Assessment of Range Hoods based on Exposure

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ABSTRACT

Cooking can be a major source of exposure to particulate matter. Range hoods can be used to reduce odours, moisture and contaminants resulting from cooking. The capture efficiency with regard to these contaminants is determined by the thermal plume and the aerodynamic properties of the range hood. There is a new ASTM (an international standards organization) test method: ASTM E3087. It measures capture efficiency under specific conditions that permits standardized comparison of range hoods under controlled laboratory conditions. The results of the ASTM test method depend on exhaust flow rate, range hood geometry, thermal properties of the sources, and the number of burners in use. This study investigates and quantifies different aspects not included in the ASTM test method but have impact on the exposure of the occupant. An example of an exposure approach is given in this paper whereby the residence time averaged $PM_{2,5}$ exposure for person in a typical Dutch dwelling has been calculated using a 2-zone model. The model was used to identify the additional key factors beyond capture efficiency that influence occupant exposure. We propose a methodology to calculate exposure based on these factors that could be the basis of a future European standard.

KEYWORDS

Range hood, capture efficiency, disturbance, exposure

1 INTRODUCTION

In homes, particles are the key IAQ component from a health impact perspective and cooking can be a major source of exposure to particulate matter, see Abdullahi (2013) for a review of this literature. Range hoods can be used to reduce odours, moisture and contaminants resulting from cooking. The capture efficiency with regard to these contaminants is determined by the thermal plume and the aerodynamic properties of the range hood. There is a new ASTM (an international standards organization) test method: ASTM E3087. It measures capture efficiency under specific conditions that permits standardized comparison of range hoods under controlled laboratory conditions. The results of the ASTM test method depend on exhaust flow rate, range hood geometry, thermal properties of the sources, and the number of burners in use (Kim et al. (2018a)). This study investigates and quantifies different aspects not included in the ASTM test method but have impact on the exposure of the occupant. For example, the flow field for capturing cooking plumes can be disturbed by the presence of cooks as they move around with their body and arms. This can reduce efficiency with roughly 30% (B. Geerinckx, 1991). This study investigated this further to examine how it influences the exposure of the cook and other people in the kitchen area.

2 APPROACH

The exposure of the user in a dwelling due to cooking emissions depends on many variables such as: source strength and location on the cooktop, capture efficiency of the range hood, presence of the cook near the cooktop for instance the activities of the cook such as, smelling, stirring, moving to and from of the cook, ventilation and infiltration diluting contaminants and impacting capture efficiency, air transport of contaminants to other rooms, time spent in different rooms in the dwelling and the effect of the outdoor pollution levels. This study investigates and quantifies these variables to determine the key parameters that could lead to the development of future exposure standards. First, we performed a literature review to determine the effect of the presence and motion of a cook and how this changes the capture efficiency of the range hood and the local flow field that determines the exposure of the cook. We then developed a calculation procedure for exposure whereby the residence time averaged $PM_{2,5}$ exposure for person in a typical Dutch dwelling has been calculated using a 2-zone model and "best practice" range hood with good capture, low fan power and very low noise levels.. The model was used to identify the additional key factors beyond capture efficiency that influence occupant exposure. We propose a methodology to calculate exposure based on these factors that could be the basis of a future European standard.

3 LITERATURE REVIEW

Jacobs (2018), did a study on the exposure of cooks under different exhaust flowrates and cooking exhaust configurations. The exposure approach based on multi zone simulations showed that the additional exposure toward $PM_{2.5}$ from cooking linearly decreases with higher capture efficiency. The results with regard two typical exhaust flowrates and three typical cooking exhaust configurations are graphicly displayed in Figure 1.

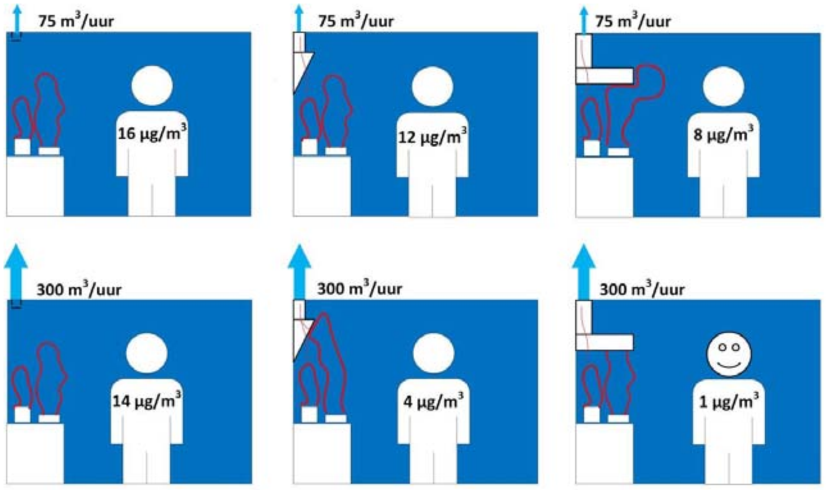

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Figure 1: Annual average PM2,5 concentration increase during occupied times in a dwelling due to cooking for different range hood flows and geometries

In the Netherlands the yearly averaged ambient $PM_{2,5}$ concentration is about 14 $\mu g/m^3$. Assuming an indoor/outdoor factor of 0,5 the indoor concentration due to ambient sources for a typical dwelling is estimated at 7 $\mu g/m^3$. Without a range hood the total exposure to $PM_{2,5}$ can be more than tripled to $16 + 7 = 23$ $\mu g/m^3$. An effective range hood in combination with a sufficient high exhaust flow can reduce the increase below 1 $\mu g/m^3$. Therefore use of an appropriate range hood can keep concentrations below the WHO (2010) guideline value of 10 $\mu g/m^3$. The results are in line with the average findings of recent monitoring studies (Chan

2017, Jacobs 2016). However, on individual level large differences can be seen. Comparing calculation to values from literature shows calculations are reasonable. Kim measured 20 cooking events in 6 homes for $PM_{2.5}$ and 28 events in 9 homes for NO_2 (Kim et al., 2018b). The results showed roughly a doubling of $PM_{2.5}$ from 2.5 to 6 $\mu g/m^3$ and an increase from 6 to 22 ppb NO_2 during cooking activities with no range hood operation. There was considerable variability from event to event between zero and more than factors of ten increase in these pollutant concentrations. Range hoods proved very effective at minimizing increases in these contaminants. A subset of four tests showed that range hood operation resulted in very small increases in contaminants when cooking: with less than 1 $\mu g/m^3$ (on average) changes in $PM_{2.5}$. Another set of seven tests showed increases of only 2 ppb NO_2 when range hoods were operated. Although these results show that range hoods can be effective in terms of keeping overall concentrations low, there are still questions about the exposure for the person doing the cooking as well as how a given capture efficiency relates to contaminant exposure for occupants. Also, if these results shows that a range hood can be very effective, can the influence of the cook be still be significant? Furthermore is the amount of influence of the movements of the cook on exposure also depending on the specifications of the hood as extract flow, geometry and flow? If so could it be an aspect to take into account if we want to compare the effect of exposure of different range hoods?

Previous studies have investigated the effect of disturbances of cooks on capture efficiency. Geerinckx and Wouters published a paper in 1991 in which they show a important effect of disturbances. The interference device (height: 1.0 m, width: 0.5 m) is designed to mimic the disturbance by the cook, see figure 2. Over a distance of one meter it moves at a speed of 0.5 m/s at a frequency of 1 movement per 8 seconds, as the authors state this is quite an active pattern. After 600 second of injecting tracer gas at a stabilized hot plate of 110 ºC, the kitchen hood is turned off and room ventilation stopped and a mixing fan is applied.

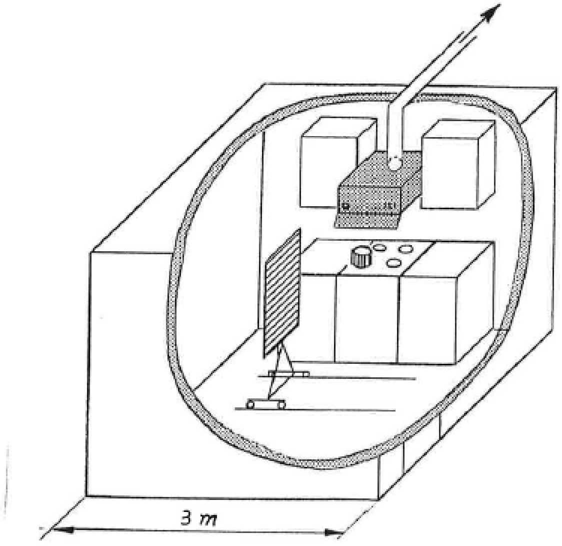

Figure 2: Schematic view of the test chamber of Geerinckx and Wouters (1991).

In figure 3 the measured concentration in the exhaust and in the test room is presented. The measured concentration pattern in the test room follows the concentration in the exhaust but is roughly a factor two lower.

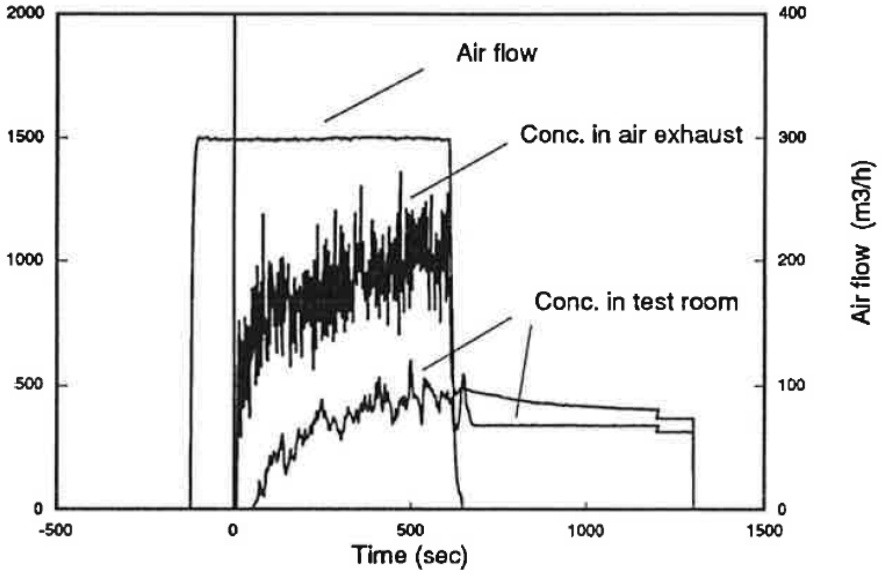

Figure 3 Measured concentrations due to disturbance

They expressed the effect of disturbances not only on the pollutant removal efficiency but also as a pollutant index . The pollutant index is defined as the relative concentration in the occupied zone using a certain kitchen hood at a certain air flow rate by taking the situation of 100 m^3/h extraction with perfect mixing as a reference. The corresponding formula is as follows:

$$P_i = \frac{C * 10^{-6}}{\frac{q}{100}\left(1 - e^{-\frac{100}{V}t}\right)}$$

Whereby P_i : pollution index of the kitchen hood
C: concentration of tracer gas (PPM)
Q : tracer gas injection flow (m^3/h)
t : injection time (h)
V : volume of the room without cupboards (m3)

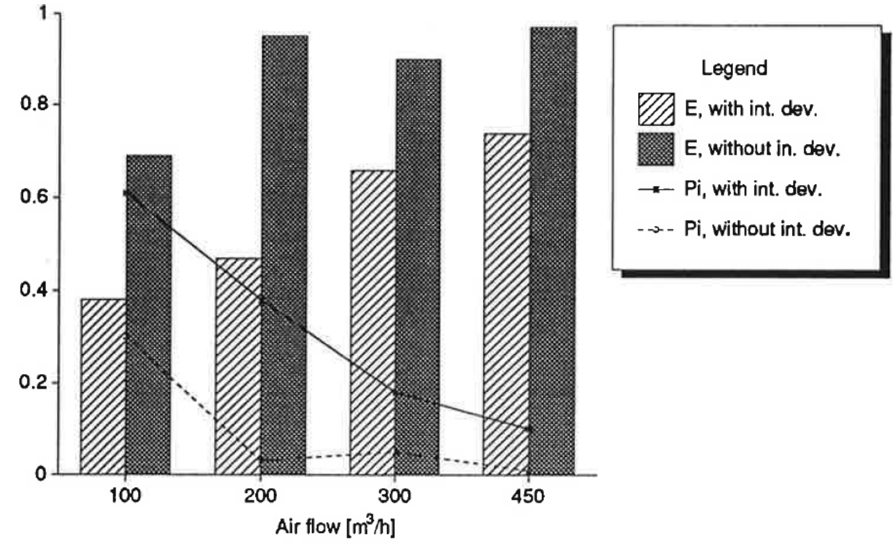

Figure 4: Range hood performance expressed as efficiency, E, and as pollutant index, Pi, with and without disturbance (Geerinckx and Wouters, 1991)

Geerinckx and Wouters showed that the disturbance reduced the pollutant removal efficiency by around 25 - 45%, see Figure 4. Table 1 shows that the pollutant index changes are much higher, changing by a factor 10 to 3. The effect on exposure of the interference device is not constant for a fixed air flow and seems to depend on extract flow and geometry of the range hood.

Table 1: Comparitiv results pollution indicess (Geerinckx, 1991)

Air flow (m3/h)	**With interference device**	**Without interference device**
450	0.1	0.01
300	0.18, 018	0.06, 0.05
200	0.39, 0.37	0.03,0.03
100	0.61,0.61	0.32,0.29
‘optimal’300	0.03	

Gao et al. (2013) combined experimental and calculation methods to determine the effect of make up air source (the geometry, velocity and location) on the exposure level. The make up air source had a major effect on the inhaled peak concentration. With inflow from an open window peak concentration was 9,4 times of that under inflow from a full open door, and 79,2 times of that under inflow from a 30 degrees open door. It is important to give good guidelines for make up air and ventilation because these can have a significant impact on exposure. These guidelines need to consider the designed of the kitchen and a range of different movement patterns for cooks.

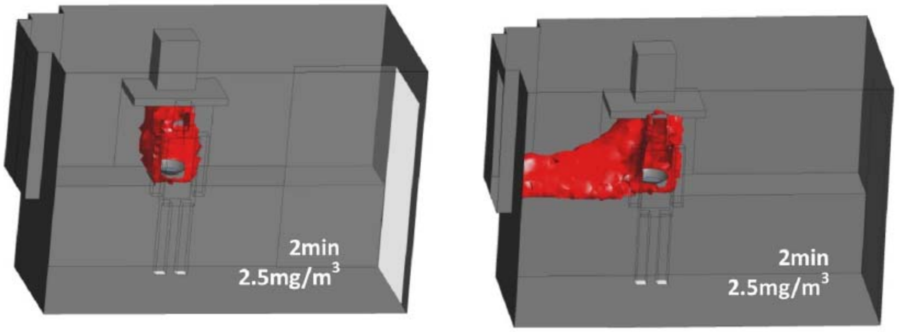

Figure 5: Iso-surfaces of particulate mass concentration (0,1-10 µm) in the kitchen space 2 min, (a) open door, window closed, (l) door closed, window half open (r) (Gao et al. (2013)

Bowen Du (2017) did a study on particle exposure and potential health risks related to cooking Chinese food. The current Chinese standard of ventilation in kitchens regulates the installation location and performance of exhausting hood, but there are no specific regulations for the exposure of the cook during cooking. Young healthy students cooked typical Chinese food in a controlled kitchen over a two day period. Measured $PM_{2.5}$ concentrations were around 10 mg/m^3 in the breathing zone. The experiments investigated a make-up air solution similar to that used in advanced laboratory fume hoods, where air is injected into a 1 cm wide slot around the cooktop bench supplying filtered air at different rates. Although designed to act as an air curtain to control the spread of contaminants it increased the exposure in the breathing zone of the cook by about a factor of five. The air injected from the slot in this particular case made the exposure of the cook worse. The students were medically examined. Although the impact on the different lung function bio markers was less clear the paper stated significant reduction of lung function among young healthy students after two days' typical Chinese domestic cooking processes.

Overall these studies show considerable variation in exposure due to the presence of cooks and devices that interfere with the air flow patterns around the cooktop.

4 MODEL DEVELOPMENT: CALCULATIONS OF FLOWS AND EFFECTS BY A MOVING PERSON

4.1 Assumptions

The model is based on mimicking the motions of a cook in the following way:

- When stir frying the cook moves twice to and from the cook plate
- The cook moves with a velocity of 0.5 m/s
- The cooks arm blocks an effective area of 0.075 m^2
- The flowrate of the hood is 50 dm^3/s with an efficiency of 80 %
- A $PM_{2,5}$ source strength under the hood on the cook plate of 10 µg/s
- A general kitchen exhaust rate of 21 dm^3/s in addition to the hood

4.2 Calculations

The equilibrium concentration in the kitchen assuming a single well mixed zone is calculated with an efficiency of 80% and no disturbances by the cook;

$C_{av\ kitchen} = q_{source}/q_{vent\ kitchen}$

$q_{source} = (100-80)/100 * 10 = 2\ \mu g/s$
$q_{vent\ kitchen} = 50 + 21 = 71\ dm^3/s$ or $0.071\ m^3/s$

$C_{av\ kitchen} = 2 / 0{,}071 = 28.2\ \mu g/m^3$

The average concentration between cook plate and range hood can be calculated as;
$C_{av\ hood} = q_{source}/q_{vent\ hood}$
$q_{source} = 10\ \mu g/s$
$q_{vent\ hood} = 50\ dm^3/s$
$C_{av\ hood} = 10/0.050 = 200\ \mu g/m^3$

The influence of the disturbance by the cook on the average room concentrations (and therefore exposure of other people in the room), is calculated using the same procedures as Geerinckx, is calculated as follows:
The volume flow due to the motion of the cook is:

$q_{dist\ flow} = A_{dist\ cook} * v_{cook} = 0.075 * 0.5 = 0.0375\ m^3/s$ or $37.5\ dm^3/s$

This pulse of flow caused by the moving cook cannot be completely exhausted by the cooker hood because its initial velocity is 0.5 m/s while the average velocity between cooker hood and the room is about 0,25 m/s. Some provisional measurements gave a flow from the cooker hood area to the kitchen with a velocity of about 0.3 m/s during this movement of the cook. Assuming that 90% of this flow caused by the cook is captured by the hood, that means 10 % is re-entering the kitchen with a concentration of 200 g/m^3.This leads to an increase of the concentration in the kitchen, which can be calculated.
The flow re-entering the kitchen $q_{re\ ent}$ is $0.1 * 0.0375 = 0.00375\ m^3/s$, with a concentration $C_{av\ hood}$ of $200\ \mu g/m^3$. This leads to an increase of the kitchen concentration due to movements of the cook of;

$\Delta C_{dist} = (q_{re\ ent} * C_{av\ hood}) / q_{vent\ kitchen} = (0.00375 * 200)/ 0{,}071 = 10.6\ \mu g/m^3$.

Compared with the $C_{av\ kitchen} = 28.2\ \mu g/m^3$ the calculated effect of the disturbance is about 38 %. This example calculation illustrates that the measured effect of disturbance on the hood efficiency carried out by Geerinckx can be calculated with reasonable assumptions.

4.3 Effect of different types of range hood configurations

Figure 6: Several configuration of cooker and exhausts

Several representative configurations have been developed and are illustrated in Figure 6:

1. Without range hood no cupboards on the sides, against the wall
2. Without range hood no cupboards on the sides, island

3. Wall mounted range hood, no cupboards on the sides
4. Island range hood
5. Wall mountain range hood with air curtain, no cupboards on the sides
6. Island range hood with air curtains
7. Wall mounted inclined range hoods
8. Downdraft range hood

These configurations were chosen to investigate the following factors:

- The capture efficiency may differ for the different configurations, e.g. the inclined hood has a lower average velocity for the same extract flow as the wall mounted range hood.
- An island range hood with the same extract flow as a wall mounted range hood will be more easily disturbed because the disturbed flow will be captured is a less effective way.

The next steps in this work will be to further develop the exposure model and add parameters that account for the above factors. The intent is to develop a simplified model that could be used in a labeling system for the relative exposure of cooks and other kitchen occupants.

5 CONCLUSIONS

- The disturbance due to cooks is important for their exposure for cooking products.
- Simple calculations can be used to estimate the reduction of the efficiency of the range hood due to the disturbance of the room flow field by the cook.
- Efficiency is an important step to compare similar types of range hoods, but if focus is on exposure the effect of disturbances have to be taken into account. Also it could be possible to design a hood which is less effected by disturbances.
- To estimate exposures it is important to account for differences in geometry, for example island and wall mounted range hoods.
- The exposure due to cooking oil products might have an effect in terms of health, which needs further research in the intensity, time and frequency of cooking oil fumes and the effects of the this exposure to health effects of the cook and inhabitants.
- Ventilation of the kitchen can play a significant role in the exposure of the cook. Guidelines on make air and ventilation can help reduce exposure to the cook.
- More research on this topic is needed:
  - Measurements of exposure
  - Measurements of disturbances
  - The effect of differences range hoods types

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