27°C, while the temperature in the atrium reaches 29.0°C or higher [3]. Arens et al. [4] also indicated that solar radiation entering the interior through transparent envelopes increases occupants' thermal sensation and deviates the indoor thermal environment from the comfort zone.

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Furthermore, Md. Jahangir Alam et al. [5] conducted research on transparent building envelopes in residential buildings and found that appropriate shading measures can enhance the performance of transparent envelopes. Yao Jian [6] discovered certain limitations in transparent building envelopes when it comes to balancing the indoor thermal environment.

Although significant progress has been made in domestic and international research on indoor temperature, particularly regarding the impact of transparent building envelopes on indoor thermal environments, further in-depth investigation is required when it comes to simulation analysis of excessive room temperatures in green buildings. This study employs numerical simulation methods to analyze the indoor thermal environment. Such methods are widely recognized and applied in various engineering practices due to their advantages of speed, detailed results, and lower costs compared to on-site measurements and wind tunnel experiments.

Ultimately, through simulation and analysis, this study aims to gain a comprehensive understanding of the causes and mechanisms behind the issue of excessive room temperatures and propose effective solutions to enhance the comfort of indoor environments in green buildings.

2 Methodology

The indoor temperature of the open office area on the 5th floor of the building is too high, and the measured temperature on site is about 26~29°C. In order to analyze the reasons for this phenomenon, the indoor thermal environment and airflow organization of the open office area were simulated.

2.1 Establishing simulation model

The floor plan of the main areas of the building studied in this paper is shown in Figure 1. Simplifications were made in the numerical modeling. Rooms with partitions between the open office area (e.g., meeting rooms, stairwells, etc.) were ignored in the modeling, and not modeling the non-office area beyond the 2.5m wide corridor on the southwest side of the 5th floor. In addition, during the on-site observation, it was speculated that the overheating in the open office area might be caused by the heat diffusion from the atrium and the 4th floor mezzanine to the 5th floor, therefore, the atrium and the 4th floor mezzanine were also modeled in this model.

The air supply outlet of the diffuser and the fresh air outlet are both upward from the air gutter embedded in the interior of the floor, and the air supply outlet of the floor diffuser is close to the return air outlet. In the actual building, there is a fresh air exhaust outlet in the southwest corner of the 5th floor. In order to make the model more similar to the actual situation, a fresh air exhaust outlet is set up in the corridor at the southwest corner of the open office area in the model. The numerical model established is shown in Figure 2.

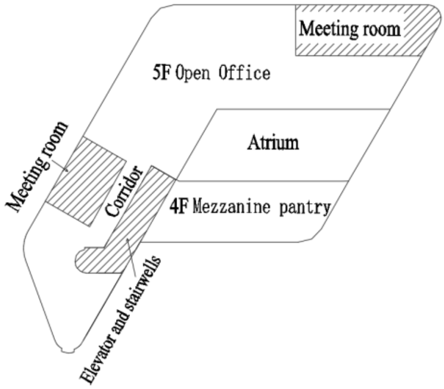


Fig. 1. The floor plan of the building.

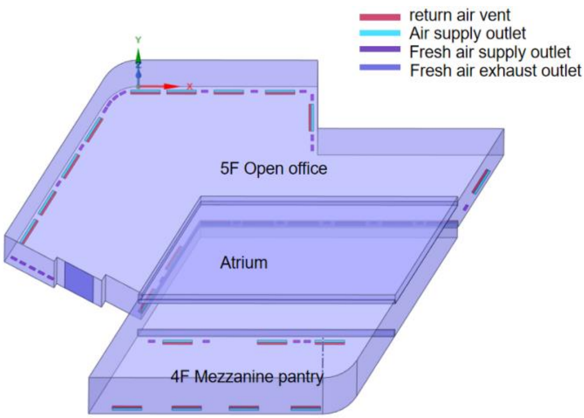


Fig. 2. The numerical model of the building.

2.2 Grid division and turbulence model selection

The quality of meshing and the choice of turbulence model have a significant impact on the simulation results. The Standard k-ε model is generally used for the simulation of completely turbulent flow, and it is the most widely used turbulence model, which is selected for numerical simulation in this paper. The above numerical models are meshed with 1 million 3 million and 5 million grids, and Fig. 3 shows the temperature change trends in the vertical direction at the central line of the open office area under the three different meshing schemes. The results show that the simulation results of the models with a grid number of 3 million and 5 million are similar, and the simulation results of the model with a grid number of 1 million deviate from the other two conditions. Therefore, the numerical model with a grid number of 3 million is selected for the subsequent simulation for the sake of computational efficiency and accuracy.

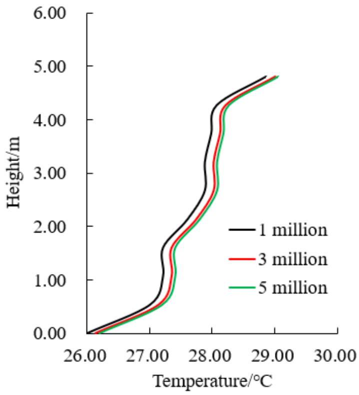


Fig. 3. Comparison of central line temperature distribution by different grid resolutions.

2.3 Boundary conditions

The measured outdoor air temperature is 36.60°C, and the temperature of the outer wall surface of the skylight at the top of the atrium is 58.20°C (shown in Fig. 4), and the boundary conditions of the enclosure are calculated based on the thermal parameters (heat transfer coefficient) of each enclosure. The air supply volume of the diffuser is 708m^3/h, the size of the air supply outlet is 0.17m×2.25m, and the air supply velocity of it is calculated to be 0.50m/s, and the air supply temperature is 17.50°C. The air supply volume of the fresh air outlet is 80m^3/h, the size of the fresh air outlet is 0.20m×0.50m, and the air supply velocity of the fresh air outlet is calculated to be 0.22m/s, and its air supply temperature is set to 17.00°C. The exhaust air volume of the exhaust air outlet set on the closed corridor is 2240m^3/h, and the size of the exhaust air outlet is the cross-section size of the corridor, which is 2.50m×4.80m. The boundary conditions are summarized as shown in Table 1.

(a) The outdoor air temperature.

(b) The temperature of the outer wall surface of the skylight at the top of the atrium.

Fig. 4. Measured data.

Table 1. Boundary conditions of numerical simulation

Boundary	Parameter	Value
Glass curtain wall	Heat flux (W/m^2)	16.00
Skylight on top of the atrium	Heat flux (W/m^2)	56.32
Non-translucent roof	Heat flux (W/m^2)	3.20
Air supply outlets for diffusers	Velocity (m/s)	0.50
	Temperature (°C)	17.50
Fresh air supply outlet	Velocity (m/s)	0.22
	Temperature (°C)	17.00

3 Results

3.1 Verification of simulation results

In order to verify the accuracy of the numerical simulation results, the temperature distribution of the two locations (shown in Figure 5) is measured in the field and simulated, respectively. As shown in Figure 6, it can be found that the measurement results and simulation results of the two locations are very close, which can prove that the simulation results agree well with the measurement results, which proves that the temperature obtained from numerical simulation is accurate and can be used for subsequent analysis.

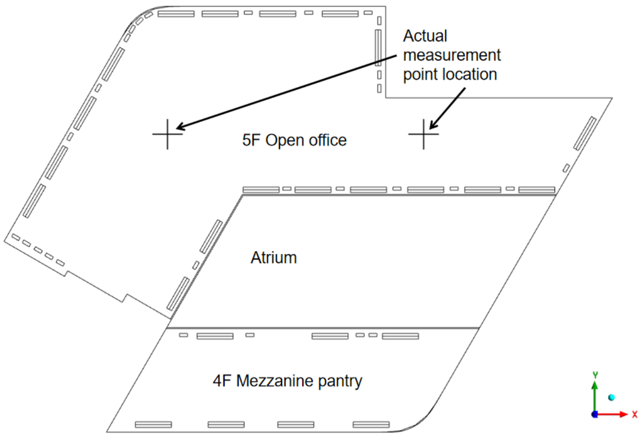
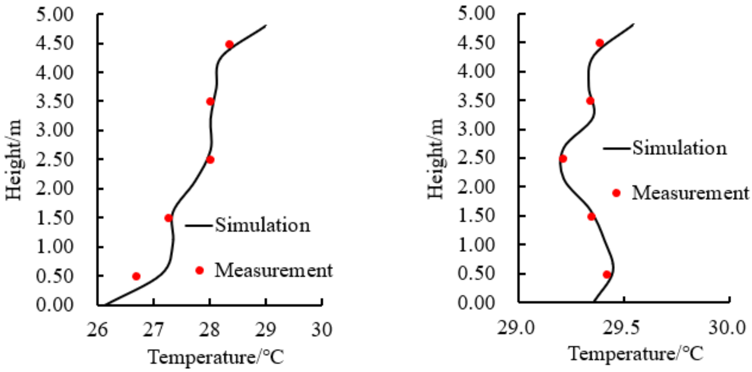


Fig. 5. Distribution of temperature measurement points.

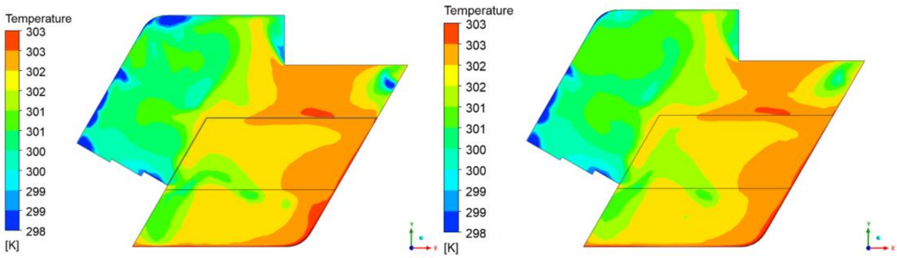


(a) Left measurement point (b) Right measurement point

Fig. 6. Validation of the vertical temperature distribution.

3.2 Analysis of simulation results

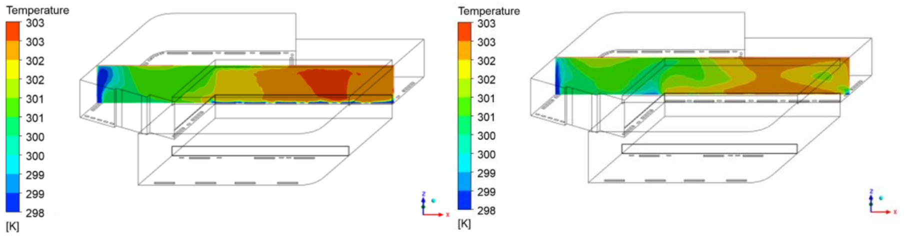
First of all, analyze the temperature distribution in the horizontal direction of the open office area on the 5th floor. The temperature distribution at a height of 1.0 m from the 5th floor is shown in Figure 7 (a), and it can be found that the overall temperature is 27°C~30°C. The left side of the open office area has more air supply and fresh air outlets, resulting in a large amount of cold air entering the area. In addition, the left area is relatively far away from the atrium resulting in the air temperature is lower than right area and stabilized at about 27°C. The temperature on the right side is 28°C~29°C, but on the rightmost side of the cross-section, the temperature is relatively low, which is caused by the weak air circulation here, and it is not easy for the cold air at the bottom of the room to be transferred. At the connection between the office area and the atrium, the temperature in this area is relatively high due to the high air temperature above the atrium, which spreads to the office area through the ceiling. As for the temperature at a height of 1.5m from the floor of the 5th floor (shown in Figure 7 (b)), it can be found that as the height rises, the distance from the ceiling is closer resulting in an increase in the overall temperature, but the distribution of temperature basically remains the same.



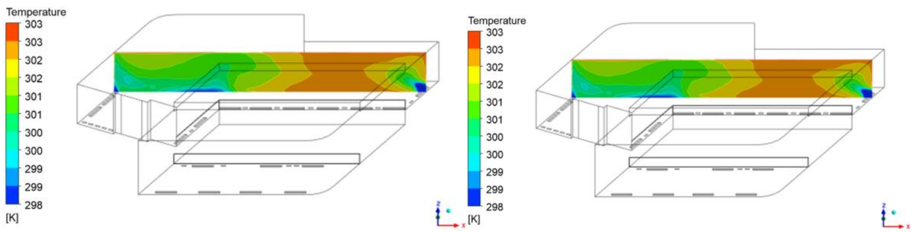
(a) 1.0 m above 5th floor level (b) 1.5 m above 5th floor level

Fig. 7. Temperature distribution in the horizontal direction.

Second, the temperature distribution in the vertical direction is analyzed. Starting from the position of the partition glass at the junction of the atrium and the open office area, four temperature distributions in the vertical direction are intercepted toward the interior of the open office area, as shown in Figure 8. It can be found that the temperature on the left side of the open area is stable. However, for the right side of the open office area, the closer to the atrium location the higher the indoor temperature, and the more severe the heat buildup near the roof. This shows that the heat is mainly diffused from the atrium to the interior of the open office area.



(a) 0.3m inwards from the junction (b) 1.8m inwards from the junction



(c) 3.8m inwards from the junction (d) 8.8m inwards from the junction

Fig. 8. Temperature distribution in the vertical direction.

Indoor airflow distribution also has an effect on the temperature of the open office. The velocity distribution of the open office at a height of 0.1m from the 5th floor is shown in Figure 9, the air velocity of the supply air outlet and fresh air outlet is large, and there is also a tendency to diffuse to the center of the open office. The airflow in the open area is strong on the left side and weak on the right side, which results in a lower temperature in the left area than in the right area. As shown in velocity vector Figure 10, there is a short-circuit cycle between the supply air outlet and the return air vent, resulting in little upward airflow and inward airflow, which does not allow the cold air to spread to the middle of the open office. The fresh air exhaust outlet can contribute to the improvement of the flow state of the indoor airflow, but the scope of influence is small.

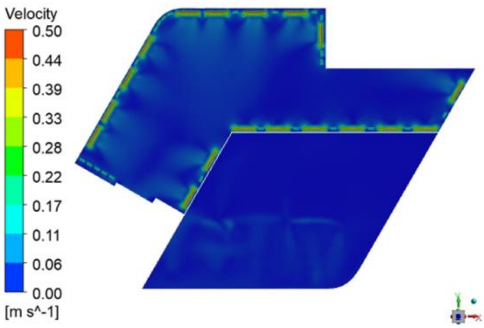


Fig. 9. Velocity distribution of the open

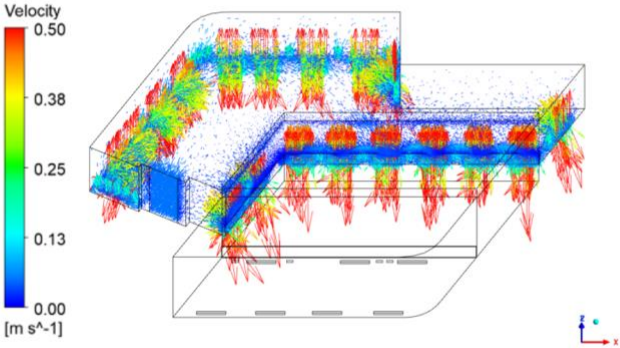


Fig. 10. Velocity vector of open office area. office at a height of 0.1m from the 5th floor.

4 Discussion

The above results provide design ideas for improving the comfort of buildings with large transparent envelopes. For example, we can reduce the area of transparent envelopes and light skylight, or install shading devices to reduce solar radiation. Increasing the distance between air supply and return vents to reduce the short-circuit effect of airflow, and optimize the angle and speed of air supply to improve the air distribution.

Through further in-depth research, we can provide more scientific and efficient solutions for green building design and indoor environmental control, and improve the energy efficiency and comfort of buildings. This is of great value for sustainable development and progress in the field of architecture.

5 Conclusion

In green buildings, the use of transparent envelopes and atriums ensures that indoor personnel are in a bright environment, but at the same time it can lead to high solar radiation and poor indoor comfort in summer. In this paper, by numerical simulation of the indoor environment of a green building in summer, the main conclusions that lead to high temperature in the office area are found as follows:

(1) The maximum error between the temperature value in the vertical direction at the center position of the room obtained from the numerical simulation and the measured results is 3%, which proves that the simulation results are accurately and can be used for subsequent analysis.

(2) The high temperature of the atrium due to the large area of transparent envelopes, especially the transparent light skylight. This leads to high temperature in the atrium, and the indoor temperature in the open areas connected to atrium is difficult to meet the comfort requirements.

(3) The air distribution modes of the open area is down-supply and down-return, and the spacing between the air supply outlet and the air return outlet is very small, resulting in short-circuit circulation between the air supply outlet and the air return outlet. The low flow of airflow upwards and towards the inside of the open area makes it difficult for hot air to escape, resulting in high indoor temperatures.

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