CFD SIMULATION OF A NOVEL VENTILATION SYSTEM OF SUBWAY STATION IN HARBIN

Xiyan Guan[1], Yiqiang Jiang[1],and Yang Yao[1]

[1]School of Municipal & Environmental Engineering, Harbin Institute of Technology, Harbin 150090, China

ABSTRACT

According to the cold climate in winter, a new novel ventilation system was put forward based on the analysis of the heat distribution at the subway station in Harbin. There was no special heating system in winter for subway station with such a ventilation system. In this paper, three dimensional model of the subway station was built, a mathematical model of the novel ventilation system was developed based on the k-ε standard turbulence model, and computational fluid dynamics (CFD) simulations for the ventilation system were performed to clarify the conditions of the temperature fields. A scientific analysis was carried out and the simulated results indicated that the temperature of the subway station was acceptable and the novel ventilation system suggested in this paper was a promising way to save energy and protect environment.

KEYWORDS

CFD simulation, subway station, ventilation system, cold climate, energy saving

INTRODUCTION

With the rapid development of the urban subway in China, more and more attention has been paid to the environment design of the subway station in order to obtain a comfortable thermal environment at the cost of lowest energy consumption. The ventilation system of subway was one of the key techniques in different environment control in the subway, especially in the cold climate zone, e.g. in Harbin. Furthermore，the investment of the subway projects was very huge and the subway should run up for a few decade years. Therefore, it's very necessary to carry out a CFD simulation and a scientific analysis.

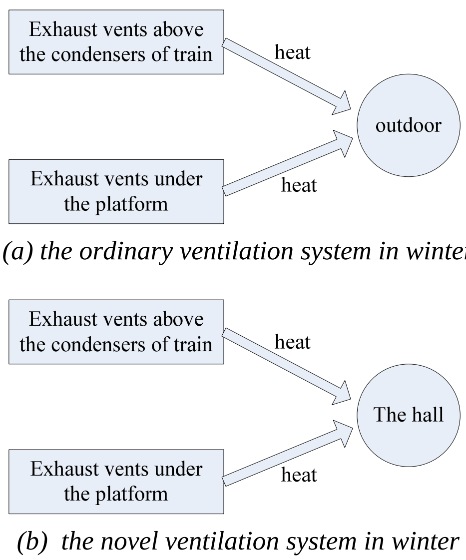
THE VENTILATION SYSTEM

According to the forms of the subway environment control system, the Open System, Closed System, Screen Door System were included. The ventilation system of Harbin subway station was an open system in summer, the methods of mechanical and "piston effect" were used to change the air from the inside to outside. In winter, the piston vents were closed, and the ventilation system was a closed system.

Difference between two kinds of ventilation system

Usually, in cold zone, there were heating systems in the subway station in winter. The ordinary platform mechanical ventilation was realized by two jet openings locating at the flange and track. The heat dissipated from the train condenser and the brake resistance was removed out by the mechanical ventilation, so the air of the platform was changed.

However, in the paper, a new novel ventilation system was put forward based on the analysis of the heat distribution at the subway station in Harbin. There was no special heating system in winter for subway station with such a ventilation system. The difference between the novel system and the ordinary was that the heat collected and exhausted from the platform was not removed out by the ventilation system. Instead, it was carried from the platform to the hall for heating. This was shown as Fig. 1.



(b) the novel ventilation system in winter

Figure 1 The difference between the novel ventilation systems and the ordinary ventilation system in winter

The station structure and its ventilation system

The subway was a typical island station, which has two run-lines. The structure of station was, length× width×height =169 m (L)×17.2 m (W)×5.8 m (H). Two circuitous ducts were located at the double ends of the station, connecting the uplink and the downlink, the width was 3.5 m, the length was 8.5m. The middle part of station was the space for passengers to wait for the vehicle, and the passageway was length×height = 4.2 m (L)×3.0 m (H). The ceiling ducts were settled above the condition condenser of the train. The design volume flow of two ducts was 26.4 m^3/s, 120 grille vents (1000 mm×600 mm) were responsible for exhaust the heat from the condenser. Under the platform, two exhausted ducts were settled according to the position of the braking resistor of the train. The design volume flow was 28.6 m^3/s, and 72 grille vents (775 mm×350 mm) were set at each side of the platform.

In the hall , the structure was length×width×height =79 m (L) × 24.6 m (W) × 3.6 m (H), and the simulated region was the dominant staying region for people. Two air ducts were arranged along the longitudinal direction of the station. The design volume flow was 55 m^3/s, and 36 vents (1000 mm× 600 mm) supply the hot air connected from the platform to the hall.

The model details are showed in Fig.2 and Fig.3.

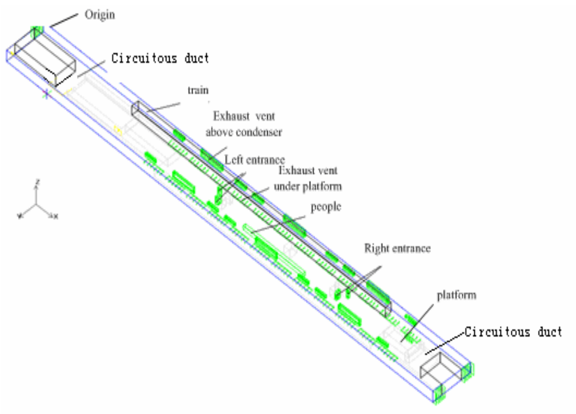


Figure 2 The ventilation system model of the platform

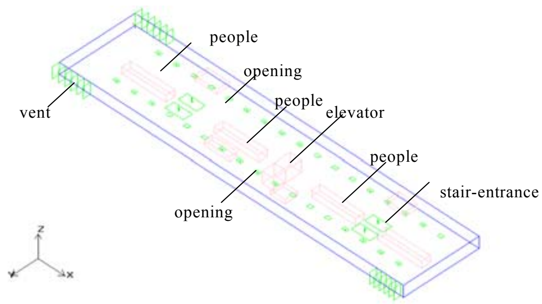


Figure 3 The ventilation system model of the hall

SIMULATION OF THE NOVEL VENTILATION SYSTEM

Modeling assumption

The geometric properties of the station were complex. Furthermore, the turbulence on the platform was transient and complex because of the coexistence of mechanical ventilation and train-driven wind. In order to ensure the reliability of the computation results, some assumptions were taken as follows:

1. The heat transfer of the office house on platform was not considered and the wall was taken as insulation wall.
2. Allocates the light load to the ceiling wall and the advertising light load to the two sides' wall uniformly.
3. Passengers exit in Figure 2&3 were processed to be time-averaged, and they were substituted by rectangular solid in the model.
4. The transient process was simplified to steady process when a train has stopped.

Boundary conditions

1. boundary conditions depended by people and the equipment

   In winter, The sensible heat of people was 160 W/person, the latent heat of people was 123 W/person, and the moisture dispersed amount was 55 g/h • person, respectively. In the subway station, the average people were 67 persons on the platform and 85 persons in the hall.

   The heat production of the train was calculated with 400 kW. The platform and the hall had heat-generating equipment such as straight elevator，light fixture，advertising lamp box，automat and so on. The boundary conditions were list in Table 1.

Table 1 Other boundary condition

EQUIPMENT	QUANTITY	POWER OF MOTOR	LOCATION
Elevator	1	11（kW/unit）	From platform to hall
Lift	2	13.5（kW/unit）	In station
Lighting	15 W/m^2		Hall and platform
Advertising lamp box	30 kW in Hall		Side wall
	40 kW on Platform		Side wall
automat	Total 20 kW		Hall

2. boundary conditions depended by ventilation system

The design parameters of the ventilation system was as below: the design volume flow of air exhaust vents on the rail roof was 28.6 m^3/s, and the desiegn volume flow of air exhaust vents on the rail flange was 26.4 m^3/s. The desiegn volume flow of air supply wents for the hall was 55 m^3/s. The fan pressure was 800 Pa.

3. boundary condition of piston wind

The piston wind was caculatied according to the formula $v = v_0 \Big/ \left(1+\sqrt{\xi_T / K}\right)$. In the calculation formula, v was the piston wind celocity, v_0 was the velocity of train, ξ_T was friction coefficient and K was piston-effect coefficient. The temprature of the piston wind was 5℃, the same as the temprature of soil in winter.

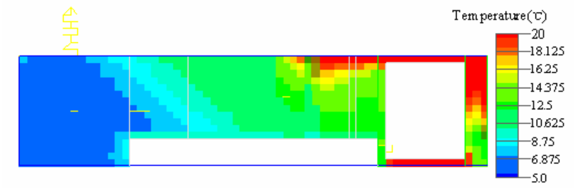
Computation and simulation

The simulation software adopted in this paper was Fluent, which can accurately simulate the physical phenomenon of air flow, heat transfer, contaminating, etc. For the simulation in engineering application, the main models selected were the Standard k-ε Model, RNG k-ε Model, Low-Reynolds Number k-ε Model, Zero Equation Model, etc. The standard k-ε model was relatively steady for indoor air flow. The simulation analysis and measurement result for the average flow filed corresponded excellently with one another in many conditions, so the Standard k-ε Model was selected for the simulation in this paper.

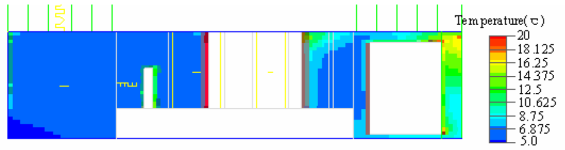
The air flow at the station was taken as incompressible steady turbulence. The physical phenomenon on heat transfer and flow was described by the basic governing equations: the Mass Conservation Equation, Momentum Equation, and The k-ε Equation. The governing equations were integrated on the spatial control volumes, and were caculated by using SIMPLE Algorithm. Except an application of a Second Order Upwind Scheme to the pressure, other parameters such as momentum, turbulent pulsation kinetic energy, and turbulent dissipation rate were calculated by using One Order Upwind Scheme.

RESULTS AND DISCUSSIONS

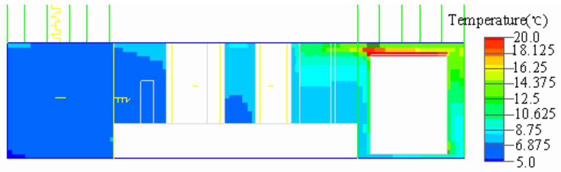
Based on the simulated results, when the train arrived the station, the temperature distribution of the platform and the hall was discussed as follows:



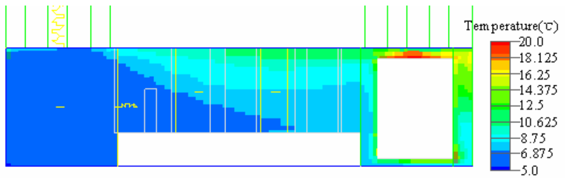
(a) The temperature of YZ plane on platform where x=75m



(b) The temperature of YZ plane on platform where x=104m



(c) The temperature of YZ plane on platform where x=128m



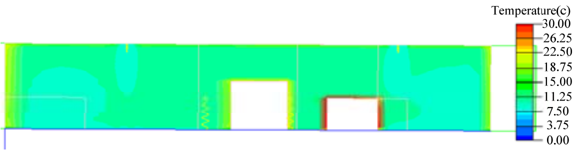
(d) The temperature of YZ plane on platform where x=140m

Figure 4 the temperature distribution of the platform in winter

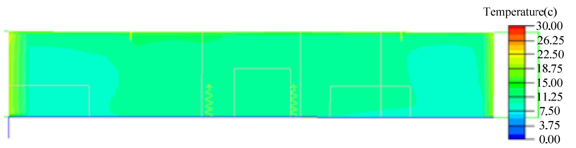
The temperature distribution of YZ cross section for the platform in winter was shown in Fig. 4. The main heat source of the station contained the people, lights, elevator and the train. It was apparent that the temperature distribution was imbalanced for the leakage of exits at the training-stop side of platform. The temperature of the flow declined with the increasing x coordinate. At the x = 75 m point, the cold train-driven wind didn't diffuse adequately, the flow temperature of the side with train was obvious higher than the other side without train on the platform. At the x = 104 m and x = 128m points, the cold air from the other side without train diffused to the platform continually, and was partly prevented by wall on the platform. At the x = 140 m point the cold air spread onto the platform greatly, and the temperature on the platform became lower. The heat production of the train and the passengers in it was calculated with 400 kW which was the greatest heat sources. Thus, the temperature around the carriage was up to 20℃. It was suitable to use the ventilation system, and the heat unnecessary can be vented in time from the exhuast vents under the platform and above the condenser.

On the platform, the temperature of the side with train was approximately between 9℃ and 12℃,while the temperature of the side without train was between 7℃ and 8℃.

Send the heat dissipated from the train, lights and other equipment on the platform to the hall by the ventilation system, the temperature diffusion of the hall was shown in Fig. 5.



(a) The temperature of YZ plane in hall where x=91.1m



(b) The temperature of YZ plane in hall where x=106m

(c)The temperature of YZ plane in hall where x=115m

Figure 5 The temperature distribution of the hall in winter

It can be seen from the Fig.5 that the elevator, auto ticket machines, the lights and the lighting box of the advertisement as heat sources had an obvious impact on the indoor air temperature. The air temperature around the elevator and the ticket machine was high, which could reach 15℃,and the heat diffused to the air continuously. It's apparent that the hot air from the ceiling ducts played an important role in heating the space of the hall. The indoor air temperature diffusion was uniform, and the average temperature was 11℃.The temperature around the passengers was 12℃ because of their own heat.

Considerring that the passengers stayed shortly at the hall and platform, it's appropriate to only meet the passengers' temporary comfortable for energy saving, when they came through the subway station. For the station simulated, the lowest temperature on the platform was 7℃, the temprature around the passengers on the platform was 12℃ because of the train, and the average temperature of the hall was 11 ℃. This was acceptable compaired with the outdoor temperature in winter which is -20℃ in Harbin.

CONCLUSIONS

The simulated results indicated that in winter the temperature on the platform can be kept no lower than 7℃ ,the temprature around passengers was 12 ℃ and the average temperature was about 11℃ in the hall by using the novel ventilation system suggested in this paper. When passenger came from the cold outside, they can have warmer sense and it satisfied the requirement of temporary comfort in cold climate.

The energy efficiency of such system was very high because the dissipated heat from the train, the equipments was collected and sent it to the hall for space heating, thus saving energy and protecting environment. The ventilation system was a scientific reference for the development and designing of the sybway environment contrl system in high-cold area.

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