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Simulation and Optimization of Indoor Thermal Environment in a Ship Air-conditioning System

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Abstract

Crew's health and productivity is strongly affected by cabins' thermal environment. This paper focuses on the numerical simulation of the indoor thermal environment in air-conditioned vessel cabins. The original air-conditioning system of the cabin was analyzed. Three modified air-conditioning systems with different air-supply outlet locations and under-supply air-conditioning system were put forward for optimization. Air temperature, air velocity and PMV distribution were discussed under Airpak simulation. The results show that under-supply air-conditioning system has good performance with little eddies and can contribute to energy saving. Indoor air temperature with under-supply air-conditioning system was 2~4℃ lower than that with original air-conditioning system, leading to lower predicted mean vote (PMV) .

Keywords: Ship air-conditioning; thermal comfort; energy saving; PMV

1. Introduction

Good environment is important for ship crews to work with high efficiency and clear mind. Air-conditioning system, the essential equipment in ships nowadays, plays an important role in providing comfortable and healthy cabin environment for crews and passengers. Different air distributions have different air temperature field and different velocity field, which are two main factors affecting occupants' thermal comfort [1]. Environmental chamber experiment [2] shows that occupants can endure relative high velocity when temperature is high, and prefer low velocity during cool environment. So for indoor working zone, comfortable air velocity varies with air temperature. Reference [4] presents that air temperature and humidity can be increased when air velocity becomes higher, which can decrease energy consumption of air-conditioning system.

The efficiency of air distribution contributes greatly to improving indoor thermal environment. With CFD simulation, Xuli[3] studied the effects of three air distributions(up-supply up-return, side-supply side-

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return and displacement ventilation) on indoor thermal comfort and concluded that displacement ventilation can provide working zone with good air quality and thermal comfort. Due to the lack of research on thermal environment in vessel cabins, the purpose of this paper is to study the thermal environment in air conditioned cabins with Airpak simulation, based on predicted mean vote (PMV). A simulation model was established for an air conditioned cabin. The original air-conditioning system of the cabins was analyzed. Three modified air-conditioning systems with different air-supply outlet locations and under-supply air-conditioning system were put forward for optimization were put forward and compared for optimization.

2. Cabin Simulation Model

2.1Model Description

The cabin model, with the dimensions of 4m×3m×2.5m high, is based on a commercial cabin of "Luojiashan" ship from Shanghai to Putuo Mountain, seen in Fig.1. The wall with circular window is the only external wall. In simulation, solar heat gain through this wall and window was taken into consideration. The other walls are interior walls. Size values of all objects in simulation model are real.

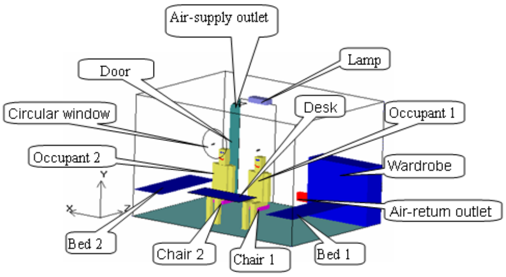


Fig.1 Diagram of Cabin Simulation Model

Airpak software can be applied to simulate air flow, air quality, heat transfer, pollutant concentration and thermal comfort of ventilation systems[5,6]. The boundary conditions of cabin simulation model were set as follows.

External air parameters are set based on measured values, $t_o = 31.8℃$, $\varphi_o = 78.2\%$, $v_o = 3.36 m/s$.

Inlet boundary conditions: inlet velocity $v = 2m/s$, turbulent kinetic energy k=0.002, energy dissipation rate $\varepsilon = 0.0008$.

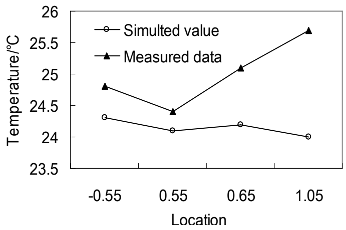
Outlet boundary conditions: outlet pressure is atmospheric environmental pressure, k and ε are freely slippy.

Wall boundary conditions: interior walls are adiabatic. Third boundary conditions are applied for external wall and window. Heat transfer coefficient for external wall is $K_1 = 0.8W/m^2 \cdot ℃$, for interior window side is $K_2 = 1.0W/m^2 \cdot ℃$, and for external window side is $K_3 = 3.5W/m^2 \cdot ℃$.

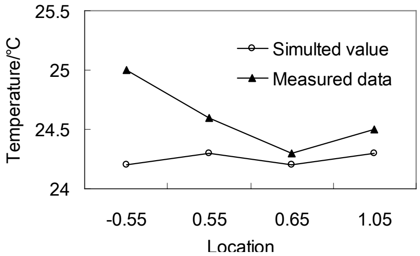
Inside heat gain is mainly based on occupants' number, 115W/person.

2.2Model Verification

In order to assure the model accurate, averaged measured data and simulated values are compared, seen in Fig. 2. In field investigation, every point was measured three times. From Fig.2, measured data are larger than simulated values. But the error is within 10%, so the model and the simulation are reliable.



a） 0.2m above floor



b） 0.8m above floor

Fig. 2 Comparison of measured data and simulated values

3. Indoor Thermal Analysis

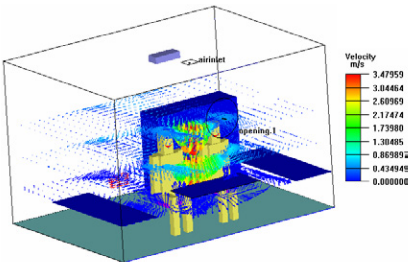
3.1Original Air-conditioning System

The original air-conditioning system of the cabin was ceiling-supply and down-side-return. The simulation results of indoor thermal environment were presented in Fig.3.

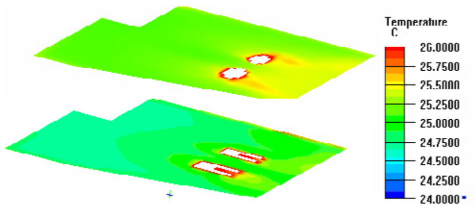
From Fig.3, we can conclude that there is no apparent short circuit of air flow for this sysytem. The air temperature in working zone is about 25℃. The zone vertically below the air-supply inlet has the low temperature, which leads to low, even negative PMV. Occupants feel a little cold. Three modified air-conditioning systems with different air-supply outlet locations were put forward and compared with the original air-conditioning system to optimize the results.

3.2Modified Air-conditioning System

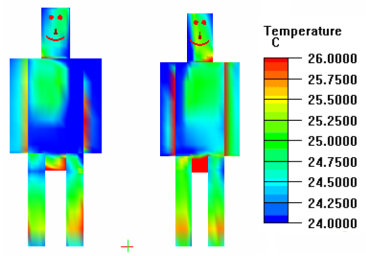
In reference [1], it is pointed out that the parameters mainly include the air-supply outlet type, number, location, air-supply temperature and air-supply velocity. Because there is only one air-supply outlet in this research, the following parameters, the variation of air-supply outlet and air-return outlet location, air-supply temperature and air-supply velocity, are investigated. Table 1 is the parameters of modified air-conditioning systems. The simulation results are provided in Fig.4.



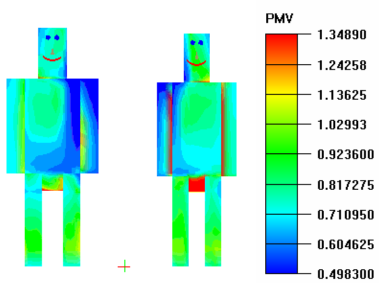
a） Velocity distribution of cross section Y=0.5, 1.0, 1.5



b） Temperature distribution of cross section Y=-0.5, 1.0



c)Temperature distribution of occupants



d) PMV distribution of occupants

Fig.3 Simulation results of original air-conditioning system

Table 1 Modified Air-conditioning Systems

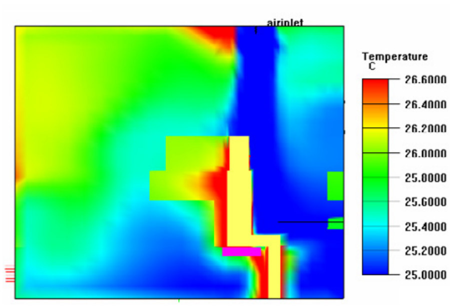
	First modification	Second modification	Third modification
Air-supply outlet location / m	（+0.5,0,0）	（+0.5,0,-0.2）	(0,0,-0.2)
Air-return outlet location / m	(0,0,0)	(-0.2, 0 ,+0.2)	(-0.2, 0 ,+0.2)
Air-supply temperature / ℃	17.5	17.0	18.5
Air-supply velocity / m3/s	0.85	Y 0.85,Z 0.85	Y0.85 X0.85
Air-supply velocity direction	Vertically down	30°from Y to Z	45°from Y to X

Note: Location coordinates of air-supply outlet and air-return outlet are deviation vectors from original air-supply location.

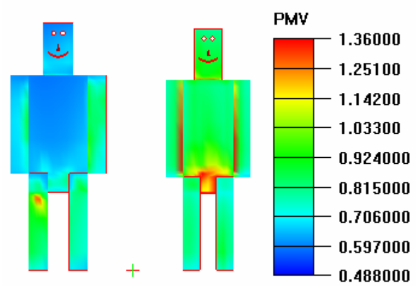
For temperature distribution, the fluctuation is the smallest for the second modification. The improvement is apparent beside desk, chair and bed. The temperature is higher for third modification than other two modifications.

For PMV distribution, the second modification has the best performance. PMV beside occupants' legs is too high for third modification.

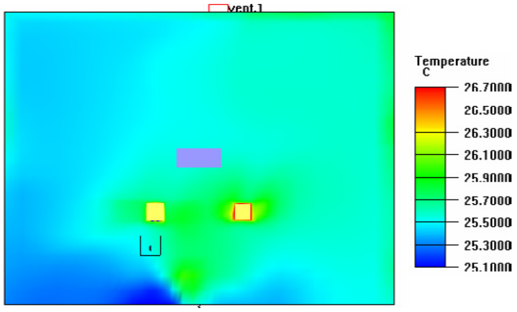
As to temperature distribution, velocity distribution and PMV distribution, the second modification is the most reasonable in three modified air-conditioning systems. Although it can be basically provided in original air-conditioning system, thermal comfort can be further improved though modification of air-conditioning system.



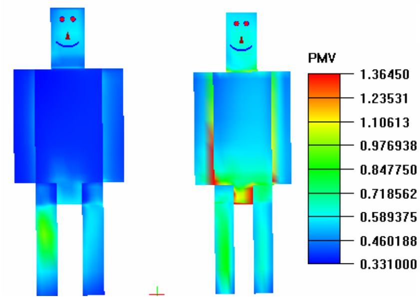
a) Temperature distribution of YZ cross section, First modification



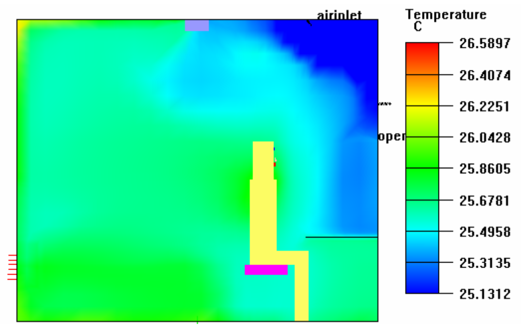
b) PMV distribution, First modification



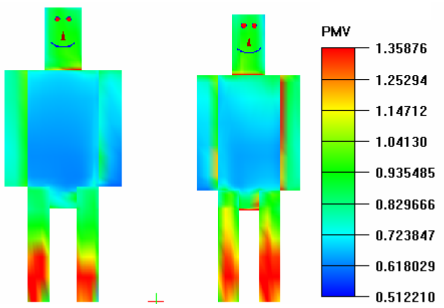
c) Temperature distribution of XZ cross section, Second modification



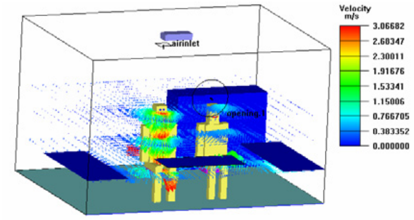
d) PMV distribution, Second modification



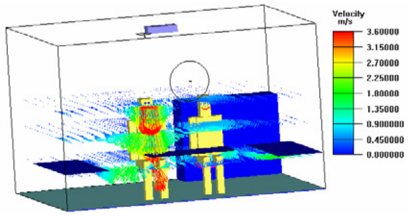
e) Temperature distribution of YZ cross section, Third modification



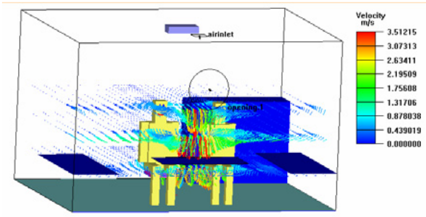
f) PMV distribution, Third modification



g) Velocity distribution, First modification



h)Velocity distribution, Second modification



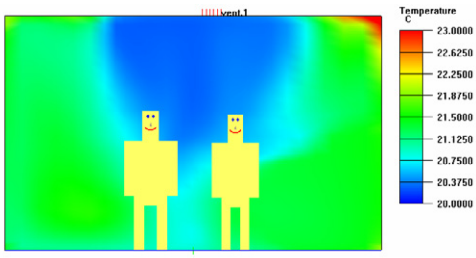
i) Velocity distribution, Third modification

Fig.4 Simulation results of modified air-conditioning system

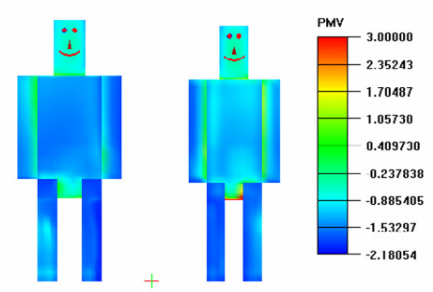
3.3Under-supply Air-conditioning System

The air-supply outlet in original system was set as air-return outlet in under-supply system and the air-return outlet in original system was set as air-supply outlet in under-supply system. In under-supply system, air-supply parameters were kept as same as those in original system. The simulation results are presented in Fig.5.

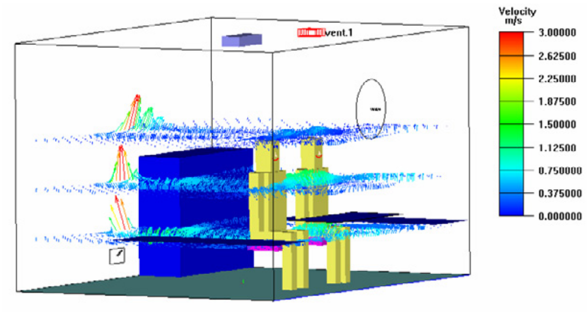
From Fig.5, Indoor air temperature with under-supply air-conditioning system was 2~4℃ lower than that with



a) Temperature distribution, under-supply system



b) PMV distribution, under-supply system



c) Velocity distribution, under-supply system

Fig.5 Simulation results of under-supply air-conditioning system

original air-conditioning system and three modified systems, leading to lower predicted mean vote (PMV). So the air-supply temperature can be elevated to a higher value to ensure both thermal comfort and energy-saving. Also, there is little eddies for velocity distribution. However, there is a problem of dust for under-supply system because air-supply outlet is located near the floor.

4. Conclusion

In this paper, the thermal environment of an air-conditioned ship cabin is simulated and analyzed with Airpak software. A simulation model was set up and verified. Through modification of air-supply outlet and air-return outlet location, air-supply temperature and air-supply velocity, the thermal comfort can be improved to some extent. Under-supply air-conditioning system has best performance, Indoor air temperature with under-supply air-conditioning system is 2~4℃ lower than that with original air-conditioning system and three modified systems, leading to lower predicted mean vote (PMV). So the air-supply temperature can be elevated to a higher value to ensure both thermal comfort and energy-saving.

Acknowledgment

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