Simulation of indoor pollutant diffusion concentration field in passive house based on CFD software

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Abstract. Due to the good air tightness of the passive house, once there are poor quality furniture materials in the room, it is easy to cause indoor formaldehyde pollution which do harm to people's health as well as the quality of their life. This article introduces the CFD software to simulate the change of indoor formaldehyde concentration in the passive house when opening the fresh air system to ensure indoor air quality and to employ a new way to the better quality of life of residents. The function of CFD software and two fluid dynamics control equations are introduced in the essay, and the finite difference method of control equation discretization is studied as well. Based on CFD software, the case is analyzed, under which the indoor formaldehyde concentration changes, according to different fresh air system inlet locations. The simulation results show that when the two air outlets of the living room are on the side of the sofa and TV cabinet, and the air outlet of the bedroom is in the corner, the formaldehyde purification rate is better, which a more reasonable air supply method is.

1. Introduction
Passive house is a kind of comfortable low-energy building, which generally does not open windows for ventilation, but uses the fresh air system with heat recovery for indoor and outdoor air exchange [1-3]. Generally, the indoor furniture in the hardbound passive house community is better, and the pollutants released by the furniture are smaller, but like the ordinary rough house in the ordinary small area, the owner of the house is transformed into the passive house by himself, Although the conditions of the fresh air system can meet the indoor comfort during the design, because the purchased furniture is not so good, it may not be considered whether the pollutants released by the furniture can be quickly purified under the fresh air conditions [4-6]. Based on this, this paper analyzes the one unit type of the passive house reconstructed by itself [7].

Dhunny A Z evaluated the performance of some famous CFD software. The Reynolds averaged Navier Stokes (RANS) equations in turbulent region are solved by standard k - model. The simulation results are verified and compared with the actual measurement results. For more complex rough terrain, WindSim gives more accurate results than open foam [8]. Li J has developed two kinds of visualization information graphs. The data cloud directly shows the influence of passive space on the main building space. The results show how the indoor environment of the building can effectively provide the required level of living comfort and quality of life [9]. Wang D designed a new type of double turbo hydraulic torque converter through CFD software simulation analysis, and determined the efficiency under different speed ratios. The simulation results verify the correctness of the proposed theory [10].
In this paper, CFD software is mainly used to study the indoor pollutant diffusion concentration field of the simulation passive house. First, through the analysis of the characteristics of CFD software and the control equation of fluid mechanics, the paper designs a renovation project of a passive house in Anhui Province, then uses CFD software to simulate the indoor pollutant diffusion concentration field of the passive house, analyses the indoor pollutant formaldehyde concentration under different fresh air positions, so as to provide information for improving the indoor air quality through the simulation of these pollutant diffusion concentration field.

2. Proposed Method

2.1. CFD Software

CFD is the abbreviation of computational fluid dynamics. It is a method to solve hydrodynamic problems by using computer technology. A computer program for solving the nonlinear partial differential equation is developed by using a computer with super numerical operation ability. The program consists of three conservation laws and various additional model equations satisfying different fluid motion and heat and mass transfer laws. The numerical solution of the boundary condition is obtained. In a word, it is a kind of technology to solve all kinds of conservation control partial differential equations of fluid flow by computer.

2.2. Hydrodynamic Control Equation

(1) Conservation equation of mass

According to the law of conservation of mass, it can be known that in the process of flow, the increase of fluid mass per unit time and the net mass flowing into the micro element body at the same time for the micro element body fixed in space position. Based on this, we can get the partial differential equation of mass conservation:

\[
\frac{\partial p}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0
\]  

(1)

(2) Energy conservation equation

According to the application of the law of conservation of energy in the fluid microelements, the increase rate of heat energy in the microelements is equal to the sum of the net heat energy entering the microelements and the work done by the volume force and surface tension on the microelements. The equation of conservation of energy expressed by specific enthalpy \( h \) and temperature \( T \) can be derived

\[
\frac{\partial (\rho h)}{\partial t} + \frac{\partial (\rho uh)}{\partial x} + \frac{\partial (\rho vh)}{\partial y} + \frac{\partial (\rho wh)}{\partial z} = -p \text{div} U + \text{div} (\lambda \text{grad} T) + \Phi + S_h
\]  

(2)

3. Experiments

3.1. Housing Overview

In a passive house renovation project in Anhui Province, the passive house has good heat insulation and heat preservation effect. Through the comprehensive function of basic heat preservation system, passive door and window system, air tight system and heat recovery system, the temperature in the room can be maintained at 20-25°C all the year round, and the temperature field is evenly distributed, even in winter, there is no cold feeling at the window and wall.

3.2. Setting of Parameters

In this paper, the two equation model, the finite volume method and the Hexa unstructured are used to divide the whole calculation area into many cell bodies. At the same time, the differential equations are discretized into algebraic equations, and the variables are substituted into the cell bodies for
calculation. In order to facilitate calculation, the whole model is a box, and all furniture and walls are set as blocks.

4. Discussion
The passive house can maintain good indoor comfort by relying on the efficient heat recovery fresh air system. However, in the design of fresh air system, human comfort is the main factor, without considering the purification efficiency of indoor pollutant concentration. In this paper, the position of the air inlet of the fresh air system is studied, and the formaldehyde concentration of indoor pollutants in different positions of the air inlet is analyzed.

4.1. Simulation of New Air Flow Field
The air distribution mode of the house fresh air system is downward air supply and upward return air mode. In this paper, three different intake solutions are analyzed and studied by unsteady state simulation. Close the fresh air system and doors and windows. After 12 hours of indoor closure, only open the fresh air system to analyze the indoor air flow field.

The details of the three solutions are shown in Table 1:

| Solution   | Bedroom air inlet location | Living room air inlet location | Set temperature |
|------------|-----------------------------|--------------------------------|-----------------|
| Solution 1 | corner                      | Both sides of TV cabinet       | 20 degrees      |
| Solution 2 | corner                      | Both sides of sofa             | 20 degrees      |
| Solution 3 | Between bed and wardrobe    | South side of TV cabinet and sofa | 20 degrees |

Under the premise of not changing the air return, replace the air inlet for analysis (green is the air return, yellow is the air inlet). The wind speed at the air inlet is constant at 1 m / s.

The 3D figure of the project is shown in Figure 1:

According to CFD simulation, the indoor air flow field under three solutions is shown in Figure 2.
In the three solutions, the fresh air in the living room finally passes through the air outlet of the kitchen, the fresh air in the main bedroom mostly passes through the air outlet of the kitchen, a few passes through the air outlet of the toilet, and the fresh air in the secondary bedroom enters the air outlet of the toilet.

4.2. Simulation of Formaldehyde Concentration Change

According to different heights (sleep 0.65M, sitting 1.1m, sitting 1.55m), six long-term activity areas of human body were selected to analyze the changes of indoor formaldehyde concentration in 10 minutes. The location of the selected point is shown in Figure 3.
Through CFD simulation, read the formaldehyde concentration of 6 monitoring points, and get the change curve of indoor formaldehyde concentration with time after opening the fresh air under different solutions, as shown in Figure 4-6.

**Figure 4.** Formaldehyde concentration distribution with time at sleeping position

**Figure 5.** Distribution of formaldehyde concentration with time at seating position

**Figure 6.** Concentration distribution of formaldehyde with time at standing point
It can be seen from Figure 4 and flow field that when solution 3 is adopted in bedroom, fresh air is less circulated from sleeping position, so when solution 2 is adopted, formaldehyde purification efficiency of sleeping position is the best.

It can be seen from Figure 5 and the flow field diagram that in the living room, as the sitting position point 1 is close to the fresh air outlet, when the fresh air is just opened, the formaldehyde concentration in solution 3 decreases rapidly. After a period of time, the formaldehyde concentration in solution 2 decreases faster than that in solution 3. For sitting position 2, it is far away from the fresh air outlet, and it is located at the intersection of wind farms in the three solutions, so the formaldehyde concentration decrease trend is similar under the three solutions.

It can be seen from the above figure 6 and flow field diagram that as stand point 1 is close to the new air outlet in solution 1 and solution 2, and is far away from the new air outlet in solution 3, when the new air is just opened, formaldehyde concentration in solution 1 and solution 2 drops rapidly, after a period of time. The fresh air of solution 3 converged at standing point 1, and the formaldehyde concentration of the three solutions was similar. In solution 3, as stand point 2 is close to two new tuyeres, the formaldehyde concentration reduction rate is much faster than solution 1 and solution 2.

According to the above, solution 3 is better in the living room and solution 2 is better in the bedroom.

5. Conclusion
In this paper, CFD simulation technology is used to simulate the three fresh air system inlets in the passive house, in order to analyze the formaldehyde concentration field in the passive house under various conditions. The conclusion is that the living room has an air outlet on both sides of the TV cabinet and sofa, and the bedroom has an air outlet in the corner, which is a more reasonable way of air supply. In this paper, the computer numerical simulation can quickly get the final effect of the design solution, reduce a lot of calculation and experiment time for designers, which has a strong guiding significance for the design work. However, in the process of numerical simulation, due to the existence of model deviation, boundary condition error and other phenomena, it can only be used as the theoretical support of design, only guide the design, not replace the design.

References
[1] Grahn A, Gommlich A, Kliem S, et al. Simulation of an MSLB scenario using the 3D neutron kinetic core model DYN3D coupled with the CFD software Trio_U [J]. Nuclear Engineering & Design, 2017, 315 (Apr.): 117 - 127.
[2] X Y Ge, L. Shao, Z L Zheng. Assessment right atrial function in patients with systemic lupus erythematosus by speckle tracking and three-dimensional echocardiography [J]. Zhonghua yi xue za zhi, 2016, 96 (47): 3815 - 3818.
[3] Xu X , Zhang C, Liu Y. Study on Three-dimensional Near Real-time Simulation Method for Pollutant Atmospheric Diffusion in Nuclear Accident [J]. Yuanzineng Kexue Jishu/atomic Energy Science & Technology, 2019, 53 (1): 173 - 179.
[4] Yin X, Wang Q, Lv X, et al. Numerical simulation of hydrodynamic and pollutant diffusion in coastal waters of Qinhuangdao [J]. Desalination & Water Treatment, 2018, 121 (JUL.): 332 - 337.
[5] He Z, Fang S, Chen Y, et al. Numerical analysis of pollutant transport and diffusion in the tidal reach of Qiantang River [J]. Huanjing Kexue Xuebao, 2017, 37 (5): 1668 - 1673.
[6] Shen Y, Hu X, Ma Y, et al. Systematic Simulation of Atmospheric Nuclear Pollution Diffusion Trajectory of a Nuclear Power Plant based on C4ISRE [J]. Research of Environmental ences, 2017, 30 (6): 835 - 843.
[7] Guo S, Wang J, Wei X, et al. Numerical simulation of premixed combustion using the modified dynamic thickened flame model coupled with multi-step reaction mechanism [J]. Fuel, 2018, 233 (DEC.): 346 - 353.
[8] Dhunny A Z, Lollchund M R, Rughooputh S D D V. Numerical analysis of wind flow patterns over complex hilly terrains: comparison between two commonly used CFD software [J].
International Journal of Global Energy Issues, 2016, 39 (3/4): 181.

[9] Li J, Lu S, Wang Q. Graphical visualisation assist analysis of indoor environmental performance: Impact of atrium spaces on public buildings in cold climates [J]. Indoor & Built Environment, 2018, 27 (3): 331 - 347.

[10] Wang D, Chang S, Yue Y J. New Hydraulic Torque Converter with Double Turbine and Adjustable GuideVane Designed by CFD Software Simulation [J]. Reneng Dongli Gongcheng/Journal of Engineering for Thermal Energy and Power, 2018, 33 (12): 93 - 97.