Exploring the optimal return air height of different air supply modes based on energy consumption analysis and TOPSIS evaluation method

Jianlin Ren*, Shasha Duan, Xiangfei Kong
School of Energy and Environmental Engineering, Hebei University of Technology, Tianjin, China

Abstract. The side return air is considered to be a ventilation form that can effectively remove indoor particulate matter, and relevant scholars have little research on the height of air return outlet for different air supply methods. In this paper, a single-person ward experimental cabin is established, and the focus is to study the effect of different side return air outlet heights on the particle removal effect under three air supply forms. And use CFD simulation to increase the type of return air outlet height, finally use the technique for order of preference by similarity to ideal solution (TOPSIS) method to comprehensively evaluate the pros and cons of 60 working conditions. The results show that the optimal return air height of top air supply and underfloor air supply is 1.2m, and the best working condition of side air supply is 1.6m air supply-0.7m air return of 12ACH. Most of the working conditions of side air supply are better, followed by top air supply, and finally underfloor air supply.

1 Introduction

In the past two years, the new crown epidemic has continued to appear all over the country [1,2], and the exposure risk of medical staff in hospitals has received special attention [3,4]. How to reduce the exposure risk of medical staff in single wards is an urgent problem to be solved. In recent years, a large number of scholars have used experimental and simulation methods to analyze the impact of different ventilation and filtration systems on indoor air quality. Xue et al. studied the ventilation performance of different ventilation forms in the office, and concluded that tiered ventilation has better pollutant removal effect and can maintain good inhaled air quality [5]. Previous studies have focused on the impact of air supply vents, but it has been gradually discovered that air return vents have an important impact on some ventilation and filtration systems. Luo et al.[6] studied the influence of the position of the return air outlet of the displacement ventilation on the performance of the local environmental control system, and concluded that reducing the height of the return air outlet can be more energy-saving. In addition, some scholars [7] have used numerical simulation to study air return height of underfloor air supply(UFAS) in a large space, and have reached similar conclusions.

In current research, most of them only consider the impact of air return outlet on air quality, and do not comprehensively consider the filtration effect and energy consumption of different air return outlet heights under various air supply forms and wind height. In addition, determining the optimal air return height is a multi-attribute decision-making problem with many evaluation indicators. Most studies are based on simple charts for analysis[8,9,10], and there is no good theoretical method to determine. In order to solve the problem of multi-dimensional evaluation index decision-making, some studies proposed to use the technique for order of preference by similarity to ideal solution (TOPSIS) method to select the best phase change materials for heating, ventilation and air conditioning applications according to the ranking results [11]; In addition, some scholars use TOPSIS method to optimize the angle of air supply blade under multi index evaluation [12]; TOPSIS is a statistical analysis method, which sorts the evaluation objects with the help of "ideal solution" and "negative ideal solution" of multi-attribute decision-making problem. The closer the final result is to 1, the better the evaluation object is. In order to solve the above problems, considering the filtering effect and energy consumption comprehensively, the optimal air return height under different air supply forms in a single ward is obtained. First, we used experiments to study the effects of top air supply(TAS), UFAS, and side air supply(SAS) on indoor air quality under the conditions of different air change(ACH) times and different distances between medical staff and patients, and different air return outlet heights. Finally, the optimal height of air return outlet under three air supply forms is obtained. Some studies indicate that lowering the height of air return outlet is more energy efficient. However, the minimum air return height of the experimental cabin is 0.7m. Therefore, we

* Corresponding author: jlren@hebut.edu.cn
use CFD simulation to increase the types of air return outlet heights and set the lowest air return height to 0.3m. The energy consumption is added to the evaluation index, and the TOPSIS method is used to comprehensively calculate and sort the results of various evaluation indicators in two dimensions (air quality and energy consumption). In the end, we propose the optimal height of air return outlet under different air supply forms, and provide a better reference solution for establishing a single-patient ward environment that meets both air quality and energy-saving requirements.

2 Methods

2.1 Experimental method

The experimental cabin simulating a single-person ward in this study is shown in Figure 1, the size of the experimental cabin is 4.94 m (length) × 4.86 m (width) × 2.2m (high). The walls, floors and ceilings of the room have good thermal insulation performance, and the experiment was kept at 24±1°C. In the experimental cabin, particulate matter was released from the mouth of the patient (the person lying down) as a source of pollution (light the incense stick), and the mouth of the medical staff (the person standing) and indoor center were used to monitor the concentration of particulate matter at two measuring points. Two dummies are not to be heated. There are two square air vents at the top of the experimental cabin, six circular air vents at the bottom, and two rows of air vents on the side walls, the upper row can be moved. In the experimental cabin, we designed three types of air supply: TAS, UFAS, and SAS. There are three types of air return outlet heights for TAS and UFAS, which are 0.7m(highly consistent with the patient's breathing zone), 1.2m and 1.6m(highly consistent with the breathing area of medical staff) respectively. Air return outlet height for SAS is only 0.7m, and air supply outlet heights are 1.2m and 1.6m. Each working condition was designed with 6ACH and 12 ACH. According to previous research[13], the medical staff was moved to three different distances from the patient. Through the above experiments, the effects of optimal air return height of each airflow organization form and the distance between medical staff and patients on the inhalation of particulate matter by medical staff were explored. We ignited the coil incense at the patient's mouth to release a certain amount of dust to simulate indoor particulate matter, turned on the fan and particle counter, and monitored and recorded the particulate matter concentration at the mouth of the medical staff and the particulate matter concentration at the indoor center point under different working conditions during the experiment. , the whole process is strictly time-controlled to ensure that the same amount of particulate matter is produced.

2.2 Simulation method

As shown in Figure 2, we have established a model that is exactly the same size as the experimental cabin, size and location of air vents in the room are also exactly same. Not only that, we simulated five different air return heights (H=0.3, 0.7, 1.2, 1.6, 2m) from floor to ceiling. In the model, two blue air inlets are TAS inlets, and six light blue circular air outlets at the bottom are UFAS inlets; red air outlets on the side walls are SAS inlets and three air return outlets. We use ANSYS Fluent software to take the entire experimental cabin as a computational domain for CFD simulation, solve the three-dimensional ventilation system field based on the RNG k-ε model and standard wall functions, and use the SIMPLE algorithm to couple the pressure field and velocity field. When the residuals of the independent parameters are reached, the results are considered to converge. In this study, Lagrangian method was used to simulate the behavior of particulate matter in the indoor space, a DPM model was set up. The patient's mouth is set as the ejection surface, and the particles are released transiently. In the simulation, temperature is 297 K, breathing speed is 0.8 m/s, and the number of particle flows is 2000, and random walk model is checked. The exit boundary is set to escape, and the remaining walls are trapped. The inlet speed is calculated based on the number of air changes. In order to ensure the accuracy of the simulation, we also carried out grid independence research and model verification. Finally, 700,000 grids were selected to simulate the working conditions, and the comparison between the experimental value and the simulated value of the particle attenuation rate $K$ showed that the model was successfully verified.

Fig. 1. Schematic diagram of the experimental cabin

Fig. 2. Schematic diagram of the CFD model

The TOPSIS method is an evaluation method suitable for mutual comparison of multiple indicators. The main principle is to select the best ideal plan and the least ideal plan according to the original data of each plan, and
calculate the closeness between the alternative plans and them, thereby pros and cons of each alternative are judged by the degree of proximity. The entropy weight method mainly calculates the entropy weight of each indicator based on the information entropy, and then further feeds back to each indicator through the calculated entropy weight value, and adjusts each indicator. In this study, TOPSIS evaluation method based on entropy weight method is used to comprehensively evaluate the advantages and disadvantages of simulated working conditions from four aspects: particle attenuation rate, suction fraction index, pollutant removal efficiency and air conditioning energy consumption, and the height of the best air return outlet of different air supply forms is selected. The specific steps of the TOPSIS method are summarized in Figure 3.

3 Results and Discussion

3.1 Experimental results

When the distance between the medical staff and the patient is 0.5m (as shown in Figure 4(a)), the best return air height of TAS is 1.2m, followed by 1.6m; the best return air height of UFAS is 0.7m, followed by 1.6m; Due to the limited conditions of the experimental cabin, in SAS, there is only a air return height of 0.7m, and the air supply heights are 1.2m and 1.6m. The results of 6ACH and 12ACH at the two different air supply heights are not much different. When the distance between the medical staff and the patient is 1.0m (as shown in Figure 4(b)), the results of the three air return heights of TAS are not much different, 0.7m and 1.2m are better; for UFAS, the return air height of 0.7m shows obvious advantages; for SAS, 1.6m air supply-0.7m air return condition of 12ACH is better. When the distance between the medical staff and the patient is 1.5m (as shown in Figure 4(c)), the results of the three air return heights of TAS and UFAS are similar, 1.6m and 0.7m are the best; for SAS, the working condition of 1.6m air supply-0.7m air return is better. The results of comprehensive evaluation indicators (particulate attenuation rate \( K \), inhalation fraction index \( IF \) of medical staff, personal exposure effectiveness \( E_p \) ) at different distances are not significantly different. Besides, it is obvious from the figure that 12ACH is better than 6ACH. The possible reasons are: 1. In TAS, under the combined action of the thermal plume and air return flow, the patient exhales more particulate matter at a height of 1.2m, and air return at this height just removes the particulate matter; Second, in UFAS and SAS, height of air return is the same as the height of the patient's breathing area. The duration of this airflow is short and the airflow distance is small, so that particulate matter can be removed in a timely and effective manner. Third, increasing the number of air changes can increase the removal rate of indoor pollutants.

3.2 TOPSIS Evaluation Results

Although the experimental results can show air return height with the best air quality under different air supply forms, due to the limited conditions of the experimental cabin, we used CFD simulation to increase the types of air return outlet heights, and set the minimum air return height to 0.3m. And the types of ventilation times are increased to 6ACH, 9ACH, and 12ACH. We can get 60 simulation conditions, by calculating the four evaluation indicators of particle attenuation rate \( K \), inhalation fraction index \( IF \), pollutant removal efficiency \( \epsilon \), and operating cost-effectiveness, and using the TOPSIS evaluation method to rank 60 working conditions, the higher the comprehensive score, the better the working condition. Since the evaluation result of each working condition has a higher score of 12ACH than 6ACH. The possible reasons are: 1. Due to the limited conditions of the experimental cabin, we used CFD simulation to increase the types of air return outlet heights, and set the minimum air return height to 0.3m. And the types of ventilation times are increased to 6ACH, 9ACH, and 12ACH. We can get 60 simulation conditions, by calculating the four evaluation indicators of particle attenuation rate \( K \), inhalation fraction index \( IF \), pollutant removal efficiency \( \epsilon \), and operating cost-effectiveness, and using the TOPSIS evaluation method to rank 60 working conditions, the higher the comprehensive score, the better the working condition. Since the evaluation result of each working condition has a higher score of 12ACH than 6ACH. The possible reasons are:

Fig. 3. Introduction to the TOPSIS method

Fig. 4. Evaluation indicators of different return air outlet heights at different distances between medical staff and patients, ((a)(b)(c) represent the distance between the medical staff and the patient is 0.5m, 1.0m, 1.5m respectively)
various working conditions at 12ACH, the gap is not large, and they are all above 0.996. It shows that most of the working conditions have good indoor air quality and energy-saving characteristics at 12ACH, which is significantly higher than that of 6ACH and 9ACH, so the number of air changes has a greater impact on the scoring results of the working conditions. In addition, the scores of the optimal working conditions under different air supply forms are obviously higher than other working conditions (especially SAS), indicating that the optimal return air height of each air supply form obtained by using TOPSIS method has a good reference value. In addition, it can be seen from the figure that most of the working conditions with SAS and TAS have good scores, most of which are higher than 0.998, and UFAS score is relatively low.

![TOPSIS evaluation results](image)

**Fig. 5. TOPSIS evaluation results**

### 4 Conclusion

In this study, experimental research and simulation analysis were carried out on the optimal air return height of three different air supply forms (TAS, UFAS, and SAS), and the following conclusions were finally drawn:

1. Increasing the distance between medical staff and patients has little effect on exploring the optimal return air height under the three air supply forms. Different distances show that the optimal return air height under the corresponding working conditions is basically the same.

2. If only air quality is considered, the optimal air return height for TAS is 1.2m, and the optimal air return height for UFAS is 0.7m. The best working condition for SAS is 1.6m air supply -0.7m air return of 12ACH.

3. If energy consumption is taken into account, we use TOPSIS evaluation method to obtain 60 simulated working conditions. The results show that the 12ACH score is the best under the same working conditions; for TAS, the best return air height is 1.2m, the score is 0.99924; for UFAS, the best return air height is 1.2m, and its comprehensive score is 0.99894; for SAS, the best working condition is 1.6m supply air -0.7m air return, its comprehensive score is 0.99962; Among the three types of air supply, SAS and TAS have higher scores, UFAS scores are relatively low.

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