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A study of fresh air control in subway stations

Yue Zhang [a], Xiaofeng Li [a,b,*]

[a] Department of Building Science, School of Architecture, Tsinghua University, Beijing, 100084, China
[b] Beijing Key Laboratory of Indoor Air Quality Evaluation and Control, Beijing, 100084, China

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ABSTRACT

This paper examines the energy consumption problems in the subway station Ventilation and Air-Conditioning (VAC) systems in a typical city, as well as identifying the fresh air-cooling load reduction as a key to energy savings. The two components of the fresh air in the stations, which are "mechanical fresh air" provided by VAC system and "unorganized fresh air" generated by piston effect, are analysed through network simulations and field measurements. The results indicate that the unorganized fresh air is sufficient to meet the demand, except for high-traffic times in the future phase. Based on the discussion, the current VAC systems in most part of China cannot sufficiently control the volume of mechanical fresh air. Accordingly, an improved system with the completely sealed fresh air damper and a matched fresh air controlling method is proposed, and the method is verified by field tests. The study informs the readers about the ways to achieve energy saving in subway stations through the control effective usage of the fresh air.

1. Introduction

The subway, as a comfortable and quick method of the transportation, is widely used in the cities throughout the world (Ampofo et al., 2004). With the large population and rapid economic development, The subway lines are sharply expanding in China. As of 2016, 32 cities have established or were currently constructing subways with the total number of 2630 and a total length of 3849 km (Liu et al., 2017). Typically, the construction of the subway lines is accompanied by huge energy consumption. In 2014, the energy consumption of the urban rail transit reached 9400 million kWh, which is 0.17% of the total energy consumption of China (China urban rail transit association, 2014). Thus, a study that investigates the energy-saving approaches is fundamental to guarantee the sustainable development of the subway stations.

In order to provide a safety and comfortable environment, hreating ventilation and air-conditioning (HVAC) system is widely used in subway (Teodosiu et al., 2016). In subway stations in most parts of China, the heating requirement is not met for a whole year, so the HVAC system changes to the VAC system in subway stations. Numerous researches have verified that the VAC system consumes a large part of the total energy usage in subway stations. DING (Da-yong et al., 2008) simulated the VAC system of a station which resulted in a huge amount of energy consumption, especially during the primary stage service. González-Gil (González-Gil et al., 2014) investigated the energy consumption in subway stations; he concluded that approximately 20% of the network energy was employed for the electricity consumption of the auxiliary system. Yang, Su et al. (Yang et al., 2015) found that the VAC system takes big part of the total energy consumption, thus they came up with an innovative environmental control system of subway to save energy. Therefore, the energy savings in the VAC system are of great importance.

There is a variety of energy saving approaches in the Heating Ventilation and Air-Conditioning (HVAC) systems, which can be summarized in two ways: one is to improve the efficiency of the devices or the reduction of the cooling loads; the other is to reduce the cooling loads. A number of Studies on the different kinds of buildings have demonstrated that the fresh air-cooling load possesses the largest energy saving potential. Mathis, Paul, et al. (Mathis et al., 2017) presented a new concept of ventilation: reducing air change rate to achieve energy saving in shopping centers. Although the key to reduce the annual HVAC energy consumption is to reduce the fresh air volume, this reduction is not easy to reach in the subway stations to that of the shopping center. Yang Le Le (2017) conducted the field measurements of the VAC system in typical subway stations in cities of China. The results present that the excess fresh air-cooling load is the main reason for high energy consumption of the VAC system. However, there remains a gap to fill with regards to the detailed and quantitative analysis of the fresh air in subway stations.

The fresh air supply of the subway stations divided into two parts: the unorganized fresh air generated by the piston effect and the fresh air

* Corresponding author. Department of Building Science, School of Architecture, Tsinghua University, Beijing, 100084, China.
E-mail address: xfli@mail.tsinghua.edu.cn (X. Li).

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provided by the VAC system. The piston effect is the forced-air flow inside or outside of the tunnel caused by moving trains, which is pronounced in subway tunnels (Cross et al., 2017) (Xue et al., 2014) (Chen et al., 1998) (Gerhardt and Krüger, 1998). Zhang, Zhu et al. (Zhang et al., 2017) built a theoretical model of unsteady piston effect, and validated the model by both CFD simulation and experimental data. Juraeva, Lee et al. (Juraeva et al., 2011) conducted computational analysis for the improvement of the tunnel ventilation, the simulation analysis helped to find better installation locations for the air-curtain to make the best use of piston wind. Gonzalez (González et al., 2014) Lin (Lin et al., 2008) and Ke (Ke et al., 2002) examined the factors that influence the Piston effect; however, these researches failed to provide the specific data or a method to estimate the fresh air volume. Thus, the unorganized fresh air considers unreliable, and the fresh air requirements are guaranteed by the VAC system in most of the design schemes.

The subway station is equipped with the environmental control systems, which are classified into three basic types: open, closed and Platform Screen Door (PSD) systems. In most cities in the southern China, the PSD system is used. Generally, the northern parts of China only need ventilation, the middle parts use a non-platform screen door system, and in the big cities of southern China, PSD system is widely applied. .

This paper concentrates on the reduction of the excess fresh air-cooling load, which has the most potential for energy savings in subway stations. First, the unorganized fresh air in a typical city -Wuxi-is studied by simulation and field tests. The VAC system type in this city is the PSD system. Second, the specific demand of the mechanical fresh air supply can be determined by checking the volume of unorganized fresh air. Furthermore, the paper explores the fresh air control capability of the VAC system and presents an improved form of the VAC system with fresh air damper sealed to provide the good control of the fresh air. The case study is representative of the PSD system with the similar applied rules The paper provides a systematic analysis for the fresh air in subway station and the problem of the VAC system, then proposes a practical approach to reduce the excess fresh air. As a result, the energy savings are achieved in subway stations.

2. Case study- analysis of unorganized fresh air

2.1. Simulation analysis

Driven by piston effect, the unorganized fresh air comes from the outdoors through the passage tunnels. The unorganized fresh air is simulated by network simulation method using Universal Subway Thermal Environment Simulation Software (STESS). STESS is developed by Tsinghua University in 1980s, which is capable of simulating the underground airflow and the heat transfer process in subways. The software possesses two main functions: one is the airflow simulation; the second is the heat transfer simulation. In the airflow simulation, the software applied an improved MKP algorithm to solve the unsteady network problems, which guarantees the ability to solve the complex subway network and speed up the calculation (Wang and Li, 2017a). MKP is a mature algorithm to solve the steady network problems (Zhu, 1989). In comparison with the widely used software SES (USA and D.o., 1997), STESS has the same simulation results in the aspect of the airflow simulation. However, STESS also has a limitation which is the lack of simulation ability when fans are situated in the tunnel.

This paper uses Wuxi-Metro line2 to build the simulation model. Wuxi city is located in Jiangsu Province in the southern part of China. The geometry of the subway tunnel and the station is on the basis of facts. Fig. 1 illustrates the schematic diagram of the simulation model. The simulation method is verified in a former study (Wang and Li, 2017b). In this model, the resistance of a branch is calculated according to the empirical values claimed in the studies (Porges, 1991), where each branch is divided into components such as sudden contraction, sudden expansion, elbow and so on. According to the field tests in Ying 's study (Wang and Li, 2017b), the resistance of the PSD ranges from 0.11 to 0.35 $Pa/(m^3/s^2)$, so the simulation model adopts the average level of 0.23 $Pa/(m^3/s^2)$.

Except for the geometry of the subway line and the resistance of the entries in the model, other input parameters are the movement details of the trains. In the simulation, the movement characters of the train are summarized with "train departure density" and "traction curve" of the train. The train departure density refers to the number of trains that depart in an hour, which presents the density of travelling trains. As passenger flow increases in future phase, it usually leads to rise in the train departure density. The train departure density used in the model in both recent and future phases are given in Table 1.

The unorganized fresh air belongs to the outdoor air which is capable to dilute the CO_2 concentration. Hence, the unorganized fresh air can be regarded as a source of the fresh air supply to meet the demand of the passengers. The minimum fresh air level is 12.6 m^3/h per person. In the meantime, the CO_2 concentration cannot exceed 1500 ppm (Ministry of Construction. GB50157–G52003, 2003) (Ministry of Construction. GB9672–1996, 1996). The fresh air demand can be calculated by 12.6 m^3/h per person, multiplied by the passenger flow. Thus, the passenger flow determines the fresh air demand. In the recent phase, the passenger flow is obtained by the measurements. In the future phase, the passenger flow is obtained from the design data; the peak of passenger flow in the design handbook is decided by the local population features as well as the investigation of the existing subway lines and passenger flow. Table 1 shows the passenger flows to calculate the fresh air demand, in both recent and future phases.

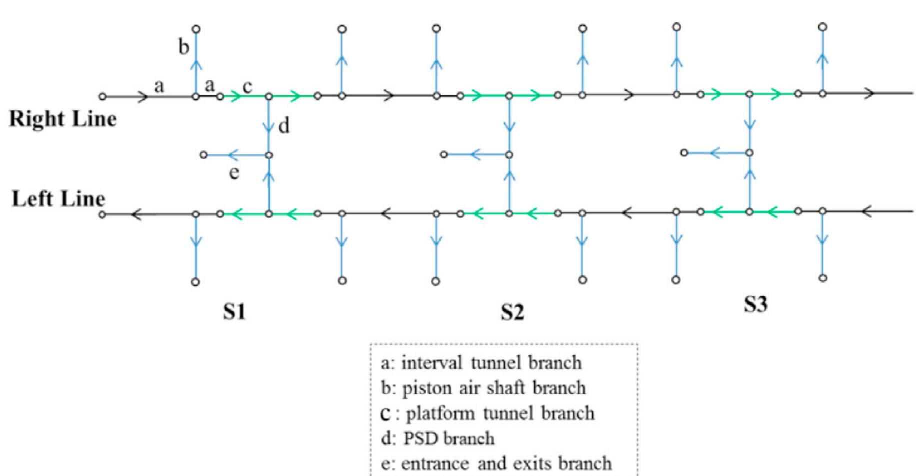

Fig. 1. Simulation model of the subway system.