THE CONTROL OF AIR QUALITY IN COMMERCIAL KITCHEN

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ABSTRACT
The paper reports on a study of indoor air quality in a simulated kitchen environment. The report illustrates the influence of makeup air on exhaust hood performance. Computational fluid dynamics and professional software Airpak 2.0 were used to explore the condition in the commercial kitchen and to assist with experimental design. This simulation reveals a complex flow situation that the thermal plume from the cook top interacts with the exhaust hood. The paper shows the differences of airflow pattern among air curtain supply, front face supply and backwall supply integrated with the local hood.

INDEX TERMS
Indoor air quality (IAQ), Commercial kitchen, Computation fluid dynamics (CFD), Local exhaust hood, Makeup air

INTRODUCTION
The exhaust gas in commercial kitchen seriously pollutes the air, which has been found in Law of Atmosphere Pollution prevention in China (State Department of People’s Republic of China 1996). Its harmful ingredient in cooking oil fume badly endangers the environment and health of cook. This problem has been discussed (Wang kaixiong and Zhu xingdong 1996). A ventilation means that can effectively remove cooking oil fume is needed to keep air quality in the kitchen, which can eliminate or reduce the harm to the health of human being. As is known that any ventilation system requires air balance. Air balance is air that exits the building must be equal to outside air that enters the building. If enough replacement air is not introduced, the indoor pollutant will be not got rid of through the exhaust hood. It will reduce indoor air quality in the kitchen, even influence the air quality in the dining room.

Once makeup air (MUA) has been added to the system, the challenge becomes introducing this air into the kitchen without disrupting the ability of the hood to capture and/or without causing discomfort for the kitchen staff. Not only can makeup air velocities impact the ability of the hood to capture and contain cooking effluent, but also locally supplied makeup air that is too cold or too hot can create an uncomfortable working environment. The strategy used to introduce makeup air can significantly impact hood performance and should be a key factor in the design of kitchen ventilation systems. Makeup air introduced close to the capture zone of hoods may create turbulence that result in periodic or sustained failures in thermal plume capture and containment. The research method of schlieren image regarding these problems has been discussed (Architectural Energy Corporation and Fisher Nickel, 2002; Richard T. Swierczyna and Paul A. Sobiski, 2003), while the method of common experiments has been researched (Duanmu Lin and Lin Bao et al, 1996). This paper is via CFD simulation to research this problem. The objective of this study is to find strategies that can minimize the impact that the makeup air introduction will have on hood performance and energy consumption. The study only focuses on makeup air introduction to the local hoods.

RESEARCH METHOD
CKV system performance testing
The phrase “hood capture and containment” is defined by ASTM (1999) in ASTM F-1704 standard test method for the performance of commercial kitchen ventilation system as “the ability of the hood to capture and contain grease-laden cooking vapors, convective heat and other products of cooking processes.” Hood capture refers to these products entering the hood reservoir from the area under the hood, while containment refers to these products staying in the hood reservoir and not spilling out into the adjacent space. The phrase “minimum capture and containment” is defined as “the condition of hood operation in which minimum exhaust flow rates are just sufficient to capture and contain the products generated by the appliance in idle or heavy-load cooking conditions, and at any intermediate prescribed load condition.” The abbreviation “C&C” refers to the “minimum capture and

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containment” flow rate as defined in ASTM F-1704.

MODEL KITCHEN
The first student refectory of Tianjin University is selected as subject investigated. The main length scales and relevant parameters for the model kitchen are listed in Table 1. It is depicted schematically in Fig 1.

![Figure 1. Physical configuration](image)

<table>
<thead>
<tr>
<th>Name</th>
<th>Geometric (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model kitchen</td>
<td>8.5×4.2×6.9</td>
</tr>
<tr>
<td>Cooking bench</td>
<td>1.27×0.8×3.4*2</td>
</tr>
<tr>
<td>Circular resource</td>
<td>0.5*6</td>
</tr>
<tr>
<td>Front door</td>
<td>2.2×1.35*2</td>
</tr>
<tr>
<td>Back door</td>
<td>1.96×1.35*2</td>
</tr>
<tr>
<td>Local hood</td>
<td>1.27×0.45×4.80*2</td>
</tr>
<tr>
<td>Exhaust opening</td>
<td>4.8×0.04*2</td>
</tr>
<tr>
<td>Local supply opening</td>
<td>0.31×0.11*10</td>
</tr>
</tbody>
</table>

PHYSICAL PROBLEM
Fig 1 illustrates schematically the physical configuration of the air environment undergoing ventilation through range hood. Initial air temperature is set at outdoor temperature. The heat flux generated by the gas fire raises the temperature of the air adjacent to this region. The buoyancy-driven airflow resulting from the temperature difference between the gas fire and ambient is assumed to be three-dimensional and turbulent. When the hood is operating, forced airflow drawn by the exhaust fans in the range hood influences flow pattern in the kitchen. In such a case, a “mixing convection” phenomenon occurs. Furthermore, the thermophysical properties of the air are independent, except for the density, for which the boussineq approximation is valid. The problem has been discussed (Che-Ming Chiang et al. 2000)

NUMERICAL METHOD
Numerical simulations of the physical problem under consideration have been performed via a finite volume method for solving the governing equations and boundary conditions mentioned above. This study applied the SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm (Patankar SV 1980) to solve those equations. The standard “two equation model” of turbulence, the k-epsilon model (Launer Be and Spalding DB 1974) was adopted. The professional software Airpak 2.0 researched by FLUENT Corporation was used to explore the airflow pattern around the range hood in the kitchen. The iteration calculation was continued until a prescribed relative convergence of $10^{-3}$ was satisfied for all flow variables of this problem and the convergence of $10^{-6}$ for all energy variables was obtained. A 0.3m×0.1m×0.3m grid system was employed for the calculations. The Reynolds and Peclet numbers for this problem are 19168 and 14244, respectively.

FULL-SCALE EXPERIMENT
In order to reveal the indoor air environment in the kitchen, experiments were also performed in a full-scale model kitchen. Model kitchen (built in the Tianjin University) that mimics the physical configuration is depicted in the Fig 1. The characteristics of the air velocity field are measured by a heated wire type anemometer. The accuracy of the heated wire type anemometer is 0.01m/s within full scale (0-20m/s). The temperature field is measured by an indoor air quality detector and the accuracy of that is ±0.5℃ within full scale (0-60℃). An infrared thermometer is also used to measure the temperature of the heating surfaces.

NUMERICAL RESULTS
The following simulated results were acquired under the winter condition. The makeup air temperature of front and back doors is respectively 20.8℃ and 22.7℃ while local makeup air temperature is 7.5℃ of outdoor air measured in Tianjin University on January 21, 2005. Local makeup air velocity is 1.0m/s and exhaust air velocity is 7.0 m/s. Thermal resources are set as constant temperature of 350℃.

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AIR CURTAIN SUPPLY
Simulated results were shown in Fig 2 and Fig 3. Fig 2 is the temperature and velocity field at x=1.42m of air curtain supply. Fig 3 is the temperature and velocity field at z=-1.7m of air curtain supply.

FACE FRONT SUPPLY
Simulated results were shown in Fig 4 and Fig 5. Fig 4 is the temperature and velocity field at x=1.57m of face front supply. Fig 5 is the temperature and velocity field at z=-1.7m of face front supply.

REAR DISCHARGE (BACK SUPPLY)
Simulated results were shown in Fig 6 and Fig 7. Fig 6 is the temperature and velocity field at z=-1.7m of back
supply. Fig 7 is the temperature field at x=1.57m of back supply.

**SHORT CIRCUIT**

The application of short-circuit makeup air hoods is a controversial topic. These internal makeup air hoods were developed as a strategy to reduce the amount of conditioned air required by an exhaust system. Research has shown that internal MUA cannot be introduced at a rate that is more than 15% of the threshold C&C exhaust rate without causing spillage. When short circuit hoods are operated at higher percentages of internal MUA, they fail to capture and contain the cooking effluent, often spilling at the back of the hood. California Energy Commission (2002) has done the work in the design guide. Short-circuit hoods are simply not recommended now. So here the style is not simulated.

**COMPARISON WITH FULL-SCALE EXPERIMENTS**

Finally, to further validate the accuracy of the numerical simulations undertaken, the predicted temperature patterns are compared with results of the temperature measurements, as illustrated in Fig 8. Fig 8 is the curve of temperature at the height of 1.8m in the operating zone. A generally good qualitative agreement can be readily observed from Fig 8.

**DISCUSSION**

In the article, the problem of influence of introducing makeup air to the exhaust hood has been studied numerically by means of finite volume method. Results from the numerical simulations undertaken indicate that:
From Fig 6 and Fig 7, we can see that back supply generally makes the kitchen temperature above 15°C and satisfies temperature design requirements. From Fig 2 and Fig 4, we find that the temperature in the operating area respectively is 12~15 °C and 13~16°C which makes kitchen staff feel uncomfortable. That is to say the styles of face front supply and air curtain supply both readily result in local low temperature and make kitchen staff uncomfortable and difficultly satisfy people’s requirements.

From Fig 3, Fig 5 and Fig 6 we can see that three patterns make oil fume spill out more easily at the lower half of the hoods. The zone of spillage under air curtain supply condition is most; face front supply taking second place, and back supply is least.

CONCLUSION AND IMPLICATIONS
From these discussions above, we can reach the following conclusion:

1. All styles of introducing makeup air to the hoods can achieve the aim of air balance, but improper location of MUA without treating makeup air makes kitchen staff uncomfortable.

2. In general, the detrimental effect of introducing MUA through an air curtain supply on the C&C is more than that of back supply and front face supply on the same premise.

3. The results show that safety factor in exhaust rates may be reduced, which may mask the detrimental influence of MUA on hood performance. Consequently, better MUA designs allow reduced exhaust rates and minimized energy costs while maintaining a margin of safety with respect to C&C.

REFERENCES
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