Exploring $PM_{2.5}$ Exposure of Chefs in Professional Kitchens

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ASHRAE's Kitchen Ventilation technical committee, TC 5.10, has researched many aspects of commercial kitchens, including what factors impact the hood performance, which is the ability of an exhaust hood to remove all the grease, smoke, heat, moisture and other cooking effluents from a kitchen space. Three research projects[1–3] characterized the grease emissions present in the exhaust for a large variety of appliances. Another[4] investigated thermal comfort in commercial kitchens. However, none evaluated the impact of those grease emissions with regard to what levels of particulate matter (PM) were reaching the staff or customers, the subject of this article.

It is well documented that exposure to high concentrations of PM, and especially smaller particles (<2.5 micron, $PM_{2.5}$) are known to negatively affect health.[5] Recently, we have become aware that people are not just exposed to elevated PM levels outdoors. Indoor activities contribute to $PM_{2.5}$ exposure as well. One major $PM_{2.5}$ contributor in dwellings was found to be cooking (e.g., stir-frying). Many studies now have focused on $PM_{2.5}$ exposure in residential kitchens.[6] However, less is known about the daily $PM_{2.5}$ exposures of chefs in professional kitchens—and how these exposure levels compare with general levels that are identified as safe based on outdoor sources, e.g., by the World Health Organization (WHO), whose daily maximum level is 25 µg/m^3. It should also be noted that the WELL Standard v2 (www.wellcertified.com) has an indoor $PM_{2.5}$ threshold of 35 µg/m^3.

The research results presented in this paper are from research conducted in Europe and focus on identifying the $PM_{2.5}$ exposure levels of chefs and staff in professional kitchens. That was done in two ways:

- The sensitivity of the exposure level to the presence and functioning of an exhaust hood and ventilation was investigated in a controlled situation (a kitchen laboratory); and
- Exposure levels were measured in-situ in several

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TABLE 1 Laboratory hood testing matrix.

NO.	NAME	COOKING APPLIANCE; PRODUCT COOKED	HOOD TYPE	HOOD AIRFLOW (FT^3/MIN/FT)	AIR CURTAIN STATUS
#1	C1	Gas Charbroiler; Hamburgers	Canopy	352 C&C^a value	On
#2	C2	Gas Charbroiler; Hamburgers	Canopy	200	On
#3	C1	Gas Range; Pancakes	Canopy	307 C&C^a value	On
#4	C2	Gas Range; Pancakes	Canopy	200	On
#5	C1	Gas Range; Stir-Fried Vegetables	Canopy	307 C&C^a value	On
#6	C2	Gas Range; Stir-Fried Vegetables	Canopy	200	On
#7	B1	Gas Charbroiled; Hamburgers	Backshelf	123 C&C^a value	On
#8	B2 ON B2 OFF	Gas Charbroiler; Hamburgers	Backshelf	123 C&C^a value	1st Part: Efficiency Enhancement On 2nd Part: Efficiency Enhancement Off

^{a}Capture and Containment

normally functioning kitchens of restaurants in the Netherlands.

In both, the investigators included factors that may influence exposure levels, like the type of food that is prepared, layout and characteristics of the kitchen, exhaust hood characteristics, overall ventilation setting, etc. During the field study we wanted to explore the actual $PM_{2.5}$ exposure of chefs and staff in professional kitchens in the Netherlands. Results from a research study[7] conducted for professional kitchens indicate that these levels are orders of magnitude higher than what is generally regarded as safe.

Laboratory Study

The objectives of the laboratory study were:

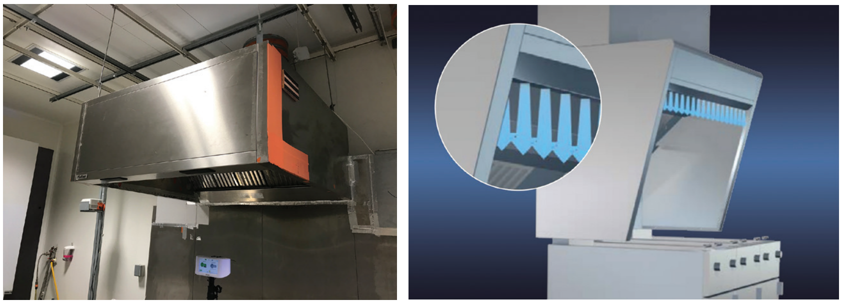
- Identify the $PM_{2.5}$ exposure of a chef in an ideal situation (in terms of ventilation).
- Investigate the effect of different cooking techniques on $PM_{2.5}$ exposure concentrations.
- Investigate the effect of different ventilation settings on the $PM_{2.5}$ exposure of a chef and concentrations in the kitchen.

In this laboratory portion of the study, the $PM_{2.5}$ exposure was monitored for different cooking processes and for different exhaust ventilation airflows. The measurement locations included the breathing zone of the chef and the indoor air in the space close to the stove or grill. *Table 1* provides an overview of the various test conditions.

All were tested with the canopy hood in two different settings. The first setting (C1) was the canopy hood at "capture and containment" (C&C) value (exhaust levels that are sufficient to remove visible vapors under the given load). The C&C values were determined using schlieren thermal imaging to ensure capture on the front and sides of the exhaust hoods. During the second setting (C2), the canopy was reduced to an airflow of 883 ft^3/min (1500 m^3/h). A photo of the canopy hood setup is shown in *Figure 1*.

Additionally, the backshelf hood (*Figure 1*, right) was tested in two settings when cooking hamburgers. The first setting was at C&C value (B1), and during the second setting (B2), the hood was allowed to spill halfway into the cooking procedure. Dimensions of the canopy hood were 53 in. (1350 mm) long by 63 in. (1600 mm) deep installed at a height of 79 in. (2000 mm) above the finished floor. The length of the backshelf hood was 43 in. (1100 mm).

FIGURE 1 Visualization of the hood characteristics. Left: Picture of the setup of the canopy hood. Right: Illustration of a backshelf hood with enhanced efficiency features.



$PM_{2.5}$ concentrations were measured at three locations (*Figure 2*): breathing zone of chef ($PM_{2.5}$ sensor type I); 0.8 ft (0.25 m) from the stove/grill ($PM_{2.5}$ sensor type II); and 6.6 ft (2.0 m) from the stove/grill ($PM_{2.5}$ sensor type II). For the measurements in the breathing zone, a tube was connected to the inlet of the measurement device. The other

FIGURE 2 (Left) Floor plan of the measurement setup. (Right) Picture of the measurement setup.

side of the tube was attached to the collar of the chef, to measure air representative for the breathing zone of the chef. A measurement interval of 1 second was applied. The measurement started at the same time as the cooking and ended when background concentrations were at baseline level. The duration of the measurement period, therefore, varied between the different measurements. The measurement interval for the measurements at 0.8 ft (0.25 m) and 6.6 ft (2.0 m) was 10 seconds. The type II sensors at these locations were placed at a height of 5.4 ft (1.65 m), assumed representative for the breathing height.

The measured concentrations during the different cooking techniques, hoods and settings of the hood were compared with the WHO limit of 25 µg/m^3 (limit value for average daily PM$_{2.5}$ exposure) and the WELL building standard limit for commercial kitchens of 35 µg/m^3 as shown in *Figures 3* and *4*.

Figure 3 presents the PM$_{2.5}$ concentrations in the breathing zone of the chef with the canopy hoods operating at a "high setting" with a variety of different cooking techniques. It can be observed that during cooking, the PM$_{2.5}$ concentrations in the breathing zone exceeded the WHO limit of 25 µg/m^3 23% of the time.

Figure 4 shows the PM$_{2.5}$ concentrations measured close to the stove/grill. The concentrations are compared to the WHO daily exposure limit and also to the guideline of the WELL building standard for commercial kitchens (35 µg/m^3). It can be observed from *Figure 4* that in the "ideal situation," both at a horizontal distance of 0.8 ft (0.25 m) and of 6.6 ft (2.0 m), the concentrations exceeded the reference values less than 1% of the cooking time.

Figure 5 presents results for a broad variety of cooking processes, tested with the "high" and "low" setting of the canopy hood (C1 and C2, respectively). In comparing the different cooking styles, it can be observed that cooking pancakes resulted in the highest PM$_{2.5}$ concentrations in the breathing zone for both ventilation settings. During the high ventilation setting (C1), the median concentration in the breathing zone during frying pancakes was 24 µg/m^3, while it was 12 µg/m^3 during broiling hamburgers and 7 µg/m^3 during stir frying. The median PM$_{2.5}$ concentration for the pancakes during the low setting (C2) was 49 µg/m^3. For the same ventilation settings, the median value during the hamburgers was 31 µg/m^3 and 10 µg/m^3 during the Chinese style wok.

Notably, the hamburgers resulted in the highest PM$_{2.5}$ concentration at a distance of 0.8 ft (0.25 m) and 6.6 ft (2.0 m) from the stove/grill. At a distance of 0.8 ft (0.25 m), the median during the preparation of the hamburgers was 34 µg/m^3, while it was only 8 µg/m^3 and 6 µg/m^3 during the frying process of the pancakes (pan fried) and Chinese style wok,

FIGURE 3 PM$_{2.5}$ concentrations in the breathing zone of the chef.

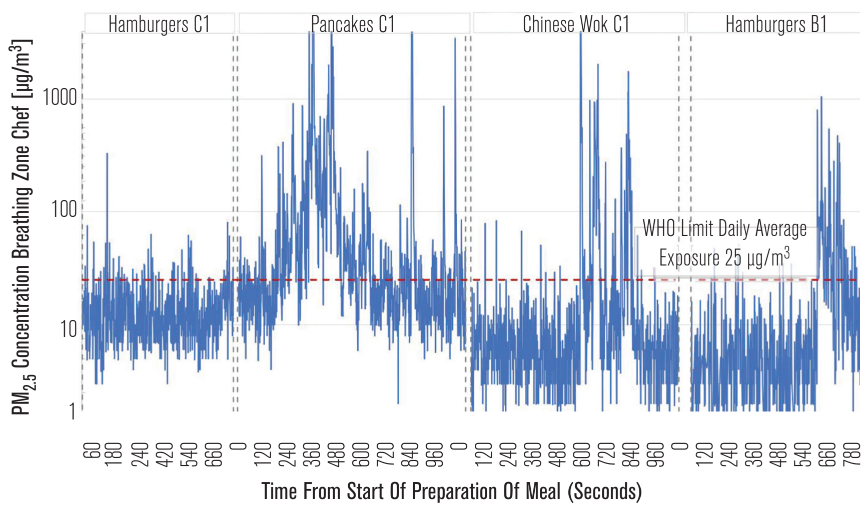
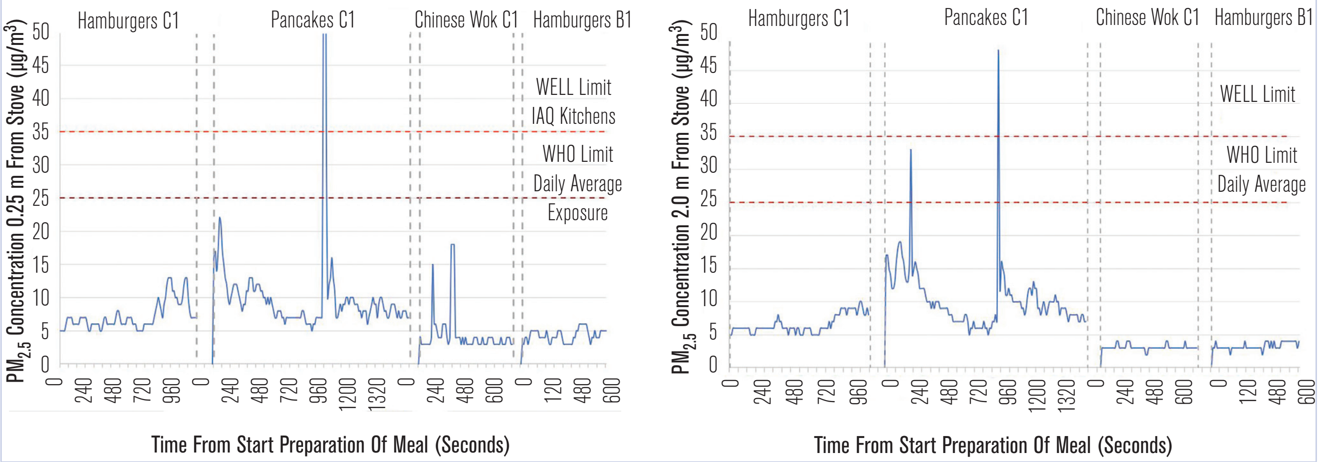


FIGURE 4 Indicative measurements of the $PM_{2.5}$ concentrations at 0.8 ft (0.25 m) (left) and 6.6 ft (2.0 m) (right) from the stove at maximum ventilation (during the highest exhaust setting of the hood for the different cooking procedures).



respectively, during the low ventilation setting.

In comparing the temperature during the different cooking procedures, there is a clear difference between the preparation of the hamburgers and the other cooking procedures. Ambient temperatures at a horizontal distance of 0.8 ft (0.25 m) from the grill exceed 122°F (50°C), while these remain around 77°F (25°C) when frying pancakes or stir frying. At a horizontal distance of 6.6 ft (2.0 m), there is still a clear difference in ambient temperature between the cooking procedures.

The hamburger cooking procedure was carried out four times to compare the two different hoods and the two different ventilation settings of each hood. For both hoods, the $PM_{2.5}$ measurements in the breathing zone confirm that the ventilation system is less efficient when the "low" setting is used as compared to the "high" setting (*Figure 5*). Especially when the efficiency features of the backshelf were switched off, $PM_{2.5}$ rapidly increased until a median value of 384 µg/m^3 during part 2 (2nd part B2 standard).

In comparing the canopy and backshelf hood, both with the highest setting (*Table 2*, #3 C1 vs. B1), the $PM_{2.5}$ exposure in the breathing zone during the hamburger cooking was slightly but significantly higher during the canopy cooking session as compared to the backshelf cooking session. This is while the percentage of time the $PM_{2.5}$ concentration exceeded the WHO limit of 25 µg/m^3 in the breathing zone was higher during the backshelf (15%) as compared to the canopy (9%). In the "low" setting, the canopy was more effective than the backshelf hood (*Table 2*, #4 C2 vs. B2).

To test the repeatability of the measurements, the first part of both backshelf measurements were carried out with the same settings (high). The results show that there are no significant differences between these two measurements (*Table 2*, #5 B1 vs. B2). This implies good repeatability.

Field Study

The objectives of the field study were:

- To identify the typical $PM_{2.5}$ exposure of chefs and other staff in real-life professional kitchens. To investigate the role of the background concentration on the exposure of the chef.

The methodology used in the field study portion of this research focused on measurements in seven restaurants in the Netherlands between November 25, 2019, and

FIGURE 5 Boxplots of the $PM_{2.5}$ exposure in the breathing zone, per meal and ventilation rate in relation to WHO limit.

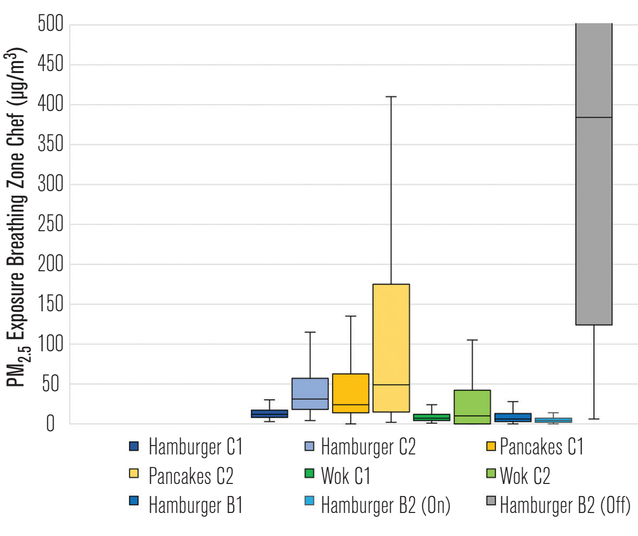


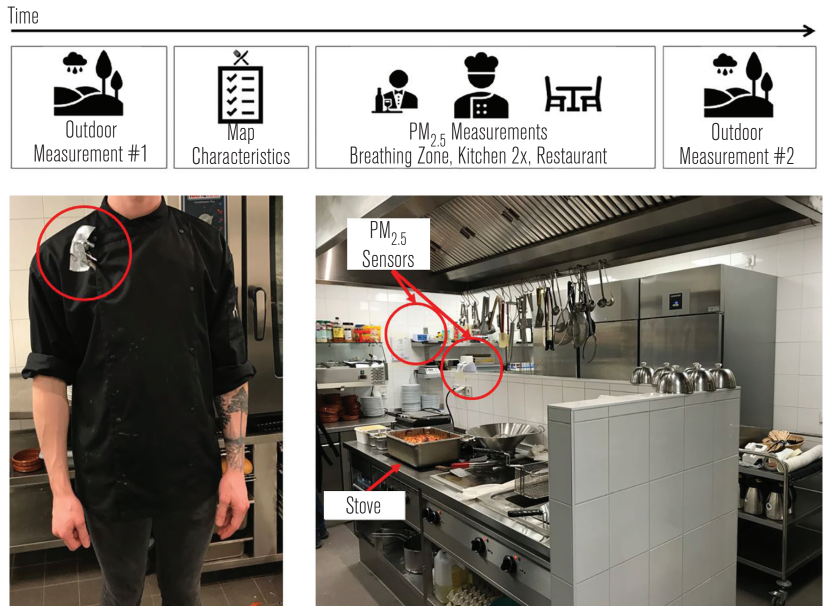
TABLE 2 Statistical comparison between $PM_{2.5}$ concentration in the breathing zone of the cook using the different hoods and the different settings of the hoods.

HOOD + AIRFLOW SETTING	MEDIAN ($\mu g/m^3$)	HOOD + AIRFLOW SETTING	MEDIAN ($\mu g/m^3$)	p-VALUE	SIGNIFICANT DIFFERENCE
Canopy, High (C1)	12	Canopy Low (C2)	31	<0.001	Yes
Backshelf, High (B1, 2nd Part)	20	Backshelf, Low (B2 Standard)	384	<0.001	Yes
Canopy, High (C1)	12	Backshelf, High (B1)	6	0.04	Yes
Canopy, Low (C2, 2nd Part)	50	Backshelf, Low (B2 Standard)	384	<0.001	Yes
Backshelf, High (B1, 1st Part)	3	Backshelf, High (B2 High Efficiency)	4	0.24	No

TABLE 3 Characteristics of the restaurants.

NO.	CUISINE	MEAL	TYPE OF KITCHEN
#1	University Restaurant	Dinner	Semi-Open
#2	Lunchroom (Eggs, Soup, Sandwiches)	Lunch	Semi-Open
#3	Italian (Pasta, Fish, Meat)	Dinner	Open
#4	Dutch (Meat, Salads, Frying, Oven)	Dinner	Closed
#5	Irish (Hamburgers)	Dinner	Closed
#6	Asian (Wok)	Dinner	Open
#7	Pancakes	Lunch	Open

FIGURE 6 Schematic of the protocol during the measurements (top); typical position of the measurements equipment (bottom).



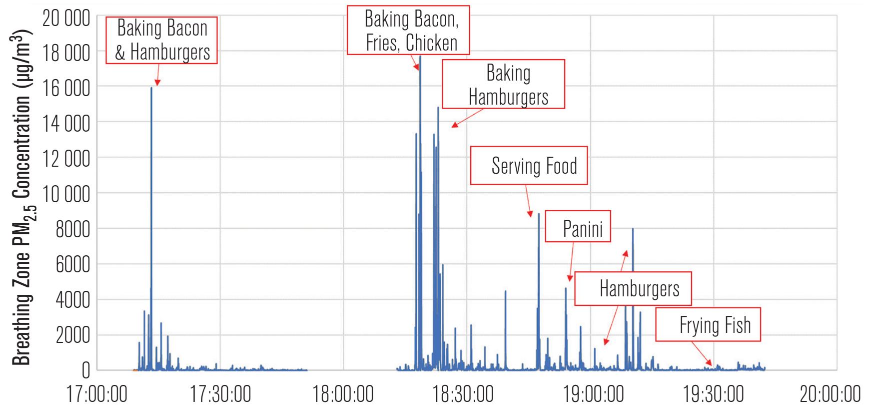
February 27, 2020 (*Table 3*). In all restaurants, measurements were performed during one evening (dinner) or one afternoon (lunch) when the restaurant occupancy was representative for a typical day. At each restaurant, $PM_{2.5}$ measurements were performed in the breathing zone of the chef during cooking, similar to what was done in the lab study, at two locations in the kitchen and outdoors. For Restaurant 3, 4, 6 and 7, measurements were also performed in the restaurant itself.

All the measurements followed a similar procedure. This is summarized in *Figure 6*, top. In the kitchen three $PM_{2.5}$ measurement locations were identified (*Figure 6*, bottom), one near the breathing zone of the chef ($PM_{2.5}$ sensor type I; measurement interval 1 second) and two at approximately 3.3 ft (1.0 m) and 6.6 ft (2.0 m) from the stove ($PM_{2.5}$ sensor type II; measurement interval 10 seconds). The duration of the measurements in the kitchen depended on the number of meals that were being prepared, but lasted at least 15 minutes. The measurements in the kitchen were stopped around 30 minutes after the last meal was being prepared.

Results and Discussion

An example of the exposure of the chef for Restaurant 1 over the course of the measurement period is presented in *Figure 7*. For the peaks it is indicated what cooking activity took place. The results show a very irregular pattern of the $PM_{2.5}$ exposure of the chef, including very steep and high peaks. This outcome is representative for the other restaurants. The peak exposure can be linked to the cooking and frying activities taking place. This may include the $PM_{2.5}$ production of the actual activity and the behavior of the chef at that time. For example, the chef may position his head between the stove and the exhaust hood. Average values for all restaurants during the measurement period, however,

FIGURE 7 Example of the exposure of the chef in Restaurant 1 as measured for the identified measurement period (*x*-axis). For some peaks the chef's activity is indicated



remain below 1 mg/m^3 and with that provide better outcomes than those presented by Shirin and Reddy.[7] Nevertheless, in all restaurants the exposure is at least 50% of the time higher than the 24 hours WHO limit of 25 µg/m^3. For most restaurants this is more than 75% of the time in the breathing zone of the chef (*Figure 8*, left), but this level is often also higher at 3.3 ft (1 m) from the stove (*Figure 8*, right). *Figure 8* also shows that the exposure for the different restaurants varies. Though it is not possible to distinguish the exact cause for the different outcomes, it is assumed that besides the cooking behavior of the chef, the type of dish being prepared also influences the particle generation. All the food discussed in *Figure 7* was prepared by the same chef, so it hints at the link between cooking activity and particle generation.

Figure 9 provides two examples measured in two restaurants (No. 3 and 7). The exposure, presented in boxplots, is compared at the different positions in the kitchen and restaurant. The outcome clearly shows that exposure in the breathing zone (BZ) of the chef is highest compared to other positions in the kitchen and the restaurant. From that it may be concluded that the source indeed is the cooking activity and that the ventilation hood is able to remove part of the generated particles.

If we ignore the peaks from the exposure measured at the BZ of the chef, it is possible to correlate the concentration at the BZ with that in the kitchen for all restaurants together. Assuming a maximum of 75% of the peak exposure for the BZ resulted in $R^2 = 0.57$ (for 50%, $R^2 = 0.74$). This would mean that the exposure in the kitchen could be partly explained from the particle concentration measured near the chef and the other way around. As a result, one also may deduce that the kitchen ventilation for the different restaurants investigated in this field study operated at a similar performance level.

To assess the importance of the peaks, *Table 4* presents a summary of the actual particle intake, per hour, of the chef in each restaurant (assuming a 0.26 ft^3/min [7.5 L/min] breathing volume rate). It includes

FIGURE 8 Boxplot of the measurements in the breathing zone (left) and at 3.3 ft (1 m) distance from the stove (right) for the different restaurants.

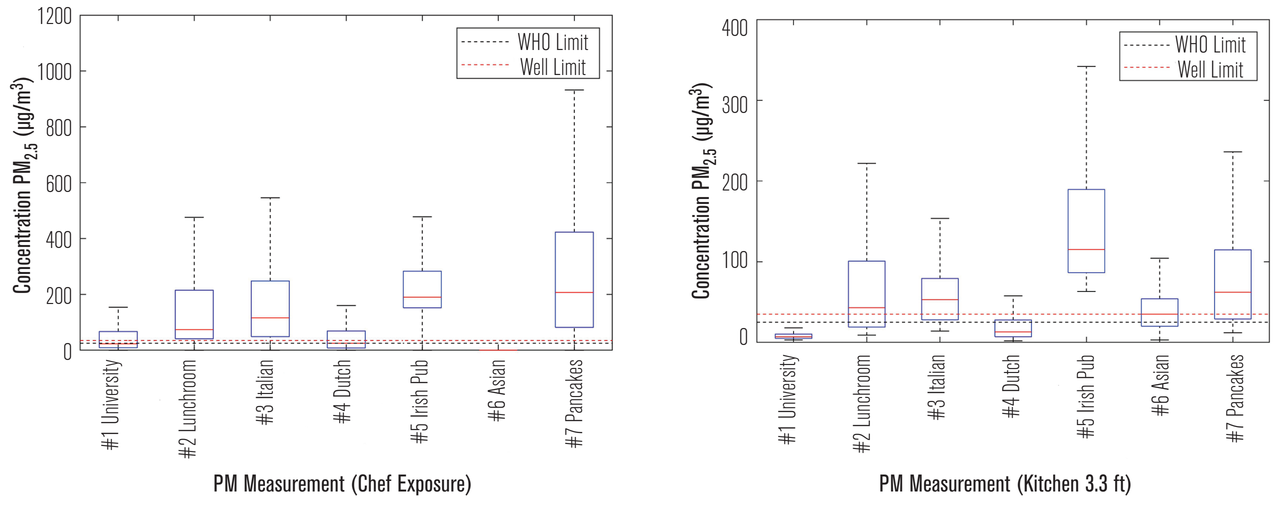
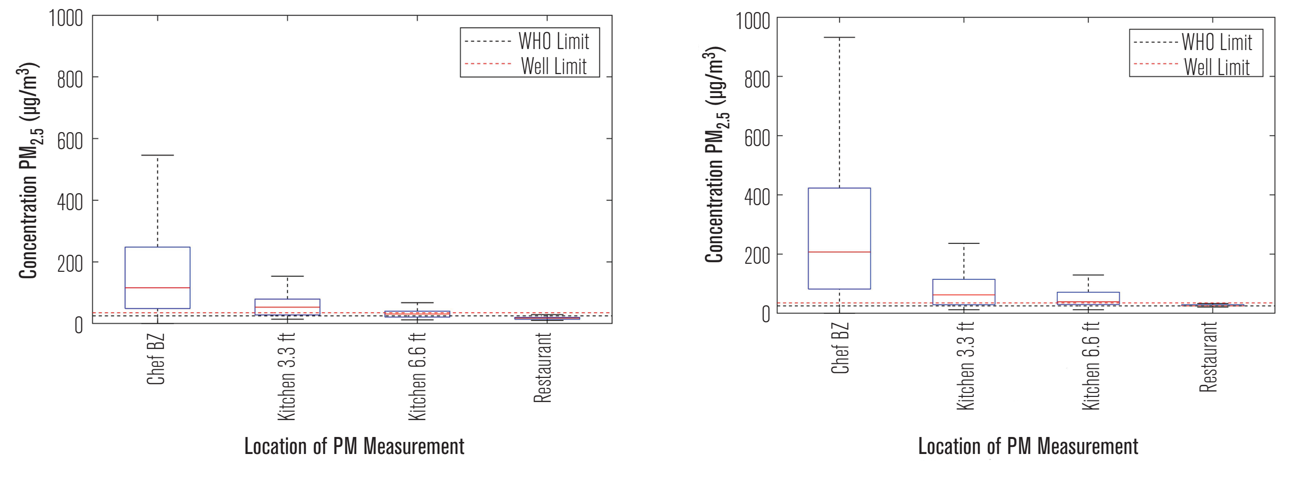


FIGURE 9 Outcomes of the measurements for Restaurant 3 (left) and Restaurant 7 (right). The results are presented in boxplots. BZ = breathing zone.



information on the relative contribution of the peaks for the upper 25% (P75–P100) and upper 5% (P95–P100) of the exposure concentrations measured.

Table 4 shows that the main problem in the total exposure of the chef is to be found in the peaks. They generally contribute to a large extent to the total $PM_{2.5}$ intake of the chef and need to be addressed when looking for improvements. In this field study it was not possible to identify the effectiveness of the cooking hoods applied. It, nevertheless, appears important to make improvements. In addition to that, the chef's behavior could most probably be optimized to reduce the exposure further.

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TABLE 4 Actual particle intake of the chef in each restaurant (average per hour). Maximum hourly intake allowed assuming 24/7 exposure to 25 $\mu g/m^3$ is 270 μg.

NR.	CUISINE	ACTUAL PARTICLE INTAKE ($\mu g/h$)	% OF INTAKE, P75 – P100	% OF INTAKE, P95 – P100
#1	University Restaurant	71	91%	71%
#2	Lunchroom (Eggs, Soup, Sandwiches)	68	68%	27%
#3	Italian (Pasta, Fish, Meat)	143	79%	50%
#4	Dutch (Meat, Salads, Frying, Oven)	26	74%	30%
#5	Irish (Hamburgers)	102	42%	12%
#6	Asian (Wok)	-	-	-
#7	Pancakes	181	70%	35%

Conclusions and Future Work

The outcomes from our laboratory study show that the hood performance can have significant impact on the $PM_{2.5}$ concentration at breathing level. The indoor air quality in the kitchen is compromised and the $PM_{2.5}$ level in the breathing zone increases when hood exhaust airflow is reduced below C&C level. It is also shown that the hood design affects the C&C airflow required to achieve the desired IAQ. The backshelf hood (test B1) requires 70% less airflow compared to the canopy hood (test C1) to achieve the same or a better IAQ. Finally, the hood effectiveness improvement measures such as the air curtain that were tested in this study significantly reduced the $PM_{2.5}$ level in the chef's breathing zone.

The outcomes from the (preliminary) field study show that there is a high risk that chefs in professional restaurants are exposed to $PM_{2.5}$ concentrations well above the WHO limits on a daily basis. These peaks were mostly observed at identified cooking activities and when the chef's head was below the hood. There is an effect of the cooking style, characteristics of the restaurant and ventilation system on the exposure level, but the results presented in this study were too limited to be conclusive on these issues. Reduction in the peak exposure for the chefs is imperative.

A simple solution refers to the behavior of the chef. However, this may be difficult to achieve in practice. In addition, the exhaust hood performance may be improved as well. Results from the lab study show that such improvements can be achieved with the new developments that come available (e.g., backshelf), though it will not yet take out the peaks completely. Instant feedback to the chef, additionally, may support effective use of the hood and improved behavior of the chef.

The outcomes of the current study may contribute to create more awareness of the exposure problem in kitchens and support a change in the design and/or operation of the kitchens. The behavior change will likely enable a healthier working situation in addition to the technical measures possible. Since the composition of the particulate matter and the pattern of the exposure (e.g., high exposure peaks) differ from general outdoor sources, specific limits for exposure to $PM_{2.5}$ in kitchens need to be developed to incorporate these health impacts.

Further research could focus on measuring additional pollutants in the kitchen environment, better defining the characteristics of the ventilation system and cooking styles as mentioned above, as well as setting standards for adequate thresholds to reduce the exposure. As discussed, behavioral change, in regard to both the position of the chef and the selection of the type of exhaust system, in addition to the technical measures (such as optimizing the design of exhaust and stove combination) may be required to enable a healthier working situation.

Acknowledgments

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