The investigation of indoor air quality and ventilation of an airport terminal building in China

Jiajie Hong¹, Borong Lin¹, 2, 3, *

¹ Department of Building Science, Tsinghua University, Beijing 100084, China
² Key Laboratory of Eco Planning & Green Building, Ministry of Education, Tsinghua University, China
³ Beijing Key Laboratory of Indoor Air Quality Evaluation and Control, Tsinghua University, Beijing, China
* linbr@tsinghua.edu.cn

Abstract. This study aims to explore the actual indoor air quality and ventilation of an airport terminal building in Hot-Summer-Cold-Winter (HSCW) zone of China, based on long-term monitoring data of CO₂ concentration, which were measured with 50 environmental sensors from September, 2017 to April, 2018. The key findings of this study can be summarized as follows: 1) The median values of CO₂ concentration were lower than 550 ppm in all areas including check-in area, security check area, departure lounge with air bridges, arrival lounge, baggage claim area except the remote departure lounge; 2) Subjective questionnaire survey found that passengers were very satisfied with indoor air quality; 3) The air contained in the large indoor space and the large amount of outdoor infiltrated air played an important role in the dilution of indoor pollutants; 4) Fresh air experiment showed that IAQ in the terminal building didn’t worsen without the supply of fresh air; 5) The number of air changes was calculated by the carbon dioxide attenuation method, and it was found that the arrival floor where gates are normally open and connected to the traffic center has large amount of air exchange. Building energy simulation results revealed that 24% heat was lost in winter through fresh air heating and 57% through air infiltration. In addition, the suggestions for ventilation improvements were also proposed.

Keywords. Indoor air quality; Airport terminal building; Long-term monitoring; Fresh air supply; Air infiltration

1. Introduction

In recent years, with the growth of China’s economy and the improvement of residents’ living standards, China’s civil aviation industry has achieved rapid development, and the state has vigorously promoted airport construction to adapt to the increasing travel demand. By 2020, there will be 224 civil airports in China. As an important part of the airport and a special type of large-scale public building, the terminal building has important research value for its energy consumption features and energy saving potential.

In order to create a healthy and comfortable indoor environment quality, the terminal pays a high energy cost, mainly reflected in the HVAC system (including the fresh air system) and the lighting system. Balaras et al. surveyed the energy consumption of 29 airports in Greece and found that the average energy consumption level (234 kWh/m²·a) is between office buildings (187 kWh/m²·a) and hotel buildings (273 kWh/m²·a) [1]. Tsinghua University conducted a survey on the energy consumption of 22 major airport terminals in China, and found that the total annual electricity consumption is between 129-281 kWh/(m²·a). The average value is about 180 kWh/(m²·a). Air-conditioning and lighting systems account for more than 60% of electricity consumption [2]. Besides, the current physical environment design of the domestic terminal building is not much different from other types of public construction. The operation is partial to extensive, lacking in refined management, and there is a lot of room for optimization. Shi et al. measured the winter indoor environmental parameters of the T1 terminal building of Chengdu Airport in China. The vertical distribution of temperature and wind speed in the check-in
hall and the departure hall was analyzed. It was found that the temperature was high, humidity was low, and the cold wind in the hall was seriously infiltrated in winter. However, the building operator did not grasp the information in time [3]. Mambo et al. used DesignBuilder to simulate the energy consumption of Manchester Airport, adding room temperature and lighting control based on the original control strategy. The calculations show that the energy-saving model achieves energy savings of up to 60% and carbon savings of approximately 70% [4].

This paper takes an airport terminal building in China as an example to conduct post-assessment research on air quality and ventilation based on indoor environmental testing. The terminal building studied in this paper is located in China's hot summer and cold winter area, with a total construction area of 97,000 m². The area currently in use is 61,322 m². The appearance and functional area division of the building are as follows.

**Table 1.** Outward appearance and functional area division of the building

| Function                  | Area (m²) | Proportion |
|---------------------------|-----------|------------|
| Reception                 | 2301      | 4%         |
| Luggage                   | 4523      | 7%         |
| Departure (remote)        | 3773      | 6%         |
| Arrival                   | 3860      | 6%         |
| Check-in                  | 5762      | 9%         |
| Departure (domestic)      | 3306      | 5%         |
| Departure (international) | 5458      | 9%         |
| Security                  | 5825      | 9%         |
| Others                    | 26523     | 43%        |
| Total                     | 61322     | 100%       |

2. **Methods**

2.1. **Combination of subjective and objective data**

In order to evaluate the air quality and ventilation in the terminal building, a total of 50 measuring points were arranged in the public area (Figure 1), and the parameters such as CO₂ concentration were recorded every 5 minutes, and data of passenger time periods (5:00-24:00) were selected for evaluation. It is considered that the CO₂ concentration in each local area where the instrument is located is uniform, and the indoor overall CO₂ concentration is calculated by weighted average of each local area. According to Chinese indoor air quality standards, the indoor air quality is up to standard when the CO₂ concentration is less than 1000 ppm.

**Figure 1.** Arrangement of the 50 measuring points in the building

Considering that the objective physical parameters may not fully explain the subjective feelings, the passengers' satisfaction with the air quality is investigated by issuing questionnaires. The questionnaire sets the following questions:
• Your satisfaction with the current indoor air quality is: very dissatisfied; less satisfied; generally; more satisfied; very satisfied; does not matter.
• What aspects of air quality do you think need improvement?: peculiar smell; feeling stuffy; high PM2.5 concentration; too dry; other reasons

2.2. Fresh air experiment
In order to explore the fresh air demand for large-scale public buildings such as terminal buildings and to qualitatively analyze its relationship with personnel density, fresh air experiments were carried out in the passenger-intensive remote departure area and the sparse domestic and international departure areas. According to the survey, the daily flight and passenger flow of the terminal are almost the same, and the dynamic amount of CO₂ can be considered to be the same. The outdoor weather conditions were similar during the test. The valve fresh air valve opening degree of the air conditioning units in these areas was set to 10% and 0% respectively, and the CO₂ curves of the two were measured and compared.

2.3. Air change rate calculation based on batch quantity
Through the long-term test, the CO₂ time series of the terminal is obtained throughout the year, and all the concentration drop sections of the terminal are identified by programming. The CO₂ generated by the passenger's breathing is used as the tracer gas, and the air change rate of different areas is calculated by the concentration attenuation method, which is used for determining infiltration rates by Parsons [5]. Data with a small fitting error ($R^2>0.85$) was screened out for evaluation of ventilation.

2.4. System load simulation
Use DesignBuilder to establish an energy consumption model for the terminal building, and input the actual outdoor weather parameters and the thermal parameters of the enclosure structure. The passenger volume is obtained from the flight information, and the actual personnel load is calculated. Lighting and equipment loads are input referenced to actual energy consumption data. According to the actual total consumption of cooling and heating, the method of heat balance can indirectly calculate the load generated by indoor and outdoor ventilation and the average number of air change rate in the whole building. This result was compared with the result calculated by the concentration attenuation method.

![Figure 2](image_url)

*Figure 2. The energy consumption model established by DesignBuilder*

3. Results and discussion
3.1. Evaluation of indoor air quality
In actual tests at several airports in China, indoor CO₂ concentrations were generally low [6]; the same results were found for this terminal building: even during the busy National Day holiday, CO₂ levels were still low (Figure 3). In almost all areas, the CO₂ concentration never exceeds 1000 ppm, so the indoor air quality is considered to be good. The high concentration of the remote departure area is because the part B of the building is not activated, of which all the flights are arranged to be executed in this area. The passenger volume is large, but the air quality is good at least 75% of the time.
Figure 3. CO₂ levels in all public areas during National Day holiday

It can be speculated that the supply of fresh air depends on the relative size of human and space volume, and the air contained in the large indoor space plays an important role in the dilution of indoor pollutants. Personnel density data can be obtained by methods such as on-site or camera counting. The number of people in every indoor unit volume can be calculated by the personnel density and the height of the floor. As can be seen from the figure below, except the remote departure area, the actual number of people in all areas of the terminal building is much lower than the design value, which corresponds to the above-mentioned CO₂ concentration level. The actual personnel density of the remote terminal area is much higher than that of other areas, which is also higher than the typical public building, and the demand for fresh air is very large naturally.

Figure 4. Personnel density of the airport terminal building and other typical buildings

A total of 300 questionnaires were issued in the international departure area and the remote departure area. The statistical results show that although 30%~45% of the passengers in the two areas have a slight discomfort due to indoor dryness and 48% of the passengers in the remote departure area feel stuffy, the satisfaction rate of indoor air quality is as high as 94%. Passengers are subjectively satisfied with air quality, which corresponds to the analysis of objective physical parameters.

3.2. Influence of no fresh air supply

For areas with low CO₂ concentration, stopping the supply of fresh air changes the CO₂ concentration increase/deceleration rate, but the overall concentration level is not significantly different from that of supplying fresh air (Figure 5: a, b, c). That is to say, the supply of fresh air is stopped, and the air quality in these areas is basically unaffected. However, for the remote departure area where the personnel density is close to the design value, the impact of stopping the supply of fresh air is significant, and the CO₂ concentration at each moment is on average 179 ppm higher than the original (Figure 5: d). The above results mean that the fresh air control strategy in each area of the large space public building should be different due to the density of personnel.
3.3. Quantify ventilation

The low CO$_2$ concentration can still be maintained without fresh air, which indicates that passive ventilation also plays an important role in diluting pollutants. The amount of ventilation is related to the size and quantity of the building opening. As a large space building, the terminal building may be beneficial to reduce the supply of fresh air due to the large amount of infiltration.

After screening all eligible time periods, taking the international departure area as an example, the calculation results of the annual air change rates are as follows (Figure 6). It can be seen that the number of air change rate varies with the season. In the transition season, due to the supply of fresh air through the AHU for free cooling, the average number of air change rate reached 0.55 h$^{-1}$, while in winter and summer it was only about 0.43 h$^{-1}$.

![Figure 6. Air change rates of international departure area](image)

Generally, infiltration is more serious in winter. The calculation results of each zone in winter are summarized as follows. It is obvious that the arrival floor where gates are normally open and connected to the traffic center has larger amount of air exchange. The total volume of the public area of the whole building is about 208,000 m$^3$, and the average number of air changes is 0.54 h$^{-1}$. Therefore, the indoor
and outdoor air exchange rate is 112,000 m$^3$/h, which is equivalent to several times the amount of infiltration of the conventional public building with the same building area.

| Table 2. Air change rates of all public areas in winter |
|-----------------------------------------------|
| Departure (international) | Security Check-in | Departure (remote) | Arrival | Luggage | Reception |
| Air change rate(h$^{-1}$) | 0.43 | 0.27 | 0.39 | 0.71 | 0.71 | 1.05 | 0.66 |

3.4. Building simulation

After modeling in DesignBuilder, load simulation is performed. The simulated values of total cooling and heating supply are 6191 MWh and 2600 MWh, respectively, which differ from the actual values by -2.7% and +5.0%, both of which are within 10%. The air change rate of both fresh air supply and infiltration obtained from the heat balance of the energy consumption model are 0.64 h$^{-1}$, which is 15.6% out of the result of the concentration attenuation method and is within an acceptable range.

The heat loss in winter is split. The result showed that the infiltration accounted for 57% (3202MWh) and the fresh air accounted for 24% (1376MWh). It is necessary to take appropriate measures to reduce infiltration and unnecessary fresh air supply. The actual fresh air volume of the whole building is estimated to be about 130,000 m$^3$/h. If the fresh air is not supplied in winter, about 150,000 m$^3$ of gas can be saved (the gas calorific value is estimated to be 33 MJ/m$^3$). If the amount of infiltration can also be reduced, the amount of gas saved will be greater.

![Figure 7. Actual and simulated values of cooling and heating supply; heat loss composition](image)

4. Conclusions

The large amount of air contained in the indoor space of the terminal building and its large air exchange have played a common role in the dilution of indoor pollutants: on the one hand, the accumulation of indoor pollutants is more difficult than other types of public construction, and passengers have high satisfaction with indoor air. On the other hand, the large amount of gas exchange leads to high energy consumption, and it is very necessary for the terminal building to reduce the supply of fresh air and the amount of infiltration. Fresh air control can be achieved by setting a CO$_2$ concentration limit (e.g. 800 ppm), that is, stopping the fresh air supply when the actual concentration is lower than it; infiltration control can be achieved by reducing the opening area of the building (such as boarding gates) and shortening the opening time. All in all, no matter which kind of building performance is to be optimized, the best way is to grasp the particularity of building function and space and match the supply and demand through certain mechanisms according to the characteristics of energy and personnel demand.
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