$PM_{2.5}$ in Dutch Dwellings due to Cooking

Piet Jacobs, Ir.
TNO, the Netherlands

Wouter Borsboom, Ir.
TNO, the Netherlands

Richard Kemp, Phd
TNO, the Netherlands

ABSTRACT HEADING

Cooking emissions have long been seen as an odour problem. However recent studies showed that Particulate Matter (PM) is the main health risk of indoor air and cooking can be a major source. A small field study within 9 Dutch dwellings indicates that depending on the conditions cooking can have a relatively large effect on the indoor exposure to $PM_{2.5}$. Four determining variables have been identified. First the cooking method: lids on or off, cooking on gas or induction and the type of food has a large effect. In general meat frying seems to generate significant PM. Second the type of range hood and the exhaust flowrate. Based on this limited study the best are motorized hoods with a high exhaust flow, followed by recirculation hoods, motorless hoods with a high exhaust flow and lastly motorless hoods just complying with the Building Standard. The third parameter is the amount of ventilation compared to the volume of the kitchen / livingroom in relation to the exhaust flowrate. In some of the larger rooms the exposure was quite high even though the peak concentration wass not, due to the fact that it took several hours to reduce the concentration to acceptable levels. The fourth parameter is the infiltration of ambient $PM_{2,5}$ by the ventilation system.

INTRODUCTION

Cooking emissions have long been seen as an odour problem. However recent studies showed that Particulate Matter (PM) is the main health risk of indoor air (Logue, 2012) and cooking can be a major source (Borsboom, 2016). Research by MacNeill in 50 Canadian dwellings indicated that in the summer 16% of the fine dust originates from indoor sources, increasing to 41% in the winter. These results could be obtained by the use of optical particle counters which enable a high time resolution e.g. 1 minute averages. Gravimetric methods provide in most cases a 24 hour average value for PM. This makes it difficult to link the measured value with the different indoor and outdoor sources.

Exposure to particle matter by outdoor and indoor sources in buildings can be reduced significantly. Studies on range hood flowrate and design optimisation showed that there could be a major reduction in $PM_{2.5}$ due to cooking. By improving flow rate and adding a damp buffer the maximum value of $PM_{2,5}$ reduced from above 800 to below 100 (Jacobs, 2016). Research in Dutch offices has shown that filtration of ambient air can reduce the indoor $PM_{2.5}$ concentration greatly (Jacobs 2015).

This explorative study aims to quantify the exposure to $PM_{2.5}$ in 9 Dutch dwellings with different ventilation systems and different cooker hoods.

Piet Jacobs is a researcher in the Department Heat Transfer and Fluid dynamics, TNO, the Netherlands. **Wouter Borsboom** is business Consultant and Richard Kemp is researcher in the same department.

EXPERIMENTAL SETUP

In the living room/kitchen of 9 dwellings $PM_{2.5}$ concentrations were determined with optical particle counters during a week. The dwellings were all non smoking. To eliminate the influence of open windows the measurements have been executed during the winterperiod 4th December 2015 to the 23rd February 2016. Two optical particle counters (OPC) have been used in parallel: a Grimm 1.109 and a Grimm 11-R. The optics of these two instruments are identical.The OPC's have been compared to each other and showed less than 5% difference in PM readings. One of the OPC's was equipped with a temperature and relative humidity sensor to investigate the effect of relative humidity on PM.The inhabitants were asked to photograph the warm meals they cooked on the electric or gas stove. This gives information about the time of cooking. In this way the observed 'peaks' could be linked to cooking or other activities. The photos also provide information on the configuration of the pans on the stove and this information will be used for further research. Table 1 gives information about the type of dwellings, size of the living room/kitchen, type of ventilation system and the flowrate. The flowrates have been measured during the installation of the measurement equipment with a Acin Flowfinder. In a few dwellings the flowrates have not been measured, in this case they have been estimated by information of the supplier.
The ambient $PM_{2.5}$ is derived from a nearby monitoring station retrieved from www.luchtmeetnet.nl. Four dwellings were ventilated by a natural supply and mechanical exhaust (system C), and four with balanced ventilation with heat recovery (system D). One dwelling was naturally ventilated (system A) by natural supply and exhaust.

Table 1. experimental conditions and characteristics

Measurement	Cooker	Hood type	Capacity [m³/hour]	Vent. system	Ventilation [m³/hour]	Volume living room/kitchen [m³]	# persons	Dwelling type
Ettenleur	Gas	motorised	700[1]	C	700 + 75[1]	240	4	detached
Delft 2	Gas	motorised	166/212/238	C	166 + 13	120	2	row
Leiden	Induction	recirculation	500[1]	D	> 100	350	4	row
Amsterdam 2	Induction	recirculation	400[1]	D	60	110	2	apartment
Bilthoven	Gas	motorless	155	D	155 + 21	85	2	apartment
Delft 1	gas	motorless	123	D	123	128	4	row
Voorschoten	gas	motorless	35[1]	C	35 +15[1]	125	4	row
Den Haag	induction	motorless	38	C	69	120	4	semidetached
Amsterdam 1	gas	no hood-	-	A	40[1]	15	2	apartment
Ettenleur	gas	motorised[2]	-	C	75	240	4	detached

[1]Estimated from supplier information. [2]During half the week the motorised hood was intentionally not used.

RESULTS

Most of the time the effects of indoor sources are larger than outdoor (ambient) sources. However when the ambient concentration is high and changing, it is difficult to determine the effect of cooking on the indoor PM. Such an example is shown in figure 1.

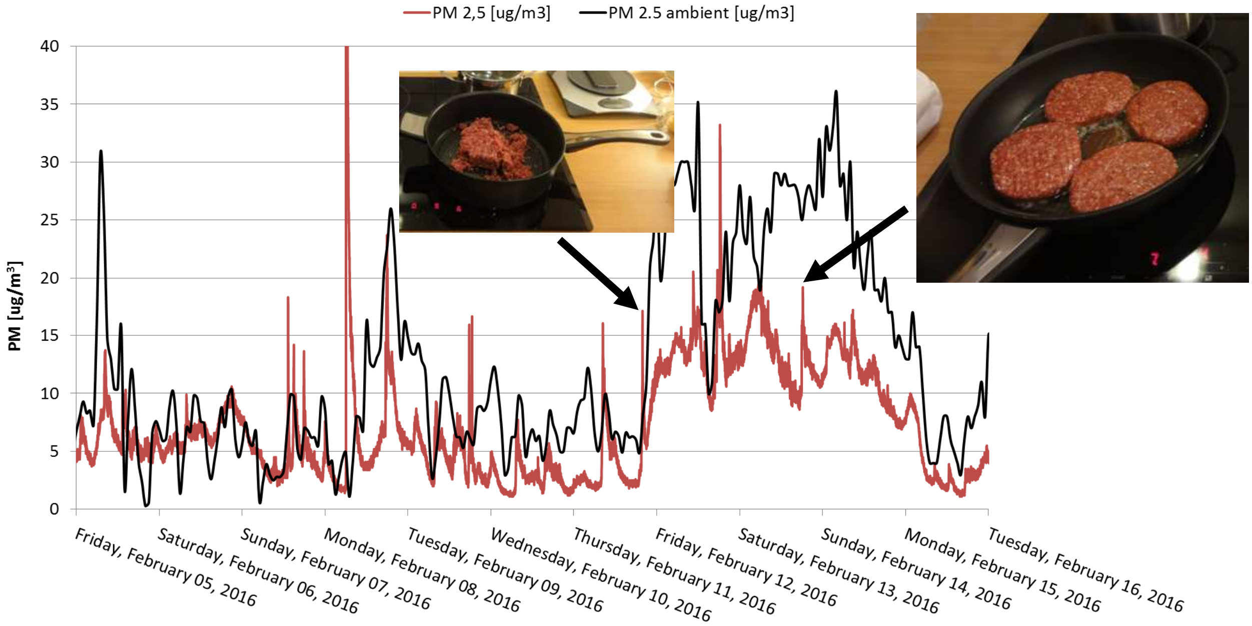

Figure 1 Den Haag, $PM_{2,5}$ indoor and $PM_{2,5}$ ambient. The effect of frying mince on Feb 11th and hamburgers the following Saturday is difficult to distinguish from infiltrated PM.

In case the (indoor exposure due to) ambient concentration of $PM_{2,5}$ is relatively low, it is relatively easy to determine the effect of cooking. Figure 2 shows the resulting PM pattern for Voorschoten. By referring to the photos it is easy to find the corresponding peaks. This example showed a very high $PM_{2.5}$ peak of 1919 μg/m³. It took more than 4 hours to go back to normal. Remarkably, the gourmet grill on New Year's Eve had a greater influence on the indoor PM than infiltration of PM due to the firework outside.

After identification of the peaks the average $PM_{2,5}$ in the period 18.00 – 23.00 hour is calculated. Peaks not related to cooking during this period are removed from this average. Then the average is compared with the average PM over the whole week. The difference, the PM increase, is shown in table 2.

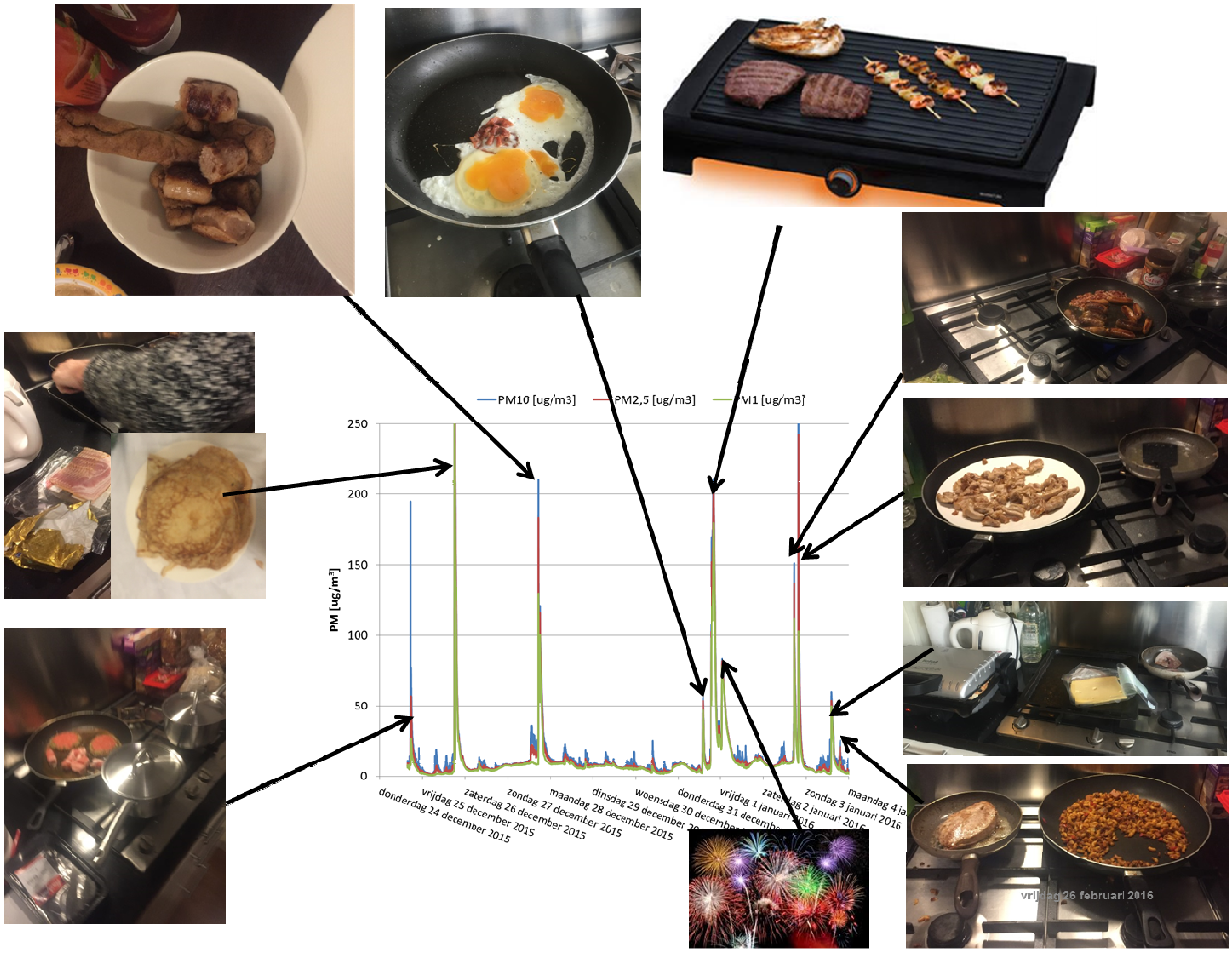

Figure 2 Voorburg, $PM_{2,5}$ indoor in relation to cooking activities.

Table 2. experimental results

Measurement	Cooker	Hood type	Capacity [m³/hour]	Air exchange rate[1] [ACH]	Max. PM due to cooking [ug/m³]	PM increase 18.00 – 23.00 hour [ug/m³]
Ettenleur	gas	motorised	700[4]	3.2	16 - 25[2]	0
Delft 2	gas	motorised	166/212/238	1.5	10 - 25[2]	0.5
Leiden	induction	recirculation	500[4]	0.3	70 - 110[2]	8
Amsterdam 2	induction	recirculation	400[4]	0.5	57	0 - 8
Bilthoven	gas	motorless	155	2.1	174	3
Delft 1	gas	motorless	123	1.0	40 - 94[2]	10
Voorschoten	gas	motorless	35[4]	0.4	242 - 1919[2]	16
Den Haag	induction	motorless	38	0.3	20	-[3]
Amsterdam 1	gas	no hood	-	2.7	651	5
Ettenleur	gas	no hood[1]	-	0.3	121 - 350[2]	44

[1]Air exchange rate with hood in operation. [2]Pancakes with bacon. [3]Ambient too high. [4]Supplier information.

Effect of relative humidity

Figure 3 shows the results of the Amsterdam 1 measurement. In the investigated apartment the bathroom was located near the kitchen. In the evening of February 3 a shower has been taken which increased the relative humidity. This effect was strengthened due to the fact that the OPC was located below a single glazed window. At this place over a long period a high humidity was measured. Most likely this has been interpreted by the OPC as PM.

After the field study the effect on the OPC reading of moisture release due to cooking has been investigated by placing the OPC at different distances from a boiling kettle. Only when located directly in the visible water vapour cloud was higher PMreported. When the OPC was located 1 meter from the boiling kettle, no increased "PM" was indicated.

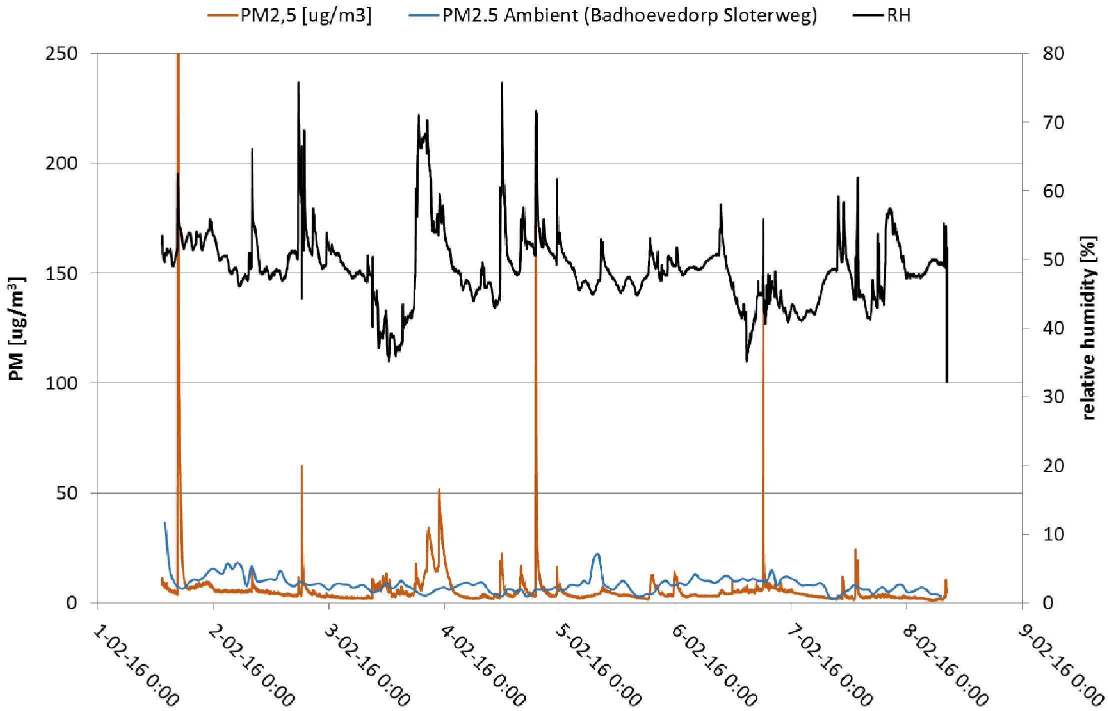

Figure 3 Amsterdam 1, $PM_{2.5}$ indoor, $PM_{2.5}$ ambient and RH in relation to cooking activities. The highest peak of 651 μg/m³ is not fully shown.

Other indoor sources of PM in dwellings

Aside from cooking $PM_{2.5}$ also originates from other indoor sources. In the Amsterdam 2 measurement hairspray was observed in the morning in concentrations up to 130 μg/m³. Further PM due to candles was observed with a maximum concentration of 40 μg/m³.

In the Den Haag measurement spraying deodorant caused peaks in the morning up to 350 μg/m³. It took several hours to return previous levels.

In the Bilthoven measurement, mostly early in the morning, relatively high peaks up to 1000 μg/m³ were observed in the relative small kitchen. It was remarkable that these peaks only lasted for one minute and then disappeared. It is believed that the peaks are caused by boiling a kettle to make tea..

In Ettenleur PM due to a firepit in the garden was observed. The indoor $PM_{2.5}$ reached 50 μg/m³.

In Delft 1 $PM_{2.5}$ due to playing children (maximum 30 μg/m³), tearing of packaging paper when opening presents (50 μg/m³), water vacuum cleaner (50 μg/m³) and the leakage of smoke from the wood stove (50 μg/m³) were observed.

DISCUSSION

Determining variables

The amount of PM released will be affected by the cooking method. In Den Haag most cooking was done while using (transparent) lids, see figure 4. This may have a positive effect on PM capture efficiency due to the fact that this reduces the amount of fumes. In combination with the induction cooking, which is more efficient than gas, this may explain the relatively small PM increase. Also the type of dishes has a large effect. By far the largest PM generator is pancakes with bacon and in general meat frying seems to generate significant PM.

Figure 4 Den Haag, typical cooking situation with lids on.

A second parameter is the type of range hood and the exhaust flowrate. The results in Table 2 can be further summarized, see table 3. Note that this is based only on 9 measurement locations, and only one week of cooking at each location. Hood design and the effect of filters on recirculation hoods are therefore not taken into consideration. Further research is required to confirm these early findings.

Increasing the capacity of the hood seems to have a positive effect. With regard to motorless hoods it has become common in the Netherlands to place two exhaust vents in the kitchen and to connect the hood with only one of them. Motorless hoods complying to the Dutch Building regulaton of 75 m^3/hour may have in the worst case only 75/2 m^3/hour exhaust capacity. This is far below the capacity of motorized hoods which are in the order of 238 – 700 m^3.

Table 3. summary of indicative findings

Type of range hood	increase in $PM_{2,5}$ exposure 18:00-23:00 [$\mu g/m^3$]
motorised hood	<1
recirculation (500 m^3/hour)	0 - 8
motorless (ca. 150 m^3/hour)	3 – 10
motorless (75/2 m^3/hour)	0 - 44

The third parameter is the amount of ventilation compared to the volume of the kitchen / livingroom in relation to the exhaust flowrate. A small closed kitchen as in Amsterdam 1 causes relative high $PM_{2.5}$ peaks up to 651 μg/m³. However due to the small volume these peaks decay relatively quickly due to the high number of air changes (air change rate 2,7 ACH). This situation is comparable with earlier cooking experiments by Jacobs [2016] in a 26 m³ climate room in which olive oil was heated, where a peak concentration of 826 μg/m³ PM_1 was found and within an hour the concentration was back at previous levels by dilution ventilation. In the field measurements in some of the larger sized rooms the exposure was quite high even though the peak concentration was not.Since the air change rate was low (below 1 ACH) it took several hours to reduce the concentration toprevious levels.

The fourth parameter is the infiltration of ambient $PM_{2,5}$ by the ventilation system. Hanninen (2005) predicted if dwellings are equipped with supply air filters an exposure reduction of 25% is possible. Studies in several offices (Jacobs 2015) show that a significant reduction of $PM_{2,5}$ is possible due to improving filter quality above M6 in the supply air. In the present study in the different dwellings, especially those with low ventilation levels, there is a significant reduction in internal PM compared to the outdoor $PM_{2,5}$. Examples can be seen in figure 1 and figure 3, where most of the time when there are no inside sources, indoor concentration of $PM_{2,5}$ is lower then ambient. The explanation for the relatively high reduction at low ventilation levels is that when the infiltration is low the absorption on indoor materials (walls, floors, furniture, etc.) has a relatively large effect.

CONCLUSIONS

A small field study within 9 Dutch dwellings indicates that depending on the conditions cooking can have a relatively large effect on the indoor exposure to $PM_{2.5}$. Four determining variables have been identified. Firstly, the cooking method: lids on or off, cooking on gas or induction and the type of dishes has a large effect. In general meat frying seems to generate significant PM. Secondly, the type of range hood and the exhaust flowrate. The best based on this limited study are motorized hood with a high exhaust flow, followed by recirculation hoods, motorless hoods with a high exhaust flow and last motorless hoods just complying the Building Standard. The third parameter is the amount of ventilation compared to the volume of the kitchen / livingroom in relation to the exhaust flowrate. In some of the larger sized rooms the exposure was quite high even as the peak concentration was not, due to the fact that it took several hours to reduce the concentration to acceptable levels. The fourth parameter is the infiltration of ambient $PM_{2,5}$ by the ventilation system.

ACKNOWLEDGMENTS

Many thanks for all the volunteers to open their houses for one week.

REFERENCES

Borsboom W., Gids W., Logue J. Sherman M., Wargocki P. 2016 Technote AIVC 68 Residential ventilation and health, ISBN: 2-930471-46-8.

Hanninen O.O, et al.2005. Reduction potential of urban PM2.5 mortality risk using modern ventilation systems in buildings., *Indoor Air* 15(4): 246-256.

Jacobs P. Voogt M. 2015 $PM_{2,5}$ measurement protocol for offices, Healthy Buildings 2015 conference Eindhoven.

Jacobs P., Cornelissen E, Borsboom W. 2016 Energy efficient measures to reduce $PM_{2,5}$ emissions due to cooking, Indoor Air Conference Gent.

Logue M.L, Price P.N, Sherman M.H, Singer B.C 2012. A Method to Estimate the Chronic Health Impact of Air Pollutants in U.S. Residences, *Environmental Health Perspectives* 120(2): 216-222.

MacNeill et al. 2013 Quantifying the contribution of ambient and indoor-generated fine particles to indoor air in residential environments,. *Indoor Air* 12/2013; 24(4).