Simulation study on the impact of air distribution on formaldehyde pollutant distribution in room

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Abstract. In this paper, physical and mathematical model of a room was established based on the Airpak software. The velocity distribution, air age distribution, formaldehyde concentration distribution and Predicted Mean Vote(PMV), Predicted Percentage Dissatisfied(PPD) distribution in the ward of a hospital were simulated. In addition, the air volume was doubled, the change of indoor pollutant concentration distribution was simulated. And further, the change of air age was simulated. Through the simulation, it can help arrange the position of the air supply port, so it is very necessary to increase the comfort of the staff in the room. Finally, through the simulation of pollutant concentration distribution, it can be seen that when concentration of indoor pollutants was high, the supply air flow rate should be increased appropriately. Indoor pollutant will be discharged as soon as possible, which is very beneficial to human body health.

1. Introduction

Computational fluid dynamics (CFD) is based on the heat transfer, mass transfer and momentum transfer theory. In addition, it combines with a number of significant technologies, such as multiphase flow technique, combustion process and chemical reaction etc. It is applied very commonly in many fields, for example environmental engineering field, mechanical field, thermal energy and power field, aerospace field and chemical field. What’s more, the field of heating, ventilation and air conditioning is one of the important application field. We can use CFD technology by establishing mathematical model and setting reasonable boundary conditions and related parameters to simulated airflow distribution in certain space [1].

However, the software Airpak is further developed on the basis of the FLUENT software. Compared with Fluent software Gambit in modeling, Airpak software is very convenient for modeling and it provides wall, staff, tuyere and tables and chairs and other modules. Different modules can also be set the corresponding parameters according to the actual situation [2].

In the grid division for Airpak software, it is also based on the Fluent software processor and the grid contains also a variety of shapes. For the two-dimensional flow model, it can be set for both rectangular and triangular form grid. For three-dimensional flow model, it can be set into a triangular prism, tetrahedron and hexahedron mesh. At the same time, it also provides encrypted setting function of the model. The important modules can be targeted encrypted in order to make the results more accurate. Equations can be selected based on the flow state correspondingly. For the turbulent flow model, zero equation model, indoor zero equation model, two equation model can be chosen to
calculate. The calculation result of Airpak can also be used with Tecplot postprocessing software for further processing. Flow chart of the Airpak calculation process is shown in Figure 1.

![Airpak calculation flow chart](image)

**Figure 1.** Airpak calculation flow chart.

Through the detection of different types of indoor pollutant concentration, indoor air pollutants have a great effect on human comfort. Indoor air quality becomes more and more poor and it is high time to take certain measures to improve the indoor air quality for our health.

Indoor air quality (IAQ) is defined in a specific environment, some elements of people's life and work suitability in the air. It is a concept which reflects the specific requirements of people. How to evaluate the quality of the indoor environment is one of the main problems that people concerned [3]. It includes indoor air temperature, humidity, air freshness and cleanliness and so on.

In recent years, due to the popularity of air conditioning system in modern architecture and improvement in the airtight construction, the indoor harmful gas can’t be discharged. The carbon dioxide emissions increased, resulting in air conditioning disease, Sick Building Syndrome (SBS) and other sub-health states [4]. Now, the research of indoor air purification has become one of the most concerned problems in the world [5]. Further research and discussion on the influence of indoor air quality on human health is very important.

Formaldehyde, a kind of popular indoor air pollutant, is an endogenous chemical. It could cause human asthma and syndrome like asthma. Formaldehyde is the main pollutant after the room decoration [6].

In this paper, taking one of the room for an example, three dimensional model was established for the ward. The computational domain was determined for the numerical model and boundary conditions were set. And then, turbulence model was selected and the division of grid was done. In the end, the indoor airflow distribution in the ward can be simulated by calculating with computer. And further by importing formaldehyde pollutant diffusion model, the pollutants distribution in the ward was simulated. Through the simulation study, it provides references for ventilation scheme selection and ventilation system design in order to improve indoor air quality in the room.

2. Air flow simulation in the room

2.1. The establishment of the numerical model

Because various boundary conditions can be set, when the numerical simulation model was built, a representative room can be selected as the calculation model instead of calculating the whole building. Thereby, on the one hand, it reduces the complexity of modeling work. On the other hand, it also improves the accuracy of the model calculation and computing speed [7].

Numerical model was set up by using Airpak software, the detail parameters are listed as follows:

1. The model is a standard room which contains two beds and a small bathroom in the room. Length, width and height of the ward were 5.3 meters, 3.6 meters, 3.6 meters respectively. The length, width and height of toilet were 2.1 meters, 1.5 meters, 1.5 meters respectively. The thickness of the outer wall was 0.24 meter and the thickness of the inner wall was 0.09 meter. The length, width and height of the coffer were 0.5 meter, 0.4 meter, 0.4 meter and the bed 2 meters, 1 meter, 0.63 meter.

2. To establish a coordinate system: the width of the room acts as the X axis right direction, the length of the room being the Y axis right direction and the height of the room being the Z axis right direction.
(3) Both the air supply outlet and exhaust outlet adopt opening model. The entrance of air supply outlet is set to speed type and the exhaust outlet being pressure type. The air supply outlet sends the air from the roof and exhaust outlet also exhausts the air from the roof.

(4) It was assumed that the wall of the room was adiabatic.

(5) The indoor zero equation (the indoor zero equation) model was chosen so as to calculate more accurately. In this paper, calculation domain of a typical room was shown in Figure 2.

![Figure 2](image1.png)  
**Figure 2.** Model of the typical ward.

![Figure 3](image2.png)  
**Figure 3.** Grid of model.

2.2. Calculation of the numerical model

In order to make the computing grid more homogeneous and the calculation result more accurate, the parameters were set as follows: The minimum number of calculation grid for solid boundary was set to 2. Maximum size of the X axis direction is 0.18. The maximum size of the Y direction is 0.18. Maximum size of the Z axis is 0.265. At the same time, the air supply outlet and exhaust outlet were encrypted processing. Through the calculation of Airpak, the grid can be gotten as shown in Figure 3.

3. Analysis of the numerical simulation calculation results

3.1. The velocity distribution

![Figure 4](image3.png)  
**Figure 4.** Velocity distribution cloud map of different cross sections.
Because the height of the bed is 0.63 m, when the patient laid in bed, breathing area is around 0.65 m high from ground in the Y right direction. Therefore, researching on the distribution of the velocity field can be more accurately analyzing personnel comfort [8]. In addition, when people stand, the height of person's breathing zone was between 0.8m and 1.5m. The analysis and calculation of velocity field in this height can be very necessary. So in this article take $Y = 1.2$ m and $Y = 1.5$ m to analyze the velocity field. Therefore, take $Y=0.65m$, $Y=1.2m$, and $Y=1.5m$ three cross section separately to analyze velocity field and the results were shown in Figure 4.

From the Figure 4, in the $Y=0.65m$ section, wind speed was lower than 0.089m/s. Especially in the area in the upper part of the both sides of the bed, whose speed was within 0.03 m/s. Because the wind speed was small, people won't feel a sense of blowing. In the $Y=1.2m$ section, wind speed was within 0.098 m/s. In the corridor between the two beds, air velocity was slightly larger than that of the upper part of the bed and the maximum speed was 0.098m/s. Because the speed was not big, people won't feel a sense of blowing. In the $Y=1.5m$ section, the speed was within 0.127m/s and the speed of under the air diffuser was larger than the other area in the same height. The wind speed reached 0.127m/s and the researchers also won't feel the sense of blowing [9].

3.2. The air age distribution in room

Indoor air age refers to the time when air particles enters the room and reaches certain point of the room, which is the time of old air being replaced by new air. Air age, therefore, not only can reflect the freshness of the indoor air but also can response the ventilation effect of each point in the room. Age of indoor air can be used to evaluate the pros and cons of air distribution in the room [10]. Air age has a direct relationship with the air quality of breathing. In order to be able to form bright contrast, we selected three different cross sections to calculate. They were $Z = 0.7$ m, $Z=2.65m$ and $Z=4.6m$ respectively. The $Z=0.7m$ section is near the door on the side of the center of the bed, $Z=2.65$ m is the center of the room and $Z= 4.6m$ section is far away from the door on the side of the center of the bed. The air age distribution in room was shown in Figure 5.

![Figure 5](image.png)

**Figure 5.** The cloud map of indoor air age distribution in different sections.

From the Figure 5, in $Z=2.65m$ section, air age near the air supply outlet was minimum and the value was 0. The air at here was fresh, which points out that the reliability of the result [11]. As can be seen from the diagram, the air age value on the side of the bed near the door was greater than that of far away from the door on the side of the bed. Age of air at the end of the bed was maximum in the area. At $Z=2.65m$ section, maximum air age was 1561.110s. It showed that the pollutant concentration was larger here and phenomenon of pollutants gathering was more serious. Therefore, people should not stay in the area for a long time.
3.3. The formaldehyde pollutant distribution in room

From the Figure 6, along the height direction of the room, pollutants concentration continuously reduced. Pollutants spread from the diffusion source to outward and the concentration also gradually reduced. Pollutant dispersion origination concentration reached 0.855 mg/m³. Due to the less time of air supply volume, the lowest concentration of pollutants concentration in the whole room also reached as high as 0.836 mg/m³. Therefore, it needs to take a breath by ventilation for a long time in order to realize the aim to eliminate pollutants and reach the limited values of indoor pollutant concentration [12]. As to the patients, it is suggested that the farther the pollutant source, the better for the health.

3.4. Distribution of Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) in room

Thermal comfort index PMV and PPD are the subjective feeling of thermal environment. PMV index represents the cold and hot feeling of the majority of people in the same environment. So PMV evaluation index can evaluate the human body’s comfort or not. But usually as a result of great difference in human physiological and psychological aspects, the PMV index only is not comprehensive, which does not reflect the extent of each person’s hot and cold feeling and comfort. Therefore Predicted Percentage of Dissatisfied (PPD) was put forward to indicate the percentage of dissatisfied with thermal environment.

PMV index adopted 7 level degrees, as shown in Table 1.

| thermal sensation | hot | warm | slight warm | moderate | slight cool | cool | cold |
|-------------------|-----|------|-------------|----------|-------------|------|------|
| PMV value         | +3  | +2   | +1          | +0       | -1          | -2   | -3   |

According to IS07730 standard, PMV, PPD indexes were given the recommended value, namely the PMV value should be between 0.5~+0.5. But it was allowed to have 10% of people still feeling not
satisfied with comfort of indoor thermal environment. By calculating, the distribution of PMV and PPD were shown in Figure 7 and Figure 8.

From the Figure 7 and Figure 8, in Y=0.65m, Y=1.2m, and Y=1.5m three cross sections, PMV index is in the range of -0.5~ +0.5, so under this condition, thermal sensation of the indoor personnel was between moderate and micro warm and comfort level is higher. But by comparison, when the patient lay in bed, it was closer to moderate level. At this time personnel comfort was better than that of the personnel standing. It is suggested that the patient should lay in bed for the health.

PPD index was less than 10% in different cross sections. It proved that the environment temperature and wind speed were suitable for people's life [13]. With the increase of height, personnel dissatisfaction percentage also increased gradually. When the patient lay in bed, the dissatisfaction percentage was lower than that of standing. It also proves that the PMV and PPD have some relationship in evaluating the personnel comfort. And it further verifies the correctness of result.

![Figure 7. PMV distribution cloud map in different cross-sections.](image)

![Figure 8. PPD distribution cloud map in different cross sections.](image)
4. Summary
In this paper, physical and mathematical model of a room was established with the the Airpak software. The velocity distribution, air age distribution, formaldehyde concentration distribution and PMV, PPD distribution in the ward of a hospital were simulated. Through the simulation, it can help arrange the position of the air supply port, so it is very necessary to increase the comfort of the staff in the room. Finally, through the simulation of pollutant concentration distribution, it can be seen that when concentration of indoor pollutants was high, the supply air flow rate should be increased appropriately. Indoor pollutant will be discharged as soon as possible, which is very beneficial to human body health.

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