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Analysis and Research on the Thermal Environment of Subway Stations in Wuhan

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Abstract: With the rapid advancement of urban construction, urban subway construction in China has entered an advanced development stage and the thermal environment of subway stations has become a key factor affecting passengers' thermal comfort. To further understand the actual situation of the thermal environment of subway stations, field measurement and CFD simulation were carried out on a subway station hall in Wuhan from July to August 2021, and the thermal environment changes and influencing factors during subway operation were compared and analyzed. The present situation of the thermal environment in subway stations was analyzed, and some suggestions and measures for improving the thermal environment were put forward.

Keywords: Urban subway; Operating period; Thermal environment; Status analysis; Countermeasures and suggestions

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1. Introduction

Subway has become one of the main means of public transport. As of August 2015, 24 cities in China have opened subways, among which 14 lines have been opened in Shanghai Metro, with a mileage of 567 kilometers, followed by Beijing Metro with a mileage of 527 kilometers. It was forecasted that by 2020, 40 cities across the country will build subways, with a total planned mileage of 7,000 kilometers. According to the US Environmental Protection Agency (EPA) 1993–1994 tracking survey data of nearly 10,000 people, people spend an average of 7.2% of their time in the subway [1-3].

With the rapid development of urban construction, urban subway projects have entered a vigorous development stage [4]. While urban rail transit brings convenience, it also has a high consumption of electric energy. In our country, the energy consumption of the metro-environmental control system in southern cities accounts for about 1/2 of the total energy consumption, while the energy consumption of the metro-environmental control system in northern cities accounts for about 1/3 of the total energy consumption [5]. Subways (underground stations and sections) are wrapped in soil, and only the entrance and exit passages and piston air wells are connected with the above-ground atmosphere. The thermal environment and air quality of subway stations are common concerns and urgent problems to be addressed in subway construction and operation. Regarding thermal transport environment of subways, "Metro Design Code" GB 50157-2013 stipulates [6-9]: the temperature of station hall and platform public area should not be lower than 12 ℃ in winter, and the temperature of station hall and platform public area should not exceed 30 ℃ in summer, with relative humidity of 40%-70% and CO_2 concentration of less than 1500 ppm;

While much conveniences have been brought by subways, it also leads to higher requirements for comfort in subway environments [10-14]. At present, the research on subway environment by domestic and foreign scholar mainly focuses on air quality. He Shengquan et al. studied the variation of $PM_{2.5}$ and PM_{10} concentrations in the air of platforms and carriages of Beijing Metro with time [15]. Scholars such as Aarnio, Cheng and Mugica monitored the concentration of respirable particulate matter in subway stations in Finland, Mexico and Taipei, China, respectively [16-18]. Some scholars have studied the thermal environment in subway stations or carriages. Wang Shugang et al. [10] have conducted long-term field tests on Shanghai and Beijing subways and conducted in-depth theoretical analysis, which has enabled domestic scholars to have a deeper theoretical and practical understanding of train heat dissipation, station temperature and flow field distribution. Wang Lihui et al. [19] tested and studied the piston wind in the tunnel and the temperature field and velocity field of the station hall platform of Shanghai Metro and recorded the change in platform temperature and station hall temperature. Ming-Tsun Ke et al. [20] studied and analyzed the thermal environment of Taipei, China subways under different working conditions by combining Subway Environmental Simulation Program (SES) and computational fluid dynamics (CFD), and found that the exhaust under the platform plate has great influence on the platform temperature field. Although many researches have been carried out on thermal environment, there is still a lack of in-depth analysis of various indicators of subway thermal environment and thermal environment in different regions.

In this study, a station hall of Wuhan Metro Line 2 was monitored and simulated on the spot, and the thermal environment status of the station hall was analyzed in depth during its operation period, and further suggestions and measures were put forward to improve the thermal environment of the subway, so as to meet the comfort needs of subway users and promote the healthy development of the urban subway environment.

2. Methods

2.1. Subway thermal environment monitoring

The subway station is located in a large station of Wuhan Metro Line 2 in Hubei Province. The station is divided into two underground floors: the first underground floor is the station hall floor, and the second underground floor is the platform floor. This study mainly monitored the data of station hall floor. Two monitoring points were set up on the station hall floor, respectively at both ends of the station hall. The distribution of instruments and equipment is shown in the **Figure 1**.

(a) (b)

Figure 1. The placement of instruments for measure the thermal environment of subway station

The monitoring instrument used in this study is shown in **Table 1**, which is composed of multiple sensors to measure air temperature, wind speed, noise, humidity and illumination. Temperature, humidity and illumination were recorded once every 10 minutes, while wind speed and noise were recorded once every minute. The collected information will be uploaded to the cloud platform and stored, which can be viewed and downloaded at any time. The device was placed at a pedestrian height of 1.2 m, At the same time, the site was connected to an external 220V power supply. The measurement period is from July 15, 2021 to August 10, 2021.

Table 1 Monitoring instruments for metro thermal environment

Instrument	**Measuring range**	**Measurement accuracy**	**Equipment size**	**Work environment**	**Picture**
Noise detector (noise0501)	30db-120db	±0.5db	8*5*12cm	Air temperature: -40％~+60％ Relative humidity: 25％~90％ Static pressure: 65kpa~106kpa	 
Wind speed detector(wind0501)	0.2m/s-10m/s	±0.02m/s	8*5*12cm	-10℃~+50℃	
Air temperature/ Humidity detector/ Illuminance detector	Air temperature: -10℃~+85℃ Humidity: -40℃~+125℃ Illumination: 0~65535lux	Humidity: ±0.3℃，±2％ RH Black ball: ±0.5℃	12*8*6cm		 
Equipment integration			47*33*73cm		

2.2. Model establishment and boundary condition setting

The spatial three-dimensional model of subway station mainly uses the platform, station hall plan (as shown in **Figures 2** and **3**) and section to obtain specific information related to buildings. The simulated area of station hall floor was 143.7 m long, 19.4 m wide and 3.2 m high, while the simulated area of platform floor was 109.5 m long, 9.8 m wide and 3.2 m high. ICEM CFD 18.2 software was used to create the model, and the completed three-dimensional model is shown in **Figure 2**.

Because of the complex structure of the three-dimensional geometric model of subway station, the unstructured grid was adopted, and the unstructured grid has better adaptability to irregular areas. The grid is partially encrypted using the part functionality in ICEM, resulting in 6.78 million grids, as shown in **Figure 3**.

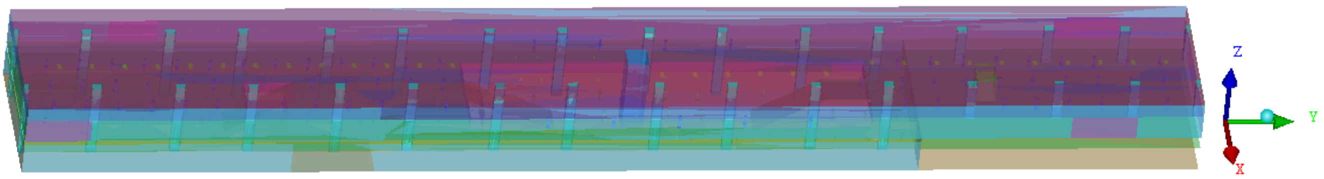


Figure 2. 3D model of subway station

Figure 3. 678w grid of subway station

3. Results

3.1. Trend analysis of temperature at each measuring point during operation period

The data was collected from 0:00 on July 28, 2021 to 23:50 on August 15, 2021, including the air temperature changes of two test points in the subway station during working, rest and outage respectively. During the investigation, a temperature acquisition sensor was used to continuously collect the air temperature data at two acquisition points, and the data acquisition interval was uploaded every 10 minutes, with a total of 5472 data collected (including 2736 data at each acquisition point).

Table 2. A1, A2 point air temperature description

	A1 point air temperature (℃)	**A2 point air temperature (℃)**
Mean	27.09	27.92
Median	27.14	28.19
Max	32.47	32.11
Min	23.85	23.38

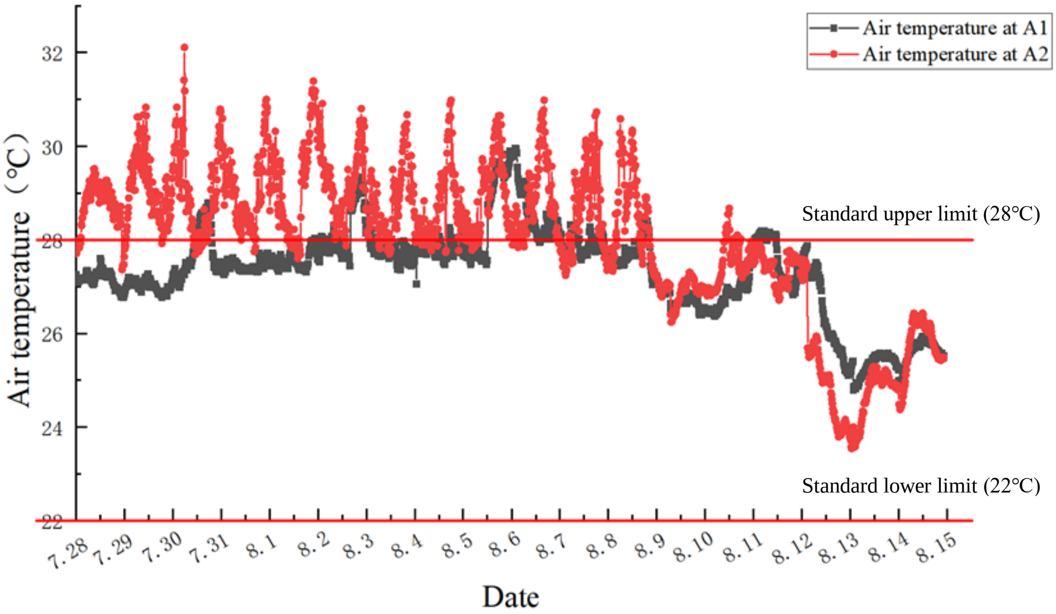
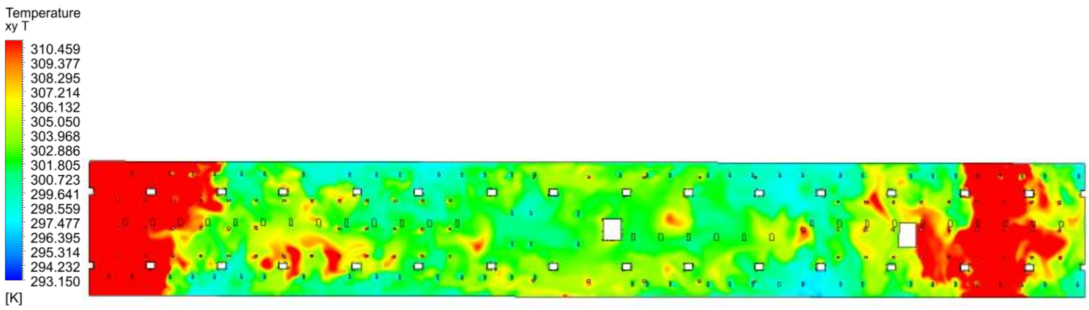


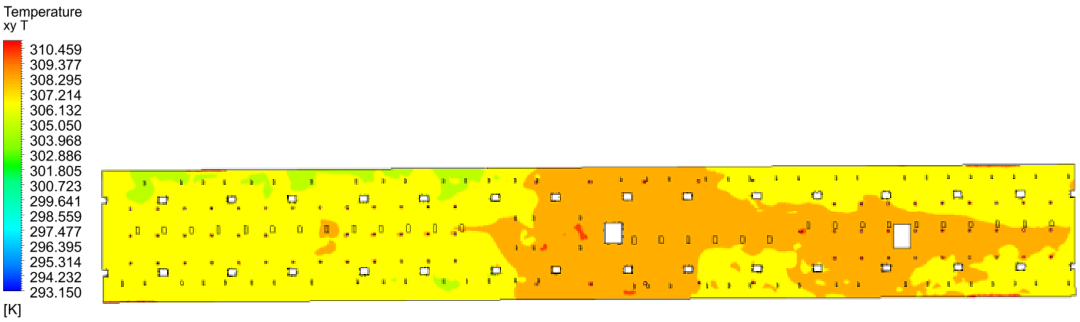
Figure 4. Scattered line chart of air temperature at each point in working days

Figure 4 shows the air temperature distribution at points A1 and A2 during the working day of the measurement stage. It can be seen that the overall distribution trend of the two curves is similar, and the data of both points fluctuate between 23–33 ℃. Before August 11th, the air temperature at A2 was higher than that at A1. The peak value of air temperature at point A1 is 29.95 ℃ (16:20 on August 5th), and the peak value of air temperature change at point A2 is 32.11 ℃ (12:10 on July 30th). The average air temperature at point A1 and A2 is 27.05 ℃ and 28.09 ℃, respectively. However, because the subway is located in an underground semi-open space, the air temperature fluctuates according to the change of weather (sunny days and rainy days). By consulting the local weather forecast, it was found that the outdoor weather on August 8–10, and August 12 and 13 was mostly cloudy or light rain, which leads to an obvious downward trend of air temperature distribution. The valley values of air temperature change at A1 and A2 points appeared at 21:00 (25.10 ℃) and 23:40 (23.53 ℃) on August 13th, respectively. The average variation ranges of A1 and A2 were 8.62 and 8.58 ℃, respectively. On July 28th to August 7th, the peaks and troughs of air temperature changed repeatedly throughout the day. From 6:00 to 19:00, the rail transit operation was relatively stable, and so the outside temperature tends to be stable.

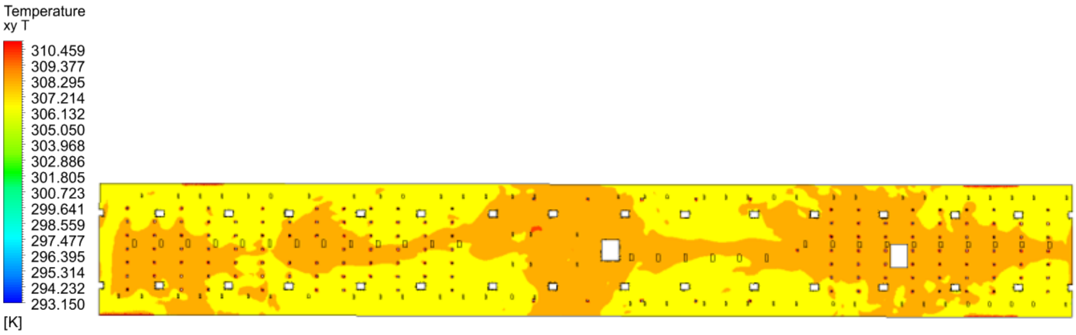
3.2. Subway station environment simulation results



(a)



(b)



(c)

Figure 5. (a) Temperature field Z = 6 m for 75 unstabilized simple human bodies in each layer (b) Temperature field Z = 6 m for 75 stable simple human bodies in each layer (c) Temperature field Z = 6m for 150 stable simple human bodies in each layer

As shown in **Figure 5**, the temperature field of horizontal section with height Z = 6m is shown. The platform floor is 4.8 m high, so Z = 6 m is the position of 1.2 m high in the station hall floor. As can be seen from **Figure 5** (a): the temperature on the left and right sides of the region; is higher because there are four sections of entrance and exit passages, which are located at the four corners of the model, and the infiltrated air-cooling load brought by it causes such a temperature field. In **Figure 5** (b), the calorific value of the entrance and exit sections was evenly released into the air, increasing the overall temperature field level. The temperature of the atrium remains at a high level like (a), and the temperature of the right half of the atrium drops slightly due to the air supply temperature of the nozzle. In **Figure 5** (c), due to the increase of human body, compared to (b), there were some higher temperature areas on the left and right sides of the temperature field.

4. Conclusion

Urban subway construction is an important process of urban spatial evolution, which can guide urban space from independent space to multi-core network development, promote the integration of different types of urban space, and improve the spatial vitality of the old city. Urban transportation network with subway as the core is an important driving force for urban spatial evolution. Therefore, in the process of urban space development, a rational layout of urban subway will have a positive effect on urban space development. Therefore, a comprehensive monitoring system for the thermal environment of rail transit tunnels needs to be established as well as a corresponding database, and more data need to be collected, so as to provide sufficient data reserves for forming a complete theory of thermal environment change trend in rail transit tunnels.

Disclosure statement

The authors declare no conflict of interest.

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