NUMERICAL SIMULATION OF THE IMPACT OF VENTILATION MODE ON SUBWAY PLATFORM AIR DISTRIBUTION

Hui Yang[1, 2], Li Jia[1], Lixin Yang[1], Peng Huang[1]

[1]Department of Power Engineering, School of Mechanical and Electronic Control Engineering, Beijing Jiaotong University, Beijing, 100044, China
[2]School of Environment and Energy Engineering, Beijing University of Civil Engineering and Architecture, Beijing, 100044, China

ABSTRACT

In this paper, three-dimensional air flow distributions in a typical island platform under both natural and mechanical ventilation operation modes were simulated for the whole process of the train entering, staying in and departing from the platform. The mechanical ventilation modes include over-platform supply/under-platform exhaust (OSUE) and over-platform supply/over- platform exhaust (OSOE). Based on the data obtained from the simulations, the effects of natural and mechanical ventilation system on platform air distribution were analyzed. At last, the characteristics of air flow field under different ventilation mode and in different train's movement phase are concluded.

KEYWORDS

Numerical Simulation, Subway platform, CFD (computational fluid dynamics), Air flow distribution

INTRODUCTION

As a means of mass rapid transport, subway would be developed greatly in the near future. It's important to improve subway platform air environment in providing the passengers a good transportation service. Obviously, heating, ventilation and air conditioning (HVAC) system plays the leading role in creating a comfortable air environment. So, many researchers focus their attention to the impacts of ventilation system and piston wind on platform air environment.

Air velocity, as well as air dry-bulb temperature, air relative humidity, ambient radiation heat, metabolic rate and clothing, are important factors affecting people's thermal comfort. It affects not only people's physiological feeling associating with temperature and other factors through acting on heat convection rate and perspiration rate, but also people's psychological feeling. Research shows that in some cases, when air velocity is higher than 0.25 m/s, people begin to feel uncomfortable. Exorbitant air velocity could result in blowy bothering feeling, mental tension and unease of mucous membrane. Nevins(Zhu 2005） suggested that the influence of air temperature and velocity at people's neck level on comfort could be concluded as an acceptable zone. When the ambient air state is in this zone, less than 20 percent tested people feel uncomfortable. Outside of the zone is defined as unacceptable. When velocity is higher than o.35 m/s, the air state is always in unacceptable zone. When train moves in or out of the subway station, it arises so called piston wind, which could make passengers feel uncomfortable.

Some works have been conducted in Japan, Russia, USA, etc., using CFD method to study air environment of subway tunnel and platform. Early in the year of 1975, Subway Environment Simulation (SES) Computer Program was established in USA (Zhu et al. 1997). SES has been widely used as the analysis and design tools for simulating temperature, humidity, air velocity in platforms, tunnels and ventilating shafts and calculating air-conditioning load under several trains running in tunnels. But in studying more details of airflow field, SES is limited because it is based on incompressible one-dimensional flow (Yau and Cheng 2000).

Recently, the progress of computer capability and numerical methods allow us to simulate flow field in three dimensions and many universities conducted some research work in this field which has been the basis for further study. But there are still some obvious limitations for present research work. For example, most simulation simplified the subway system as a steady problem, which means that the real train moving process can not be simulated; for some other simulations, although transient mode were adopted, the evaluated durations were very short limited by some technical conditions.

In this paper, according to existing subway stations, a typical simplified geometrical model of subway station was established. Using this model without mechanical ventilation system, the impact of piston effect on platform airflow velocity was simulated. Then two different mechanical ventilation systems, which are over-platform supply/under-platform exhaust (OSUE) and over-platform supply/over-platform exhaust (OSOE), were added separately in the same geometrical station model. The impacts of the two mechanical ventilation methods on platform air environment were simulated. The whole simulated process includes three phases, which are a single train entering, staying in and departing from the station, and lasts 60 second. CFDesign program was selected as the simulation tool. This program has significant advantages in dealing with interactions between moving solid and its surrounding fluid by "Motion Module", which uses a so-called "masking" technique. The main idea of this technique is that as a moving solid passes through fluid, its elements mask the fluid nodes, which means that the motion of the solid would dominate the velocity on those nodes.

CFD MODEL DESCRIPTION

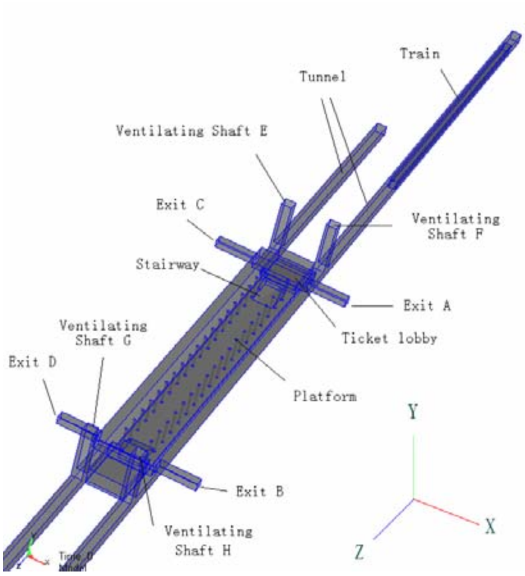


Figure 1 Geometrical model of the station

The station is comprised of two rectangular tunnels with a 4 m by 4 m cross section and an island platform which is 150 m long by 14 m wide by 9 m high and its valid length is 120 m. Two stairways with 8 m width, 8 m length and 5m height located in the two ends of the platform connect the platform with two ticket lobbies with 22 m width, 10 m length and 4 m height and there are two exits in each of the ticket lobby. The train is simplified as a rectangular block with 2.8 m width, 3.5 m height and 120 m length. Four ventilating shafts above the two tunnels are located near the two ends of the platform and their cross section is 4 m by 4 m. The height of the ventilating shafts is 20 m. The geometrical model of the station is shown as figure 1.

Based on above geometrical station model, OSOE and OSUE ventilation systems were added separately. In OSOE system, there are 25 air supply inlets with 0.4 m width, 0.8 m length at 4.5 m level above the lengthways central axis line of the platform and 12 air exhaust outlets with 1 m width, 1.2 m length are placed at the same level as inlets along the lengthways central axis line of the two track ways. In OSUE system, the outlets are moved to the bottom of the two track ways' sidewall.

The whole simulated process includes three phases, which are a single train entering, staying in and departing from the station, and lasts 60 second. The simulated times for the three phases are 24 seconds to decelerate from 20 m/s to 0 m/s for arriving in the platform, 20 seconds to stay in the platform and 16 seconds to accelerate from 0 m/s to 20 m/s for departing from the platform.

Standard k-ε turbulence model is used in the simulations. Pressure boundary conditions are set for the end surfaces of the two tunnels, the ticket lobby exits and the ventilating shafts and airflow rate boundary conditions are set for all the vents of mechanical ventilation system. In this paper, the whole computational domain is treated as an isothermal field.

SIMULATION

NATURAL VENTILATION CASE

As benchmark for comparison, the air flow field in the platform without mechanical ventilation system during the process of the train's movement was simulated firstly. In the computational domain, 721791 tetrahedron elements were generated during the meshing process.

The velocity distribution in the cross section through the platform waiting line at some typical moments of the train's moving process is shown in Figure 2. Here waiting line is defined as 1 m away from the edge of the track.

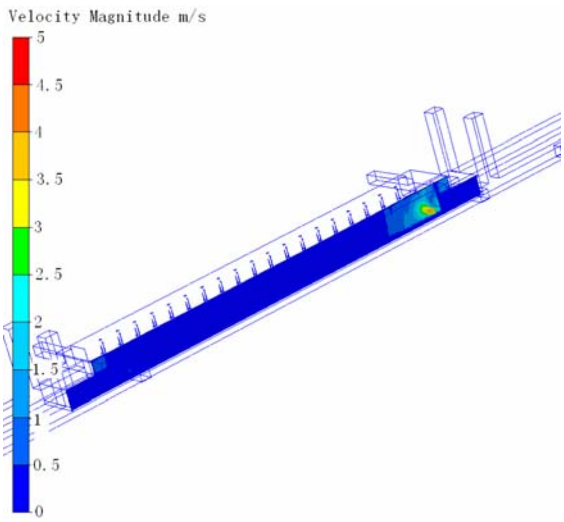


Figure 2.1 t=2 second
(train in tunnel)

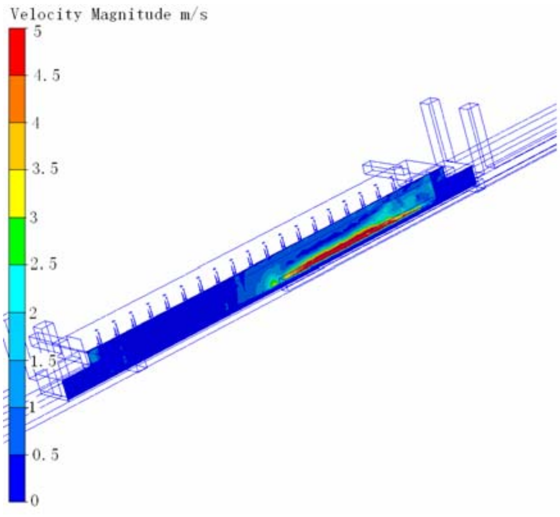


Figure 2.2 t=12 second
(half train entering the platform)

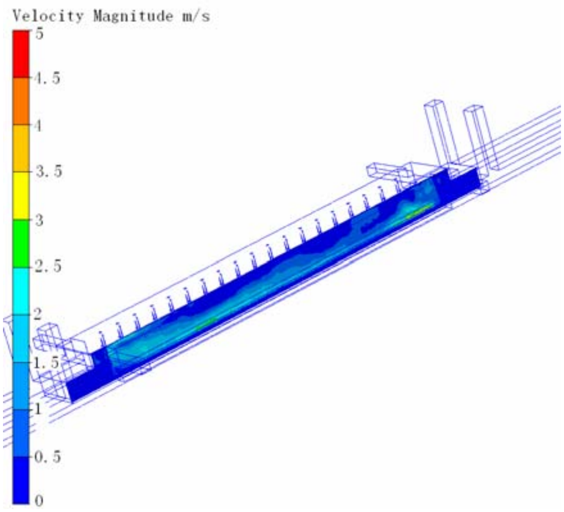


Figure 2.3 t=36 second
(train staying in the platform)

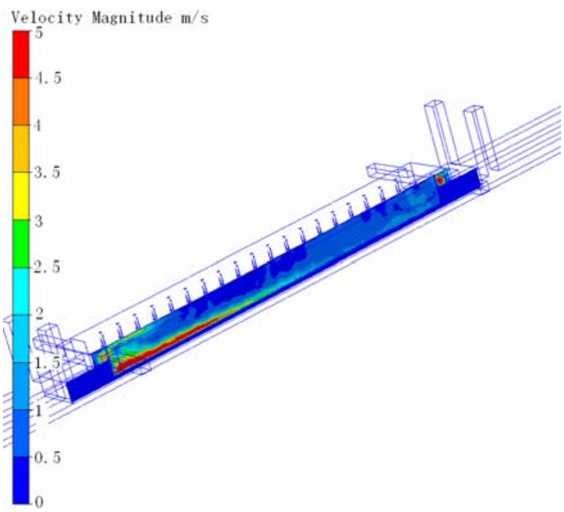


Figure 2.4 t=60second
(train in other side of the tunnel)

Figure 2 indicates that the air field disturbed by the piston wind is enlarged from the platform end near the train to the whole area of the platform with the train approaching and entering the platform. This influence still exists during the 20 seconds when the train stays in the platform because of the inertial movement of the air. The air is pulled to form certain velocity in the waiting area of the platform with the train departing from the platform.

Figure3 shows the air velocity curves at the level of 1.3 m along the waiting line near the train's moving track side on the platform (approximately at passengers' neck level). These eight curves represent the air velocity on seven different moments of the train's moving process and the average velocity of the seven moments respectively. X-coordinate represents the distance from the platform centerline. It indicates that great air velocity is aroused by piston effect during the train's moving process. That makes the air state of the area near the waiting line always in unacceptable zone. In some locations, air velocity is over 5 m/s when the train enters and departs from the platform.

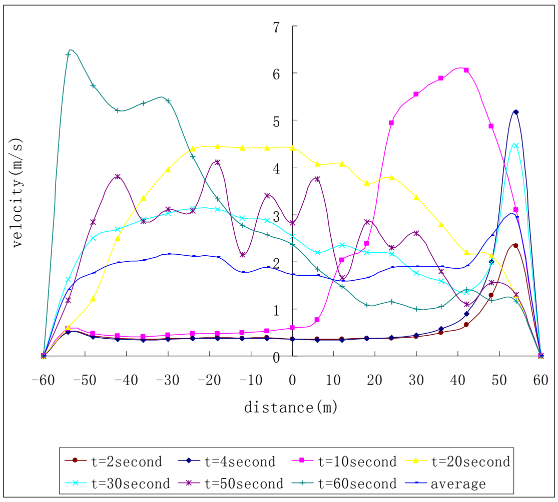


Figure 3 Air velocity curves at the level of 1.3 m along the waiting line of the platform under natural ventilation mode

Figure4 shows the air velocity distribution at the horizontal plane with 1.3 m height from the floor of the platform at the 12th second while the train is entering the station and Figure5 is the air velocity curves at the level of 1.3 m along the lengthways central axis line of the platform. It's obvious that the air velocity in the area near the waiting line between track and the columns is very high and in the area between the two rows of columns, air velocity is comparatively low.

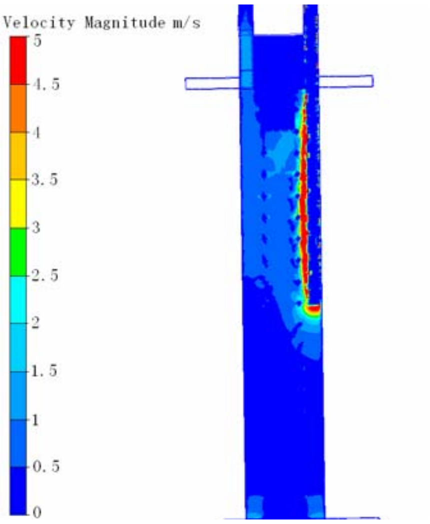


Figure 4 Air distribution at 1.3 m level of the platform under natural ventilation mode at the 12th second

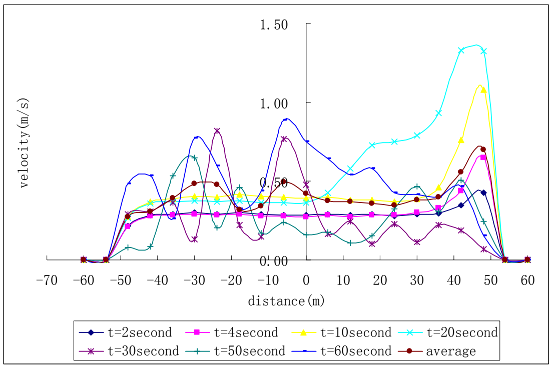


Figure 5 Air velocity curves at the level of 1.3 m along the lengthways central axis line of the platform under natural ventilation mode

MECHANICAL VENTILATION CASE

The air flow fields in the platform with both OSOE and OSUE ventilation system during the process of the train's movement were simulated separately. For proving the influence of mechanical ventilating air flow rate under both OSOE and OSUE ventilation modes, four cases were set as table 1. The tetrahedron elements number created in computational domain under different simulated cases are also listed in table 1.

Table 1 flow rate and element number in different simulated cases

case	flow rate (m^3/s)		Element number
	inlet	outlet	
OSOE1	1	2.1	954859
OSOE2	2	4.2	
OSUE1	1	2.1	1085031
OSUE2	2	4.2	

Air distribution in area near train's moving track ways

When the train is entering the station, air velocity in this area is controlled by piston wind and the influence of ventilation mode can be ignored. That can be proved by figure 6, which shows air velocity curves at 1.3 m level along the waiting line at the 2nd second under 5 different ventilation conditions.

The effect of ventilation mode on air velocity in this area can be observed when the train stays in and departs from the station. Simulation result shows that at level below 4.5m in this area, air velocity is decreased and above 4.5 m, it is increased under mechanical ventilation mode.

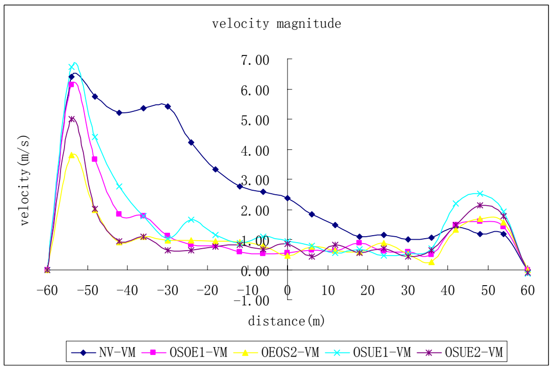


Figure 6 air velocity distribution at 1.3 m level along the waiting line under different ventilation conditions (t=2 second)

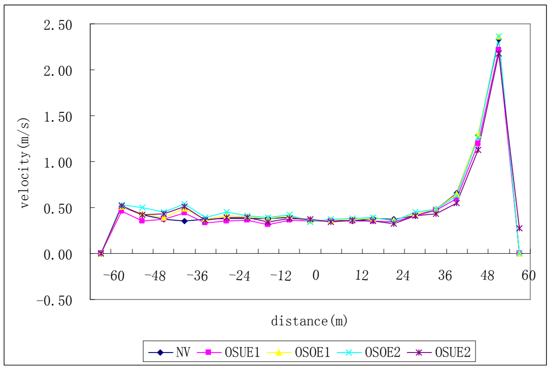


Figure 7-1 velocity magnitude

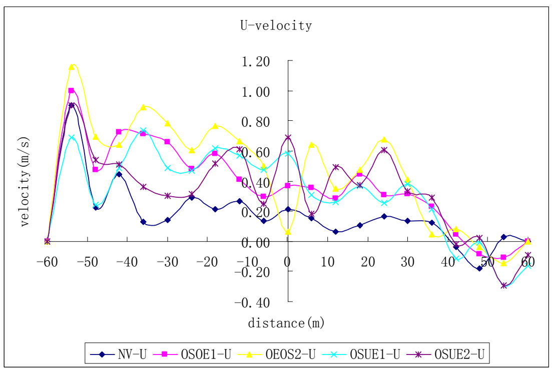


Figure 7-2 U-velocity

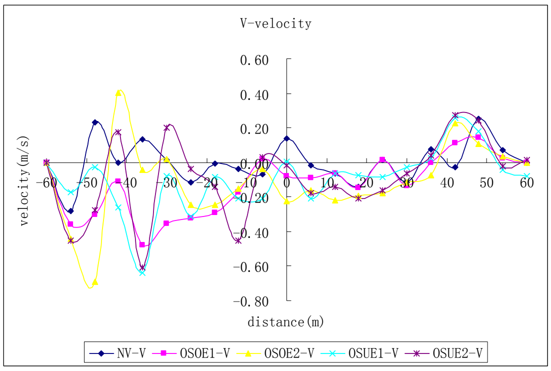


Figure 7-3 V-velocity

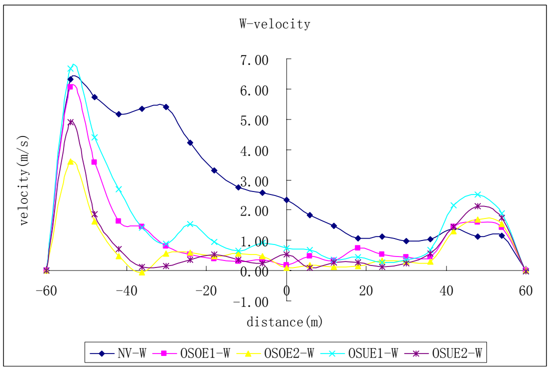


Figure 7-4 W-velocity

Figure 7 shows air velocity curves at 1.3 m level along the waiting line at the 60th second under 5 different ventilation conditions. Figure 7-1 shows velocity magnitude and Figure 7-2, 3, 4 show the projections of velocity vectors on X, Y and Z directions. It implies that although velocity magnitude is mainly dominated by air velocity along Z direction, which is induced by train's movement, air velocities along X and Y directions aroused by mechanical ventilation systems counteract the piston effect. So air velocity drops in this period and the drop is enforced with the increase of inlet flow rate. Comparing with OSUE system, slightly more air velocity reduction is aroused by OSOE system. That means mechanical ventilation system would make passengers in this area feel more comfortable by reducing air velocity when the train stays in and departs from the station.

Air distribution in area near platform lengthways central axis line

Figure 8 and Figure 9 present under OSOE2 case, air velocity distribution in the horizontal plane, 1.3 m high from the floor of the platform, at the 12th second and the air velocity curves at the level of 1.3 m along the lengthways central axis line of the platform. Comparing them with figure 4 and figure 5, it can be derived that air velocity in platform is greatly increased under mechanical ventilation mode, especially in the area around the central axis of the inlets. The simulations also indicate that the air velocity in this area is increased with inlet air velocity and the influence of outlet position is not very significant.

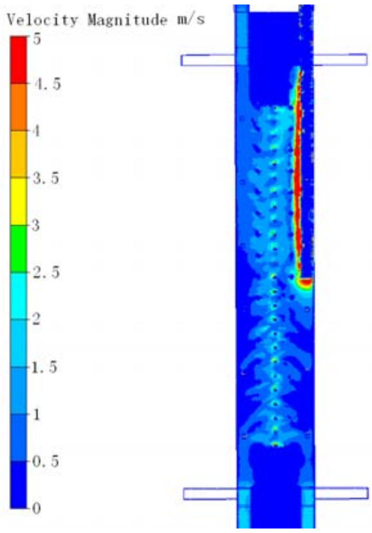
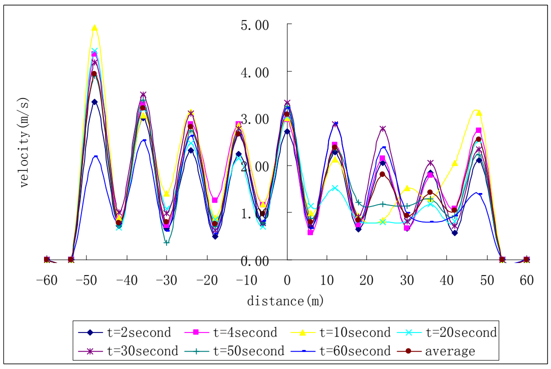


Figure 8 Air distribution at 1.3 m level of the platform under OSOE2 ventilation mode at the 12th second

Figure 9 Air velocity curves at the level of 1.3 m



along the lengthways central axis line of the platform under OSOE2 ventilation mode

CONCLUSIONS

According to above analysis of the transient simulations under both natural ventilation and mechanical ventilation mode, several conclusions can be obtained as follows:

- Great air velocity is aroused by piston effect in the area near the waiting line of the platform during the train's moving process under both natural and mechanical ventilation modes and in some location, air velocity is over 5 m/s. Mechanical ventilation system does not have influence on air velocity in this area below 2 m level during the train entering process. Whereas during the process of the train staying in and departing from the station, the mechanical ventilating flow has obvious counteraction to piston effect and the air velocity at 1.3 m level is decreased, which benefits for improving passengers' comfort. The air velocity drops is enforced with the increase of inlet flow rate and slightly more air velocity reduction is aroused by OSOE system than OSUE system.

- The influence of mechanical ventilation system on platform air distribution is mainly concentrated in the area below the inlets. Air velocity in the area near the lengthways central axis line of the platform is promoted by air jets from inlets and the position of outlets dose not have distinct influence on air velocity in this area.
- Ventilation efficiency can not be obtained in this paper because heat effect and pollutant dispersion have not been considered. More simulation researches would be held in our future work.

ACKNOWLEDGMENT

The authors would like to express their appreciation for the support from the Science Development Foundation of Beijing Municipal Education Commission, Beijing University of Civil Engineering and Architecture and Beijing Jiaotong University.

REFERENCES

A Zigh, I ONG and K KANG. 2000. "CFD application for subway stations," 10th International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels, Boston, USA., UK. BHR Group Limited, 2000, pp939-951.

I Y MAEVSKI and J F FAY. 2000. "Simulation and ventilation system design for the Tren Urbano Subway Project in Puerto Rico," 10th International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels Boston, USA., UK. BHR Group Limited, 2000, pp 465-483.

N Hur, C-S Won, K Jegal and C Cha. 2003. "A numerical simulation of the Trackway Exhaust System (TES) for underground station of Seoul 9th line: ventilation operation and smoke exhaust operation in case of a carriage fire," 11th International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels. Luzern, Switzerland. UK. BHR Group Limited, 2003, pp231-241.

R M H Yau and V S Y Cheng. 2000. "CFD analysis of pressure fluctuation due to train passage in tunnel," 10th International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels Boston, USA., UK. BHR Group Limited, 2000, pp953-965.

Zhu Yingxin, Qin Xuzhong and Jiang Yi. 1997. "Economic Analysis for Platform Screen Door in Subway Thermal Environment Control," Building Science. Vol. 4, pp 42-46.

Zhu Yingxin. Building Environment (2nd Edition). 2005. China Architecture & Building Press.