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Analysis of Fresh Air Volume of Air-conditioning System for Railway Vehicles

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Abstract:The relevant standard requirements both in domestic and abroad provide the basis for designing air-conditioning system of railway vehicles present. However, there are great differences in the fresh air volume indicators among different standards requirements, and the requirements of each vehicle procurement contracts are also different. The design of air-conditioning become difficult above these. In this paper, the fresh air volume of different type railway vehicles is analyzed from health and equipment electricity consumption according to the railway vehicles air-conditioning system standard requirements in domestic and abroad. Some advises for designing air-conditioning system of railway vehicles through the fresh air volume calculation and comparison for domestic air-conditioning system of railway vehicles was provided.

Keywords: railway vehicle; air-conditioning system; fresh air volume

1 Introduction

Generally, according to the transport distance and passenger's traveling time, railway vehicles are divided into long-distance trains and short-distance trains. The adjacent stations distance is long and the ventilation inside the vehicle only depends on the fresh air and exhaust of the air conditioning system for long-distance train. The adjacent stations distance is short and the door of vehicles be opened and closed frequently in most station for short-distance train. So, switch doors play an important role in ventilation for the short-distance train that the requirement standards of fresh air volume become lower than the long-distance train.

However, it has been suggested that the fresh air volume of the short-distance train should be the same as the long-distance trains for passenger comfort. Then new problems have been raised for standardization of fresh air volume, design and manufacture of the air conditioner, and so on. The short-distance trains are generally city rail, subway and urban rail transit that are characterized as large passenger capacity, which is generally 1. 5 times more than long-distance trains. If commuting and peak travel is considered then the passenger capacity should be more than 2 times the long-distance trains. If the demand for average person fresh air is same as the long-distance trains, the total fresh air volume of air conditioners will increase greatly and the cooling (heat) capacity of air conditioning units will have to be increased correspondingly. And the power consumption of air conditioners will be also increased. There are some new problems for the power of railroad lines. Therefore, the study of rail passenger air conditioning volume becomes significance practically.

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2 Fresh air volume for air conditioning of railway vehicles

2.1 Relevant standards at domestic and abroad

The relevant requirements for railway vehicles fresh air volume of air conditioning at domestic and abroad have been published in the standards[1~9]. The requirements for the new air volume are different in these standards shows as the Table 1. The standard[9] stipulated: the normal carrying capacity should be regarded as full seats for Class A car and Class B vehicles if the quantity of passenger have not be defined. The contract specification should be clearly defined by all standing area as 2 people every square meter for calculation. The distribution of vehicles for Class A car and Class B vehicles see the Table 2 [9].

Table 1 Standard of fresh air volume requirements

No.	Literatures	Terms	Fresh air volume requirements	Remarks
1	Literature[1]	Section 3.1	$\geq$20 m^3/(h · p)	Railway vehicles
2	Literature[3]	Appendix F Table F.1	Te$\leq$-20 ℃, Each seat (sleeper) 10 m^3/h -20 ℃<Te$\leq$-5 ℃, Each seat (sleeper) 15 m^3/h -5 ℃<Te$\leq$26 ℃, Each seat (sleeper) 20 m^3/h +26 ℃<Te$\leq$+40 ℃, Each seat (sleeper) 15 m^3/h Te>+40 ℃, Each seat (sleeper) 10 m^3/h	Long distance railway vehicles
3	Literature[2]	Table 5	Summer 20~25 m^3/(h · p) Winter: the areas south of BeiJing15~20 m^3/(h · p)	Long distance railway vehicles
4	Literature[4]	Table 11	Te$\leq$-15 ℃, Each seat (sleeper) 10 m^3/h -15 ℃<Te$\leq$-5 ℃, Each seat (sleeper) 15 m^3/h -5 ℃<Te$\leq$26 ℃, Each seat (sleeper) 20 m^3/h Te$\geq$+26 ℃, Each seat (sleeper) 15 m^3/h	Long distance railway vehicles
5	Literature[5]	Appendix H	Te$\leq$-20 ℃, Each seat (sleeper) 10 m^3/h -20 ℃<Te$\leq$-5 ℃, Each seat (sleeper) 15 m^3/h -5 ℃<Te$\leq$26 ℃, Each seat (sleeper) 20 m^3/h Te$\geq$+26 ℃, Each seat (sleeper) 15 m^3/h	Long distance railway vehicles
6	Literature[6]	Section 12.5	Passenger vehicle should not be less than 10 m^3/(h · p); vehicles only ventilated should not be less than 20 m^3/(h · p)	Metro
7	Literature[7]	Section 12.2.15	When using the air conditioning system, the amount of fresh air supplied to each passenger per hour should not be less than 12.6 m^3, and the total fresh air volume of the system should not be less than 10%	Metro
8	Literature[8]	Section 5.13.2 a)	Fresh air volume meet GB/T 7928-2003	Metro
9	Literature[9]	Appendix G	Class A: normal$\geq$15 m^3/(h · p), lowest 10 m^3/(h · p) Class B: normal$\geq$12 m^3/(h · p), lowest 8 m^3/(h · p)	Metro

Table 2 Vehicle classification

	Class A	Class B
Passenger standing	<4 persons/m^2	≥4 persons/m^2
The average travel time	>20 min	≤20 min
The average running time between two stations	>3 min	≤3 min

2.2 Analysis of the fresh air volume for standards

2.2.1 Long-distance trains

The maximum fresh air volume is 25 $m^3/(h \cdot p)$ and the minimum is 10 $m^3/(h \cdot p)$ in summer for the long-distance trains as the Table 1 shows. The maximum fresh air volume is 20 $m^3/(h \cdot p)$ and the minimum is 10 $m^3/(h \cdot p)$ in winter for this kind train. The fresh air volume can be adjusted according to the variation of temperature externally whatever summer or winter. The travel time is longer. The adjacent stations distance is long. The parking time is short. These are the characteristics for the long-distance trains. The fresh air ventilation of the car is depended on air-condition entirely so that the volume of fresh air becomes large to meet the passengers requirements. However, the minimum fresh air volume is 10 $m^3/(h \cdot p)$ in winter.

2.2.2 Metro and suburban railway vehicles

The maximum fresh air volume is≥15 $m^3/(h \cdot p)$ and the minimum is 8 $m^3/(h \cdot p)$ in summer for metro and suburban railway as the Table 1 shows. There is no other requirement for winter and the fresh air volume can be adjusted according to the variation of temperature externally. The travel time is short. The adjacent stations distance is short. The doors of vehicles are opened and closed frequently. So switch doors can play a role in ventilation for the short-distance train except air-condition. The requirements of fresh air volume are less and the passages feel comfort at the same time.

2.2.3 Fresh air volume of air conditioning system

Whether for long-distance trains or metro and suburban railway vehicles, the fresh air volume has a minimum and maximum requirements from the passenger comfort considerations.

The greater fresh air volume, the more air ventilation, the lower CO_2 content in vehicle passages feel more comfortably. However, it brings other problems such as increasing heat load in the vehicle, increasing the cooling capacity for the air conditioning unit, increasing the power consumption of the air conditioning unit, increasing the load of the power supply network, increasing the energy consumption if increasing the amount of fresh air. It is suggested that the fresh air volume of air conditioning system can be designed according to the maximum fresh air volume requirement of passenger. In actual application, the fresh air volume should be adjusted according to the change of temperature outside of the vehicle. So that it could meet the requirements both passenger comfort and the supply requirements of power grid for electric air conditioning system load of railway vehicles.

3 Analysis of fresh air volume from health perspective

3.1 Allowable value of CO_2 content in car and fresh air

3.1.1 CO_2 content allowed value in the vehicle

The purpose is making the air fresh in the vehicle permanently in the method of introducing fresh air into inside and exhausting gas outside. The main indicator to measure the air whether fresh is the carbon dioxide concentration which is the oxygen inhaled by the human body through the lungs and exhaled Carbon dioxide. Although the carbon dioxide harmless to the human body, the passengers feel sleepy, sleep knock, fatigue, cannot pay attention when the concentration of carbon dioxide in the air is too high.

In a full seated vehicle the carbon dioxide concentration become higher and higher if the passengers continue to breathe the oxygen in and spit the carbon dioxide out but no fresh air input. This results that the passengers feel sleepy, sleep knock, fatigue and can not pay attention. In a word, in order to make the travelers enjoy a pleasant journey, certain amount of fresh air should be sent into the vehicle to make the comfortable for travelers.

The following factors influence the size of the new air volume: 1) The carbon dioxide concentration allowed in vehicle; 2) The carbon dioxide emissions by human; 3) The preheating power requirement by fresh air to ensure that the vehicle heating equipment to work normally and the vehicle supply to meet the requirement.

The size of the fresh air volume mainly depends on the allowable concentration of carbon dioxide in the vehicle (volume ratio), some of the existing domestic standards [1-2]. The provisions in Table 3.

Table 3 Allowable concentration of CO_2 standards in vehicle

Standards	Literature[2]	Literature[1]
The allowable CO_2 concentration	≤0.15%	≤0.15%
Application	Railway vehicles	Transportation
Standard setting unit	Ministry of Railways	Ministry of Health

3.1.2 Fresh air volume to meet the allowable concentration of carbon dioxide in the vehicle

The carbon dioxide emissions show in the Table 4 according to human physiological test data.

Table 4 CO_2 emissions of person

Energy metabolism rate	Person status and intensity of activity	CO_2 emissions $m^3/(h \cdot p)$
0	Sleep or quiet	0.013
0~1	Mild activity	0.022
1~2	Light work	0.030
2~3	Medium work	0.046
3~4	Heavy work	0.074

The passengers generally sport slightly sport in travels. The CO_2 emissions desirable is 0.022 $m^3/(h \cdot p)$. For example, the volume of the 25T-type vehicle is 155 m^3, and it could contain 118 persons. The CO_2 content of air at atmosphere is 0.03%. Under the operating condition with the door closed, the CO_2 concentration per hour in the vehicle may be 1.705%.

Making the CO_2 concentration in the vehicle is 0.15% permanently and the amount of fresh air should be V. Then:

$$(155+V)\times 0.15\% = 1.705\%\times 155+0.03\%\ V$$

$$V=2008.5\ m^3/h.$$

So that it can calculate the fresh air volume is

$$2008.5\div 118 = 17.02\ m^3/(h \cdot p)$$

The minimum ventilation rate in the breathing zone shall be 4 L/(s · p) for the auditorium (full seating) according to Reference[10]. And the minimum ventilation volume is 14.4 $m^3/(h \cdot p)$. The new air is mixed with fresh air (about 1/3) and returned air (about 2/3) not all fresh air as the air conditioners for rail working principle. So that the fresh air volume should be divided by a ventilation coefficient $Ev=0.8$ and the fresh air volume is 18.0 $m^3/(h \cdot p)$ which is meet the fresh volume calculation 17.02 $m^3/(h \cdot p)$ based on the fact that the CO_2 concentration is maintained at 0.15% according to Reference[10].

It can be seen that the fresh air volume required for most of the time is 15 $m^3/(h \cdot p)$ and 20 $m^3/(h \cdot p)$ according to the new air volume requirements in Ref[1] and Ref[5]. The fresh air volume requirement is 10 $m^3/(h \cdot p)$ only when the outside temperature below is 15 ℃, which is basically consistent with the fresh air flow rate standard in document[5] and lower than document[1] requirement.

3.2 Impact of travel time for passenger

The travel time should not exceed one hour for urban and suburban rail vehicles as the air conditioners suitable. The main rail vehicles standards should be applied when the travel time exceed one hour according to trunk rail vehicles are required[9].

The travel time is divided in the conceding of comfortable for passages. The ride comfortable for passengers is not influenced in the result of the question of no enough fresh in vehicle because the travel time is short, the distance is short between two stations and the fresh or exhausted air could be switched passing the opened and closed door according to document[9]. The main ventilation fresh air method is based on air-conditioning system for long-distance trains because the travel time is long, the distance is long between two stations and the fresh or exhausted air could not be switched passing the opened and closed door. Therefore, the air conditioning should meet the requirements of passenger breathing ventilation for long-distance trains.

The railway vehicle air conditioner should be distinguished by the travel time whether more than one hour. It is be regarded as long-distance travel if more than one hour and the amount of fresh air can be performed in accordance with the literature[1-3]. It is be regarded as short-distance travel if less than one hour and the amount of fresh air can be performed in accordance with the literature[6].

4 Impact of train power supply capacity

The main consumable electric equipment in train is traction system, braking, control system, air conditioning system, lighting, electric boiler and communication signals. The traction system is called main electricity part and the other equipment electricity is called auxiliary power. The auxiliary power accounts about 30% of the total electricity consumption of the train, while air conditioning system electricity accounts more than 80% of auxiliary power according to the using department. Therefore the air conditioning energy consumption accounts more than 24% of the total train energy consumption.

In the calculation of heat load of air conditioning units, when the external temperature is 35 ℃ and the relative humidity is 60%, the fresh air volume every person is 15 m^3/h, then the fresh air load accounts 33% of the heat load of the whole vehicle. If the fresh air volume is increased to 20 $m^3/(h \cdot p)$, the heat load of fresh air will increase 11%, the air conditioning unit power consumption will increase about 5%, and the total train power consumption will increase 1.2%.

There is only one train in period power supply area for long-distance train because the power grids are zoned for power supply.

Therefore, the train power consumption increases by 1.2% when the fresh air volume increases to 20 $m^3/(h \cdot p)$ which have no much impact on the line power grid. But that will have some impact for locomotive.

For subway and suburban rail vehicle, if one railway line is 30 km, the running time is 30 min, the departure interval is 2 min for morning and night peak trip time, and there are 15 trains on the same line, the line total power load will increase 18% if the power consumption increases by 1.2% for every train. The stability of the power supply will have a greater impact for this situation. Therefore, it is not only one question for air-conditioning system to increase the amount of fresh air but also for the power supply of line and train. The power supply capacity margin should be sufficient when design period, the existing line is difficult to achieve.

5 Fresh air volume of air-conditioning for vehicles in existing railway

5.1 Long-distance trains

The case of over-seating is not considered for long-distance train. There are 118 seats and 2 air conditioning units (type KLD29) for model 25T hard seat train. The total air volume is 4 500 m^3/h, and the fresh air volume is 1 500 m^3/h. If the extra fresh air sent from outside is 3 000 m^3/h, the fresh air volume of every person is 25.4 m^3/h for calculation. The fresh air volume of every person is 23.1 m^3/h by the case of 10% over-seating to reach 130 person which meet the requirements of the literature[1-3].

5.2 Subway and suburban trains

The seat should be full and there are two persons every square meter for all standing areas for calculation to subway and suburban trains according to literature[9] to get normal passenger capacity (PC1) parameter. For example, one subway train, the length of one vehicle is 18.8 m, the width is 2.46 m, the quantity of seats is 44, the standing area is 35.7 m^2, there are two persons every square meter for calculation, then the total persons is 71, and the normal 115 seats should be added at the same time. All of this is called PC1.

The total person numbers multiply by the minimum fresh volume is 20 m^3/h which should be taken into account the maximum fresh air volume when design period[6]. So the whole vehicle fresh air should be not less than 2 300 m^3/h. If the number of people standing on the station stands is 4 on per square meter, then the number of people standing is 143, so the total number of people is 187. It is the Full Passengers Capacity (PC2). The amount of fresh air should be not less than 2 356 m^3/h according to the literature[7] per fresh air volume not less than 12.6 m^3/h to calculation.

If the number of people standing on the station stands is 6 on per square meter, then the number of people standing is 214, so the total number of people is 258. It is the over-seats passengers capacity (PC3). The amount of fresh air should be not less than 2 580 m^3/h according to the literature[7] per fresh air volume not less than 10 m^3/h to calculation.

When the air-conditioning system is designed with a fresh air volume of not less than 2 580 m^3/h, it can meet the requirements of normal passenger capacity (PC1), full passenger capacity (PC2) and over-seats passenger capacity (PC3 and the literature requirements)[1,7,9].

6 Conclusions

Through the literature requirements and the analysis of health perspective, take analysis of the fresh air volume. We make calculation to the fresh air volume of air conditioning of vehicle. The existing literature standards are basically reasonable which should distinguish long-distance trains and short-distance trains differences according to the analysis comparison of calculation for the new air volume air conditioning system of vehicles.

The basic requirement of satisfaction for passenger such as breathing and comfort should be considered firstly during the design period of fresh air volume for air condition system of vehicle to ensure that the CO_2 concentration in the vehicle meets the requirement (≤0.15%) and the fresh air volume is 20 m^3/h at the same time.

The fresh air volume should be not less than 20 m^3/h during design period for long-distance trains. The application should be based on external temperature to adjust. All above to ensure passenger travel comfort, consider the grid power supply, take into account the air conditioning thermal and cooling capacity and energy saving needs.

For subway and suburban trains, the PC1, the PC2 and the over-seats passengers capacity should be considered during design period. The maximum fresh volume will be selected when the three parameters are calculated in the air conditioning system design.

The peak passenger capacities maybe not reach to PC3 for subway and suburban trains. The low passenger capacities maybe not reach to PC1 for these trains. Therefore, in order to save energy, the fresh air volume of air-conditioning system could be adjusted according to the actual amount of passengers in vehicle.

The fresh air volume of air conditioning is not only related to passenger comfort but also to the power supply capacity and energy saving of the power grid. All of these factors should be taken into accounted during air conditioning design period for railway vehicles.

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