THE MEANING OF EFFICIENCY ON THE REQUESTED AIR FLOW RATE IN COMMERCIAL KITCHENS

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Keywords: kitchen ventilation, heat load based design, capture efficiency

ABSTRACT

To fulfill all needs of indoor air conditions in an economical manner, the total approach of ventilation design should be used. This means that the ventilation system is designed based on the target values of indoor air quality and the actual heat loads of the kitchen appliances. The most accurate method to calculate the requested airflow rate is a heat load based method. In this method, the amount of heat carried in a convective plume over a cooking appliance at a certain height is calculated. Also in order to reach the optimal entirety of the whole plan, the capture efficiency should be considered and finally the influence of the general ventilation on the total efficiency should be taken account.

INTRODUCTION

Kitchen design requires the expertise of many different specialists to produce designs that meet the requirements of productive and cost-effective working environments. The decisions of various designers strongly affect each other. Owners and end-users are important players in design process as well as cooking and ventilation equipment manufacturers. Due to the wide diversity of their expertise, a common understanding is needed to accelerate the process and to fulfill the set targets.

Concerns over the indoor environment have increased during recent years as a result of knowledge about the significance of thermal conditions and air quality on the health, comfort and productivity of workers. In a commercial kitchen, working conditions are especially demanding. There are four main factors affecting thermal comfort, these being: air temperature, radiation, air velocity and air humidity. At the same time, high emission rates of contaminants are released from the cooking process. Ventilation plays an important role in providing comfortable and productive working conditions and in securing contaminant removal.

Ventilation and air conditioning systems are requested in commercial kitchens because (1) the air is polluted by odours and particles of fat, (2) hygiene requirements of air quality must be met, (3) heat is created due to convection and radiation, (4) moisture is created by preparation of meals and washing and (5) comfortable and productive working conditions should be maintained. To meet this task, supply and exhaust air systems shall be installed in the kitchen areas so that odours, air pollutants, extra heat and moisture are drawn off.

The published studies demonstrate quite clearly the health risk of cooking. Thiebaud (1995) indicates that the fumes generated by frying pork and beef were mutagenic. Hence, the chefs are exposed to relatively high levels of airborne mutagens and carcinogens. Vainiotalo (1993) carried out measurements at eight workplaces. The survey confirmed that cooking fumes contain hazardous components. It also indicated that kitchen worker may be exposed to relatively high concentration of airborne impurities.

Although cigarette smoking is considered to be the most important cause of lung cancer, smoking behavior cannot fully explains the epidemiological characteristics of lung cancer among Asian women, who rarely smoke but contract lung cancer relatively often. Ng (1993) study found that over 97 % of the women in Singapore do not smoke. Thus, the presumable source of indoor air pollution for housewives is passive smoking and cooking. This study indicates that greater relative odds of respiratory symptoms were associated with the weekly frequency of gas cooking.

The previous studies depict the importance of the well-designed ventilation in the kitchen. The efficiency of the exhaust system should be specially emphasized. The remove efficiency of the total system must be guaranteed and impurities spreading throughout the kitchen should be prevented.

To fulfill all needs of indoor air conditions, the total approach of ventilation design should be used. This means that the ventilation system is designed based on target values of indoor air quality (IAQ) and the actual heat loads of the kitchen appliances, and in addition to the effect of the general ventilation for the performance of the exhaust system should be analyzed.

CALCULATION OF THE EXHAUST AIR FLOW RATE

A properly designed and located exhaust hood or exhaust unit of ceiling is essential for effective kitchen ventilation. The ventilation system is used to capture the heat, odour and vapor emitted during cooking process and to contain it until the fan can exhaust them outdoor. The ventilation system also brings the air to refresh the working place by replacing the exhausted air.

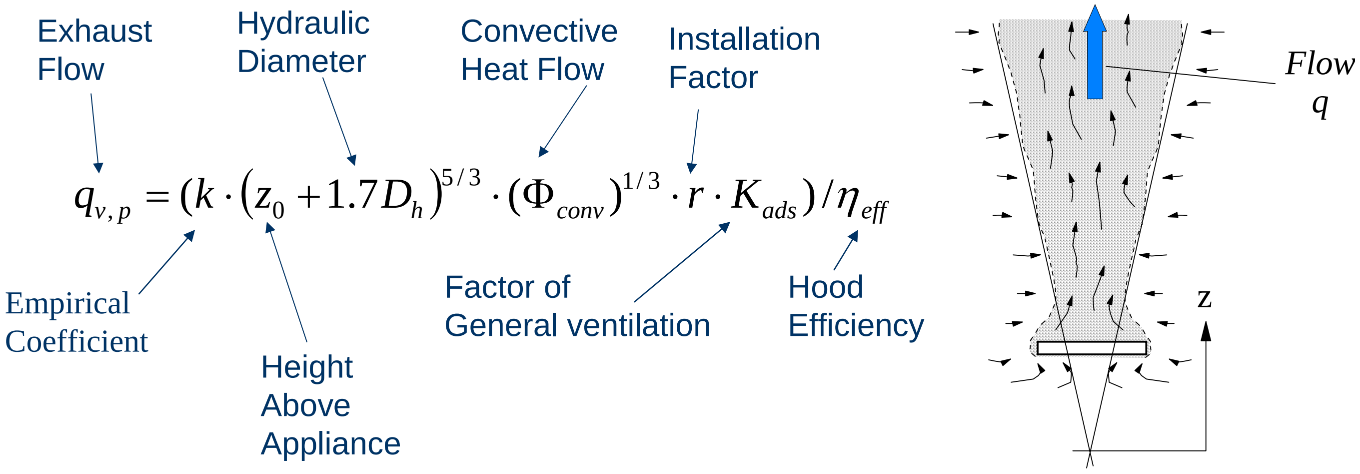
There are many methods available to calculate the requested airflow rate. For example, the "Rule of Thumb "method is that the number of air change is taken into consideration. Another method called " Face Velocity" where the flow rate is established by considering the captured velocity and area under the hood. Both of these methods do not take consideration the type of appliances under the hoods. Hence in many cases, the estimations always exceed the actual requirements or demands.

As for the "Heat Load" method, consideration is made for the cooking appliance convective heat output, the area of exposure, the distance of the extract unit and the effect of the general ventilation for the contaminant removal efficiency. The main idea is to adjust the required airflow rate based on the convection heat gain or more specific based on the thermal plume of a kitchen appliance. The most well-known code which utilizes this approach is German VDI (VDI 1999). In Fig. 1, there is shown the main parameters that should be taken into account in the specification of the air flow rate.

Based on a case-study calculation (Kosonen 2001), in the medium-load case (European cooking) rough method like face velocity oversized the whole system 2- or 3- times compared with the heat load based method like VDI. This over estimation is 1.4 –1.8 even with the extra-heavy load (Asian cooking).

It should be noted that radiated heat can not be removed with the extract system. To maintain sufficient indoor conditions year-round, the air-conditioning system is always needed in the kitchen. Without mechanical cooling, the air temperature in the kitchen will be time to time over 30 ^{o}C during summer time. That definitely reduces performance of workers.

If a hood is not able to capture and contain the foul air within the kitchen area, both humidity and temperature will increase in kitchen and at the same time pollutant will spread over the kitchen and possible to the surrounding dining and shopping areas. Specially, high contaminant removal efficiency is critical in the front-cooking restaurants where the actual cooking happen close the customers.



$$q_{v,p} = (k \cdot (z_0 + 1.7D_h)^{5/3} \cdot (\Phi_{conv})^{1/3} \cdot r \cdot K_{ads}) / \eta_{eff}$$

Figure 1. In the heat load design, the air flow rate is calculated based on the generic plume equation.

MEANING OF THE CAPTURE EFFICIENCY

As described before, the calculation of the thermal plume is the basis of hood design. The thermal plume from hot appliances takes up the contaminant and heat that are released during the cooking process. If convective heat is not removed directly above the cooking equipment, impurities will spread throughout the kitchen. When appliances are installed under an effective hood, only the radiant heat contributes to the cooling load in the space. Conversely, if the hood is not providing sufficient capture and containment, thereby increasing both humidity and temperature

The capture jet technology increases the efficiency of the hoods. The capture jet has the effect of forming a protective barrier that prevents heat, smoke, grease and other contaminants from spilling into the kitchen thereby reducing air-conditioning load and making for a more comfortable and safe environment for employees working in the kitchen.

It is possible to get remarkable savings both in investment and life-cycle costs by using high efficient exhaust systems. Also, the energy efficient system is more environmental friendly; the total greenhouse gas emission is much lower.

In a series of tests conducted by Architectural Energy Corporation (AEC) in USA, the capture jet hood performed favorably over traditional style back shelf hoods. In fact, the exhaust-only hood required 100% greater exhaust air to capture than the capture jet hood during idle conditions and 36% greater exhaust air during cooking conditions (Schrock 2000). In Fig. 2, there is demonstrated the effect of the capture on the hood efficiency using Schliering thermal imaging and CFD technologies.

At the same time with this optimization of exhaust flow rate saving can then be infer from

a) Operation Cost (power consumption and air conditioning cost to replenish the non – convective heat exhausted)

b) Initial Capital Investment (due to larger and oversized equipment installation)

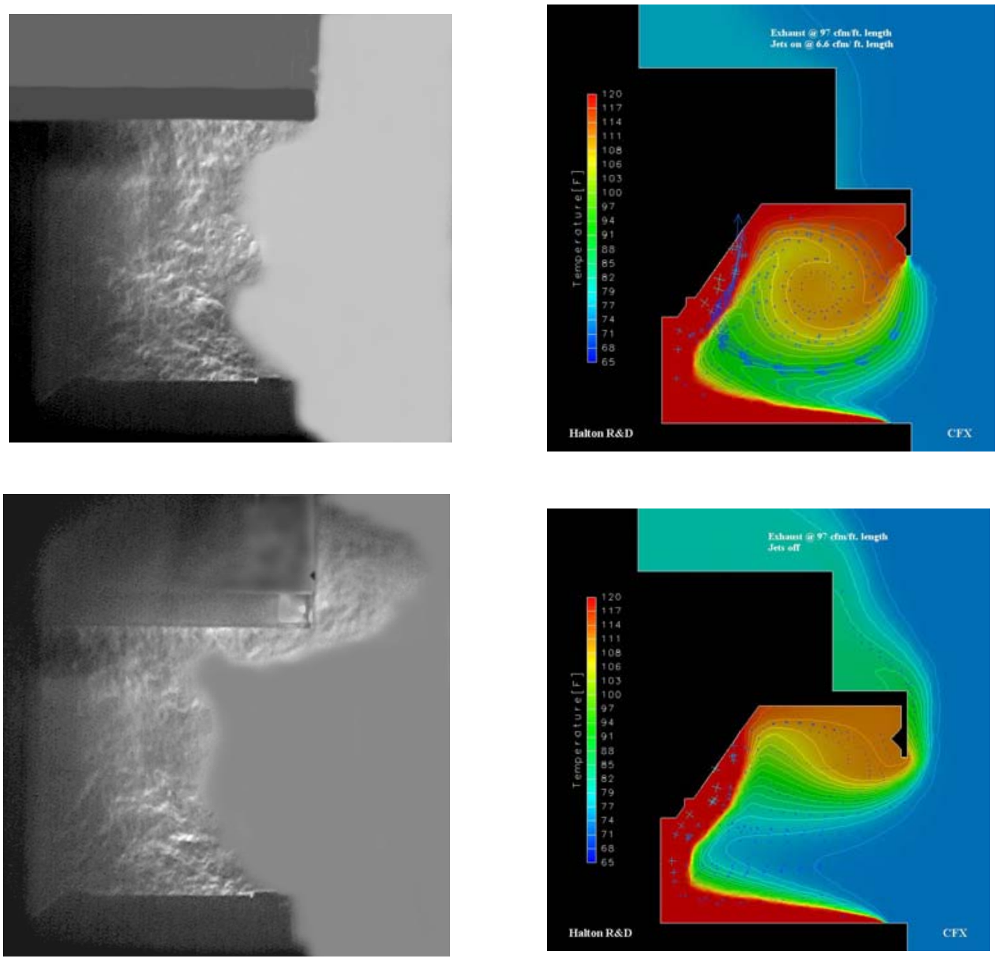


Figure 2. The comparison of the efficiency of the capture jet (panels over) and a traditional exhaust hood (panels below) using Schliering thermal imaging and CFD technologies.

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 capture efficiency of the total system must be guaranteed and spreading of impurities throughout the kitchen should be prevented.

The efficiency of the exhaust system can be improved with a small capture jet installed at the ceiling surface. The air jet is projected horizontally across the ceiling, which helps to direct heat and air impurities towards the exhaust. This capture jet represents only about 10 % of the total supply air flow rate. The efficiency of the capture jet concept was studied by Kosonen and Mustakallio (2003).

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 capture jet, the average contaminant level in the occupied zone was 40 % lower and the estimated energy saving potential can be as much as 23 %. In Fig. 3, there is demonstrated the effect of the capture jet on the contaminant level in a case-study kitchen (Kosonen and Mustakallio 2003).

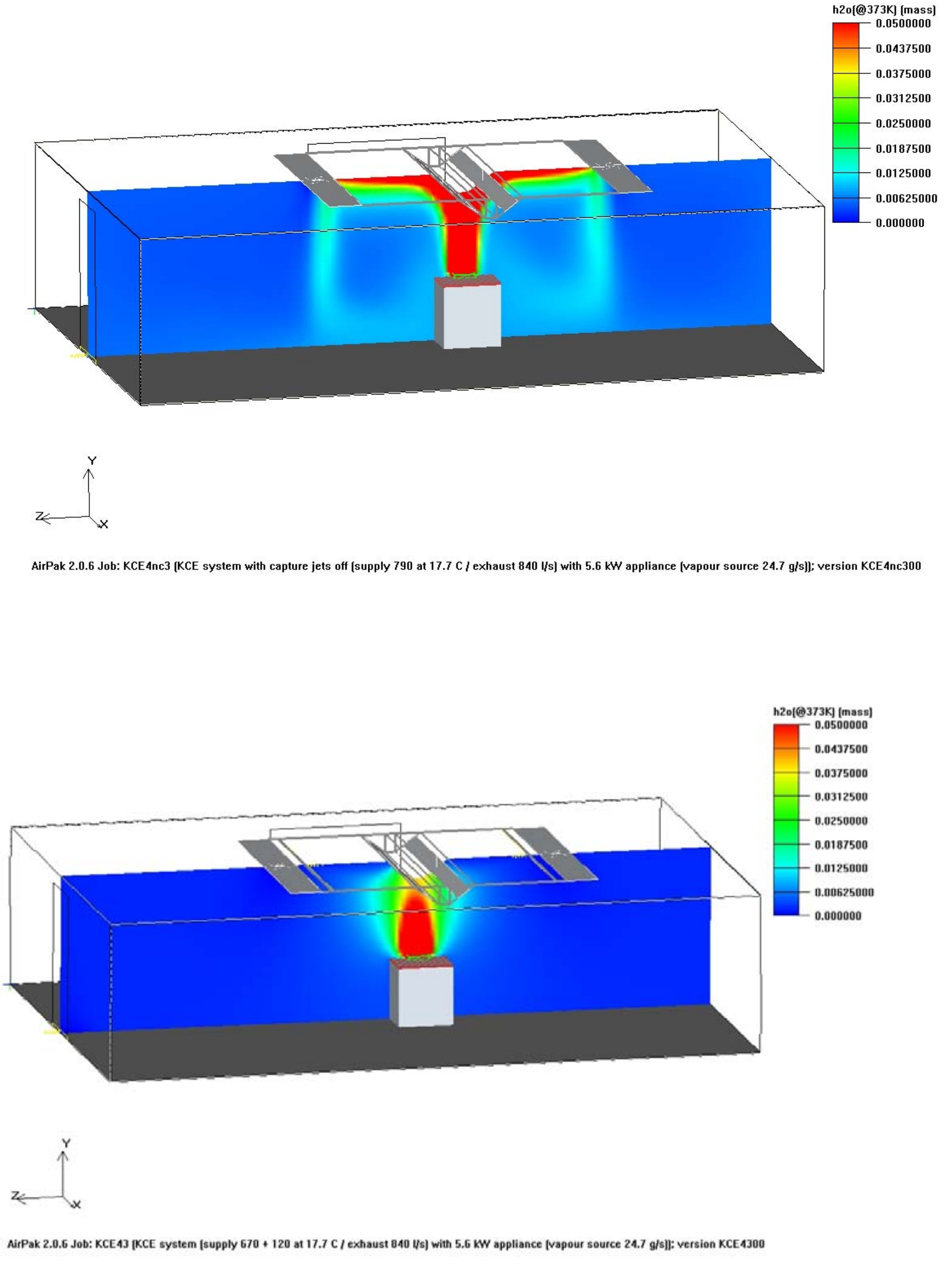


Figure 3. Contaminant levels of a case-study kitchen without the capture jet (panel over) and with the the capture jet (panel below).

THE EFFECT OF GENARAL VENTILATION ON THE TOTAL EFFICENCY

The total approach for the ventilation system should be kept in mind. Application of a low velocity displacement ventilation system allows for a reduction in exhaust airflow by 19 % compared to a

conventional mixing ventilation system (VDI 1999). VDI proposes to use the spillage factor of 1.05 for thermal displacement system where the units are located in the working area. The factor of 1.25 is proposed to use with the normal mixed ventilation. In the other words, the air flow rate should be 5 – 25 % higher that the generic plume equation indicates.
The effect of the selected ventilation concept on the contaminant removal efficiency of the ventilated ceiling was studied with tracer gas method. For practical design, the spillage factor of the supply air on the theoretical plume equation was introduced (Kosonen 2005).
The thermal displacement ventilation has the best containment removal efficiency. It was possible to obtain high ventilation efficiency (98 %) .The average efficiency was about 5 % higher than with the concepts of the ceiling supply.
However in practice, the utilizing of the thermal displacement ventilation system is many cases difficult because of the space constrain in kitchens. Still if the space allows, the thermal displacement ventilation is the first option for the supply air solution.
Based on the conducted measurements of the centralized capture jet concept, it is possible to derive a correlation of the used airflow rate and theoretical convection flow (spillage factor) as a function of the containment removal efficiency. To obtain 85 % and 90 % containment removal efficiency, it leads to the flush-out factor of 1.2 and 1.5 with the ceiling supply capture jet (Kosonen 2005), Fig. 4.

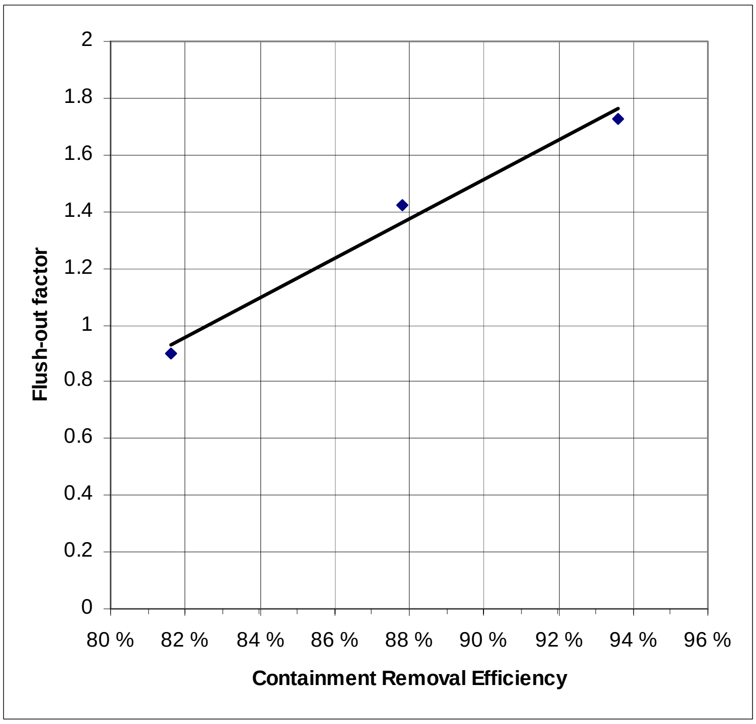


Figure 4. The flush-out factor of the supply air of the ventilated ceiling with the capture jet as a function of the containment removal efficiency.

CONCLUSIONS

Kitchen design requires the expertise of many different specialists to produce designs that meet the requirements of productive and cost-effective working environments. To fulfill all needs of indoor air conditions, the total approach of ventilation design should be used. This means that the ventilation system is designed based on the target values of indoor air quality and the actual heat loads of the kitchen

appliances, and in addition to the effect of the general ventilation for the hood performance should be analyzed.
It is still quite common practice to estimate exhaust airflow rates based on rough methods. The characteristic feature of these methods is that the actual heat gain of the kitchen appliance is neglected. Thus, the exhaust airflow rate is the same: even under the hood is heavy load like a wok or light load like a pressure cooker. These kinds of rough estimation methods do not lead to optimal solutions; the size of the whole system will be oversized and so the investment costs and running costs will increase.
Using a heat load based method gives the most accurate airflow rates. Based on the conducted study, in the medium-load case rough method like face velocity oversized the whole system 2- or 3- times compared with the heat load based method. This over estimation is 1.4 –1.8 even with the extra-heavy load.
At the moment, there are modern measurement and simulation technologies to study the kitchen environmental. Schliering thermal imaging visualizes the convection heat coming from the kitchen appliance. By using this technology, it is possible really see normally invisible thermal plume. Also Computation Fluid Dynamics (CFD) has become an invaluable tool to assist R&D work by providing an accurate prediction of results prior to full scale mock-ups or testing for validation purposes.
The modern technology solutions enable to reduce the size of the total system. Using high efficiency capture jet hood is possible to use 30 % lower air flow rates than with normal exhaust hood. Using the capture jet in the ventilated ceiling, it is also possible to improve the total effectiveness of the ventilated ceiling system. In the scenario with capture jet, the average contaminant level in the occupied zone was 40 % lower and the estimated energy saving potential can be as much as 23 %.
The application of a low velocity displacement ventilation system allows for a reduction in exhaust airflow by 15 % compared to a conventional mixing ventilation system. VDI proposes to use the spillage factor of 1.05 for thermal displacement system and 1.25 for the mixed ventilation system. To obtain 85 % and 90 % containment removal efficiency of the ventilated ceiling system, it leads to the flush-out factor of 1.2 and 1.5 with the capture jet ceiling supply system.

ACKNOWLEDGMENT

The study is supported by Technology Agency of Finland (TEKES).

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