Kitchen ventilation system design and its effect on restaurant IAQ

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Abstract. It is well established that exposure to high level of Particulate Matter (PM), especially smaller particles below 2,5 micron (PM2.5) has a negative impact on health. We also know that cooking is the major contributor to PM levels in dwellings (Jacobs et al, 2016). A recent field study in restaurants (Kulve et al, 2020) also showed elevated levels of PM exposure, exceeding those recommended by World Health Organization (WHO). It is obvious that ventilation systems do not meet the objective of providing good Indoor Air Quality (IAQ) in restaurants with high level of PM exposure. This presentation addresses ventilation system design and its effect on PM level in the commercial kitchen setting. The study was conducted in a ventilation laboratory setting using a charbroiler and gas fryers cooking hamburgers, and French fries. Two types of ventilation hoods were tested as well as two air distribution strategies: mixing and displacement ventilation. The study replicated elevated levels of PM2.5 concentrations with inadequate ventilation design and demonstrated that properly designed ventilation system can protect kitchen personnel from high PM exposure. The study also emphasized the importance of IAQ sensors in restaurants to guarantee adequate performance of ventilation systems.

Keywords. Indoor Air quality, Ventilation, Commercial Kitchen, PM2.5, Health, Thermal Comfort
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1. Introduction

Indoor Environment Quality in commercial kitchens (IEQ) refers to the air quality within and around the working place of kitchen personnel. Commercial kitchen and cooking appliances are major contributors to pollutant releases in the indoor environment. Health effects from indoor air pollutants may be experienced soon after exposure or, possibly, years later (WHO).

It is well established that exposure to high level of Particulate Matter (PM), especially smaller particles below 2,5 micron (PM2.5) has a negative impact on health. It is known that cooking is the major contributor to PM levels in dwellings (Jacobs et al, 2016).

Recent field study in restaurants such as (M Loomans et al 2020) also showed elevated levels of PM exposure exceeding those recommended by World Health Organization (WHO). The study concluded that chefs in professional kitchens are exposed to PM2.5 concentrations well above the daily exposure limit of 25 $\mu g/m^3$ as defined by the WHO for the general public (average values ranging from 57-402 $\mu g/m^3$, with peaks >1 mg/m^3). The study showed also that cooking activities (such as baking) and the location of the chef (below or next to the hood) are important factors influencing the high values measured in the breathing zone

Known air quality issues related to cooking processes multiplied by the scale in professional kitchens lead to growing concerns about the employees and customers health.

The ventilation system plays a central role in the improvements of the IEQ.

The measurements are meant to evaluate the relative impact of the following parameters on the IEQ in professional kitchens: Exhaust airflow (with/without use of an air curtain system – see description in 2.1), the cooking type and appliance and the air supply method. This last parameter appears to be the least often considered, even if it has a considerable impact as will be shown later in this paper.

To compare the different scenarios, it has been decided that PM 2.5 quantities will be the variable to be compared, as this is a well-known and often shared parameter. It's also common to use the PM2.5 in IEQ studies. Other measurements such us CO^2 and Volatile Organic Compounds (VOCs) have been measured and will be briefly discussed below.

2. Experimental set-up Description

2.1. *Cooking and Ventilation systems*

Extraction and supply

The Extraction hood used was a traditional hood used in the professional kitchen setting.

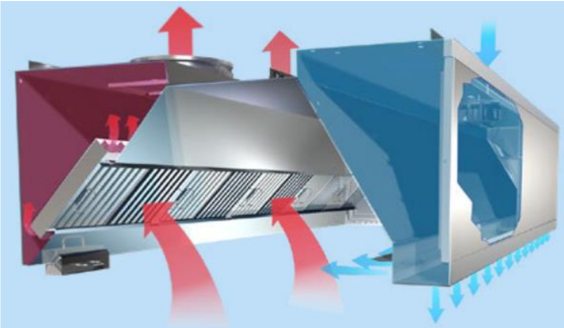


Fig. 1 - Schema of the extraction hood used for the tests

The hood was equipped with an air curtain system that consists of two sets of nozzles, one vertical and one horizontal. The horizontal nozzles push vapours back towards the filters. The vertical nozzles increase the containment volume and prevents vapours escaping from cooking areas. (See Fig.1 air curtain represented with blues arrows). The air curtain system could be enabled / disabled for the front and lateral sides of the hood, respectively and individually.

Two types of supply air systems were tested:

- One was provided by a wall mounted **air displacement unit.** This was done through two sets of grids of 2-OFF *H1900 x L520mm* with low velocity
- The other, using two **ceiling mixing units** that were mounted on the ceiling. they provided the same amount of airflow as the air displacement unit but with higher velocity through circular slots.

Fig 2 – Mixing and displacement units

Airflow Regimes

For each test, 3 airflow regimes were tested: **high, medium, and low**. The high corresponded to the Capture & Containment **(C&C) level** as measured in the laboratory according to the ASTM1704. The medium and low were both conducted at **75% of the C&C level, with (medium) and without (low) the air** curtain system, respectively.

Table 1 – Exhaust air flow regime $[m^3/h]$

Exhaust Regime	Broiler	Fryers
High	2000 + air curtain	1500 + air curtain
Medium	1500 + air curtain	1180 + air curtain
Low	1500 & no air curtain	1180 & no air curtain

Cooking Appliances

Two types of cooking appliances have been used: a gas charbroiler for burgers and 4 deep fryers for frozen French fries.

- **Broiler**: Charbroiler Vulcan (model 36) Griddle's installation at 900mm height
- **Fryers**: gas Electrolux L900xl800xH900

Fig. 3 - Cooking appliances - Fryers and Charbroiler

Cooking Procedure for Burgers

The tests started with a heating period. The griddles were turned on for approximately 30 minutes to reach 300°C. For each test, 5 series of 15 burgers each were cooked. The cooking of burgers was timed to be 3.5 minutes per face. A brushing and reheat to reach 300°C were done after each series.

Cooking procedure for French fries

Oil was pre-heated to 180°C. Each round was done using 2 baskets at the same time which represents around 1kg of French fries. Each batch of French fries were cooked for 10 minutes.

2.2. *Tests Layout*

All the measurements were done in an air-tight lab chamber of dimensions (l x w x h) 9m x 6m x 3.4m.

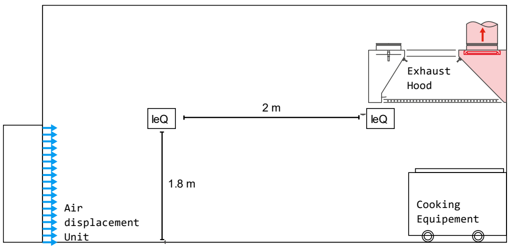


Fig. 4 - Ventilation, appliances, and sensors layout – Displacement air units

IEQ sensors were installed in two positions:

1. **The breathing zone** of the chef under the hood,
2. **2m from the hood** at 1.80m from the floor.

PM 2.5 was measured using the following sensor: FS4408 (Transducer particulate matter / particles, active output (0-10V and 4-20mA)

Table 2 - PM sensor description

Measurement range PM2.5/PM10	0 μg/m^3 ... 1000 μg/m^3
Accuracy PM2.5/PM10	±5 ug/m^3 + max. ±4% FS (@ 20°C, 45% RH., 1013 mbar)
Temperature dependency	±1% FS / 10 K
Response time (t90)	< 10 s
Long term stability	±1% FS/year

3. Results

The results of the tests will be presented in the following order: Tests on the charbroiler and on the fryers with two different air supply modes (displacement and mixing).

PM2.5 levels will be shown under the hood and at 2m distance with 3 different airflow regimes: high, medium, and low.

The Low velocity displacement was installed on the opposite wall situated at 4.8 m from the front of the hood. Mixing air units were situated in the ceiling at 1.2 and 3.2 m from the front of the hood.

3.1. *The Charbroiler with Low Velocity Air Supply (displacement)*

It can be seen that, with C&C airflow level, the PM2.5 concentrations under the hood and in the room stay in average at 9 $\mu g/m^3$ and 4 $\mu g/m^3$ accordingly.

In case of Medium and Low airflow regimes (1500 $m^3.h^{-1}$ with and without air curtain), the PM2.5 concentration are much higher. The tables below summarize the concentration levels.

Tab. 3 - PM2.5 in the breathing zone and in the room – Charbroiler - Displacement [μg/m^3]

	Breathing zone		**In the Room**	
Airflow	**Avg.**	**Max.**	**Avg.**	**Max.**
High	9	412	4	6
Medium	52	718	46	220
Low	118	289	280	636

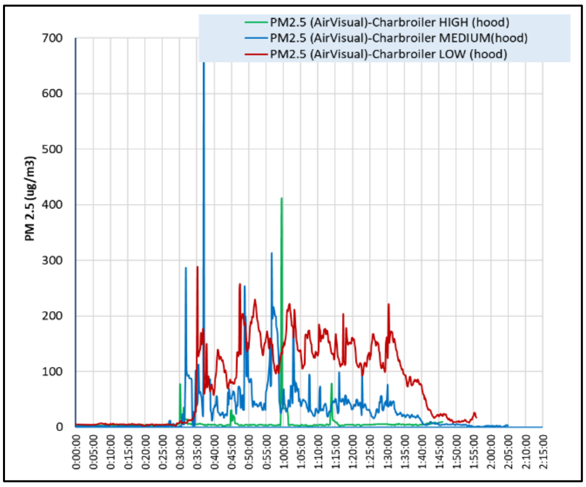


Fig. 5 - PM2.5 measurements **under the hood**, charbroiler with burgers with 3 air flow regimes and displacement air supply

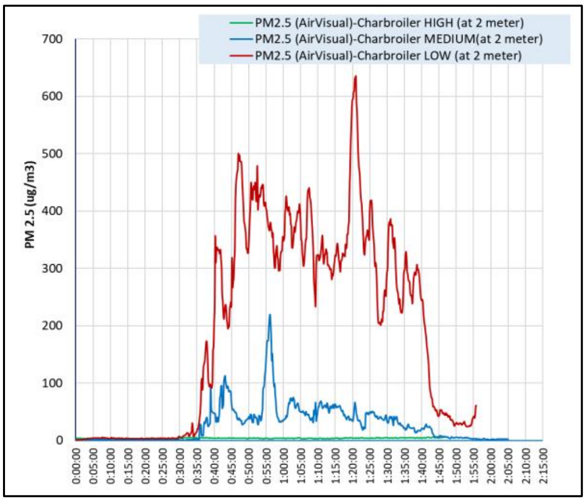


Fig. 6 - PM2.5 measurements at **2m from the hood**, charbroiler with burgers with 3 air flow regimes and displacement air supply

It can be seen that the concentrations in case of Medium and Low airflow regimes are higher than the WHO recommendation (25 $\mu g/m^3$). Levels in the absence of the air curtains were 6x higher in the room and 2x higher under the hood.

The measurements above shows that the air curtain helps to reduce the PM2.5 concentration levels in the room and therefore improve the IEQ in the kitchen (up to 6x times). This improvement is true in case of air supply with low velocity displacement in the room. Later in this paper it will be shown that this is not true for the case of mixing supply from the ceiling.

It was also seen that there were 4 PM2.5 peak events under the hood. That was due to the brushing and cleaning of the broiler. Indeed, after each round, the broiler was brushed with a metal comb to remove residue from the griddles.

3.2. *The Charbroiler with Mixing Air Supply (from the ceiling)*

The second round of test results were obtained following the same procedure as above but using a **mixing air supply from the ceiling.**

The method of supply air introduction was changed whilst all other parameters remained identical. The vertical air mixing supplies nearly the same airflow (90% of the supply) as the displacement method.

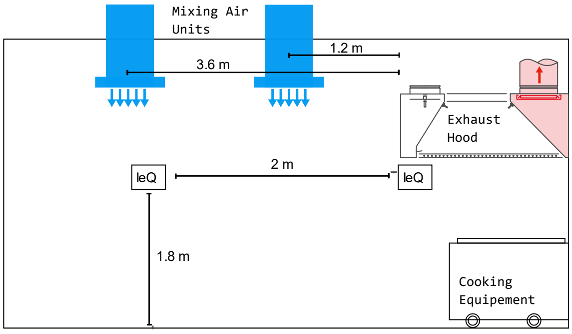


Figure 7 - Ventilation, appliances, and sensors layout – mixing air units

Firstly, it can be seen that there were higher concentrations during the mixing supply test compared to the displacement method test. During the "high" test regime, concentrations under the hood and in the room were on average 32 $\mu g/m^3$ and 17 $\mu g/m^3$, respectively.

Also, it can be seen that, in this case, there was no significant difference between the Medium and Low regimes. This shows that the air curtain doesn't have any impact on reduction of PM2.5 concentrations.

Tab. 4 - PM2.5 in the breathing zone and in the room – Charbroiler - mixing [µg/m^3]

	Breathing zone		In the Room	
Airflow	**Avg.**	**Max.**	**Avg.**	**Max.**
High	32	887	17	41
Medium	344	1001	254	782
High	397	1002	222	470

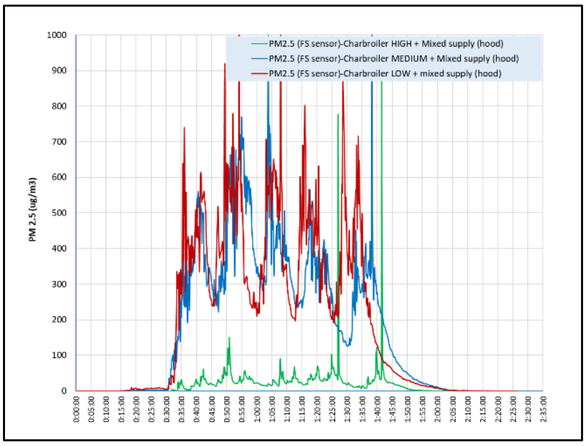


Fig. 8 - PM2.5 measurements under the hood, charbroiler with burgers with 3 air flow regimes and mixing air supply

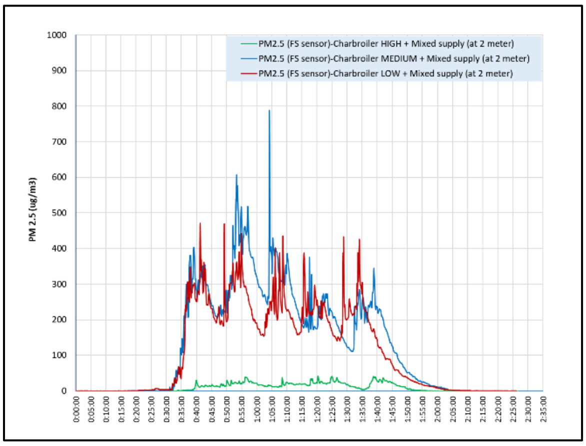


Fig. 9 - PM2.5 measurements at 2m from the hood, charbroiler with burgers with 3 air flow regimes and mixing air supply

3.3. *The Fryer with low velocity air supply (displacement)*

In this case, the max air flow was reduced to be at the appropriate C&C level: 1500 m^3/h.

Firstly, it can be seen that the concentrations were, on average, 10x lower than in the case of the broiler.

Tab. 5 - PM2.5 in the breathing zone and in the room – Fryers - Displacement [µg/m^3]

	Breathing zone		In the Room	
Airflow	**Avg.**	**Max.**	**Avg.**	**Max.**
High	0	1	0	1
Medium	1	3	1	4
Low	7.5	26	12	51

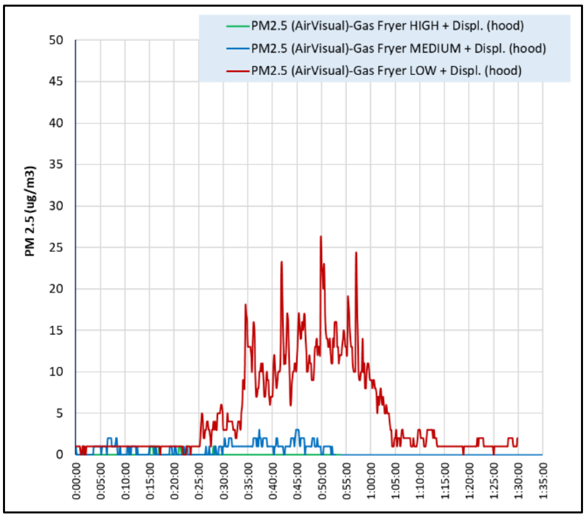


Fig. 10 - PM2.5 measurements under the hood, 2 fryer baskets with 3 air flow regimes and displacement air supply

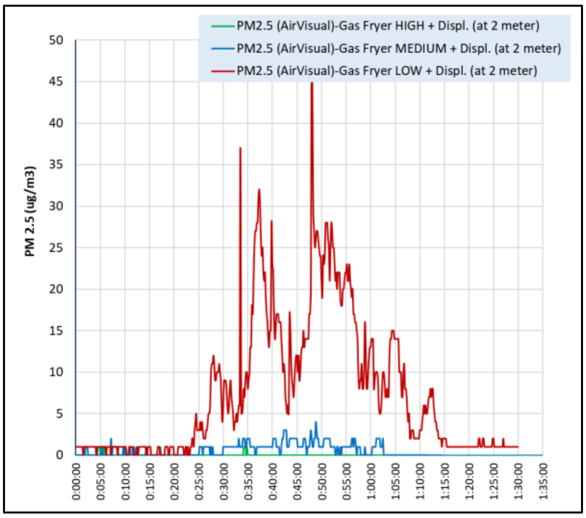


Fig. 11 - PM2.5 measurements 2m from the hood, 2 fryer baskets with 3 air flow regimes and displacement air supply

3.4. *The Fryer with Mixing Air Supply (from the ceiling)*

As per the charbroiler test, all variables apart from the method of supply air introduction remained constant between the different airflow regimes.

Tab. 6 - PM2.5 in the breathing zone and in the room – Fryers - Mixing [µg/m^3]

	Breathing zone		In the Room	
Airflow	**Avg.**	**Max.**	**Avg.**	**Max.**
High	0.2	0.3	0.2	0.4
Medium	1	2.5	1	2.5
Low	7.5	12	7.5	12

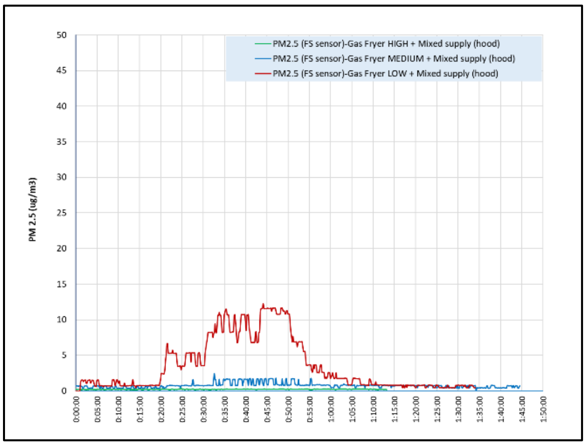


Fig. 12 - PM2.5 measurements under the hood, 2 fryer baskets with 3 air flow regimes and displacement air supply

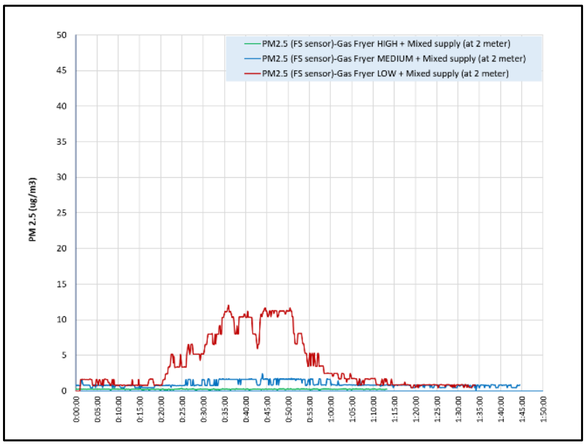


Fig. 13 - PM2.5 measurements 2m from the hood, 2 fryer baskets with 3 air flow regimes and displacement air supply

4. Discussion

4.1. *Indoor Air Quality*

the results above show that ventilation configuration (exhaust and supply) has a significant impact on the IEQ. The C&C level as determined by the ASTM1704 maximises the extraction efficiency of the hood. Although, frequently the C&C airflow cannot be adequately reached on live job sites. In this case, the IEQ could be heavily deteriorated.

In the case of broiler, we can see that the air curtain system helps improve the IEQ quality in case of air flow lower than C&C. this improvement could be 6x higher, but this could only be obtained by using the appropriate supply system. In our case, the displacement supply air method rather than the mixing air supply method. This could be explained by the turbulences created by the vertical supply. The air velocity in the supply slots is high and one of the supply slots is located close to the front end of the hood (1.2 m). The tables below sum up the results.

In the case of fryers, it was seen that there was no impact of the supply air system on the IEQ. This could be explained by the plume dynamic of the fryer

compared to the charbroiler. The fryer plume tends to follow the backwall due the Coandă effect. That means that the majority of the plume is situated toward the back of the hood; therefore, the wall curtain and supply air system have negligible impact on the plume dispersion.
On the other hand, the charbroiler tends to have a vertically ascending thermal plume and the total depth of the equipment is greater than that of the fryer. (900mm charbroiler depth vs 400mm fryer depth) Therefore, it is more susceptible to air dynamics in front of the hood, as the plume begins closer to the front lip of the hood.

4.2. *Thermal Comfort of the Chef*

Using these measurements, we can also explore the impact on thermal comfort of the chef. Indeed, the temperature at the breathing zone of the chef reached 40°C on average during the fryer tests. That means that even though the chef is protected by the natural rear plume dynamic of the fryers, it still can have a negative impact on the thermal comfort.

We compared temperatures and humidity at the breathing level of the chef with and without the curtain air system.

The following figures show the temperature (in blue) in Relative Humidity (in red) in the beathing zone of the chef. Fig 14. Gaz fryer at 75% of C&C with curtain air system and Fig 15. Is without the curtain air system.

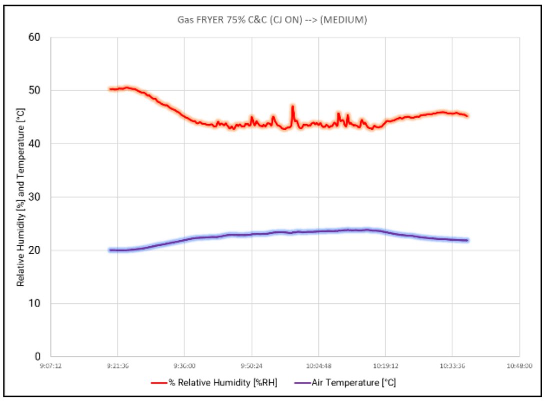


Fig. 14 - Temperature and humidity in the breathing zone with the air curtain system

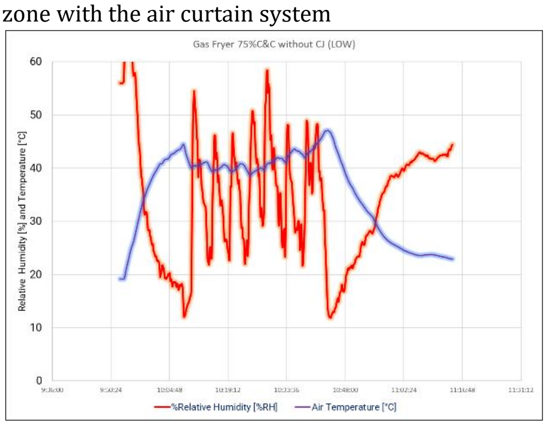


Fig. 15 - Temperature and humidity in the breathing zone without the air curtain system

It can be seen that in the absence of the air curtain system that the temperature is relatively high (average of more than 40°C). The relative humidity fluctuates between 20% and 50%. The fluctuations are correlated to frying series. The French fries are frozen before cooking and thus generate a significant amount of humidity.

When the air curtain is ON, temperature is, on average, equal to 21°C. The humidity is stable and, on average, equal to 45%RH. In this latter situation, the chef cooking is in a better thermal comfort environment.

5. Conclusions and next steps

The objective of this study was to study the impact of ventilation system design and its effect on PM level in commercial kitchens and therefore on the employees' health in these spaces.
3 main parameters have been studied: the cooking appliance type, the airflow settings, and the air supply method.
These three parameters have been found to have a substantial impact on the PM2.5 level in the kitchen and in the breathing zone of the chef.

<u>For cooking appliances:</u> cooking burgers on a broiler has been shown to generate a large effluent load compared to cooking fries with the fryer. At 75% of the C&C airflow without air curtain. The broilers generate up to 394 $\mu g/m^3$compared to 8 $\mu g/m^3$ for fryers in the breathing zone of the chef.
These levels are 15 times higher than the WHO limit of 25 $\mu g/m^3$.

<u>For airflow settings:</u>
Three airflow regimes have been compared: C&C level, 75% of C&C both with and without air curtain system.
The C&C airflow ensures a good level of IEQ in the kitchen and in the breathing zone.
Degradation of the C&C to 75% deteriorates the IEQ: PM levels increase between 5-15x times dependant on the location, use of the air curtain system and the air supply method.

<u>For air supply method</u>:
Two methods were tested, mixing from ceiling and displacement from the wall. The former method increases the turbulences in front of the hood and reduces the extraction efficiency of the hood.
In the case of 75% of C&C airflow, the air curtain system plays a crucial rule in reducing the propagation of the PM (x6 times), when used with an air displacement unit. In the case of the mixing unit, the IEQ is degraded and the air curtain system has no impact on the reduction of the PM level.

In the case of the fryer, PM appears to be less of an issue because of the plume dynamic, tending to travel toward the back wall and is well captured by the hood. However, the use of the air curtain helps improve the thermal comfort of the chef by reducing temperature and the RH variations.

All of the above shows that the ventilation system is crucial in maintaining a healthy environment in the kitchen.

This study does not include the impact of human behaviour in the kitchen (i.e. hot food stored outside of hoods, doors kept open etc). We would expect that to have a significant impact on IEQ. More field studies will be needed to evaluate this parameter.

For the next studies in the lab, we'll be studying more appliances (Asian woks) and different types of hoods (proximity hood, canopy etc). That should help us to have a deeper understanding of the IEQ in commercial kitchens and how to improve it.

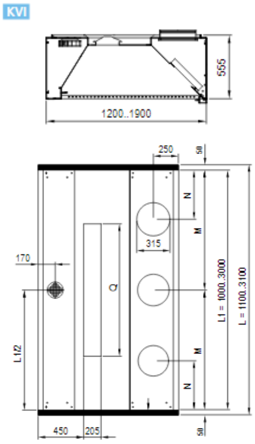
6. References

[Jacobs et al.] Jacobs P., Borsboom,W.A., Kemp R.E.J. PM2.5 in Dutch dwellings due to cooking. ASHRAE and AIVC Conference, 12-14 September 2016, Alexandria, VA, USA

[M Loomans et al. 2020] Loomans M,Te Kulve M, Atze Boerstra A. Particulate matter exposure of chefs in professional kitchens. International Society of Indoor Air Quality and Climate – ISLAQ - 2020

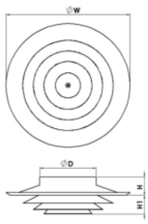
7. Appendices

Hood



L	M	N
1600	L1/2	450

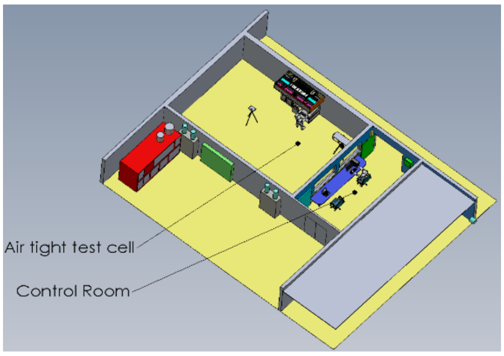
Mixing units dimensions



W 457 mm
H 80 – H1 75
D 199

Lab
The laboratory consists of 2 rooms, a test cell and a control command cell. The test cell is approximately 9m long by 6m large by 3.4m high. 2 doors allow installation of equipment and communication to the control command room. Once closed the test cell is airtight.

Exhaust (VFE) and Compensating Air Fans (VFS), with variable-speed drives, to allow for operation over a wide range of exhaust air flow rate from 200m3/h to 7000m3/h. Speed Inverters are controlled by the Datalogger in order to maintain a 0Pa or close to 0Pa pressure difference between outdoor and indoor. The ducting enables multiple configurations, from wall installation (this case) to island.



Air flow rate is measured by Laminar Flow Elements complying with ISO 5167 or equivalent, on ducting of exhaust and air supply.

Temperature and moisture content of exhaust and air supply are monitored, and air supply temperature is tempered by a Chilled or Heat Water system enabling to reach realistic and stable conditions inside the test cell.

Fig. 16 - lab layout – (with charbroiler)

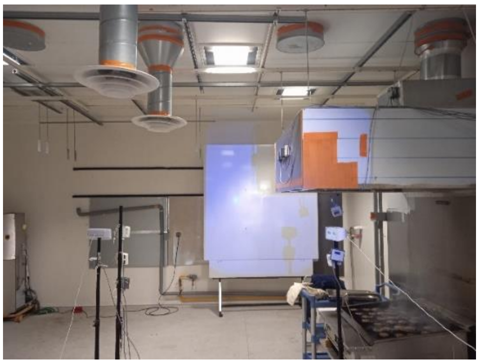


Fig. 17 - Burgers cooking

Fig. 18 - Stir-frying

Sensors PM 2.5 : FS4408 (Transducer particulate matter / particles, active output (0-10V and 4-20mA)

Measurement range PM2.5/PM10	0 µg/m³ ... 1000 µg/m³
Accuracy PM2.5/PM10	±5 ug/m³ + max. ±4% FS (@ 20°C, 45% r.F., 1013 mbar)
Temperature dependency	±1% FS / 10 K
Response time (t90)	< 10 s
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