Analysis of the effect of air purification equipment on indoor pollutants in Northeast China in winter

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Abstract. In this study, 3 residential buildings with installed high-efficiency filter fresh air system, coarse-efficiency filter fresh air system and air purifier were selected respectively to analyze the purification effect of different air purification equipment on indoor pollutants in winter. Data on ventilation and concentrations of PM2.5 and CO₂ were collected through long-term online monitoring. The test results showed that under the same outdoor pollution condition, the average indoor PM2.5 concentration of residential buildings equipped with high-efficiency filter fresh air system and air purifier was 33.62µg/m³ and 34.32µg/m³, respectively. However, the purification effect of coarse-efficiency filter fresh air system was poor, and the indoor PM2.5 concentration over-standard rate reached 13.11%. It was a slow process for the fresh air system to reduce indoor CO₂ concentration. The fresh air system needed to be opened continuously for 4 hours to stabilize the CO₂ concentration, and the decrease rate could reach 53.6%. Whereas, it took only 14 minutes for natural ventilation to reduce the indoor CO₂ concentration by 54.3%, but the window opening time was limited in winter. The use of high-efficiency filter fresh air system can ensure indoor comfort and maintain concentration of indoor pollutants at a low level in winter.

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1 Introduction

In recent years, haze is one of the most urgent environmental pollution problems to be solved in China. PM2.5, which has an aerodynamic equivalent diameter of less than or equal to 2.5 microns, is the most harmful component. With the rapid development of our country and the improvement of national living standards, more and more people begin to pay attention to the living environment. The human harm caused by haze is mainly reflected in the diseases of the respiratory system and cardiovascular system, and it also has a certain impact on people's mental health[11]. The study by Liang et al. show that the peak PM2.5 concentration is significantly associated with the delayed increase effect of human influenza cases. For every 20 μg/m³ increase in PM2.5 concentration, the risk of human death increase by 1.4-1.5 times[2]. In Northeast China, the season with the most frequent haze is winter. Affected by heating, the exhaust gas produced by burning coal is one of the main causes of outdoor air quality problems. Affected by outdoor temperature in winter, occupants in Northeast China have less time to open windows, and the sealing performance of building maintenance structure is improved, which also cannot prevent outdoor PM2.5 from infiltrating into the room through cracks in doors and windows. Some research results show that particulate matter pollution have a strong seasonal trend, and indoor and outdoor particulate matter concentrations have the same change trend. Indoor PM2.5 concentration is affected by outdoor PM2.5 concentration to a certain extent, and indoor PM2.5 concentration is generally lower than outdoor PM2.5 concentration. In winter, outdoor particulate matter is the main source of indoor particulate matter[1-4].

Frequent haze, limited window ventilation conditions and insufficient fresh air will bring more serious indoor pollution problems. Insufficient ventilation will cause indoor CO₂ accumulation. When the CO₂ concentration reaches 1000 ppm, people will feel dull and start to lose concentration[5]. Compared with summer, the indoor CO₂ concentration in winter has been maintained at a higher level[6].

At present, the highest use rate of air purification equipment in the domestic market is air purifier and fresh air system. In recent years, the fresh air system has gradually sprung up in China. Some hardbound buildings with fresh air system become the absolute selling point of real estate, and also more and more people begin to consciously put the fresh air system into the decoration system. In this study, three residential buildings equipped with high-efficiency filter fresh air system, coarse-efficiency filter fresh air system and air purifier respectively were selected. Through data collection, compare the purification effects of these three kinds of air purification equipment on indoor PM2.5 and CO₂, and put forward appropriate air purification methods.

2 Sample selection

Three residential buildings equipped with air purification equipment were selected for long-term monitoring in Northeast China. Occupants showed a high level of participation, which ensured a steady online rate of monitoring equipment. The data had high validity and continuity, which could effectively reflect the overall ventilation condition of the residential buildings and provided strong support for data analysis and conclusion. The detailed residential information is shown in Table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Purification method</th>
<th>Residential area(m²)</th>
<th>Decoration year</th>
<th>Decoration way</th>
<th>Floor no.</th>
<th>Building floor no.</th>
<th>Window type</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1</td>
<td>High-efficiency filter fresh air system</td>
<td>130</td>
<td>2017</td>
<td>Latex paint + composite wood</td>
<td>6</td>
<td>6</td>
<td>Casement window, double glazing, plastic-steel frame</td>
</tr>
<tr>
<td>N2</td>
<td>Coarse-efficiency filter fresh air system</td>
<td>55</td>
<td>2016</td>
<td>Latex paint + composite wood</td>
<td>9</td>
<td>34</td>
<td>Casement window, double glazing, plastic-steel frame</td>
</tr>
<tr>
<td>N3</td>
<td>Air purifier</td>
<td>125</td>
<td>2017</td>
<td>Latex paint + solid wood + ceramic tile</td>
<td>1</td>
<td>7</td>
<td>Casement window, double glazing, plastic-steel frame</td>
</tr>
</tbody>
</table>

3 Test methods

The online monitoring sensors used in this study are shown in Figure 1. Ikair, an indoor air quality sensor(Fig. 1a), was used to monitor the change trend of indoor PM2.5 and CO₂ concentrations in real time for a long time. The sensor parameters are shown in Table 2. The sensor was calibrated in the Key Laboratory of Indoor Environmental Quality Control of Tianjin University before long-term monitoring. During the monitoring period, a master computer was left to check the drift of long-term data. At the same time, a fresh air system sensor with network data interface(Fig. 1b) was installed. The monitor probe extended into the inside of the tuyere to judge whether the fresh air system was turned on according to the wind pressure value. Inserted the air purifier into the installed Xiaomi smart socket(Fig. 1c), and judged whether the air purifier was turned on according to the energy consumption. In order to understand the behavior and habits of opening windows of occupants, the Xiaomi window sensor(Fig. 1d) was selected for long-term monitoring. The above sensors were connected to the residential wireless network through the mobile phone APP, and the data was transmitted to the monitoring platform after the connection was successful. Testers could obtain instantaneous and continuous data throughout the winter on the platform. The downloaded data could be used to judge the use of residential purification equipment and analyze the indoor PM2.5 and CO₂ pollution.
Table 2. Sensor parameters.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Principle</th>
<th>Range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM2.5 sensor</td>
<td>Laser scattering</td>
<td>1~1000µg/m³</td>
<td>±40µg/m³</td>
</tr>
<tr>
<td>CO₂ sensor</td>
<td>Infra-red</td>
<td>400~10000ppm</td>
<td>±40ppm</td>
</tr>
</tbody>
</table>

Fig. 1. Online monitoring sensors. (a) Indoor air quality sensor, (b) Fresh air system sensor, (c) Smart socket, (d) Window sensor.

4 Results and discussion

Figure. 2 to Figure. 4 respectively show the variation trend of indoor PM2.5 concentration in residential building with high-efficiency filter fresh air system (N1), residential building with coarse-efficiency filter fresh air system (N2) and residential building with air purifier (N3) for two consecutive months in winter. When the average outdoor PM2.5 concentration was 60.16µg/m³, the average indoor PM2.5 concentrations of N1, N2, and N3 residential buildings were 33.62µg/m³, 44.71µg/m³, and 34.32µg/m³, respectively. The exceeding rate, that is, exceeding the secondary concentration limit of 75µg/m³ specified in the national standard GB/T 18883-2002 "Indoor Air Quality Standard"[7], was 4.92%, 13.11%, and 9.84%, respectively. The level of indoor and outdoor particulate matter mass concentration is evaluated by IO ratio. Through analyzing the sampling data, the difference of indoor and outdoor particulate matter mass concentration can be intuitively obtained, and the reasons for the change of indoor particulate matter mass concentration can also be understood[8]. The I/O of N1, N2 and N3 residential buildings were 0.66, 0.93 and 0.62, respectively. It could be seen from the results that indoor PM2.5 concentration had the same change trend as outdoor PM2.5 concentration, and high-efficiency filter fresh air system and air purifier had a significant effect on purifying outdoor pollution. However, turning on the coarse-efficiency filter fresh air system did not play a purification role to a certain extent. On the contrary, it would introduce outdoor pollution into the room and affect the indoor air quality.

Figure. 5 shows the change of indoor CO₂ concentration between 5:00 and 14:00 in the residential building with high-efficiency filter fresh air system. The residential building was closed from 5:00 to 7:25, and the CO₂ concentration was maintained between 1000.00 and 1100.00ppm. When the fresh air system was turned on, the CO₂ concentration began to decrease. The fresh air system was kept on continuously, and the indoor CO₂
concentration finally stabilized at about 485.00 ppm, with a decrease of about 53.6%. This process needed to last for more than 3 hours. The change trend of indoor CO₂ concentration in the residential building with an air purifier from 6:00 to 9:00 is shown in Figure 6. Data from the door and window sensors of the residential building showed that the occupant opened the window between 7:32 and 7:47. The average concentration of CO₂ in the residential building was 1158.64 ppm under the closed condition, and the CO₂ concentration dropped sharply to 536.00 ppm after the window was opened. Keeping the window open, the indoor CO₂ concentration also decreased slightly, and the drop rate could reach 54.3%. After the window was closed, the indoor CO₂ concentration would rise under the influence of human factors. If indoor personnel went out or moved to other rooms and there was no CO₂ emission source, the CO₂ concentration would gradually approach the outdoor CO₂ concentration and remained stable through infiltration ventilation over time. Ventilation is one of the effective means to improve indoor air quality. In a short time, natural ventilation could reduce the concentration of indoor pollutant from a higher level to a lower level, while mechanical ventilation had a poor effect on reducing the concentration of indoor pollutant in a short time.

**Fig. 5.** The variation trend of indoor CO₂ concentration in residential building with high-efficiency filter fresh air system.

**Fig. 6.** The variation trend of indoor CO₂ concentration in residential building with air purifier.

### 5 Conclusions

In this study, long-term dynamic online monitoring was adopted to obtain the changes of indoor PM2.5 and CO₂ concentrations in residential buildings under different ventilation and purification methods, and the main conclusions were as follows:

The high-efficiency filter fresh air system had a significant purification effect on outdoor PM2.5, and the indoor PM2.5 exceeding rate was only 4.92%. It was not recommended to use the coarse-efficiency filter fresh air system when the outdoor pollution was serious. For residential buildings that could not install fresh air systems due to indoor decoration conditions, it was necessary to use air purifiers, which could keep the average indoor PM2.5 concentration below the first-level concentration limit of 35 μg/m³ set by the national standard.

Mechanical ventilation was a slow process to reduce the concentration of indoor pollutants. The instantaneous effect of turning on the fresh air system to reduce the concentration of indoor pollutants was worse than that of opening windows. Opening the window for 3 minutes could reduce the indoor CO₂ concentration by more than 50%, while the fresh air system needed to be continuously turned on for more than 3 hours to achieve the same effect. However, in order to ensure indoor comfort, the window opening time was limited in winter in Northeast China, and the CO₂ concentration would still rise after closing the window. Keeping the fresh air system turned on continuously could ensure that the indoor CO₂ concentration was maintained at a low level, and the long-term effect was significant.

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8. A. Challoner, L. Gill, B&EE, 80, 159 (2014)