Air distribution analysis of clean air conditioning in operating room of hospital

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Abstract. Study on the clean air conditioning in operating room, the CFD numerical simulation method is used to analyze the indoor air distribution. In this paper, the air supply speed and the position of the air return outlet are analyzed. The results show that the air supply speed is the main factor affecting the air distribution in the operating room and the particle concentration distribution in the operating area. From the perspective of the indoor air distribution, the effect of continuous arrangement of air return outlet is the best. The results can be used for reference in the design of air distribution in the operating room of the hospital in the future.

1. Introduction

The air conditioning in the operating room of the hospital embodies the design principle of "patient-centered", and requires a high level of cleanliness. In addition to the cooling and dehumidification functions of air conditioning system in the operating room, which is more important to guide the indoor air flow, so that the dust particles are under control, especially the bacterial concentration in the operating area[1-3]. Different air distribution forms have different effects on the control and discharge of dust particles. Therefore, it is of great practical significance to use reasonable air distribution forms or to improve the existing air distribution to further reduce the infection rate of surgery.

CFD technology is used to simulate the influence of air supply speed and air return position on air distribution during the actual operation of clean operating room[4]. It mainly includes simulating the purification effect under different air supply speed, analyzing the influence of air supply speed on the working section wind speed and pollutant concentration in the operation area, comparing the purification effect of different air return positions.

2. Design parameters

The air conditioning system in the operating room of the hospital generally adopts the whole air system[5], and its design parameters are shown in Tab 1.

| Room name | Temperature (℃) | Humidity (%) | Air volume (m³/h) | Ventilation times (times/h) | Fresh air volume (m³/h) | Exhaust volume (m³/h) | Air inlet (m) |
|-----------|-----------------|--------------|-------------------|-----------------------------|------------------------|------------------------|---------------|
| Operation room | 22-25 | 35-60 | 1800 | 22 | 800 | 300 | 2.6×2.4 |

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3. Mathematical model

3.1. Gas phase standard k-ε model control equation
The standard k-ε two equation turbulence model is used in the gas phase, which can get better overall prediction effect. For the three-dimensional field of the operating room, the general basic control equation of the gas phase is:

\[ \text{div}(\rho V \varphi) = \text{div}(\Gamma_{\text{e}} \text{grad} \varphi) + S_\varphi + S_p \]  

(1)

3.2. Control equation of particle phase dispersion model
The volume fraction of pollutant particles in the clean room is less than 10%, which is suitable for the discrete phase model. The indoor dust pollutants are described by the discrete phase model[6]. The equation of the particle's motion track can be obtained from the various external force equilibrium equations of the particle's motion in the fluid:

\[ \frac{d u_p}{d t} = \frac{18 \mu}{\rho_p d_p^2} \frac{C \text{Re}}{24} (u - u_p) + F \]

(2)

4. Physical model and simplification

4.1. Establishment of clean operating room model
Suppose the size of the operating room is 6m×6m×2.8m. The operating table with a size of 0.6m×1.4m is placed in the center of the operating room. The size of the air supply port is 2.6m×2.4m and it is located in the center of the ceiling. The size of exhaust outlet is 0.4m × 0.25m. The operating room is equipped with front and rear doors, with a 0.01m gap at the lower edge. Set the static pressure difference at the door joint to 8Pa. There are 5 medical and nursing staff in the operating room, the patient’s body size is 0.4m×0.3m×1.7m. The heat dissipation of indoor instrument is 30W. A shadowless lamp holder is placed in the middle of the air supply outlet. Two shadowless lamps are hung on both sides of the operating table, with a heat dissipation capacity of 300W[6]. The model is shown in Figure 1.

Fig.1 The model of Clean operating room

4.2. Model simplification
Considering the radiation heat transfer, S2S model is selected to simulate only the radiation between the wall and the human body[7]. In order to simplify the simulation process, the physical model is simplified and assumed as follows:

(1)The indoor air flow is incompressible constant physical Newtonian fluid, which flows in a steady state;
(2)The air conditioning in the operating room does not bring pollutants;
(3)The normal height of human body is adopted, with an average height of 1.7m;
(4)The initial value of pollutant concentration in the room is 0;
(5)The number of pollutant particles is 600/person/minute, The particle size of pollutant is 6 μm.
5. Simulation results

5.1. Velocity field

In order to present the air distribution more clearly, the velocity field at \(x=3.5\) m section is intercepted. The distribution of velocity field under different air supply speeds is shown in Figure 2.

It can be seen from Fig.2 that when the air supply speed is less than 0.35 m/s, the anti-interference ability of the air supply flow is greatly weakened, and the transverse diffusion between streamlines is large. When the air supply speed is greater than 0.35 m/s, the distribution of the velocity field is basically the same, and the air supply flow has strong anti-interference ability, which can form local unidirectional flow under the air supply outlet. Reflecting the characteristics of the mainstream area theory, it can send the clean air directly to the area that needs to be protected most, meet the requirements of high-level cleanliness with small air volume, and effectively protect the operating table area.

Figure 3 shows the distribution of velocity field at \(x=3\) m section, where there are people and shadowless lights blocking the air flow. Compared with the above figure, the clean air is disturbed under the shadowless lamp, and the protection of the key area (above the operating table) is poor. The shadowless lamp blocks the vertical downward movement of the clean air flow, and the air supply flow is disturbed under the shadowless lamp. Due to the destructive effect of shadowless lamp on one-way flow, it is suggested that when placing shadowless lamp, the medical staff should avoid the surgical incision as much as possible, and do not make the lamp cover directly above the surgical incision, so that the clean air can be sent to the upper part of the surgical incision to improve the aseptic degree of the surgical incision.
The air distribution in clean operating room is directly affected by the position of air return port. In order to make the air supply flow cover the operating table, and the air flow is not short circuited, it is required that the position of the air return outlet is not more than 0.5m above the ground, the lower end is not less than 0.1m from the ground, and the air speed of the air return flow is not more than 2m/s. According to the domestic scientific research results, when the operating room width is less than 3m, one side down return air is used, and when the operating room width is more than 3m, two sides down return air is used. When the indoor pressure allows, the return air port shall be equipped with primary or medium efficiency filter screen, otherwise, in the operation of indoor personnel and the cleaning work before and after operation, the return air may contain more hair and textile fibers, which are inhaled through the return air pipe. On one hand, it is easy for the pipe to accumulate dust and bacteria, on the other hand, the primary filter in the unit will be polluted faster. The replacement frequency of filter screen increases the maintenance cost.

Figure 4 shows the simulation results of the velocity attenuation in the operation area when the air supply speed is 0.35m/s under four types of air return outlets.

It can be seen from Fig.4 that when the air return at the lower part of both sides is long, if the air return outlets are arranged continuously, it can be seen that the air flow is relatively stable, and the air
flow is slightly violent when the air return openings are facing and the air return outlets are arranged in a staggered manner. When the four corner return air is adopted, the mixing effect of air flow is obvious. Compared with the first three cases, except for the large eddy current on both sides of the upper part, the eddy current also appears at the lower part.

5.2. Concentration field
The process of particle emission from human body is shown in Figure 5 (to show clearly, enlarge the particle). Analyze the concentration field under the air supply speed of 0.35m/s, as shown in Fig.6.

![Process of particle emission from human body](image)

Fig.5 Process of particle emission from human body

As the main indoor particle source, the concentration of particles around the medical staff is relatively high, but the particle concentration around the human body decays rapidly, and the particle concentration in the local air supply area is lower than that in the left and right of the human body. In the surrounding area, the particle concentration is only reduced to below the particle at the distance from the human body. It can be seen from Figure 6 that for the concentration field with the air supply speed of 0.35m/s, the local unidirectional flow can effectively control the diffusion of indoor pollutants and maintain the high cleanliness of the core working area.

![Particle concentration field in operating room](image)

Fig.6 Particle concentration field in operating room

6. Conclusion
In this paper, CFD is used to simulate the air distribution at different air supply speeds and different air return positions. The air flow pattern and pollutant concentration distribution in clean operating room were analyzed, and the following conclusions were obtained:

(1) When the air supply speed is greater than 0.35m/s, the air supply flow has a strong anti-interference ability, which can directly send clean air to the area that needs protection most, and use a smaller air volume to meet the requirements of high-level cleanliness, so as to effectively protect the operating table area.

(2) When the air return outlet is arranged continuously, the air flow is relatively stable; when the air return outlet adopts the four corner air return, the air mixing effect is obvious, and vortex appears on both sides of the upper part and the lower part.
(3) When the air velocity is 0.35m/s, the local unidirectional flow can effectively control the diffusion of indoor pollutants and maintain the high cleanliness of the core working area.

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References
[1] Tu G.G, Chen X.F. (2005) Simulation and experimental verification of air distribution in a clean operating room. Cleaning and air conditioning technology, 1: 63-68.
[2] NOH K C, KIM H S, OH M D. (2010) Study on Contamination Control in a Mini-environment Inside Clean Room for Yield Enhancement Based on Particle Concentration Measurement and Airflow CFD Simulation. Building and Environment, 45 (4): 825-831.
[3] Zhang H.T, Wu W.L, Xiang L.J. (2013) Application of CFD in energy saving design of electronic clean room. Refrigeration and air conditioning, 27 (6): 565-568.
[4] Li Jiuru, Li Xiang, Chen Juhui, et al. (2018) Simulation of typical air distribution characteristics in clean room. Journal of Harbin University of technology, 23 (6): 24-28.
[5] Zhou J.J, Fang G.F, Wu B, et al. (2013) Simulation and optimization of air flow pattern in vertical unidirectional flow clean room. Journal of Zhengzhou University (Engineering Edition), 34 (6): 112-115.
[6] Chen X.F. (2005) Study on airflow distribution in clean operating room of hospital. Tianjin university, Tianjin.
[7] Guo C.Y. (2006) Analysis of airflow distribution in clean operating room. Beijing university of technology, Beijing.