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Study on the thermal comfort characteristics under the vent with supplying air jets and cross-flows coupling in subway stations

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ABSTRACT

The coupling air organizations between supplying air jets and platform piston winds prevail on the platforms of the subway stations without platform screen doors (PSD) all over the world. The thermal comfort characteristics under the vent are studied in this paper. Firstly, the coupling mechanism of these two airflows is described based on the cross-flow theory. Secondly, Relative Warmth Index (RWI) is selected to evaluate human thermal comfort level with dynamic coupling airflows in the transitional areas. Calculated by the RWI theory model, it can be concluded that air velocities can be enhanced to compensate the supplying air temperature increasing without affecting human thermal sensations with RWI within 0-0.15. Thirdly, experimental studies are carried out and it can be seen that the average RWI values of vertical points under the vent increase from [−0.29, −0.03] in uncoupled conditions to [0.23, 0.14] in coupling conditions, leading to human thermal sensations greatly improved. The experimental RWI values of horizontal points move into the comfort zone a lot under coupling airflows conditions, compared with the uncoupled conditions. In conclusion, the coupling airflows of supplying air jets and cross-flows can improve the transitional thermal comfort and bring forward huge energy-saving potential in air-conditioning systems by allowing the supplying air temperature to be increased in transitional subway stations.

1. Introduction

In the subway stations without platform screen doors (PSD), the piston winds, aroused in the tunnel, will influence the platform thermal environment dynamically and intermittently, corresponding to trains' operation. These dynamic, intermittent and periodic coupling airflows between air-conditioning supplying air jets and platform piston winds below the vents form the most typical air organizations in the subway stations without PSD in large and medium cities all over the world. Moreover, subway platforms belong to the transitional areas since the total standing time of a person in subway stations is about 2–5 min as persons walking from the outside, entrance, station hall, stairs, platform and trains in turn. Therefore, how to evaluate the thermal comfort level under those dynamic coupling airflows is the key issue of the subway environment design and operating in terms of thermal comfort and energy conservation, which will be studied in this paper.

The influence of the dynamic platform piston winds leads to the velocity and temperature surrounding the persons varying with time on platforms. For the past decades, lots of studies of dynamic thermal comfort focused on the airflow characteristics. Ahmet [1] designed a human subject test to study the cooling effectiveness of dynamic airflow condition, indicating that most subjects were either satisfied with the increased airflow speeds or preferred more airflow. Zhao's group [2] developed two types of air supplying devices, rotating desk [3] and swing plate [4], intending to use fluctuating air movement to serve a transient thermal environment for acceptable thermal comfort and energy conservation. Candido [5] conducted a field experiment involving 2075 respondents to identify air movement acceptability levels inside naturally ventilated buildings in Brazil. The results showed that subjects not only preferred more air movement, but also demanded air velocities that were close to (and sometimes greater than) the upper limit of the velocity recommended by ASHRAE. Yu [6] compared the demands for indoor air movement in Copenhagen and Beijing and showed

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that both Danish and Chinese subjects tended to choose relatively high air velocities to remain thermally neutral if they were in a warm environment. Based on the experiment study, Arens et al. [7] proposed that the personally controlled air movement provides a likely alternative to mechanical air conditioning within a certain velocity zone. Zhai [8] designed an experiment to examine the effect of air movement on human thermal comfort, and illustrated that, with certain air movement, it was possible to maintain thermal comfort, even the air state were up to 30 °C and 60% relative humidity. These studies built up the relationship between dynamic airflows and human thermal comfort, providing valuable references for the research work reported in this paper. However the thermal comfort characteristics under dynamic airflows have not been focused on the transitional areas, such as the subway platforms.

The thermal comfort demand in subway is different from that in the stable thermal environment. Owing to massive air volume exchanges induced by the train piston-effect, subway environments are highly transient and non-uniform [9]. It has been reported that higher air velocities may be appropriate in the case of a warm station to meet the transient thermal comfort demand [10]. By field study in six subway stations in three seasons, the recommended comfort range is 15.9–31.5 SET* °C for the platform, which was a wider range than those reported in previous studies [11]. Taking RWI as the thermal comfort index, Wang [12] compared and analyzed the designing temperature standard among the subway stations between domestic and abroad. The designing temperature 29 °C and 28 °C in station hall and platform, respectively, were proposed in Chengdu city, China. Xu [13] monitored the thermal environment in a railway station on site and found that RWI was much more suitable to describe the persons' thermal sensations in this transitional environment, compared with PMV. These studies pointed out the environmental characteristics and thermal comfort demand in subway station. However, the influences of the coupling airflows of supplying air jets and cross-flows on the thermal comfort have not been studieds in subway stations without PSDS.

This paper aims to study the dynamic thermal comfort characteristics below the vent with supplying air jets and cross-flows coupling so as to provide references for optimizing the environment design and operation in subway stations. The correlative three parts studies are carried out in the following.

Firstly, taking the platform piston wind as the cross-flow, its dynamic velocity distributions are theoretically introduced to support the following experiment setup. Furthermore, the coupling mechanism of platform piston winds and supplying air jets are analyzed theoretically for the first time, based on the cross-flows theory. The deflection process of the coupling trajectories is the key factor inducing the thermal comfort sensations variation. Thus, these mechanism studies grasp the root properties of coupling airflows and provide the essential foundations for the following RWI selection and experimental study.

Secondly, RWI, as the thermal comfort index, is selected to reflect the thermal comfort sensations with the two coupling airflows below the vent, providing an important gripper in the following experimental study. Furthermore, the deflection of the coupling trajectory in mechanism study brings forward the obvious variations of the velocity and temperature of the typical points below the vent. Therefore, the theoretical deduction of RWI values varied with velocity and temperature are developed in this part to assist the following experimental results analysis.

Thirdly, based on the mechanism analysis, the experiments are carried out focusing on the RWI variation of the sampling points in vertical and horizontal directions below the vent during two airflows coupling process. The experimental results are analyzed in view of the mechanical model and RWI theoretical deduction.

2. Coupling mechanisms of two airflows below vents

The following coupling mechanisms between platform piston winds and supplying air jets below the vent provide some guidance for thermal comfort index selection and further experimental study. The dynamic velocity distributions of platform piston winds lead to the different thermal environment below the various vents. Both of them are analyzed in the following.

2.1. Distributions and variations of platform piston winds

The thermal comfort below the vent is the study focus. Usually, there are about 30 air supply vents in a standard subway platform. The distributions of platform piston winds on the overall platform influence the thermal environment under the various vents in different positions. Theoretically, the platform piston wind is regarded as a wall jet with the tunnel piston wind at the tunnel exit as its origin. Schematic of the platform piston wind wall jet is shown in Fig. 1 (The tunnel piston wind variation characteristics are demonstrated in literature [14]). Where, u_0 is the piston wind velocity at the tunnel exit in m/s and b_0 is the tunnel width in m. According to the classical wall jet theory [15], the platform piston wind can be approximately divided into the initial and the main sections in the developing process along the platform length direction. Furthermore, along the platform width direction, the initial section can be divided into a free shear zone, a potential flow core area and a boundary layer, while the main section is composed of a free shear zone and a boundary layer [16]. The velocity values in different sections and zones vary dramatically. Thus it can be concluded that the velocity values range of the platform piston wind vary obviously below the various vents according to their positions.

Simultaneously, the velocities variation trends with time of platform piston winds below vents are similar. Fig. 2 [16] shows the velocity variation of point 1 during train-in process based on the

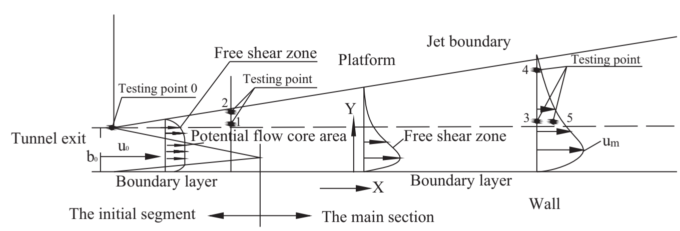

Fig. 1. Schematic of the platform piston wind wall jet theory.

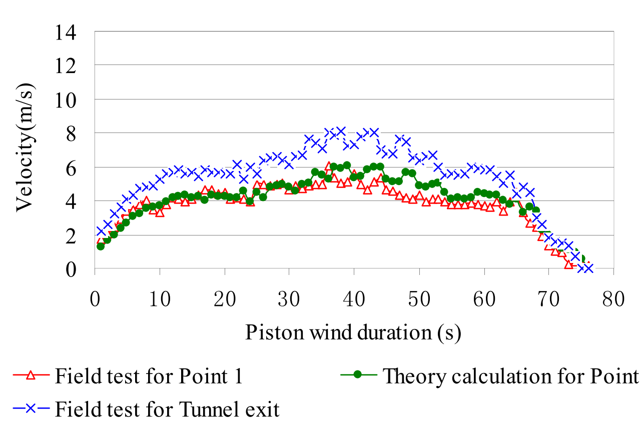

Fig. 2. Platform piston wind velocities of Point 1 in field measurement and theoretical calculation.