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Simulation of Airflow Organization in Medical Cabin Based on Simplification Model of Orifice Plate Supply

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Abstract. To improve the air environment of the ship's medical cabin, A series of experiments and numerical stimulations were carried for the research on the medical cabin's indoor air quality. By changing the opening rate, the different schemes of the full orifice air supply and the partial orifice air supply are compared about indoor air distribution and thermal comfort . The result shows that the full orifice air supply is better than the partial orifice air supply, and reducing the opening rate is more helpful to improve the indoor airflow under the full orifice air supply.

Introduction

With the deepening of the development of marine resources, the requirements the crew's health are also increasing, especially for the medical compartment environment requirements are further improved[1]. Reasonable airflow organization is an important guarantee for a good indoor environment[2]. The US CDC proposed two airflow organizations suitable for use in medical wards, which in the ceiling evenly arranged a number of air outlet, in the vicinity of the floor was exhaust popular [3]. ZHAO Bin et al. simplified the boundary conditions of numerical simulation of orifice air supply. They use STACH-3 to simulate the scheme, obtained the simulation results which are consistent with the experimental data of the actual air supply, and proposed the "N-point orifice momentum model" [4]. Zhao Lei et al. simulated the air flow in the cold storage of the ship by CFD, and use the physical library to verify a good preservation effect [5]. Through the relevant literature can be seen, the orifice air supply has a lot of research and application, but its research in the ship medical cabin is relatively less. Numerical simulation of the airflow in the medical compartment with orifice air supply was done and reasonable air supply scheme was given to provide reference for the design and application of the orifice air supply in the ship medical compartment.

Experimental

Experiment model. In order to verify the rationality of the model of the orifice air supply, the temperature distribution test of the whole orifice air supply was carried out in the artificial engineering laboratory of HEU. Experimental room size 4.8m × 3.3m × 2.8m, the outlet for the louver, the size of 0.6m × 0.4m, indoor measuring point layout is shown in Fig.1. The experimental room was simplified in order to facilitate the numerical simulation. There are 48 air inlets in this laboratory. Each four blocks are simplified as a square inlet, totaling 12.The aperture length of model 1, 2, and 3 are 3cm, 5cm, 10cm, the room simplified model is shown in Fig.2.

Boundary conditions. Entrance boundary conditions: air supply volume of 1600m^3 / h, air supply temperature of 24 °C. Exit boundary conditions: the effective area of the return air outlet is 0.6, set to pressure outlet boundary conditions, outdoor pressure is 0 Pa. Wall boundary conditions: the external walls and floors are given the first type of boundary conditions, the external walls and external windows of the temperature were 20.3 °C and 19 °C. Fluorescent cooling 40W, computer chassis heat 60W.

Mathematical model. The mathematical model uses $k-e$ equation model with high reliability for air flow and heat transfer problems during air conditioning and ventilation. The general control equation is shown in Eq. 1.

$$\frac{\partial(rf)}{\partial t}+\operatorname{div}(r\boldsymbol{U}f)=\operatorname{div}(G_f\,\mathbf{grad}f)+S_f \tag{1}$$

Where f is Generic variable, u, v, w, T are Solve variables, G_f is Generalized diffusion coefficient, S_f is Generalized source terms.

Fig.1 indoor measurement site layout

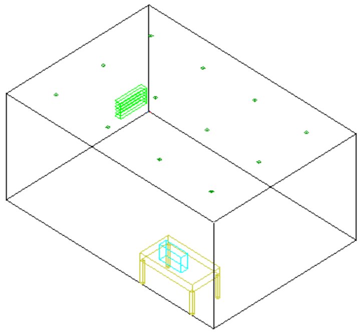
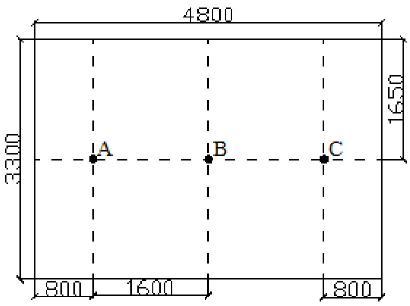
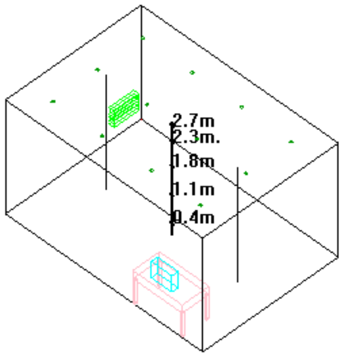


Fig.2 simplified room model

Experimental verification. There are three test tree A, B and C in the artificial environment laboratory. Each tree is arranged five measuring points, measuring points arranged as shown in Fig.3. This experiment was carried out in winter conditions, the temperature test using PT100 thermal resistance temperature sensor which the accuracy of is 0.1 °C, the data collector using the Agilent. The air volume is 1600m^3 / h, the air supply temperature is 24 °C.



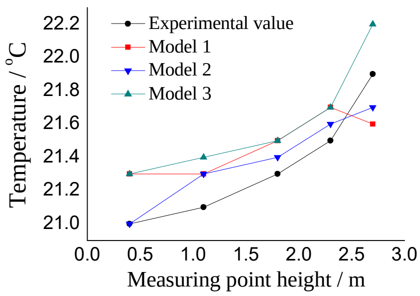
(a) layout of measuring points



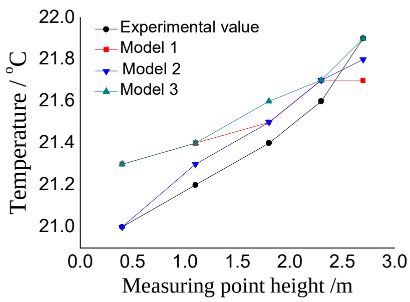
(b) axonometric of measuring points

Fig.3 arrangement plan of measuring point

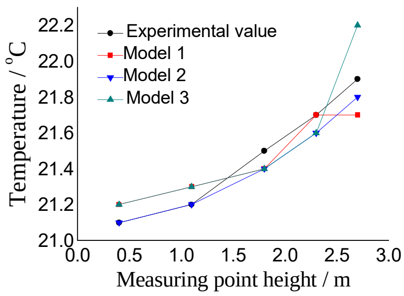
After the three models are verified by grid independence, the accurate results can be obtained when the number of meshes is about 1 million. The simulation results of the measuring point temperature are compared with the experimental values, as shown in Fig.4.



(a) Tree A



(b) Tree B



(c) Tree C

Fig.4 Comparison of temperature points

The simulated results of each tree were almost the same as the experimental results and the gradient change was almost coincident. The errors of model 1, 2 and 3 are 19.26%, 9.63% and 20.74%. Then the smallest error of model 2 with 5cm × 5cm inlet was selected as the simplified model.

Numerical simulation of medical cabin

Medical cabin model. The cabin is a 4.3m × 2.1m × 4.5m (length × width × height) cuboid crew medical cabin, the rear bulkhead adjacent to the outside, there is a porthole (not open), the front compartment and corridor adjacent, the upper and lower , The left and right bulkheads are adjacent to the air conditioning compartments. The room has three main areas: the patient living space, the bathroom and storage space. This paper will focus on the distribution of airflow in the patient living space. The medical compartment model room simplified model is shown in Fig.5.

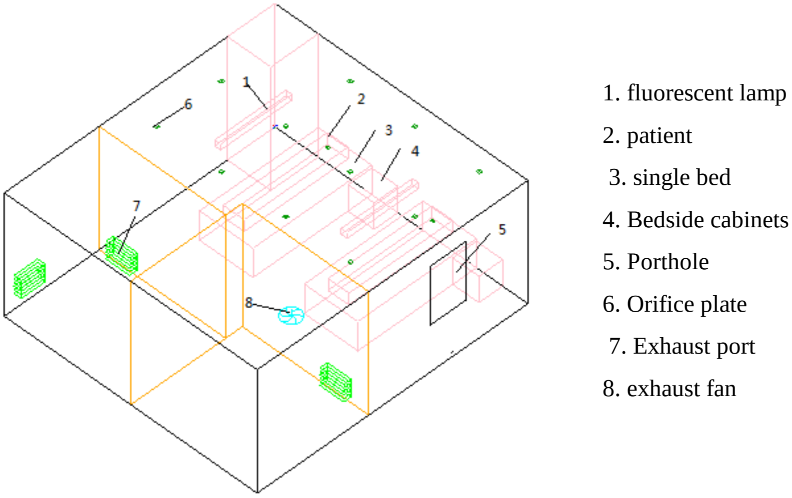


Fig.5 Medical compartment model

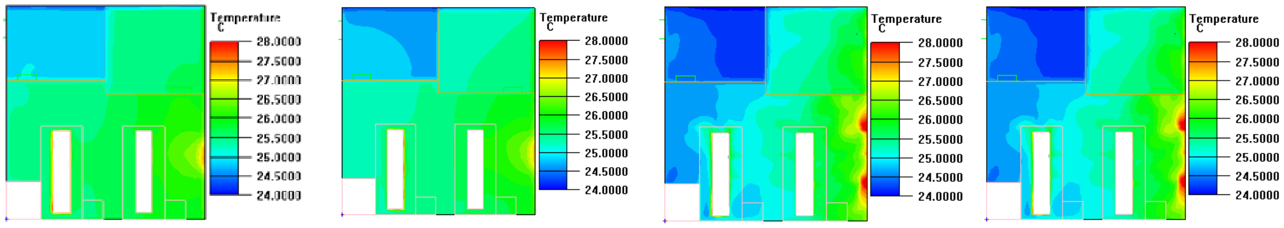
Boundary conditions. Entrance boundary conditions: air supply air volume of 240m^3 / h, air temperature of 22 °C, the CO_2 concentration of 300ppm. The rate of CO_2 exhalation is 0.005 L / s and the concentration is 500 ppm in the mouth of the person. Exit boundary conditions: the effective area of the return air outlet is 0.6, set to pressure outlet boundary conditions, outdoor pressure is 0Pa. Wall boundary conditions: rear bulkhead heat flux density of 17.7W / m^2, porthole located in the rear bulkhead heat flux density of 477.6 W / m^2, the former bulkhead and corridor communication, heat flux 1.8 W / m^2. Fluorescent cooling of 40W, staff cooling of 55W.

Simulation results and analysis. The air chamber of the medical cabin with full orifice air supply and partial orifice air supply was simulated and analyzed. According to the different porosity, the advantages and disadvantages of different schemes are compared. Orifice air blowing hole rate is best between 0.2% to 5%, according to the room roof size and simulation of the feasibility: The full orifice air supply is 0.23%, 0.50%, 0.85% and 1.88%. The partial orifice air supply is 0.56%, 0.83%, 1.11% and 1.39%.The main research environment is the surrounding of the patient, so the cloud map are selected body center section y = 0.6m, and each of the evaluation indexes was selected by analyzing the mean value of the surroundings and the mean value of the room.

The indoor temperature distribution of each scheme is shown in Fig.6 and Fig.7. It can be seen that in the full air supply of the orifice, with the increasing of opening rate, the temperature around the human body and the indoor average temperature Show a decreasing trend. When the porosity is 0.23%, the ambient temperature is 25.89 °C, and the indoor temperature is the closest to the design temperature. In the partial orifice air supply, the temperature first increased and then reduced. When the porosity is 0.83%, the temperature is best. According to the opening rate from small to large, the average indoor temperature of the full orifice air supply is 25.53 °C, 25.48 °C, 25.14 °C and 24.72 °C, the indoor average temperature of the partial orifice air supply is 25.45 °C, 25.96 °C, 25.53 °C and 25.50 °C. In the two different air supply forms, the indoor temperature of the partial orifice is higher than that of the full orifice, and is closer to the design temperature. In general, When the full orifice air supply is 0.23% and the partial orifice air supply is 0.83% ,the indoor temperature distribution is better than that of the other schemes.

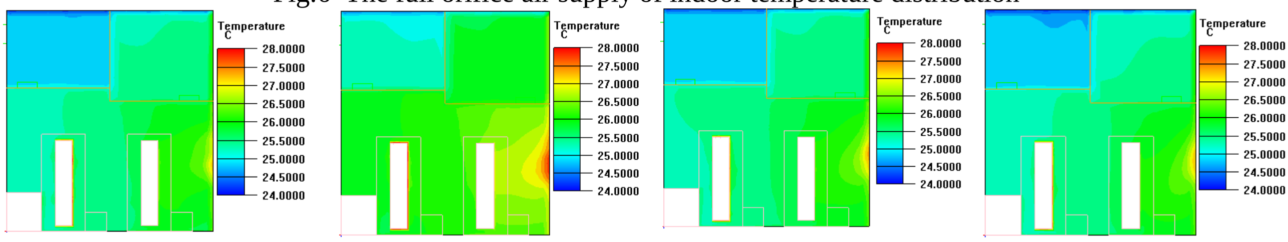
The PMV distribution of each scheme is shown in Fig.8 and Fig.9. It can be seen that indoor average PMV values are between -0.1 and 0.1. Although in the local area appears high or low, the whole area is within the comfort range. According to the opening rate from small to large, the PMV of the full orifice air supply is 0.19, 0.25, 0.24 and 0.04. The PMV of the partial orifice air supply is 0.13, 0.28, 0.13 and 0.14. For the full orifice air supply, PMV basically consistent, perforation rate of 0.23%, the human body around the PMV more uniform, better human comfort. When the opening rate of 0.23%, the body around the PMV more uniform, better human comfort. For the partial orifice, the PMV around the human body changes greatly with the increase of the porosity, and the porosity of 0.83%, which is more comfortable than the other three schemes.

The CO_2 concentration of each scheme is shown in Fig.10 and Fig.11. It can be seen that the overall CO_2 concentration in the two air supply forms is lower than the concentration limit specified in the specification. And the dilution effect of indoor pollutants is good. According to the opening rate from small to large, the CO_2 concentration of the full orifice air supply is 0.19, 0.25, 0.24 and 0.04. The CO_2 concentration of the partial orifice air supply is 0.13, 0.28, 0.13 and 0.14.The indoor CO_2 concentrations is about 317ppm, and it’s clean. Only the full hole orifice blowing rate of 0.85%. The human head CO_2 concentration is higher than other programs. When the full orifice air supply is 0.23% and the partial orifice air supply is 0.83% . The indoor temperature distribution is better than that of the other schemes.



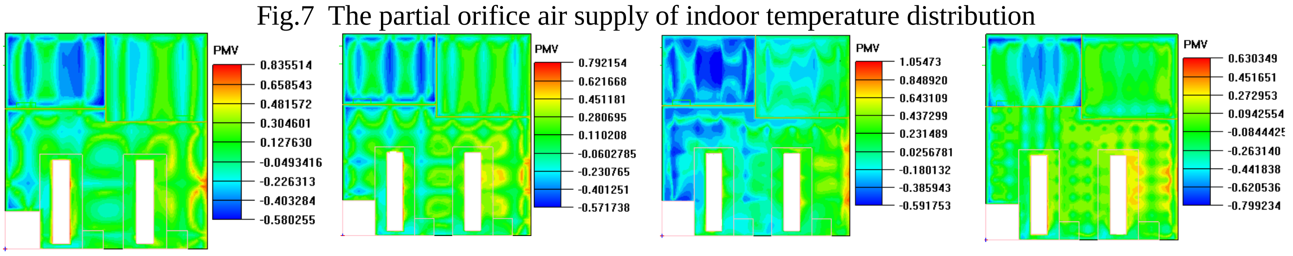
(a)0.23% (b)0.50% (c)0.85% (d)1.88%

Fig.6 The full orifice air supply of indoor temperature distribution



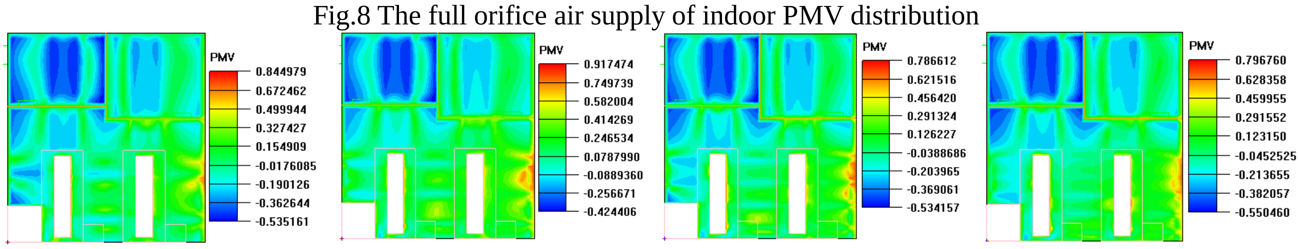
(a)0.56% (b)0.83% (c)1.11% (d)1.39%

Fig.7 The partial orifice air supply of indoor temperature distribution



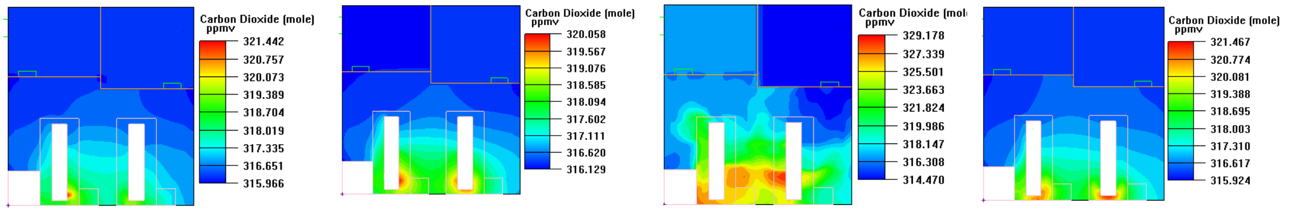
(a)0.23% (b)0.50% (c)0.85% (d)1.88%

Fig.8 The full orifice air supply of indoor PMV distribution



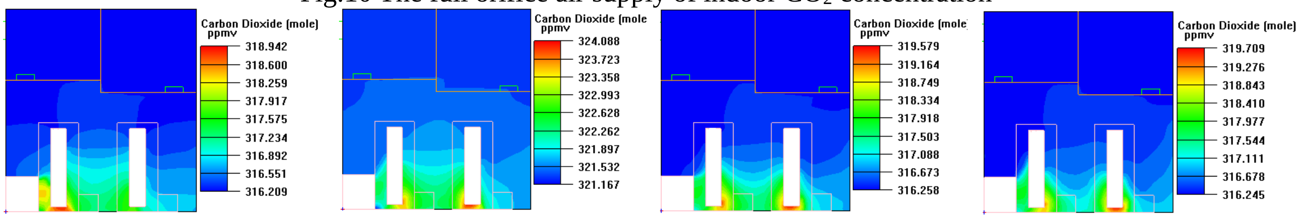
(a)0.56% (b)0.83% (c)1.11% (d)1.39%

Fig.9 The partial orifice air supply of indoor PMV distribution



(a)0.23% (b)0.50% (c)0.85% (d)1.88%

Fig.10 The full orifice air supply of indoor CO_2 concentration



(a)0.56% (b)0.83% (c)1.11% (d)1.39%

Fig.11 The partial orifice air supply of indoor CO_2 concentration

Comprehensive evaluation. The object of this paper is ship's medical cabin, So pay more attention to the air supply on the indoor pollutant dilution effect and indoor air freshness. The temperature, PMV and CO_2 concentration were evaluated by AHP. The weights of the three evaluation indexes were 0.17, 0.33 and 0.50 respectively. After the comprehensive evaluation of the eight programs, the weight of 0.1429, 0.1278, 0.1078, 0.1291, 0.1296, 0.1254, 0.1323 and 0.1076. The calculations proves that the optimal scheme is the full orifice air supply with a porosity of 0.23%. followed the partial orifice air supply with a porosity of 1.11%.

Conclusions

A series of experiments and numerical stimulations were carried for the research on the medical cabin's indoor air quality. Some conclusions can be obtained:

(1) When the air supply boundary condition is simplified for the orifice air supply model, simulation with a number of 5cm × 5cm inlets arranged is closer to the actual situation.

(2) The indoor temperature distribution, PMV distribution and CO_2 concentration are better than those of the other schemes when the full orifice air supply is 0.23% and the partial orifice air supply is 0.83%.

(3) By the AHP method, eight kinds of air supply schemes were evaluated synthetically. Considering the temperature, PMV and CO_2 concentration, the best way to air supply is the full orifice air supply with a porosity of 0.23%.

Acknowledgements

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