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Research on Subway Air-Conditioning System Design

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Abstract. The design of subway air-conditioning system accounts for not only the general characteristic, but also the following factors the different working circumstances and the big passengers' density. In order to provide sufficient refrigerating capacity to offset the heat quantity of subway carriage, it is indispensable to install a reasonable air-conditioning, heating and aeration system to improve the comfort. In this paper the research object is the velocity and temperature change of the airflow inside the subway, and the research method is computer simulation. We study the performance and temperature change of the airflow using UG and CFD, compare and analyze the variation of the airflow in the same cross section of different models. Through comparing and analyzing the velocity and temperature change of the three models, this paper finds that the model that installs the inlets at the two sides of the subway is senior to that installs the inlets at the top of the vehicle.

Introduction

As the level of subway transportation is developing ceaselessly, the air-conditioning system has become the standard device of subway vehicle. The moving characteristic and the large number of passengers determine the particularity of the air-conditioning system. The design of subway air-conditioning system accounts for not only the general characteristic, but also the following factors that the working circumstances of subway vehicle in different cities are different and the passengers' density is large. Urban subway lines generally cross the city center and commercials areas, so the traffic is intensive. Through the analysis of characteristic of subway transportation, this paper put forward some references for subway air-conditioning system design and focused on the effect of the location of the inlet and outlet and the velocity on the airflow in the vehicle.

Factors that affect the airflow

The interior dimensions of the subway. Since there are strict requirements to the height of the tunnel entrance, so the height of the subway is also limited and the height is about 2.1 meters. Besides, the vehicle is long and its length is much larger than the height. In such a narrow space, the uniform distribution of the internal airflow is a big problem. If the inlet and outlet are not arranged properly, it is likely to cause the dead zone so that the temperature variance between any two points is prone to be excessive in the longitudinal direction.
Interior air velocity. The "Railway Vehicle Technology" specifies that the breeze velocity should not be more than 0.35m/s in the summer. From Figure 1, we can find that the airflow velocity should not be more than 0.5m/s when the internal temperature is 26°C. Yet the velocity should not be too low and the minimum shall not be less than 0.07m/s to avoid a "static region".

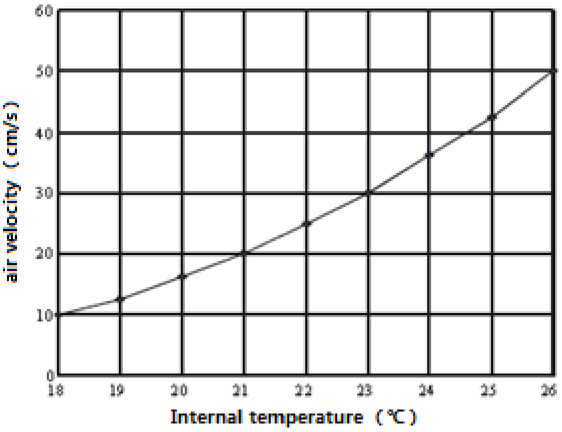


Figure 1 The relationship between the vehicle temperature and the airflow velocity

The arrangement of the inlet and outlet. The quality of the airflow, the interior temperature, the humidity, the wind area and other performance indicators all have direct relationship with the arrangement of the inlet and outlet. Common arrangements are in two ways. One is that the inlet is placed above and the outlet is also placed above, and the other is that the inlet is placed above and the outlet is placed below. Ventilation is divided into natural ventilation and forced ventilation and the latter is better. However, the arrangement of inlet and outlet should not be stereotyped and it should be based on the actual size of the specific body structure and the overall layout of the body.

The passengers' density. The passengers' density is another factor that can affect the airflow. "Underground railway vehicles general technical conditions" (GB7928-87) provides that the capacity for 1 m^2 is 6 persons, yet in some circumstances it may even reach to 8 persons.

Subway Vehicle Modeling

Research object. The interior body is a narrow space with small height. The air jet in the initial mixing layer mixes with the air at the top to avoid airflow directly landing to the work areas, which may make the passengers feel cold. The mixed airflow becomes more uniform and goes down stably. The scope of air jet stream is much greater than that of the return air. So as long as we can control the angle and initial velocity of the airflow and select the appropriate outlet, we can get a stable and uniform airflow area in the vehicle.

According to the different locations of inlet and outlet and the passengers' density conditions, there are three different models of vehicle body structure.

The modeling using UG. The modeling is based on the layout of Beijing subway. The vehicle dimensions are 9500mm×2440mm×2100mm. Since the model is to study the airflow of the interior vehicle, so the modeling inside the vehicle is mainly passengers and seats. The heat radiation of the window and door is low, so it is not need to be considered in the model. In model 1 the inlet is placed at the top of the vehicle and the outlet is placed underneath the seat. The dimensions of the inlet are 1339mm×309mm×30mm. Two inlets are arranged in the middle of the vehicle body so that the passengers will feel more comfortable. The dimensions of the outlet are 500mm×300mm×30mm. We use a cylinder to simulate the passenger. And the diameter and height of it are 200mm, 1650mm respectively. The modeling using UG is shown in Figure 2.

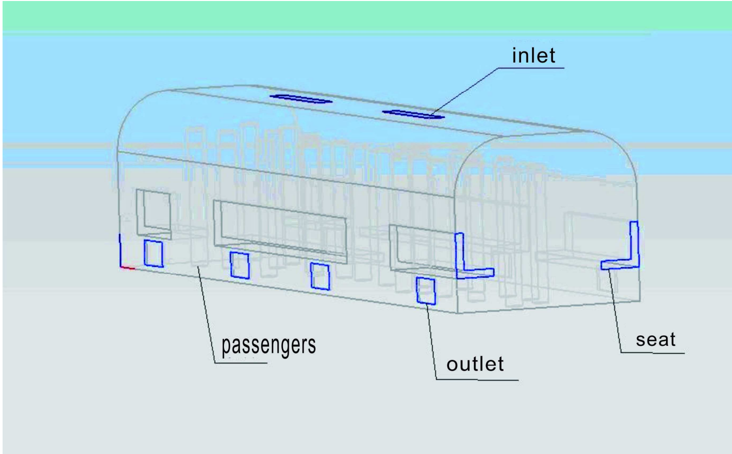


Figure 2 Body structure of model 1

We place the inlet at the rounded corners of the roof throughout the body length and the outlet is placed underneath the seat in model 2. In this model it is assumed that it is quite crowded interior the vehicle and the passengers' density is great. Under this circumstance all the passengers can be set as a cubic. The modeling of the vehicle body is shown in Figure 3.

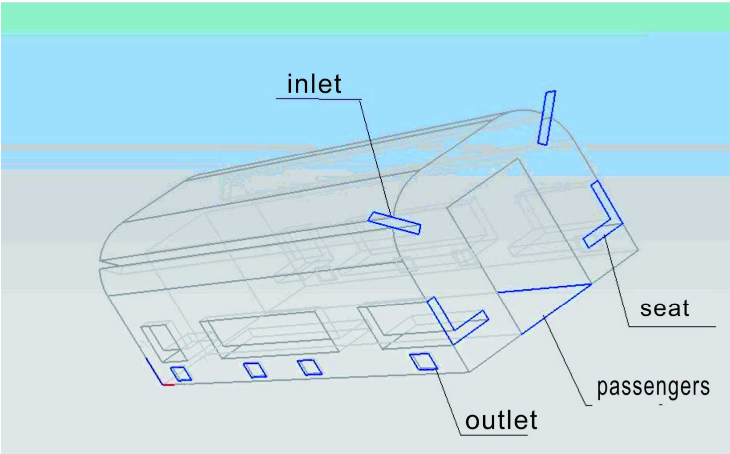


Figure 3 Body structure of model 2

The body structure of model 3 is the same as model 2. However, the passengers' density is lower and we also use the cylinder to simulate the passenger. The modeling of the vehicle body is shown in Figure 4.

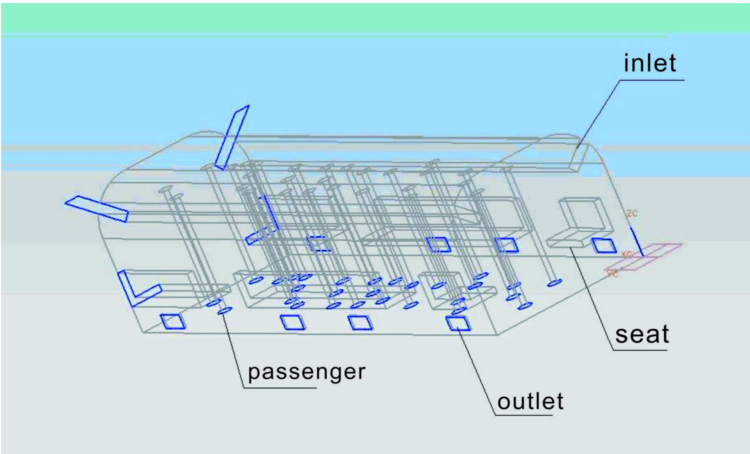


Figure 4 Body structure of model 3

The CFD calculations of models

CFD (Computational Fluid Dynamics) is a computer and image display that uses numerical calculation to finish the related work about the fluid flow and heat transfer system of physical phenomenon. Computer Numerical Simulation of Fluid Mechanics is a study of fluid flow and other physical phenomenon of modern technologies. In this paper, FLUENT software was adopted to add boundary conditions for the model and calculate.

In the Boundary Conditions under the Define menu we can set the boundary conditions of the model.

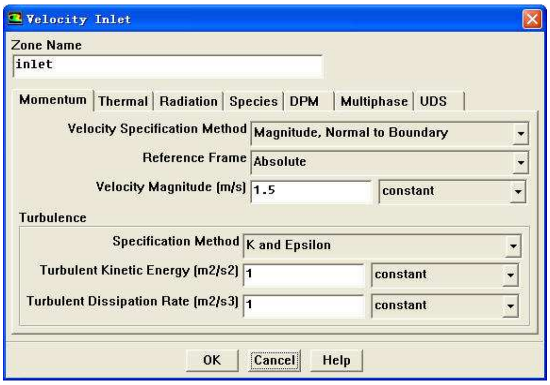


Figure 5 Inlet boundary conditions setting

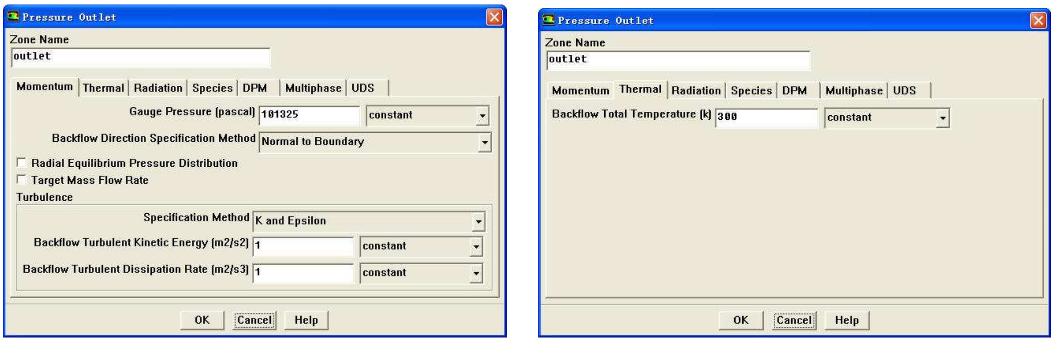


Figure 6 Outlet boundary conditions setting

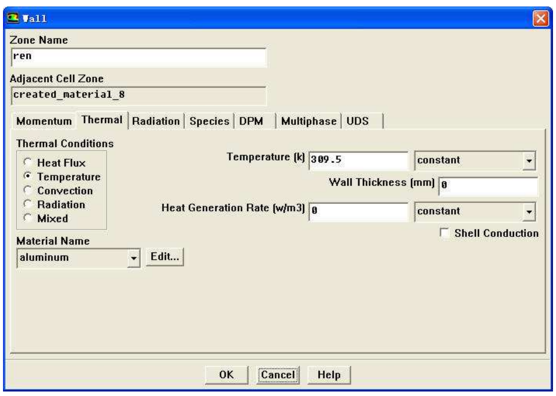


Figure 7 Passengers boundary conditions setting

Figure 5 –Figure 7 are the inlet, outlet, and passenger's boundary conditions setting respectively.

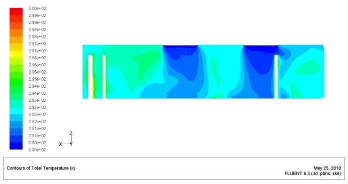
Table 1 Refrigeration boundary conditions setting of the model

	working condition 1	working condition 2
air velocity of inlet	1.5m/s	2.5m/s
temperature of inlet	290K	290K
pressure of outlet	101325Pa	101325Pa
temperature of outlet	300K	300K
temperature of passengers	309.5K	309.5K

Table 1 shows the two refrigeration boundary conditions of the subway vehicle. The three models built in UG all use the two working conditions shown in Table 1 to calculate.

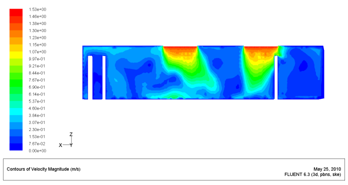
Analysis of the calculation results

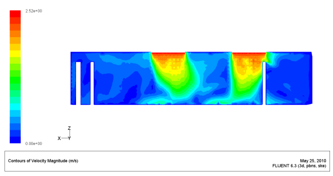
The model of the vehicle body is simulated and calculated, and we analyze the pictures of the temperature and velocity variance of different sections of the models. The pictures of the calculation results are shown in Figure 8-Figure 13.



v=1.5m/s v=2.5m/s

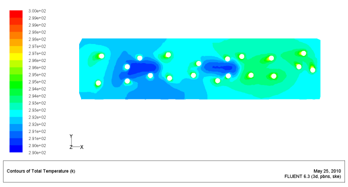
Figure 8 The temperature contours of Y direction in model 1





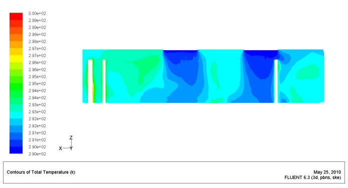
v=1.5m/s v=2.5m/s

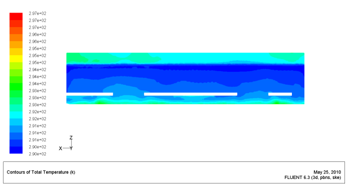
Figure 9 The velocity contours of Y direction in model 1



v=1.5m/s v=2.5m/s

Figure 10 The temperature contours of Z direction in model 1





model 1 model 2 model 3

Figure 11 The temperature contours of Y direction when v=1.5m/s

v=1.5m/s v=2.5m/s

Figure 12 The velocity contours of X direction in model 1

v=1.5m/s v=2.5m/s

Figure 13 The temperature contours of X direction in model 3

From Figure 8 we can find that the temperature of the passengers areas is 4~5°C lower than that of the front vehicle body. Because the inlets are located at the top of the passengers areas, so the fresh air from the inlet can have sufficient heat exchange with the air in the passengers area, thus reducing the air temperature inside the passengers area. As can be seen from Figure 9 and Figure 10, the temperature of the rear area is about 4~5°C lower that of the front area, which may be caused by the uneven distribution of the airflow from the inlet. Meanwhile in model 1 when the velocity is 2.5m/s the internal temperature distribution is more even, yet it changes largely when the velocity is 1.5m/s. This will result in the situation that some passengers feel cold while others feel hot. Therefore in model 1 most passengers will feel comfortable when the inlet is located at the top of the vehicle and velocity is 2.5m/s.

From Figure 11 we can find that the temperature variance of model 1 is obviously large and that in model 3 is relatively uniform. This shows that the method that inlet is placed at the top of the vehicle also has some deficiencies comparing with the method that places the inlet at the two sides of the vehicle body throughout the vehicle. However, when we compare model 2 with model 3 (Model 2 for full passengers), the temperature variance of model 2 is more uniform. This indicates that in our simulation the bigger passengers' density can make the temperature more uniform when the location of inlet has been fixed. Thus the passengers can feel more comfortable.

Through the above analysis of the temperature and velocity variance of the airflow, we can obtain the distribution situation of the airflow and the temperature. This provides an important basis for improving the uniform distribution of airflow, as well as reducing the interior temperature deviation.

According to the modeling and simulation of the subway air-conditioning system, we can get the following results:

1 Establishing an appropriate geometric model, adopting the actual boundary conditions and using the standard two-equation turbulence model to simulate the airflow distribution in the subway is feasible.

2 Increasing the air temperature and airflow from the inlet appropriately can improve the site environment, thus making temperature distribution more uniform.

3 In the method that places the inlet above and outlet below, the temperature and velocity distribution in the vehicle body is uniform and the fresh air can reach to the passenger areas. Even if in the big density area, the velocity changes little and the velocity field is satisfactory.

Conclusion

This paper has reached some conclusions about the subway air-conditioning system using CFD to simulate the airflow. However, there are also many areas needed improvement and the future work can stretch from the following aspects:

1. The model can be more detailed and the position of the inlet can be arranged more reasonable, thus the results of the simulation can be more persuasive.
2. Due to the time limits, this paper does not simulate the method that places the inlet and outlet both above. In future work the inlet and outlet can be both arranged at the top of the vehicle body for analysis, and the more conclusions results may be obtained.
3. This paper ignores the heat of the vehicle body and the temperature variance among different passengers, which may cause some effects on the research results. In future studies, we can try to set the heat of passengers as the boundary conditions.

Acknowledgements

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