Effect of Vertical Air Circulation on the Thermal Environment in a Large Space

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Introduction

Large premises, such as airport terminals or international conference centers, have high ceilings and large floor area. Most of passengers who use these facilities do not stay for a long time as they do in office blocks or residential housings, but occupy the buildings en masse for short periods of times. The indoor thermal environment in these architects is subject to rapid deterioration by the radiant heat or outer thermal conditions. Furthermore, for aesthetic reasons, glass panels are applied extensively as building materials for the construction of transparent walls and roofs in these large structures.

The purpose of the present study is to investigate the effect of vertical air circulation on thermal environment in an airport passenger terminal. Two ventilation models, each with or without vertical air circulation, are analyzed by way of numerical results for airflow, temperature and PPD(1) distribution.

The Model

Draft Design

Figure 1 shows the schematic of a lobby region of an airport passenger terminal employed in the present study. Its dimensions are 25m in width, 18.5m in height and 100m in length. The lobby region consists of ticketing/arrival lobby on the first floor and a departure lounge on the second floor. As seen from Figure 1, the lobby region is installed with a total of 32 supply diffusers and 22 exhaust diffusers for space cooling. People, machinery and lighting in the lobby region are assumed to generate a total heat of 146,632W based on indoor load calculation. Ventilation facilities for cooling are concentrated in the activity zone on the first and second floors.

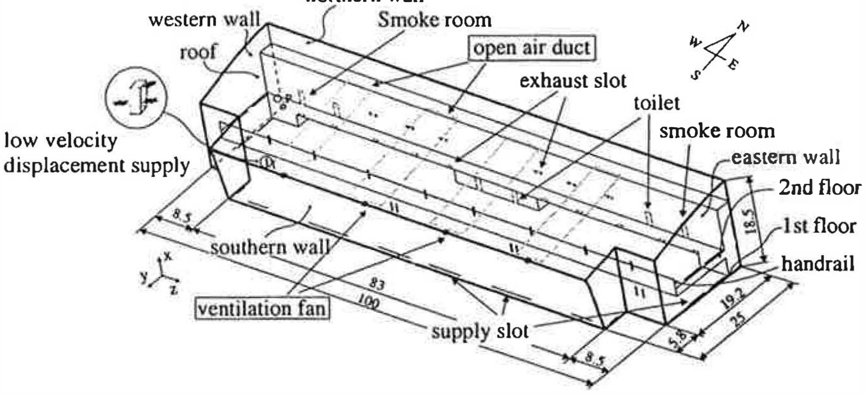


Figure 1. Schematic diagram of an airport lobby of the draft design. [unit;m] (Only, the devices in rectangular box are applicable to the ventilation fan design).

Vertical Air Circulation Design

The draft design may be expected to have a high roof temperature due to hot air rising by heat generation from the floor level. In order to reduce the roof temperature effectively, the vertical air circulation is employed as a ventilation system design with a jet fan and an open air duct. This design is contrived to reduce the roof temperature by way of macro air circulation. The vertical air circulation design has 4 additional jet fans and 4 open air ducts as shown in Figure 1.

Results and Discussions

To analyze the thermal environmental characteristics of the draft design and the vertical air circulation design, three planes of interest are selected ; Two are vertical planes and the other is a horizontal one. The former are two x-y planes both of which are located 58.5m from the western wall(z=0m) and eastern wall(z=100m), while the later is a y-z plane 1.5m above the second floor, respectively; where the breathing line of a passenger is deemed to be present.

Thermal Environment in the Draft Design

For the draft design, Figure 2 shows the distribution of velocity and temperature at the selected vertical planes. The temperature distribution is found to lie in the range of 24°C–25°C on the second floor and the average temperature is less than the design temperature of 26°C. However, local temperatures as high as 30°C–50°C are observed in the ceiling, which is due to thermal storage effect resulting from the thermal stratification through flow stagnation. This considerable temperature difference between the second floor and roof generate noticeable radiant heat exchange, so much that the thermal environment for passengers can be severely deteriorated.

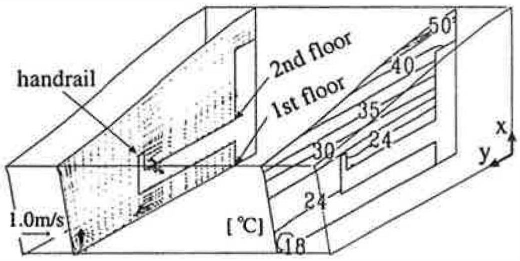


Figure 2. Distributions of velocity(left) and temperature (right) at the vertical x-y plane of the draft design (z=58.5m)

Distributions of velocity, temperature, and PPD at the selected horizontal plane are shown in Figure 3(a), 3(b), and 3(c) which display a half of the eastern section. The temperature distribution in Figure 3(b) reveals a temperature range of 22°C–25°C and an average temperature of about 24°C which is lower than the design temperature of 26°C. In other to calculate the PPD(Predicted Percentage of Dissatisfied) distribution, an MRT(Mean Radiant Temperature) is calculated at 31.4°C with the aid of mean wall surface temperature. As seen in Figure 3(c), the range of PPD distribution is 5–30% at the breathing line. It is also noted that the average PPD is about 21% and the average PMV(Predicted Mean Vote) is about +0.8, giving a level of thermal comfort which may be considered 'slightly warm'. Although the distribution of temperature in human

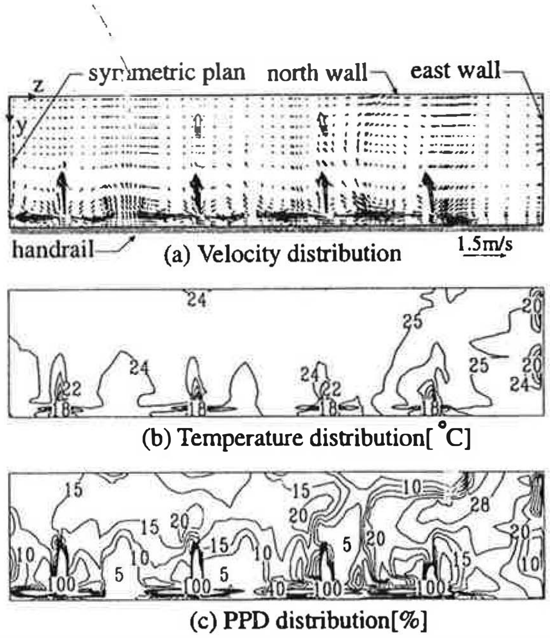


Figure 3. Distributions of velocity temperature, and PD at the half horizontal y-z plane of the draft design. (x=7m)

activity regions show values lower than the design temperature, the thermal comfort is hard to attain by the draft design. This outcome may be contributed to the presence of radiant heat which in turn is a result of thermal storage effect in the ceiling shown in Figure 2.

Thermal Environment in the Vertical Air Circulation Design

Figure 4 shows the distributions of velocity and temperature at the selected vertical planes in the vertical air circulation design. Comparing the temperature distribution of the draft design with that of the vertical air circulation design, shows that the latter design produces a roof temperature ranges of 26°C to 30°C, which is 10°C lower than the corresponding range of the draft design. In addition, the vertical air circulation design yields smaller temperature difference between the roof and the second floor.

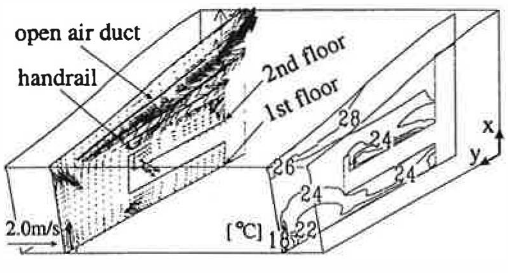
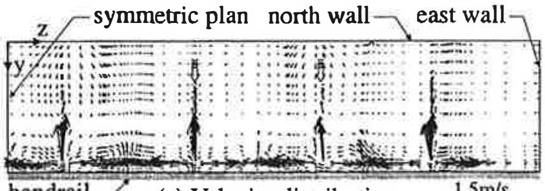
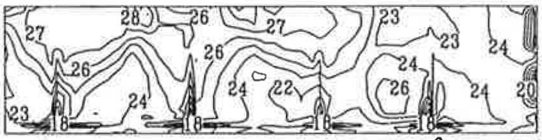


Figure 4. Distributions of velocity(left) and temperature (right) at the vertical x-y plane of the vertical air circulation design.(z=58.5m)

Figures 5(a), (b) and (c) show the distribution of velocity, temperature and PPD, respectively at the eastern half of the selected horizontal plane in the vertical air circulation design. It is seen from Figure 5(b) that temperature varies from 22°C to 30°C with a mean temperature of 25.5°C, which is slightly higher than the mean temperature of the draft design. As shown in Figure 5(c), PPD distribution at the human breathing line is between 5% and 15%. It is also noted that the average PPD is 8% and the average PMV is +0.3, giving that a level of thermal comfort is 'neutral' which means 'comfortable'.



(a) Velocity distribution


(b) Temperature distribution[°C]

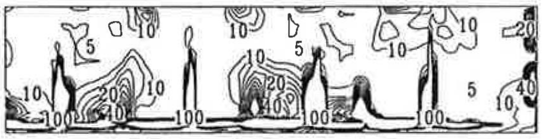

(c) PPD distribution[%]

Figure 5. Distribution of velocity, temperature, and PPD at the half horizontal y-z plane of the vertical air circulation design. (x=7m)

Conclusions

In the present study, the thermal environment in an airport passenger terminal with or without vertical air circulation has been investigated by means of numerical simulation. For both case models, the temperature in a human activity region is less than the design temperature of 26°C. The level of thermal comfort is 'slightly warm' for the model without vertical air circulation, while it is 'neutral' for the model with vertical air circulation. Therefore, it is thought that the vertical air circulation can improve human thermal comfort in respect of ventilation in a large space.

References

1. ASHRAE. ASHRAE Handbook-Fundamentals, 1997, Chapter 8.1–8.26.