Building and Environment 126 (2017) 68–81

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Energy performance investigation of an innovative environmental control system in subway station

Huan Zhang [a, b], Tong Cui [a, b], Minzhang Liu [a, b], Wandong Zheng [a, *], Chunguang Zhu [a, b, **], Shijun You [a, b], Yazhuo Zhang [b]

[a] School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, PR China
[b] National Engineering Laboratory for Digital Construction and Evaluation Technology of Urban Rail Transit, Tianjin 300072, PR China

ARTICLE INFO

Article history:
Received 14 July 2017
Received in revised form
15 September 2017
Accepted 18 September 2017
Available online 20 September 2017

Keywords:
Environmental control system
Subway
Piston effect
Platform door
Energy performance

ABSTRACT

More than 70% of the non-traction energy consumption is attributable to environmental control system in subway stations, in which ventilation system accounts for the largest portion. Energy savings will be affected significantly if the environmental control system can be improved effectively. This paper proposed an innovative environment control system. The system features an innovative platform door with controllable vents, aiming to improve the energy performance and thermal environment in subway station. This study used on-site experimental data and numerical simulations to analyze the thermal environment of the station for optimizing the controllable vents of innovative platform doors including position, size and open angle. Moreover, the operation control strategy for the innovative environmental control system was put forward. The energy performance of the innovative environmental control system was discussed for the five cities, which represent five climate zones of China. The results showed the innovative environmental control system could satisfy the requirements of thermal comfort. Compared with the traditional platform screen doors system, the energy consumption could be reduced by 20.64%–60.43%.

1. Introduction

With the rapid development of urban rail transit, subway has become the backbone of urban public transportation. By the end of 2016, 32 cities have been served by underground railway in China. Because of its high capacity of transportation, subway consumes a large amount of energy [1]. In particular, the energy consumption for non-traction requirements is of the same magnitude as the energy used to move rolling stock [2]. Environmental control system in subway stations is responsible for delivering healthy and comfortable indoor conditions such as air temperature, humidity and velocity. Some studies revealed the environmental control system presents more than 70% of the whole energy consumption for non-traction purposes, in which the ventilation devices contribute over 75% [3,4]. Therefore, the optimization for environmental control system of subway stations would imply a great potential of energy saving.

A lot of research about environmental control system has been done on the active approach to optimize the ventilation and air-conditioning system. Fukuyo [5] studied the task-ambient air-conditioning systems, which can improve thermal comfort and decreased air-conditioning loads. Yang et al. [6] analyzed the efforts of ventilation and air-conditioning system with frequency conversion technology on the energy-saving potential of subway system. Some studies [7,8] focused on the optimization of ventilation system for indoor air quality control and the minimization of energy demand in subway station. Wang et al. [9] conducted field tests and developed autonomous HVAC control systems to help reduce the energy consumption in Beijing subway stations.

On the other hand, a significant amount of research focused on the passive approach to achieve the energy-saving effects in subway stations. When a train moves through a tunnel, it induces a strong air flow due to the rapid displacement of the train in the tunnel. The phenomenon is called piston effect [10,11]. Several analyses [12,13] were made on optimizing the environmental control system in tunnels by the piston effect. Some studies [14–16] used the numerical simulation to analyze the piston wind on the environment

* Corresponding author.
** Corresponding author. School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, PR China.
E-mail addresses: wdzheng@tju.edu.cn (W. Zheng), zhucg@tju.edu.cn (C. Zhu).

https://doi.org/10.1016/j.buildenv.2017.09.023

Nomenclature

u_i	The velocity component in i direction (m/s)
xi	The coordinate component in i direction (m)
t	The time (s)
ρ	The molecular density (kg/m^3)
k	The molecular conductivity (−)
k_t	The thermal conductivity caused by turbulent diffusion (−)
p	The static pressure (pa)
η_t	The turbulence viscosity coefficient (pa·s)
h	Sensible enthalpy (−)
ε	Dissipation rate of turbulent kinetic energy (−)
E_i	The experimental value (−)
S_i	The simulation value (−)
$\bar{E}$	The average value of experiment (−)
$\bar{S}$	The average value of simulation (−)
V_t	The instantaneous air volume from the outside into the station (m^3/s)
V	The air volume from the outside into the station (m3)
c	The constant-pressure specific heat of air (kJ/kg·K)
q_t	The instantaneous braking energy into the station (kW)
Q	The braking energy into the station per train (kJ)
V_i	The instantaneous volume of the piston wind flow into the platform on the train side (m^3/s)
V_d	The instantaneous volume of the piston wind flow out of the platform on the non-train side (m^3/s)
V_o	The instantaneous volume of the piston wind flow out of the exits (m^3/s)
t_i	The air temperature of the piston wind flow into the platform on the train side (°C)
t_d	The air temperature of the piston wind flow out of the platform on the non-train side (°C)
t_o	The air temperature of the piston wind flow out of the exits (°C)
Q_l	The cooling energy from the outdoor fresh air (kJ)
T_o	The outdoor air temperature (°C)
T_n	The air temperature in the station (°C)
Q_o	The load of the station (kW)
t_0	The time interval between the trains (s)
T_s	The temperature of the supply air (°C)
V_r	The instantaneous volume of the piston wind flow into the exits (m^3/s)

of subway station. The results showed the piston effect has a significant influence on natural air ventilation in subway. Nowadays, platform doors are installed commonly in subway stations for securing the safety of passengers. Platform bailout doors (PBD) leave an area to connect the platform and tunnels, so the piston wind can flow into the platform. Hu et al. [17] presented the energy consumption of the environmental control system with PBD can be reduced by piston effect in non-air-conditioning seasons. However, the braking energy generated in the tunnel track will enter the platform with the piston wind, which results in the extra energy consumption in air-conditioning seasons. In contrast, platform screen doors (PSD) separate the platform from the tunnel completely, so the piston wind cannot flow into the station and the braking energy is kept away from entering the platform [18–20]. Thus, installing PSD has significant advantage of reducing the cooling load in air-conditioning seasons but it can increase the energy consumption on mechanical ventilation in non-conditioning seasons.

An innovative environmental control system featuring an innovative door with controllable vents was proposed in order to combine the advantages of PSD and PBD systems. Fig. 1 schematically shows the innovative environmental control system at platform level. The innovative system consists of the innovative platform door system, ventilation system and air conditioning system. Through the coordination between the controllable vents and the HVAC devices, the innovative system can be switched in different operation modes. With the controllable vents closed in air-conditioning seasons, the environmental control system operates as the traditional PSD system. The fresh air fan (FAF) brings in the outdoor fresh air to mix with the return air from the return air fan (RAF), and the air is finally supplied to the station by the AHU fan [21]. In this circumstance, the environmental control system only serves for the public area of the station, so it is helpful to reduce the cooling load from the tunnel. With the controllable vents open in non-air-conditioning seasons, the environmental control system operates as the PBD system, and it can take fully use of the piston effect to ventilate and remove the heat of the station. If the outdoor climate is allowed, all the ventilation devices will be turned off. When the cooling energy from outside cannot balance the heat of the station, the RAF and the AHU are open. It has a significant influence on energy savings of mechanical ventilation system. However, the available information on the innovative environment control system is limited. Yang et al. [22] created a numerical model of the environmental control system with controllable vents and put up a control scheme to analyze the energy saving effect in eight cities, but the optimization of the controllable vents such as position, size and open angle has not been systematically studied yet. As a result, the potential of energy savings has not been fully explored. At present, only one subway station (Yunjinlu station, Shanghai) practically adopted the innovative environmental control system in China. Therefore, research and analysis are required on the applicability of the innovative environmental control system.

This paper focused on the innovative environmental control system, aiming to improve the energy performance in subway stations. A three-dimensional full-scaled geometrical model of a subway station was created based on Taiyuanjie (TYJ) station. The process of train arrival and departure was simulated by the dynamic mesh method. The simulation results were validated with the experimental data. Then the validated model was used to analyze the thermal performance of the station for optimizing the controllable vents of innovative platform doors including position, size and open angle. In addition, this study proposed an operation control scheme for the innovative environmental control system. The energy performance of the innovative environmental control system was analyzed for the five cities from different climate zones.

2. Modeling and experimental validation

2.1. Numerical method

A full-scaled geometrical model of a subway station is built in this paper, based on a typical subway station in China - Taiyuanjie (TYJ) station. TYJ station, which is located in the middle of Shenyang subway line 1, represents a typical subway station adopting the PBD system. Fig. 2 shows the model of TYJ station.