Study on the Purification Effect of Clean Fresh Air on PM2.5 in the Bedroom

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Abstract. In order to study the purification effect of clean fresh air on PM2.5 in bedroom, the concentration distribution of PM2.5 in bedroom was numerically simulated using RNG k-e turbulence model based on DPM discrete phase model. In the case of severe haze, clean fresh air is introduced to meet the needs of indoor personnel. Aiming at two common types of airflow in the bedroom (same side/opposite side upper and lower back) and two different air supply speeds, studied the purification effect of fresh air on PM2.5. The results showed that there was no significant difference in the decrease rate of PM2.5 in the respiratory surface under the two inlet velocities. In the first 600s, the concentration of PM2.5 decreased by 75% with the inlet and outlet were on the same side, while the PM2.5 concentration decreased by 63% with the inlet and outlet were on the opposite side. The PM2.5 concentration distribution was more uniform when the inlet and outlet were on the same side than the opposite side. It is concluded that the air supply position has a greater influence on the purification effect than the air inlet velocity when the fresh air volume is constant. When the inlet and outlet were on the same side the introduction of the clean fresh air in the bedroom is more effective in purifying the PM2.5 than the opposite side.

1. Introduction
With the influence of the outdoor smog and people's life activities, indoor particle pollution becomes a big problem [1] which affects people's physical and mental health seriously, and become one of the major components of indoor pollution. When the indoor air of fine particles of pollutants to a certain concentration, it will pose a great threat to human health and even threaten people's lives [2-5]. According to the current relevant research data at home and abroad show that PM2.5 concentration in the building are generally high, so the control of indoor particulate matter without delay.

At present, most residential buildings are equipped with mechanical ventilation to improve the indoor environment. However, the mechanical ventilation used in the buildings is not equipped with a particle-specific filtering device [9]. Although the air-handling equipment also has some filtering effects, for fine particles, its purification effect fails to meet people's needs. Bedroom is the essential resting place for people, it is very important to control the particles in the bedroom. Currently, two main methods to remove indoor particles are air purification and fresh air systems [10]. Fresh air systems can better meet people's needs in terms of hygiene requirements. However, at present, the research on indoor particulate matter mainly focuses on the correlation research of indoor and outdoor particulate matter [6-8]. There is insufficient research on the purification of indoor PM2.5 after introducing fresh air into treatment.

The purification effect of clean fresh air on PM2.5 in bedroom is studied. Under the condition of guaranteeing the fresh air quantity needed by indoor personnel, the purification efficiency of clean fresh air on PM2.5 and the distribution of indoor PM2.5 are studied.
2. Theoretical analysis
Since the PM2.5 distribution is mainly affected by the airflow organization, and the influence factors of the airflow organization are mainly the air supply position and parameters. In this paper, the fresh air is introduced to meet the fresh air demand of the indoor personnel, not bear the indoor heat load. Therefore, does not consider the influence of supply air temperature for the research, the influence of the air supply position and the air supply speed on the PM2.5 distribution was studied.

This study is typical of gas-solid two-phase flow. The RNG k-ε model was applied to simulate the airflow. For the PM2.5 in a bedroom, due to the volume fraction of discrete items is less than 10%, a Discrete Phase Model (DPM) was used for simulating the PM2.5 injection and dispersion.

3. Model
Taking the resident bedroom in typical residential buildings as the simulation object, the size of bedroom is 3.6 m x 4.8 m x 2.6 m, the bed is 2 m x 2 m x 0.5 m, the table is 0.6 m x 1.5 m x 0.8 m, the wardrobe is 2 m x 0.5 m x 2 m, The layout is shown in figure 1.

![Figure 1. Bedroom and vents set simplified diagram](image)

Taking into account the convenience of the introduction of fresh air in the outdoor, the position of the fresh air supply port is shown in figure 1. There are two settings of S1 and S2. Since the exhaust vent is usually not provided in the bedroom, the air is discharged from the door seam, and the door slit is simplified here as the outlet as shown in figure 1, and the size is 0.4 m × 0.1 m.

4. Condition Setting
The amount of fresh air is determined by the number of indoor air changes and the amount of fresh air required by personnel. The number of air changes in the bedroom is 1/h, the required air volume is 40 m$^3$/h. The number of indoor personnel is 2; the total fresh air required is 60 m$^3$/h, so the introduction of fresh air volume is 60 m$^3$/h.

Indoor PM2.5 distribution is mainly affected by air distribution. In this paper, the air distribution is changed by changing the position or inlet velocity. The position of air supply is shown in figure 1. Referring to the size of wall-mounted air conditioner and air purifier in bedroom, two kinds of air inlets with sizes of 0.4 m × 0.05 m and 0.2 m × 0.05 m are selected in this paper, and the indoor air inlet velocities are calculated to be 0.83 m/s and 1.67 m/s, respectively. According to the location of the inlet and the inlet velocity, the following four simulation conditions are designed.
Table 1. Simulation Case Setting Table

| Case | Inlet and outlet setting | Air volume Q/(m$^3$·h$^{-1}$) | Inlet velocity v/(m·s$^{-1}$) |
|------|--------------------------|-------------------------------|-------------------------------|
| 1    | opposite side            | 60                            | 0.83                          |
| 2    | opposite side            | 60                            | 1.67                          |
| 3    | same side                | 60                            | 0.83                          |
| 4    | same side                | 60                            | 1.67                          |

When the fog is severe, the outdoor PM2.5 concentration is 200 μg/m$^3$, and the high-efficiency filter is used in the fresh air treatment equipment. The purification efficiency of PM2.5 is 90%, that is, the PM2.5 concentration in the air supply is 20 μg/m$^3$. The height of the bed is 0.5 m, the height of the respiration surface is 0.6 m when sleeping, in the simulation study, $z = 0.6$ were taken as the monitoring surface.

5. Simulation Results

5.1. Flow field and PM2.5 Concentration Distribution under Different Working Conditions

5.1.1. Case 1: Set inlet and outlet on the different sides, the inlet velocity is 0.83 m/s. It can be seen from the velocity profile in figure 2 that the airflow distribution is complicated, and multiple airflow vortices appear on the monitoring surface. Figure 3 shows the specific distribution of the PM2.5 concentration on the monitoring surface. As can be seen from figure 2 and figure 3, the PM2.5 concentration distribution is affected by the airflow field. PM2.5 concentration is relatively high in the area with low airflow velocity, while PM2.5 concentration is relatively low in the area with high airflow velocity.
5.1.2. Case 2: Set inlet and outlet on the different sides, the inlet velocity is 1.67 m/s. Comparing with the velocity profile in figure 2 and figure 4, it can be seen that under the premise of unchanged supply air position and fresh air volume, there is no obvious difference in the distribution law of the flow field when adjusting the inlet velocity. As the distribution of PM2.5 is affected by the air distribution, the air velocity increases, and the distribution of PM2.5 changes accordingly. As can be seen from figure 5, the PM2.5 concentration above the bed is significantly lower than case 1.

Figure 3. 1000s plane $z = 0.6$ PM2.5 concentration profile

Figure 4. Plane $z = 0.6$ velocity profile
5.1.3. Case 3: Set inlet and outlet on the same sides, the inlet velocity is 0.83 m/s. Figure 6 shows the velocity distribution of the monitoring surface at the speed of 0.83 m/s from S2. On the whole monitoring surface, the vortices mainly appear in the corners, and the velocity of the air flow above the bed is relatively high. Figure 7 shows the specific distribution of PM2.5 on the monitoring surface. The PM2.5 concentration in the breathing surface of the bed was greatly reduced, and the PM2.5 concentration distribution on the respiratory surface was relatively uniform.
5.1.4. **Case 4**: Set inlet and outlet on the same sides, the inlet velocity is 1.67 m/s. Comparing the velocity profile of figure 6 and figure 8, it can be seen that the distribution law of the airflow velocity is almost the same, but after increasing the inlet velocity, the airflow velocity on the bed is increased as a whole. Figure 9 shows the specific distribution of PM2.5 on the monitoring surface. The overall PM2.5 concentration on the bed is slightly lower than other areas.
Changes in PM2.5 Concentration

Figure 10 shows the curve of PM2.5 average concentration varying with time at different working conditions. It can be seen that the introduction of fresh air has a good purification effect on indoor PM2.5.

It can be seen from figure 10 that there is not much difference between the case 1 and the case 2, and the changes of the case 3 and case 4 curves are the same basically. In the first 600 s the concentration of PM2.5 in the monitoring surface of case 1 and case 2 decreases by 57% and 63% respectively, while the concentration of PM2.5 in the monitoring surface of case 3 and case 4 decreases by 74% and 75% respectively. After that, slowly descend until dynamic equilibrium is reached.

It can be obtained that the adjustment of inlet velocity has little effect on the purification efficiency of PM2.5, and the position of the vent has a great influence on the purification efficiency, and the purification efficiency of the same side air supply to PM2.5 is higher than that of the opposite side.

6. Summary

Considering the needs of personnel and energy consumption, this paper selects the minimum fresh air
volume required for indoor purification of indoor PM2.5. Because of the different purification conditions of clean fresh air to PM2.5 under different setting conditions, Aiming at two common types of airflow in the bedroom and two different inlet velocities, the purification effect of fresh air on PM2.5 was studied. The research results are as follows:

a) When the fresh air volume is constant and the vent position is the same, the change of the inlet velocity has no significant effect on the purification effect.

b) In the bedroom, when the fresh air volume and the inlet velocity is the same, the change of the vent position has a great influence on the purification effect. When the inlet and outlet were on the same side the introduction of the clean fresh air in the bedroom is more effective in purifying the PM2.5 than the opposite side.

c) In the bedroom, when using the minimum clean fresh air supply, the indoor PM2.5 will fall about 12% faster with the inlet and outlet were on the same side than the opposite side in the first 600s.

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