The influence of the capture jet on the efficiency of the ventilated ceiling in a commercial kitchen

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ABSTRACT
The ventilated ceiling is a flexible solution for kitchen ventilation where the heat loads are relatively low and aesthetics is a concern. The use of hoods is an ideal solution for locally handling contaminants produced in concentrated areas. Thus, special attention should be taken on the ventilated ceiling which removes air at the ceiling level. The simulations conducted show that the capture jet improves the total effectiveness of the ventilated ceiling. Indoor air quality is enhanced in an energy efficient manner. The capture jet assists the function of the exhaust unit and the plume extracts effectively. Without the capture jet, a portion of the plume is re-circulated back to the working area. That increases the concentration of the contaminant level in the occupied zone. The conducted simulation indicates that the average contaminant level of the whole occupied zone is 40% lower with the capture jet.

INDEX TERMS
Ventilated ceiling; Kitchen ventilation; Capture jet

INTRODUCTION

Ventilation and air conditioning systems are required in commercial kitchens to: (1) remove odours and particles of fat; (2) comply with hygiene requirements; (3) remove moisture and heat that is generated from the preparation of meals and washing and (4) provide comfortable and productive working conditions. To meet these tasks, supply and exhaust air systems shall be installed in the kitchen areas so that odours, air pollutants, extra heat and moisture are removed.

The ventilated ceiling is a flexible solution for kitchens where the heat loads are relatively low and aesthetics is a concern (DW/171, 1999). Structurally, the system consists of a stainless steel element that covers the entire ceiling or only the active cooking area of a kitchen, on which air inlets, exhaust air outlets with grease filters and light fittings are installed. The efficiency of the exhaust system can be improved with a small capture jet installed at the ceiling surface. The air jet is horizontal across the ceiling and this helps to direct heat and air impurities towards the exhaust.

The efficiency of the exhaust system should be specially emphasized with the ventilated ceiling systems where the exhaust is located at the ceiling level. The removal efficiency of the total system must be guaranteed and impurities spreading throughout the kitchen should be prevented.

In this paper, the effect of capture jet on the efficiency of the ventilated ceiling was studied using CFD simulations. The simulations were conducted with and without the capture jet in a simple one-appliance kitchen layout to get the view of the pollutant levels in the kitchen environment.

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METHODS

The effect of capture jet on the efficiency of the ventilated ceiling was evaluated using CFD simulations in a case-study kitchen. The software package used was AirPak 2.0.6. The studied ventilated ceiling comprised of exhaust, supply and capture jet units, lights and ceiling elements between the exhaust and the supply units (Figure 1) The capture jet air is supplied horizontally across the ceiling. This jet helps to direct heat and air impurities towards the exhaust.

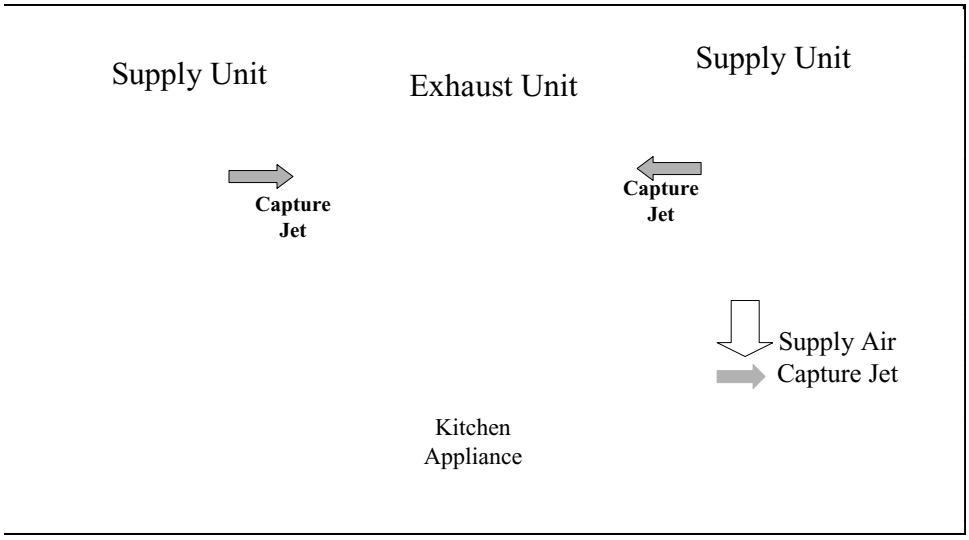

Figure 1 The layout of the studied case-study kitchen.

The same mock-up kitchen was simulated with the normal design condition exhaust airflow rate of 840 l/s. The supply air was distributed either from the ceiling element (670 l/s) and the capture jet unit (120 l/s) or only from the ceiling element (790 l/s). In these cases, the kitchen space was slightly (6%) under-pressurized.

The kitchen appliance (size 800 mm × 800 mm × 870 mm (H)) was a range with a frying pan. The surface temperature of the appliance was about 200°C with the total heat gain of 5.6 kW. The supply air temperature was 18°C and the room air temperature was 22°C. The pollution source in the simulations was 24.7 g/s of water vapour.

The ventilated ceiling is 4.3 m (L) × 3.5 m (W) at 2.3 m from the floor level. The average contaminants are calculated for a 4.8 m (L) × 5.2 m (W) × 1.8 m (H) volume. The central point of the calculated volume is the mid-point of the range. The occupied zone is subdivided into four different control zones from which average contaminant levels are also calculated. Figure 2 shows the calculated control zones.

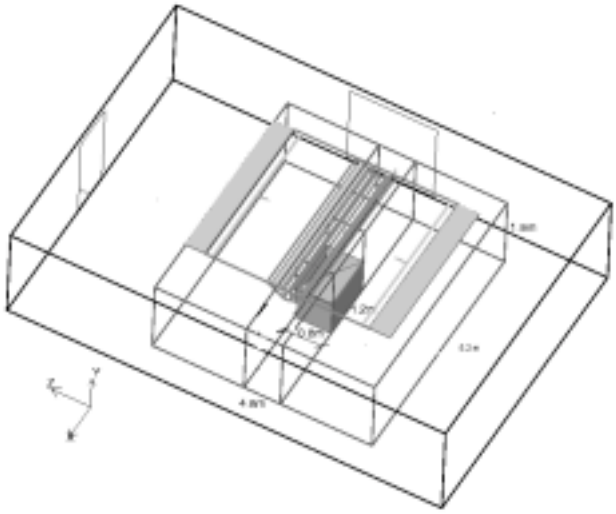

Figure 2 The calculated four control zones in the occupied zone.

RESULTS

Figures 3 and 4 show the velocity fields with and without the capture jet. In the scenario without the capture jet (Figure 3), the part of the plume is re-circulated back into the occupied zone. This is due the ceiling supply that is taking part in the induction air from the plume. This implies a reduction in the efficiency of the extract system. However, with the capture jet (Figure 4), the capture jet assists the function of the exhaust unit and the plume extracts effectively without any re-circulation to the kitchen space. Figures 5 and 6 show the contaminants with and without capture jet. Figure 5 shows clearly that a part of the plume is re-circulated back to the occupied zone. With the capture jet set-up, the plume rises directly to the exhaust unit (Figure 6) and the plume extracts more effectively from the kitchen space.

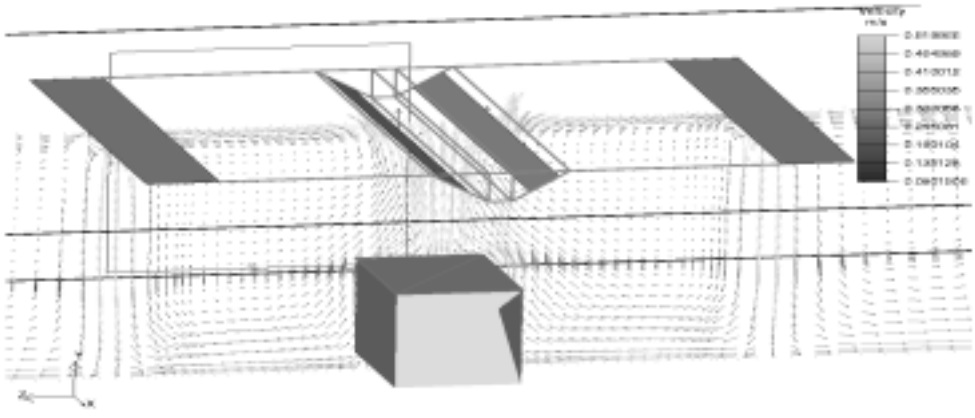

Figure 3 Velocity profile without the capture jet.

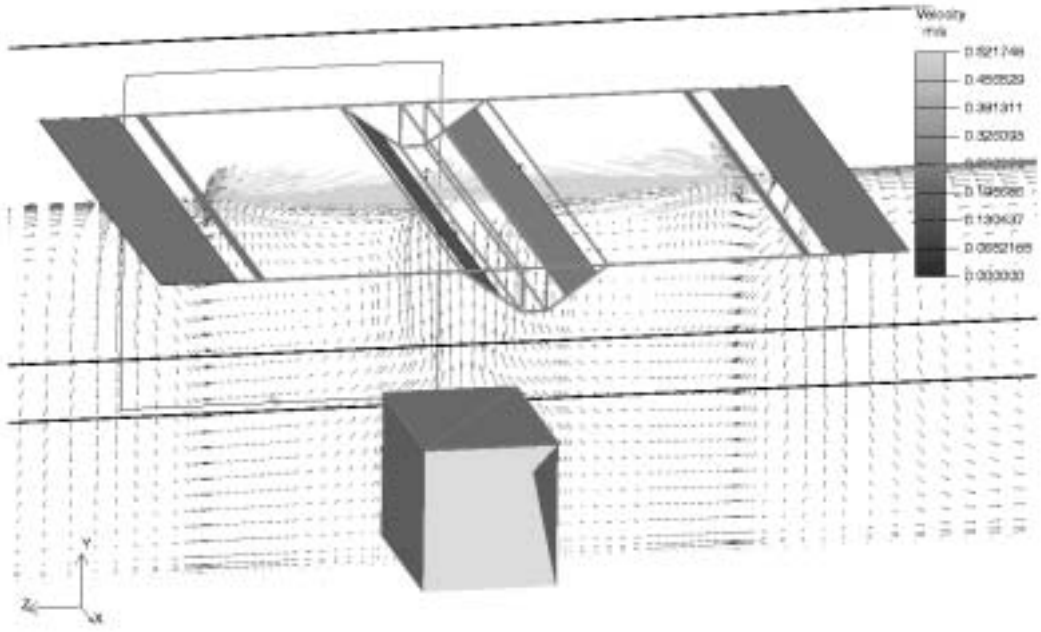

Figure 4 Velocity profile with the capture jet.

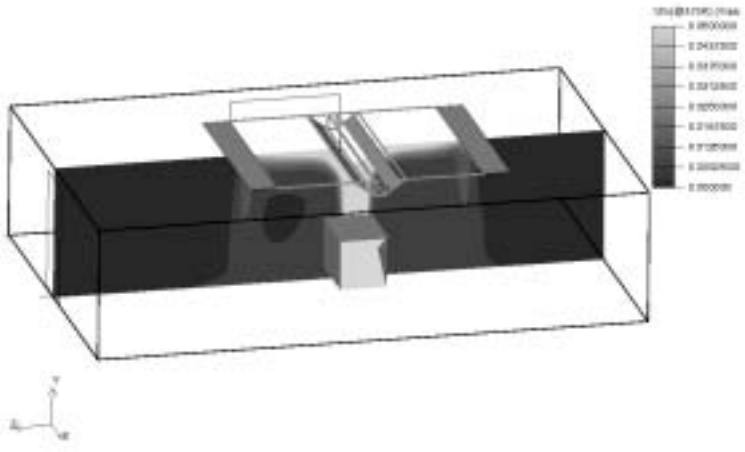

Figure 5 Contaminant level in the kitchen space without the capture jet. A portion of the plume is re-circulated back to the occupied zone.

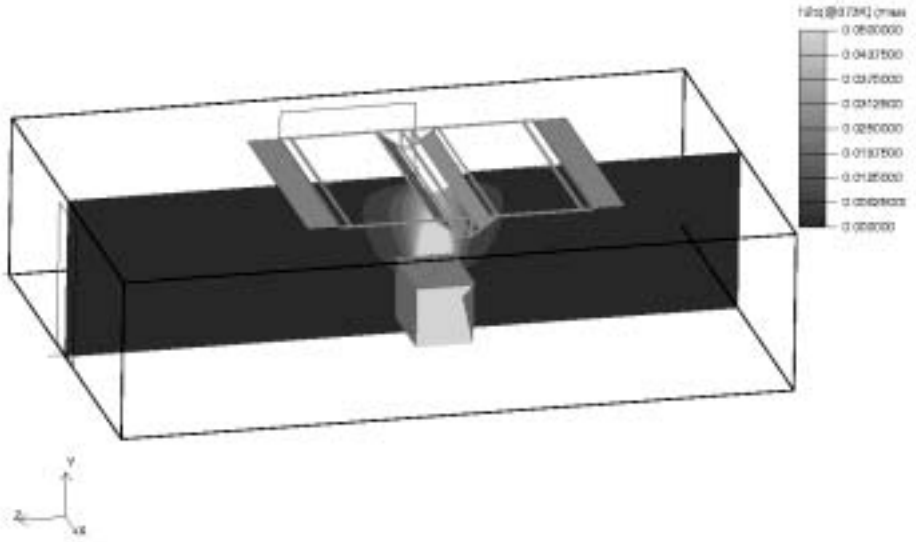

Figure 6 Contaminant level in the kitchen space with the capture jet. The plume is rising nicely towards the exhaust unit.

The contaminant levels with the capture jet are much lower in the occupied zone. Also, it is to be noted that the form of the contaminant profiles are different: with the capture jet, the highest contaminant levels are close to the range. Without the capture jet, the convection flow brings a part of the plume back in the occupied zone. This means that underneath the supply unit and close to the floor the contaminant levels are quite high.

Using average contaminant level in the occupied level, it is possible to get a more generic view of the total indoor air quality. The average value is a suitable indicator to estimate the level of the pollutants that affect the worker during hours of employment.

The occupied zone is divided into four different control zones from which average contaminant levels are calculated. In the calculation, the volume just over the range is not taken into account.

Table 1 presents the average contaminant levels in the four control zones and also the average contaminant level in the whole occupied zone. In the two parallel control zones with the range ($-z$ and $+z$) where most of time chefs are working, the average contaminant level is about 50% lower with the capture jet. In the two other zones ($-x$ and $+x$), which are in the same raw with the range, the average contaminant is about 30% lower.

Based on the simulation, it is possible to reach significant improvement in indoor air quality with the capture jet. The average contaminant level in the whole occupied zone is 40% lower with the capture jet concept.

Table 1 The average contaminant levels in the four control zones with and without the capture jet

Studied volume	Jets on (g/g)	Jets off (g/g)	Difference to jets off case (%)
$-z$	2.823×10^{-3}	5.597×10^{-3}	–50
$+z$	3.011×10^{-3}	5.785×10^{-3}	–48
$-x$	3.389×10^{-3}	4.940×10^{-3}	–31
$+x$	3.933×10^{-3}	5.439×10^{-3}	–28
Average	3.289×10^{-3}	5.440×10^{-3}	–40

DISCUSSION

The main purposes of kitchen ventilation are to prevent the dispersion of effluents from cooking processes into the surroundings and to achieve satisfactory thermal conditions by capturing the excess heat that is generated during cooking.

The use of hoods is an ideal solution for locally handling contaminants produced in concentrated areas. Thus, special attention should be taken on the ventilated ceiling which removes air at the ceiling level. In the worse case, the supply airflow pattern may spread heat and impurities around the working area of the kitchen.

In the design process, the main idea is reach the adjusted target value of indoor air quality. The energy consumption is strongly dependent on the set indoor air quality target. Thus energy consumption and the contaminant level are not separate things; they should always be analysed simultaneously. During the design phase, the requested exhaust airflow rate should be calculated based on the existing convective load of kitchen appliances. This amount of air carried in a convective plume should be theoretically calculated and adjusted by matching the exhaust airflow rate.

The capture jet air is supplied horizontally across the ceiling. This jet helps to direct heat and air impurities towards the exhaust making use of the push–pull ventilation strategy. The conducted CFD simulations have demonstrated that the capture jet could help to improve the total effectiveness of the ventilation system.

CONCLUSION

The supply air distribution strategy has a remarkable influence on the pollution removal effectiveness and thermal environments. In the ventilated ceiling, the capture jet could improve the total effectiveness of the ventilation system. In the scenario with the capture jet, the average contaminant level in the occupied zone was 40% lower.

ACKNOWLEDGEMENTS

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REFERENCES

DW/171 (1999). *Standard for Kitchen Ventilation Systems*. London: Heating and Ventilation Contractors' Association.