Simulation Study on Human Thermal Comfort by Position of Kitchen Vent

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Abstract
In order to improve the internal environment of the kitchen and improve the comfort of the cooking staff, the residential kitchen based on the ceiling air supplement mode is taken as the research object. In this study, CFD simulation software was used to simulate the temperature field and velocity field of the ceiling opening above the Personnel and away from the cooking area. The distribution and trend of temperature and wind speed in the kitchen under two working conditions are obtained: when the ceiling opening is located directly above the cook, the airflow in the cooking area is disordered and the speed around the human body fluctuates obviously. Cooking personnel will have a more obvious sense of blowing, air outlet from the stove closer to the personnel caused by facial temperature instability, cooking personnel’s chest CO2 concentration gradually increased. When the ceiling opening is far away from the cooking area, the speed change amplitude around the human body is relatively low. As the cooking time increases, the temperature gradient on the body surface and the roof becomes larger and eventually stabilizes. More and more CO2 is discharged to the kitchen roof with the emission of high-temperature flue gas, which rapidly increases the CO2 concentration on the roof. Due to the supplement of outdoor fresh air, the indoor air quality has been improved, and the temperature and wind speed around the human body tend to be stable in the late cooking period. By comparing and analyzing the two working conditions of the ceiling air supply outlet located directly above the Personnel and away from the cooking area, we can know that when the ceiling opening is properly far away from the working area, it can effectively improve the thermal environment in the kitchen and improve the thermal comfort of the kitchen cooks.

Highlights
- Kitchen
- Ceiling ventilation
- Thermal comfort
- CFD simulation

Introduction
With the rapid development of the national economic and technological level, people's living standards have been greatly improved, and the requirements for the surrounding health environment have also increased. According to statistics, we spend more than 90% of our lives indoors and indoor air quality is closely related to our health. An important part of the composition of a home building, the kitchen is an undesirable interior environment due to its specific working conditions. Fumes and hot gases are inevitably produced in the indoor environment during cooking, resulting in terrible indoor air quality and comfort that can seriously affect people's health and productivity.

Many researchers domestic and international have conducted extensive research on the thermal comfort of kitchens in recent years. In 1970, Fanger pioneered the study of predicted mean vote (PMV) and predicted percentage of dissatisfaction (PPD). X Zhou et al. conducted a human experiment on 20 chefs when cooking in the kitchen. This study measured the skin temperature and environmental parameters of chefs and obtained their thermal sensation votes by means of questionnaires. Comparison of the actual thermal sensation poll results with the predictions of the four thermal comfort models. The results showed that all models were able to predict trends in thermal sensation, but none had adequate accuracy. B Zhou et al. investigated thermal comfort with the kitchen windows open and closed and found that there was a significant decrease in overall thermal sensation and comfort when cooks entered the non-air-conditioned kitchen from the air-conditioned room, but with increasing cooking time, it improved. Lan Haixia studied the applicability of a typical thermal comfort model to near-zero energy residential kitchens in severe cold regions and found that the unevenness of the indoor thermal environment distribution is enhanced in near-zero energy residential kitchens in severe cold regions when using directly make-up air from outdoor air where the thermal environment at ankle height is most significantly affected by make-up air from the kitchen.

In this study, CFD simulation software is used to simulate the temperature and velocity fields in a residential kitchen with the ceiling ventilation mode directly above the Personnel and away from the cooking area. Analysis of the temperature and velocity distribution under different operating conditions is carried out. As a reference for the optimization of thermal comfort in the kitchen environment.

Methods
Physical model
In this paper, the velocity field around the human body
and the temperature field is studied by CFD numerical simulation with the ceiling opening position as the variable. The model of a ceiling kitchen in Shenyang City is chosen as the object of the simulation. As shown in Figure 1, the overall geometry of the kitchen is 3.45m×2.18m×3.3m, and the kitchen contains doors, windows, suspended ceilings, ventilation outlets, hand sinks, cooker hoods, people, and cupboards, etc. The dimensions of the window are 1.16m×1.45m, the height of the ceiling is 0.9m and the width is 2.18m; the range hood is horizontally installed directly above the cookware and it is 0.72m from the height of the stove. For the simulation to be more realistic, a human model was established and the average height of women in Shenyang city of 165cm was chosen for modeling and analysis.

When solving indoor flow and heat transfer problems using numerical computation, the partitioning of the mesh will directly affect the speed and accuracy of the numerical simulation. In this study, unstructured tetrahedral grids were used to divide the selected kitchen, in which doors and windows, air inlets, stoves and human bodies were locally encrypted to increase the accuracy of the calculation results. In the calculation, the number of grids and the time step pass the independence test. The number of grids in this paper was set to 755175, as shown in Figure 2, to achieve a balance between grid convergence and computational efficiency.

The indoor air is simulated as incompressible fluid, and the airflow conforms to the mass conservation equation, momentum conservation equation, and energy conservation equation. Hence, the Realizable k-ε method is used in this study to solve the continuous field in kitchen space, and the control equations are discretized using the SIMPLEC algorithm. The pressure term is treated by the force weighting method. The convective and viscous terms are discretized using the second-order upwind format.

Continuity Equation:
\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0
\]

Momentum-conservation Equation
\[
\frac{\partial (\rho u)}{\partial t} + \nabla \cdot (\rho u u) = \nabla \cdot (\mu \nabla u) + S_i - \frac{\partial p}{\partial x_i}
\]

Energy-conservation Equation
\[
\frac{\partial (\rho T)}{\partial t} + \nabla \cdot (\rho u T) = \nabla \cdot (\kappa \nabla T) + S_r
\]

The kitchen type of boundary conditions and values are set, and the cooking source boundary conditions are used in the form of constant heat flow to simulate the cooking process. The pan surface is the source of cooking fumes, which is set as a velocity-inlet boundary with a velocity of 1m/s and a temperature of 150°C. The door gap is set as a pressure-inlet boundary for the make-up air inlet, with a make-up air temperature of 20 °C in the adjacent room. The exhaust of the range hood is set to the velocity-outlet boundary with a velocity of -8.28m/s; the initial indoor ambient temperature is 20°C at Shenyang winter heating temperature. The source of particulate matter emission is the mass inlet, and the personnel and wall are set as the wall.

The cooking process is accompanied by the generation of high-temperature smoke, which will have a radiation effect on the human body and the surrounding environment. The cooking personnel and the kitchen indoor environment are especially sensitive to the thermal radiation generated, so in the process of numerical simulation calculation again, therefore, in the process of numerical simulation, a thermal radiation calculation model that meets the requirements of the actual law should be selected. The DO model was chosen as the radiation model.

<table>
<thead>
<tr>
<th>Working Condition</th>
<th>Form</th>
<th>Initial condition</th>
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<tbody>
<tr>
<td>Condition 1</td>
<td>Air inlet form 1</td>
<td>Temperature: 20 °C CO2 concentration: 2500ppm</td>
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<tr>
<td></td>
<td></td>
<td>Ground heat flux: 300W/m²</td>
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<tr>
<td></td>
<td></td>
<td>Range hood speed outlet: 8.28m/s</td>
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<tr>
<td></td>
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<td>Human heat flow: 20W/m²</td>
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Table 1: Simulated conditions.
Results and discussion

Distribution of temperature and speed at different ceiling opening positions. When the ceiling opening is located directly above the cooker, it is regarded as condition 1, and when the ceiling opening is far away from the cooking area, it is regarded as condition 2. The temperature, velocity, and CO2 concentration fields were analyzed in the X=1.05m and Y=1.4m planes and Z=0.5m planes, respectively, as shown in Figures 3 to 8.

Figure 3: Velocity distributions of X=1.05m and Y=1.4m sections under condition I.

Figure 4: Velocity distributions of X=1.05m and Y=1.4m sections under condition II.

Figure 5: Temperature distribution of Z=0.5m section under condition I.

Figure 6: Temperature distribution of Z=0.5m section under condition II.

Figure 7: Cloud diagram of CO2 concentration distribution at X=1.05m and Z=0.5m sections under condition I.

Figure 8: Cloud diagram of CO2 concentration distribution at X=1.05m and Z=0.5m sections under condition II.

Based on the analysis of the simulation results, the cold outdoor air flowed into the area above the ceiling first by the outdoor supplementary air opening, and gradually filled the area above the ceiling, while under the action of the pressure difference between the area above and below the ceiling, the cold air flowed into the room by the supplementary air opening on the ceiling. At the end of the cooking period, the room is affected by the fresh air temperature, and the temperature of the area below the room gradually decreases. Even though the original room is heated by low-temperature radiant floor heating, there is still an accumulation of cold air below the room, so the thermal comfort of the cooking staff in the room gradually decreases as the cooking progresses. In the later stages of...
cooking, the temperature behind the cooking staff gradually converges with the outdoor fresh air temperature, which seriously affects the health of the cooking staff. The airflow in the cooking area is disorganized, the speed around the human body fluctuates significantly, the personnel will have a more obvious sense of blowing wind when cooking, and the supplementary air outlet is closer to the stove, which leads to the unstable temperature of the personnel's face, and the CO2 concentration in the personnel's chest gradually increases, after a long time of cooking, the exhaust hood cannot remove all the CO2 generated from cooking outside, and some of the CO2 spills out, resulting in the CO2 concentration in the lower part of the room being higher than that in the other areas in the upper part of the room. The CO2 concentration in the lower part of the room was high compared to the other areas in the upper part of the room.

As the ceiling opening is located far from the cooking area, the fresh air flows into the room through the ceiling opening, resulting in a significantly higher wind speed on the inside of the room, exceeding the requirements of the winter indoor wind speed specification. However, the change in velocity around the cooking staff in the room was relatively low, with the wind speed remaining at around 0.4m/s. The cooking staff did not feel the wind blowing significantly, and as the cooking time continued, the impact of the fresh air on the room became greater. The temperature gradient between the cooking staff and the roof becomes larger and eventually stabilizes. The temperature and air velocity around the human body stabilized in the later stages of cooking. In comparison, the closer the ceiling opening is to the working area, the more efficient it is in removing indoor pollutants, but the thermal comfort of the room is reduced. As the ceiling opening moves away from the work area, the thermal comfort of the room increases and the efficiency of the room in removing pollutants decreases. However, the overall air quality in the room is still significantly improved by the addition of fresh outdoor air.

**Conclusion**

In this paper, the CFD numerical simulation of temperature, velocity, and CO2 concentration distribution in the kitchen is carried out. Considering the different positions of the ceiling air supply opening, two different operating conditions are set up to compare the influence of the ceiling opening position on the temperature, velocity, and CO2 concentration distribution in the kitchen. The results show that the ceiling opening is appropriately far away from the working area, which can effectively improve the thermal environment of the kitchen and improve the thermal comfort of the kitchen cooks.

When the ceiling opening is located directly above the personnel, the airflow organization in the cooking area is disordered, the velocity fluctuation around the human body is obvious, and the personnel will have a more obvious sense of blowing when cooking. The close distance between the air supply outlet and the stove leads to the instability of the facial temperature of the personnel, and the concentration of CO2 in the chest of the personnel gradually increases. When the ceiling opening is far away from the cooking area, the velocity change around the human body is relatively low. With the continuation of the cooking time, the temperature gradient on the surface of the human body and the roof is large and eventually tends to be stable. More and more CO2 is discharged to the kitchen roof with high-temperature flue gas so that the CO2 concentration of the roof increases rapidly. Due to the supplement of outdoor fresh air, the indoor air quality is improved, and the temperature and wind speed around the human body tend to be stable in the later stage of cooking.

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