A Study on Air Conditioning Thermal Comfort in Building Atrium in Winter

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Abstract. The building atrium is a large space formed by integrating various functions. It runs through multiple floors and is directly or indirectly connected with each floor. In the atrium, people can not only enjoy the air quality of the interior space but also create an open and natural environment characteristic of the outdoor space. In this paper, a winding corridor atrium is the research object, using CFD simulation software to establish a mathematical model. The temperature field, velocity field, and PMV-PPD of the atrium under various working conditions were studied by numerical simulation method, and the thermal comfort of the working area at the bottom of the atrium and the corridor area of each floor were analyzed emphatically. The building atrium is set up in two forms: the upper part is airtight and the upper part is not airtight. Through theoretical analysis and comparison of simulation results, it is concluded that the non-enclosed atrium will help to improve the thermal comfort of the top, and at the same time aggravate the phenomenon of low temperature in the working area at the bottom of the atrium.

1 Introduction

Under the condition of air conditioning and heating in the building atrium in winter, the hot air rises, and the thermal pressure causes cold air to invade or infiltrate below the middle interface (especially the doors, windows, holes, and gaps at the bottom of the atrium), and above the middle interface (especially the top holes, gaps) hot air leaks out. The vertical temperature gradient of the atrium is great, the upper part is overheated and the lower part is cold, the air-conditioning area cannot reach the design temperature, the human body feels uncomfortable, and the air-conditioning energy consumption is high.

In view of the characteristics of the building atrium, such as various forms, large space, large cooling and heating load, and complex air distribution, the effect of air conditioning is not easy to guarantee. In recent years, the research on atrium air conditioning methods and their effects has attracted more and more attention.

The thermal environment of the tall atrium can be predicted by computer simulation. Set by building mathematical models, boundary conditions, using the CFD software to carry on the numerical simulation, and analysis of simulation results, can help professional personnel to optimize the design scheme, find out both can satisfy the requirement of the human body comfort and efficient energy-saving, adequate air conditioning scheme.

2 Model establishment and setting of boundary conditions

2.1 Overview of the model

The research object of this paper is the corridor-style atrium of a hotel, with a size of 26m×16m×18m (length×height×width), consisting of three inner walls, one outer wall (south-facing glass curtain wall), roof, and ground, as shown in Figure 2.1. The indoor heat load of the atrium in winter is 47KW. Figure 2.1a shows a model of an enclosed atrium. Set up heating air outlets on the east and west walls 4m from the ground, using circular nozzles with a radius of 200mm, a total of 18, and the air outlet spacing is 3m. Set up return air vents at 0.3m from the ground, with a size of 0.4m×0.4m, a total of 10, the air outlet spacing is 6m, and the distance from the wall is 1m. Figure 2.1b is a simplified model of an unsealed atrium. There are three openings around the top of the atrium in Figure 2.1a, each with a size of 6m × 0.5m, and other conditions remain unchanged.

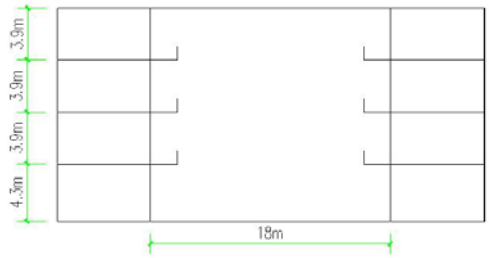

Fig 2.1 Schematic diagram of the cloister-style atrium

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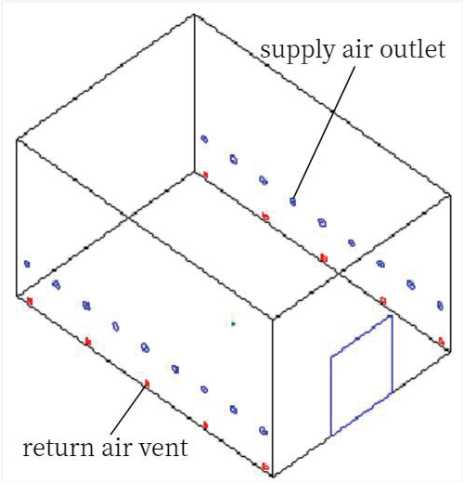


Fig 2.1a Simplified model of closed atrium

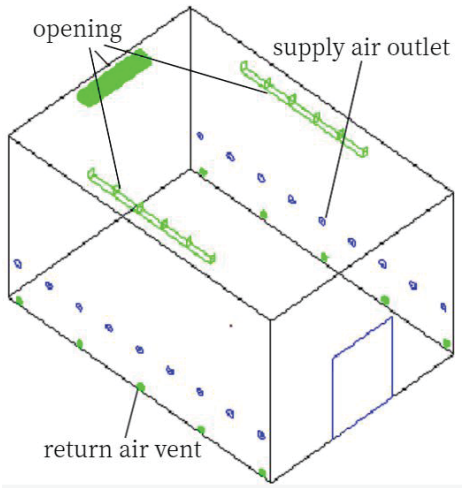


Fig 2.1b Simplified models of the non-enclosed atrium

2.2 Boundary conditions

The boundary conditions of this paper are set as follows:

1. Outdoor calculation parameters: the dry bulb temperature of the air conditioner in winter is -7.7 ℃, and the outdoor atmospheric pressure in winter is 1019.1hpa.
2. Indoor calculation temperature: the indoor design temperature of the air conditioner in winter is 20°C, and the relative humidity is 50%.
3. The boundary conditions are set to the second type of boundary conditions. The ground is set as the first boundary condition.
4. The inner wall is set as the adiabatic boundary condition.
5. Boundary conditions of air-conditioning tuyere: the air supply temperature of hot air heating is 28℃, and the speed is 5m/s.

3 Analysis of simulation results

ASHRAE STANDER 55-1004 stipulates that the temperature difference between a person in a standing position at 1.8m from the ground and at 0.1m from the ground does not exceed 3℃. Under the heating condition in winter, the indoor wind speed is not more than 0.3m/s; the comfortable indoor temperature in winter is 21 ℃ ~24℃. The Chinese standard stipulates that the thermal comfort requirements of level I are: -0.5⩽PMV⩽0.5, PPD⩽10%; the requirements of level II thermal comfort are: -1⩽PMV<-0.5 or 0.5<PMV⩽1.0, PPD⩽27%.

3.1 Simulation results and analysis of an enclosed atrium

(1) Distribution of temperature field

Figures 3.1.1a~3.1.1e show the temperature distribution on different sections.

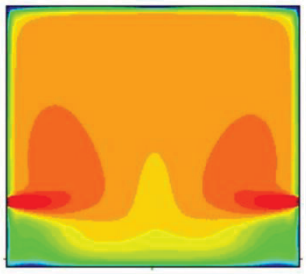


Fig. 3.1.1a Temperature distribution at section X=0

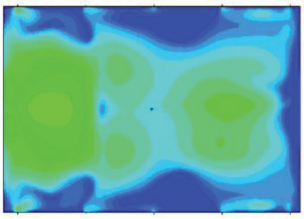


Fig. 3.1.1b Temperature distribution at section Y=0.1

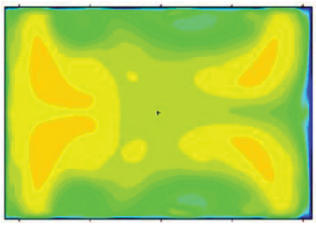


Fig. 3.1.1c Temperature distribution at section Y=1.8

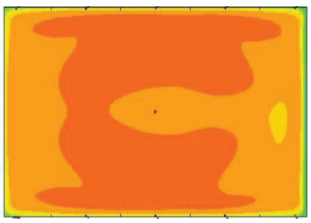


Fig. 3.1.1d Temperature distribution at section Y=8

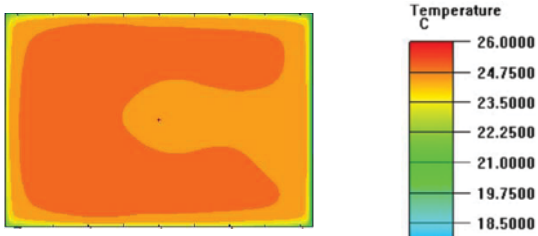


Fig. 3.1.1e Temperature distribution at section Y=14

(2) Distribution of the velocity field

Figures 3.1.2a~3.1.2c show the velocity distribution on different sections.

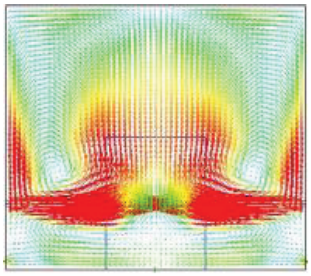


Fig. 3.1.2a Velocity distribution at section X=0

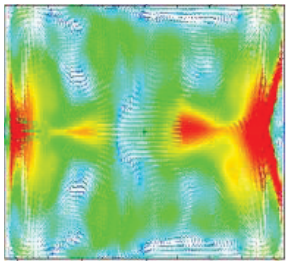


Fig. 3.1.2b Velocity distribution at section Y=1.8

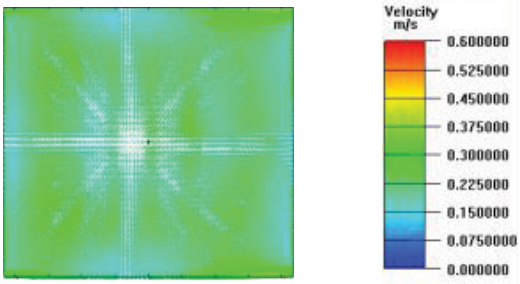


Fig. 3.1.2c Velocity distribution at section Y=14

As can be seen from the graph, the hot airflow rises under winter heating conditions, resulting in lower temperatures in the working area at the bottom and higher temperatures in the upper atrium area, with a large vertical temperature difference. The temperature in most areas upward of the nozzle is higher than the comfort temperature of the human body, and the temperature in the human activity area below the nozzle is around 21°C, which is within the specified range.

Under this condition, the wind speed is relatively high at the tuyere and in the direction where the two jets from east and west meet upward, about 0.45m/s to 0.55m/s, and the wind blowing feeling is strong; in the middle area of the room, the wind speed is slightly higher, at 0.35m /s ~ 0.45m/s, there is a sense of wind; other areas wind speed is between 0.2m/s ~ 0.3m/s, in line with the relevant regulations in the specification.

The stratification of PMV and PPD values under this working condition is obvious. The PMV and PPD values in the area above the air outlet are high, the body feels hotter and the dissatisfaction rate is high here. The air outlet downward area is more comfortable; near the ground, that is, the temperature below the ankle of the human body is lower, the human body's cold feeling is more obvious, and the dissatisfaction rate is high.

3.2 Simulation results and analysis of non-enclosed atrium

(1) Distribution of temperature field

Figures 3.2.1a~3.2.1e show the temperature distribution on different sections.

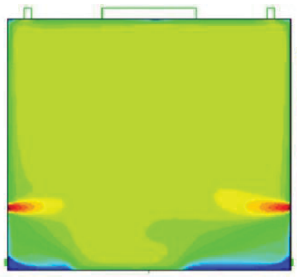


Fig. 3.2.1a Temperature distribution at section X=0

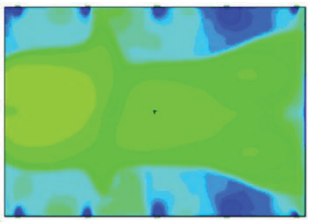


Fig. 3.2.1b Temperature distribution at section Y=0.1

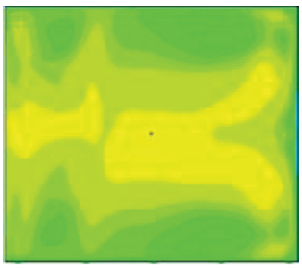


Fig. 3.2.1c Temperature distribution at section Y=1.8

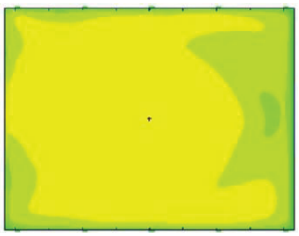


Fig. 3.2.1d Temperature distribution at section Y=8

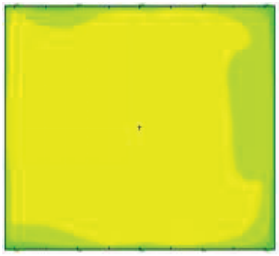
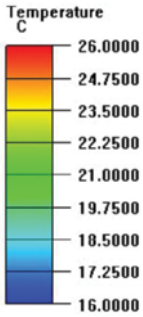


Fig. 3.2.1e Temperature distribution at section Y=14



(2) Distribution of the velocity field

Figures 3.2.2a~3.2.2c show the velocity distribution on different sections.

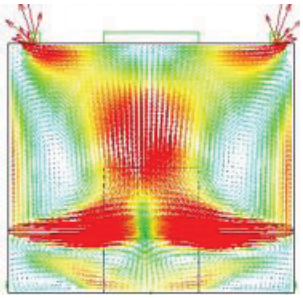


Fig. 3.2.2a Velocity distribution at section X=0

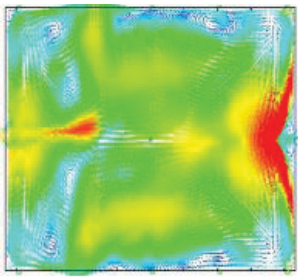


Fig. 3.2.2b Velocity distribution at section Y=1.8

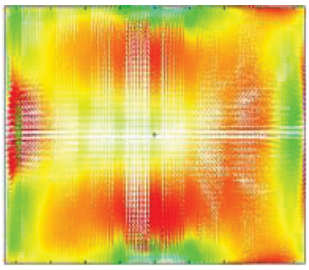
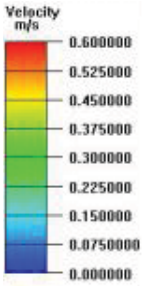


Fig. 3.2.2c Velocity distribution at section Y=14



It can be seen from the figure that the temperature near the tuyere is slightly higher at about 23°C. The peripheral opening at the top accelerates the outward spread of the upper heat, resulting in a low temperature near the ground at around 17°C. The temperature of the human activity area and the corridor below the air outlet is about 21°C, which is within the specified range.

Under this condition, the wind speed at the tuyere and in the direction where the east and west jets meet upwards is relatively large, about 0.4m/s to 0.5m/s, and the blowing feeling is strong. In the middle area of the

room, the wind speed is slightly higher, between 0.3m/s and 0.4m/s, and the human body has a feeling of blowing. The wind speed in other areas is between 0.2m/s and 0.3m/s, which is in line with the relevant regulations in the specification.

Under this condition, the PMV and PPD distributions are relatively uniform. The PMV is slightly higher above the air outlet and in the opening area around the top, and the body feels warmer. When the PMV is low and the PPD is high near the ground, the body will feel cold and the dissatisfaction rate is high. The dissatisfaction rate in the corridors on both sides is low, and human comfort is better in most other areas.

4 Conclusions

The temperature at the top of the closed atrium heated by hot air is too high, and the maximum temperature in the highest corridor area can reach above 27°C, and the human body will have an obvious heat sensation. However, the temperature of the working area at the bottom of the atrium is low , and there will be an obvious cold feeling, and the vertical temperature gradient of the atrium is great, which cannot meet the human comfort requirements.

In the non-closed atrium with hot air heating, the thermal comfort of the top corridor area is improved, and the phenomenon of low temperature in the working area, at the bottom of the atrium, is aggravated at the same time.

There is little difference in the indoor velocity between the non-closed atrium and the closed atrium below 6 m, and the velocity distribution in the space above 6m of the atrium is affected in the case of openings.

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