Electronics, Communications and Networks
A.J. Tallón-Ballesteros et al. (Eds.)

doi:10.3233/FAIA231170

Measurement of Winter Air Infiltration and Its Impact on Energy Consumption in the Transportation Hub's Transfer Hall

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Abstract: Due to the necessity of transfer, the outer door of the transportation hub's transfer hall is often kept open, resulting in significant cold air infiltration during the winter season, leading to increased heating energy consumption. This research utilized the air velocity measurement method, and air volume balance method to investigate the extent of cold air infiltration and indoor thermal comfort in a transportation hub transfer hall in Beijing during winter. The measured results indicated that during the winter test period, air permeability accounted for 57.6% of heat loss. Therefore, the cold air infiltration of the transfer hall in winter should be focused on.

Key words: transfer hall, air infiltration, field measurement, questionnaire survey, energy consumption

1. Introduction

Due to the dense passenger flow and transfer demand, the outer doors and channels of the transportation hub's transfer hall are usually in a normally open state. The open outer doors and skylights become the channels for outdoor air to directly penetrate or even penetrate [1, 2], which leads to complex air flow in large spaces, as well as a high proportion of building energy consumption (40-85%) in heating, ventilation and air conditioning systems [3-8]. According to the reference [9], the air permeability of the transportation hub in winter is significantly higher than that in summer and transition season. Therefore, measuring and analyzing the cold air permeability in the transfer hall of the transportation hub in winter is of great importance to evaluate and reduce its impact on energy consumption.

The commonly used methods for measuring air permeability mainly include fan supercharging method [10], wind speed measurement method [11, 12] and tracer gas method (SF_6, CO_2, etc.). In large space buildings, the accuracy of fan supercharging method is significantly affected by the uneven pressure distribution during measurement [13, 14]. The wind speed test method requires finding all airflow channels and multiplying the average wind speed by the effective cross-sectional area, which is the most direct way to measure air permeability. However, it is difficult to identify all air

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flow leaks in such a large space, and wind speed measurements must be verified by checking the balance of air volume between the entrance and exit or by comparing the results with other methods [15]. The tracer gas method is widely used in office and residential buildings and has a small error [16-20]. However, in tall spatial buildings such as transfer halls, it is difficult to store and release enough tracer gas to achieve a significant concentration difference between indoor and outdoor air.

From the above analysis, it can be seen that in buildings with large open Spaces and open doors, air infiltration is very common and serious, especially in winter. More attention should be paid to accurate measurement and analysis, but the current single measurement method has certain limitations. Therefore, this study adopts air velocity method and air volume balance method to measure and analyze air permeability and its impact on energy consumption, in order to determine effective strategies to reduce air permeability, so as to achieve building energy saving and thermal comfort.

2. Materials and Methods

2.1. Case Study

The study case is a comprehensive transportation hub building in Beijing (39°54 'N, 116°25' E), which is mainly a transfer hub for subway, above-ground public transportation and long-distance transport vehicles. With a total construction area of 90,381m^2 and an above-ground construction area of 519, 90 m^2, the building is divided into East Building, North Building and South Building according to different functions (Figure 1). Among them, the ground floor of the east building consists of transfer hall and waiting hall, with a height of 15.3m, which is a tall space. The transfer hall is the main research object of this paper. The transfer hall is equipped with floor radiant heating and air conditioning system as heating facilities in winter. Entrances to the outside of the transfer hall are North exit/Entrance a, South exit/entrance f, and bus transfer exit b-e (Figure 2). Due to frequent transfers, these exits are almost always open, even in winter when the outdoor temperature is lower (Figure 3). Since the outer door is always open, the air conditioning system and fresh air system of the transfer hall are closed throughout the winter, and the radiant floor heating system is in normal operation.

2.2. Method of Measuring

When the temperature difference between indoor and outdoor is large and the outdoor wind speed is low, the wind speed test method can be used to estimate the air permeability range of a large volume building [21]. The error source of wind speed test method is mainly instrument error [22]. For the wind speed test method, the air velocity is measured at the open outer door of the transfer hall (Figure 2), and the average value is obtained through multiple measurements. Calculate the amount of air permeability for the entire transfer hall from Eq. (1).

$$G_s = \sum_{i=1}^{n} A_i\, u_i \tag{1}$$

where G_s is the total permeability volume flow of the transfer hall; A_I is area for import and export; u_i is average air penetration velocity at all test locations in each airflow channel.

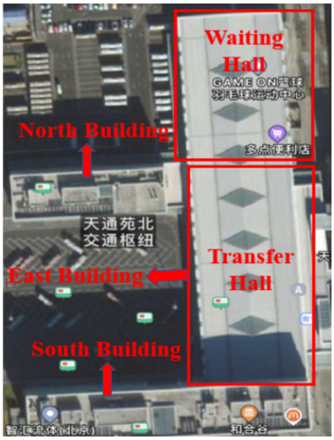


Figure 1. Top view of the transportation hub.

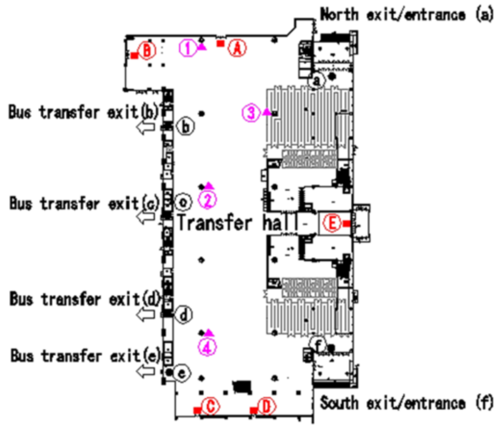


Figure 2. Plan of the transfer hall.

(a) North exit/entrance. (b) Bus transfer exit. (c) South exit/entrance.

Figure 3. Photo of some entrances and exits of the transfer hall.

It is difficult to identify all the leakage points in the large space, so the wind balance of the entrance and exit is examined in this paper to verify the correctness of the measured wind speed. The air volume of the space should meet the mass balance, as shown in Eq. (2).

$$G_s + G_K - G_P - G_N - G_L = 0 \tag{2}$$

where G_K is fresh air volume flow of the air conditioning system; G_P is exhaust system volume flow, m^3/h;G_N is infiltration volume flow at the interior door connected with transfer hall indoor, this value can be positive or negative; G_L is retaining structure or other pipe leakage air volume, m^3/h.

2.3. Measure Point Layout

The physical parameters measured are air temperature (Ta), air relative humidity (φ), CO_2 concentration (C), and air velocity (U). The measuring instruments and their accuracy are listed in Table 1. All indoor air sensors are not uniformly arranged according to the characteristics of the indoor environment in different areas. The plane arrangement of the indoor environment measured points is shown in Figure 2, and the positions of measured points 1-4 are respectively. In the vertical direction, as shown in

Figure 4, each test point is located at the ground, 1.5 meters, 3 meters and 4.5 meters away from the ground, respectively. Ta, φ, C and U are measured, with a total of 16 test points and 64 test parameters. The plane positions of the air infiltration measured points at the outer door are from a to f, and the air infiltration measured points at the inner door are from A to D (Figure 2). u_i is the average air infiltration speed at all test locations of each air channel.

Table 1: Measuring instruments.

Measuring Parameters	Instrument Name	Precision	Range Range
Temperature	Temperature and humidity recorder	0.2 ℃	- 10 ~ 40 ℃
Black sphere temperature	Thermal comfort tester	0.3 ℃	0 ~ 40 ℃
Relative humidity	Temperature and humidity recorder	5%	0 ~ 100%
CO_2 concentration	Carbon dioxide tester	0.001%	0 ~ 0.5%
Air speed	Hot wire anemometer	±2.5% m/s	0.5 ~ 50.0 m/s
Local temperature field	Thermal imager	±2 ℃	- 20 ℃ ~ 650 ℃

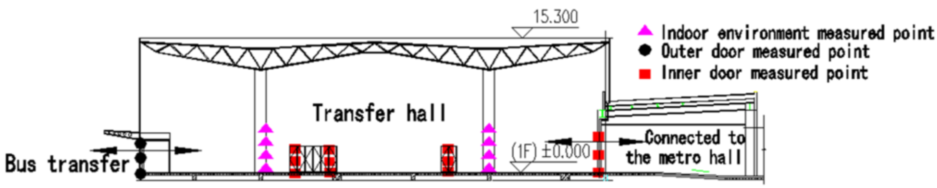


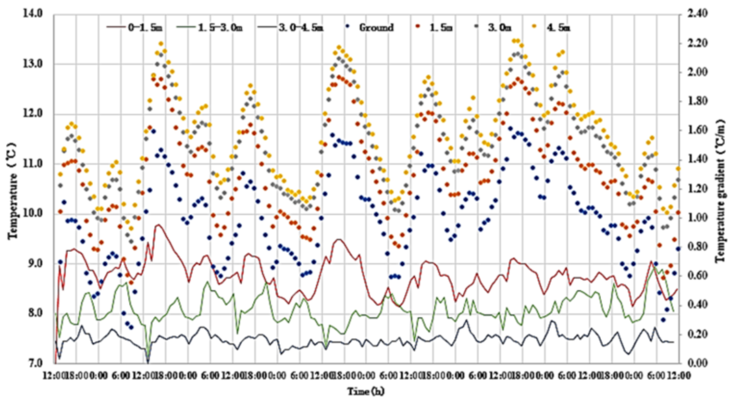
Figure 4. Measured point in vertical direction.

The air velocity was measured at 15 evenly distributed locations (3x5 arrays) in each cross-sectional area, with the velocity at each location being the average of each measurement and the direction of flow recorded simultaneously, for a total of 150 wind velocity test points. Each of the above measurement parameters was tested at a 10-minute interval.

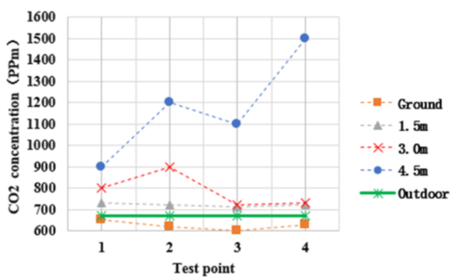
3. Result analysis

3.1. Indoor environment

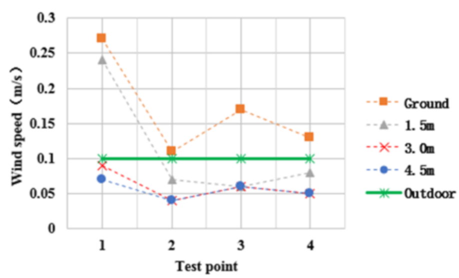
Figure 5(a) hourly values of indoor temperature at each test point during the test. As can be seen from the Figure 5(a), even if the transfer hall adopts the floor radiant heating system, there is still a significant temperature stratification phenomenon in the transfer hall in winter. The air temperature at the ground is 7.7-11.7 ° C, and the air temperature at 4.5 meters from the ground is 9.8-13.5 ° C, and the average temperature gradient in the height direction below 1.5 meters is 0.61 ° C /m, which is far greater than the average temperature gradient of 0.16 ° C /m in the height direction of 3 to 4.5 meters, mainly due to a large number of cold air infiltration.



(a) Indoor air temperature.



(b) CO_2 concentration



(c) wind speed

Figure 5. Measured indoor environment.

Figure 5(b) shows the average CO_2 concentration at each measuring point in the transfer hall. It can be seen that the CO_2 concentration also has obvious stratification in height. The average CO_2 concentration at the ground and 1.5 meters from the ground is 625PPm and 720PPm, respectively$_2$, which is closer to the outdoor CO_2 concentration of 670PPm (The average value at the measuring point is 1.5 meters from the ground). Figure 5(c) is the average wind speed of each measuring point, it can be seen that the average wind speed at 1.5 meters from the ground is 0.11m/s, which is closer to the outdoor wind speed of 0.10m/s (the measuring point is the average value at 1.5 meters from the ground). The distribution law of indoor CO_2 concentration and wind speed also indicates that there is an obvious cold air infiltration phenomenon in the transfer hall.

3.2. Cold Air Penetration

Figure 6 shows the measured average wind speed at the indoor and outdoor exits of the transfer hall. Points a-f are the outdoor entrances and exits, and A-E are the indoor entrances and exits of the transfer hall and other areas. See Figure 2 for the specific locations. The air flow rate from the outside to the indoor is positive, and the air flow rate from the indoor is negative. The outdoor fresh air brought in by cold air infiltration is converted into 0.5 air exchange times /h. As can be seen from Figure 6, the inflow wind speed at the south and north exit entrances is low, while the flow rate at the bus transfer exit is high, mainly because there are curtains at the south and north exit entrances, which can reduce part of the cold air infiltration.

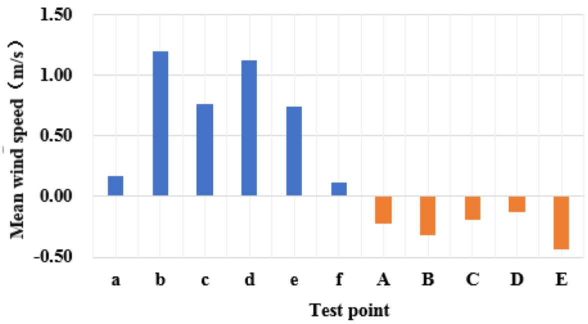


Figure 6. Measured wind speed.

When the air conditioning system and ventilation system are closed, G_K =0, G_P =0 can be obtained from the calculation Eq. (3):

$$G_s = G_N + G_L \tag{3}$$

According to the average wind speed of the outdoor and indoor entrances and exits of the transfer hall (Figure 6) and the calculation Eq. (3), G_L=29635m^3/h can be obtained. It can be seen that most of the air volume permeates from the envelope structure or other pipes.

3.3. Impact on Energy Consumption

Through the analysis of actual measurement, it can be seen that the outer door of the transfer hall of the transportation hub is in a normally open state, and the cold air permeates seriously in winter. A large amount of cold air entering the transfer hall directly affects the indoor thermal comfort. On the other hand, in order to maintain the indoor thermal comfort, this part of cold air needs to be heated to the indoor temperature, thereby increasing the heating energy consumption.

The increased heat load caused by cold air infiltration in winter can be calculated by Eq. (4).

$$Q = 0.278VC_p\rho(t_n - t_w) \tag{4}$$

Where: Q is heat consumption for cold air penetration, W;

V is the amount of cold air flowing in, m^3/h;

C_p is the specific heat of cold air at constant pressure, KJ/Kg•°C;

ρ is the density of cold air, Kg/m^3;

t_n is the interior design temperature, °C;

t_w is the outdoor calculation temperature, °C;

0.278 is the unit conversion factor, 1KJ/h=0.278W

Since the air conditioning system and fresh air system of the transfer hall are closed in the whole winter, the heat load of the transfer hall in winter is mainly composed of two parts: the heat load of the envelope structure and the heat load of the cold air penetration. Figure 7 shows the proportion of heat load in the transfer hall in winter. It can be seen that the heat load caused by cold air infiltration accounts for 57.6% of the total heat load, which directly determines the energy consumption of heating in winter.

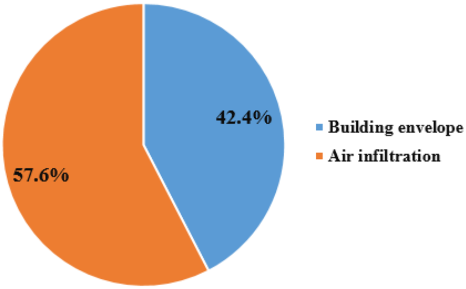


Figure 7. Proportion of heat load.

4. Conclusion

This study takes the transfer hall of a transportation hub in Beijing as the research object, adopts the wind speed test method to measure the cold air permeability of the transfer hall, and continuously monitors the indoor air temperature, CO_2 concentration and air speed. The measured data show that there is serious cold air infiltration in the transfer hall. The correctness of the wind speed test method is verified by checking the air volume balance between each inlet and outlet. Through theoretical calculation, it is found that the heat loss of cold air permeation accounts for 57.6% of the total heat load. Therefore, the cold air infiltration of the transfer hall in winter should be focused on.

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