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MASTER'S THESIS

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ABSTRACT:

This thesis investigates the challenges by recirculating the air from range hoods compared to extracting it. Two types of range hoods were tested with both recirculation and extraction on different airflow rates while cooking a typical Norwegian meal: fish and wok mix. Several optical particle counters measured the particle concentration throughout the experiments to see the exposure of $PM_{2.5}$ to the cook and people sitting at the dining table. Capture efficiencies were also calculated. The recirculating experiments resulted in $PM_{2.5}$ values that were 3-19 times higher than extracting. The capture efficiencies correspond to this giving recirculating extremely low or negative CEs, while extracting have CEs up to 98%. This concludes that recirculating range hoods still have some improvements to do before it is comparable to extracting range hoods.

KEYWORDS (one per line):
Recirculating hoods
Cooking emissions
Exposure

Candidate: 400

Preface

This master thesis marks the end of a 2-year study in Energy and Environment in Buildings at Oslo Metropolitan University. The thesis corresponds to 30 credits and is written in collaboration with, and as a part of, SINTEF's project "Healthy Energy-efficient Urban Home Ventilation".

The master thesis has been challenging, but educational. Certain topics covered in this thesis have given me a deeper understanding and more expertise that will be useful in further work.

I would like to thank my supervisors Peter G. Shild and Kari Thunshelle for their valuable insight and support throughout this period. I have benefited greatly from their professional knowledge and constructive feedback. Furthermore, I would want to express my gratitude to SINTEF's helpful employees, Aileen Yang and Bjørn Ludvigsen, for the time they have spent helping me with the endless questions and lab problems.

Lastly, I would like to thank my lab partner, Øystein Eliassen, for doing the experiments with me, as well as data analyzing and discussing the results.

Iselin Alvestad: Iselin Alvestad

Master in Energy and Environment in Buildings

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Summary

Indoor air quality (IAQ) is a main concern today, considering people spend about 90% of their time indoors. One of the most important sources to indoor air pollution is cooking, an activity conducted daily in most residencies. Cooking emits a lot of $PM_{2.5}$ which can cause severe health affects by both acute and long-term exposure. The need for properly working range hoods is therefore extremely important. With new compact energy-efficient apartments in urban cities, the installation of regular extracting range hoods can cause certain challenges like room for ducts, ventilation losses and additional thermal bridges. Recirculating range hoods have therefore become of interest lately.

This thesis will investigate the challenges by recirculating the air from range hoods compared to extracting it. Together with SINTEF's project "Healthy Energy-efficient Urban Home Ventilation" several experiments were conducted in the spring of 2022. Two types of range hoods were tested with both recirculation and extraction on different airflow rates while cooking a typical Norwegian meal: fish and wok mix. The aim was to attempt to ascertain whether recirculating range hoods are efficient enough in terms of exposure, capture efficiency and moisture control to be comparable to extracting range hoods. The range hoods that were tested was one standard wall-mounted hood and the other was a downdraft system. They were both tested on airflow rates of 108, 250 and 350 m^3/h, and an additional 500 m^3/h on the downdraft. Two Grimms and three AeroTraks were set out on different locations to measure the particle concentration during cooking, in addition to other instruments measuring the surrounding conditions.

The recirculating experiments resulted in $PM_{2.5}$ values that were 3-19 times higher than extracting, showing that the latter is significantly better than recirculating in terms of exposure, no matter which hood was being used. However, recirculation worked better on the downdraft system than on the standard hood. The results also show that the cook is at least three times more exposed to $PM_{2.5}$ than people sitting at the dining table when cooking food. This emphasizes the importance of properly working range hoods. The calculated capture efficiencies showed that the extracting experiments had incredibly high CEs, up to 98%, whereas the recirculating experiments had either extremely low or negative CEs. This means that extracting range hoods are able to capture the cooking fumes far better than recirculating hoods. Moisture content on the other hand had only an increase of 5% on the recirculating experiments which is small enough to have minimal effect on the indoor air quality.

Summary in Norwegian

Innendørs luftkvalitet er et viktig tema i dagens samfunn, med tanke på at folk tilbringer omtrent 90% av tiden sin innendørs. En av de største kildene til innendørs luftforurensing er matlaging, en aktivitet som utføres daglig i de fleste boliger. Matlaging avgir mye $PM_{2.5}$ som kan forårsake alvorlige helseproblemer ved både akutt og langvarig eksponering. Behovet for fungerende kjøkkenhetter er derfor ekstremt viktig. Med nye kompakte energieffektive leiligheter i urbane byer kan installasjon av vanlige avtrekksvifter forårsake visse utfordringer som plass til kanaler, ventilasjonstap og ekstra kuldebroer. Resirkulerende kjøkkenvifter har derfor blitt av stor interesse i det siste.

Denne masteroppgaven vil undersøke utfordringene ved å resirkulere luften fra kjøkkenhetter sammenlignet med å trekke den ut. Sammen med SINTEFs prosjekt «Healthy Energy-efficient Urban Home Ventilation» ble det utført flere eksperimenter gjennom våren 2022. To typer kjøkkenvifter ble testet med både resirkulering og avtrekk på ulike luftmengder under tilberedning av et typisk norsk måltid: fisk og wok. Målet var å forsøke å finne ut om resirkulerende kjøkkenhetter er effektive nok når det gjelder eksponering, osoppfangningsevne og fuktighet til å kunne sammenlignes med vanlige avtrekkshetter. Kjøkkenviftene som ble testet var en standard veggmontert hette og den andre var et «nedtrekkssystem» hvor matosen blir trukket ned i kokeplaten. De ble begge testet med luftmengder på 108, 250 og 350 m^3/t, og ytterligere 500 m^3/t på nedtrekkssystemet. To Grimmer og tre AeroTraker ble plassert på forskjellige punkter i rommet for å måle partikkelkonsentrasjonen under matlagingen, i tillegg til andre instrumenter som målte forholdene i omgivelsene rundt.

Resirkuleringsforsøkene resulterte i $PM_{2.5}$-verdier som var 3-19 ganger høyere enn avtrekk ut. Dette viser at sistnevnte er betydelig bedre enn resirkulering med tanke på eksponering, uansett hvilken kjøkkenvifte som ble brukt. Likevel fungerte resirkulering bedre på nedtrekkssystemet enn på standard-hetten. Resultatene viser også at kokken er minst tre ganger så utsatt for eksponering av $PM_{2.5}$ enn personer som oppholder seg ved spisebordet under matlaging. Dette understreker viktigheten ved en velfungerende kjøkkenvifte. De beregnede osoppfangningsevnene viste at avtrekkseksperimentene hadde utrolig høye verdier, opptil 98%, mens de resirkulerende eksperimentene hadde enten ekstremt lave eller negative verdier. Dette viser at avtrekk fanger opp matosen vesentlig bedre enn resirkulering. Fuktighetsinnholdet derimot hadde kun en økning på 5% på de resirkulerende forsøkene. Dette anses som lite nok til å ha minimal effekt på luftkvaliteten innendørs.

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1 Introduction

Indoor air quality (IAQ) is one of the main concerns today, considering people spend about 90% of their time indoors (EPA). Each year, about 4 million people die from illnesses attributable to indoor air pollution, according to the World Health Organization(WHO) (WHO, 2021b). On top of that, about half of deaths due to pneumonia among children under 5 years of age are caused by particulate matter (PM) inhaled from household air pollution. Indoor air pollution can come from various sources, like smoking, cleaning products, building materials, or heating systems. One of the most important indoor sources is cooking, which has been identified to have a significant amount of particle emissions and contributes to three major indoor air quality issues: odors, moisture, and health (Walker et al., 2021). Both acute and long-term exposure to cooking can cause adverse health effects like cardiovascular disease and respiratory morbidity. This emphasizes the importance of kitchen ventilation and the use of range hoods.

Cooking is a huge part of our day-to-day lives, and some people cook several times a day, making them extremely vulnerable to particulate matter exposure. Cooking emissions are highly variable and depend on a lot of different factors. The cooking method, for instance, has a large impact on emissions, whether it's dry, water-based, or oil-based (O'Leary et al., 2019). Emissions are also affected by burning, grilling, or frying the food; these have a higher emission rate, presumably due to the high temperature. Different oils can also have an impact. Oils such as corn, coconut, and olive oil have higher emission rates than oil from soybeans, safflower, or canola (Torkmahalleh et al., 2012). Food type, seasoning, and cooking equipment are also important factors.

Because of today's growing urban population and the emphasis on energy and environment, buildings must be more space- and energy-efficient in order to achieve sustainability goals. The outcome is therefore smaller, more compact and airtight apartments with open kitchen-living room solutions. For highly energy-efficient homes, the installation of regular extracting range hoods can cause certain challenges like ventilation losses and additional thermal bridges (Walker et al., 2018). Furthermore, extracting range hoods demands a significant amount of space for the ducts from each apartment to link to the common duct that runs to the roof. Recirculating range hoods have therefore become of interest lately. With these types of hoods, the air from cooking will be filtered and blown back into the room without any extra ducts. The question is whether the moisture, odor and the particulate concentration reduction are enough when recirculating the air. Controlling the moisture content is essential to prevent mold and condensation and has been the main reason for range hood requirements in building regulations (Walker et al., 2021).

The project "Healthy Energy-efficient Urban Home Ventilation" at the SINTEF community will investigate the challenges by recirculating the air compared to extracting it. The aim of this study is to attempt to ascertain whether recirculating range hoods are efficient enough in terms of exposure, capture efficiency (CE) and moisture control to compete with extracting range hoods.

1.1 Research Questions

The research questions for the thesis goes as follows:

- Can recirculating range hoods, when properly integrated with the residential ventilation system, perform better or equally as conventional extracting hoods, in terms of exposure to particles, moisture and capture efficiency?
- Should TEK17 differentiate the requirements for recirculating hoods and exhaust hoods due to different exposure and moisture control?

2 Theory and literature

2.1 Ventilation

There are two main ventilation systems: natural and mechanical. Natural ventilation is driven by pressure differences between the inside and outside of the building (DesigningBuildings, 2021). It can be more economical than other types of ventilation systems because of the use of natural forces and large openings (Atkinson et al., 2009). Mechanical ventilation can be divided into three categories: exhaust-only, supply-only, or balanced (CleanAlert, 2021). They are all driven by fans or other mechanical plants, which makes them less economical. Exhaust- and supply-only systems are simply either only extracting the indoor air out or supplying with fresh outdoor air inside, respectively. Balanced ventilation, on the other hand, is a combination of these two, where the ventilation provides an equal amount of exhaust and supply air (CleanAlert, 2021). SINTEF Building Research Design Guides recommend that ventilation systems should be operated in a balanced manner, and because of TEK17's energy requirements, systems have to be balanced in most cases (Byggforsk, 2017b).

The fundamental principle for residential ventilation is to extract the air from the most polluted rooms and supply fresh air to the least polluted rooms (Byggforsk, 2017a). The exhaust is therefore often placed in the kitchen and the bathroom, where there are a lot of emissions from cooking, and showering, etc. Supply air is then supplied into rooms like the living room and bedrooms. This is to prevent moisture, odor, and pollution from spreading from the kitchen and bathroom to the living room and bedrooms. There must also be openings between the rooms with exhaust and supply air, or an overflow valve. Figure 1 is an example of this solution, which is very common in modern apartments.

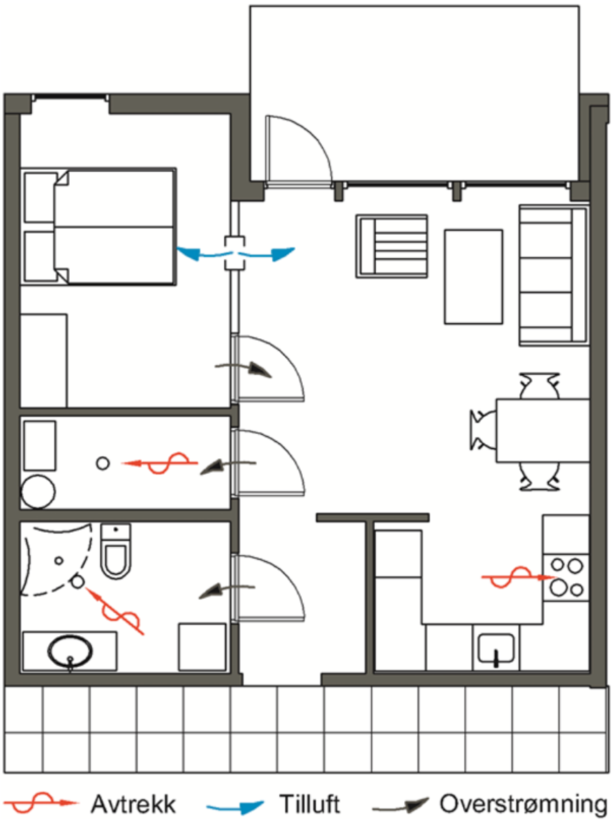


Figure 1 – Illustration of exhaust (red), supply air (blue) and overflow openings (black) in a one-bedroom apartment with open kitchen and living room solution (Byggforsk, 2017a).

2.1.1 Requirements for kitchen ventilation

To ensure acceptable ventilation for good indoor air quality there are several requirements that must be followed. Norway's regulations on technical requirements for construction works (TEK17) §13-1 states as follows: (Byggkvalitet, 2017)

Buildings shall have ventilation that ensures satisfactory air quality through:

a) Ventilation adapted to the rooms' design, intended use, pollution and humidity loads;

b) Satisfactory air quality in the building with regard to odor; and

c) Indoor air that does not contain harmful concentrations of pollutants that pose health hazards or cause irritation.

TEK17 also requires that occupied dwellings shall have an average supply of fresh air of 1.2 m^3/h per m^2 floor area, as well as minimum 26 m^3/h per bedspace in the bedroom when the room is in use. While rooms not intended for continuous occupancy shall at least have a fresh air supply of 0.7 m^3/h per m^2 floor area.

When it comes to kitchen ventilation there are some pre-accepted technical specifications that meet the requirements if the extraction volume is minimum as stated in the table below.

Table 1 – Pre-accepted technical specifications for kitchen ventilation in TEK17 (Byggkvalitet, 2017).

Room	Primary exhaust	Additional exhaust
Kitchen	36 m^3/h	108 m^3/h

Nevertheless, SINTEF states from previous experience that the minimum requirements do not sufficiently remove pollution emitted from cooking. It is therefore important to provide new recommendations. In addition, TEK17 does not differentiate the requirements for extracting and recirculating range hoods which can cause lower performance for recirculating hoods.

In other countries there are different requirements for kitchen ventilation. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) demand a mechanical ventilation in kitchens with a vented range hood at minimum 50 L/s (180 m^3/h) or 5 air changes per hour (ASHRAE, 2015). For downdraft they demand 150 L/s (540 m^3/h). While in Denmark they require only 20 L/s (72 m^3/h) on vented range hoods, which is way smaller than ASHRAE's demand and will probably not remove enough contaminants from cooking. Table 2 shows an overview of the requirements regarding kitchen ventilation in the Scandinavian countries and Finland (Norconsult, 2020).

Table 2 – Requirements for kitchen ventilation in the northern countries (Norconsult, 2020).

	Norway	Sweden	Denmark	Finland
General air changes [$m^3/h/m^2$]	1,2	1,26	1,08	1,26
Kitchen primary ventilation [m^3/h]	36	36	-	29
Kitchen additional ventilation [m^3/h]	108	140	72	90
Other requirements		Efficiency of range hood min.75%	Efficiency of range hood min.75%	Efficiency of range hood min.50%

As seen in the table there is a variety in requirements in different countries. The kitchen ventilation ranges from 72 m^3/h to 176 m^3/h, which can make a huge difference in pollution reduction and minimizing health hazards.

To this day, there are still no requirements for recirculating range hoods in Norway other than TEK17's one statement: "Recirculation should not be used if it contaminates rooms where people are present" (Byggkvalitet, 2017). This thesis will therefore do experiments on recirculating range hoods to see if they are efficient enough when it comes to pollution, odor, and moisture, and if they are comparable to regular extracting hoods.

SINTEF's previous recommendations have been to avoid using recirculating hoods with carbon filters. The filter only removes some particles before supplying the air back to the room and does not remove moisture accumulated during cooking.

2.1.2 Recirculating vs Extracting range hoods

Recirculating range hoods are hoods that extract the air from the kitchen, filter it, and blow it back into the room (Lieze, 2021). The air is circulated, hence the name "recirculating" range hood. This type of hood is slightly less powerful than a regular extracting range hood, which brings the extracted air outside. The difference between recirculating and extracting range hoods is illustrated in figure 2. With recirculation, there is a carbon filter that has the property of absorbing dirt. When the contaminated air from cooking gets sucked into the hood, the filter absorbs particles and odor before it is sent as clean air back to the kitchen (Lieze, 2021). Recirculation is suitable when there is no discharge to the outside. For instance, downdraft systems on kitchen islands often use recirculation because the ducts go down into the cabinets with no possibility of venting them outside.

Although it can be seen as a great solution, considering space, and the cost of duct materials, there are some disadvantages with recirculating range hoods. For the used air to be clean, it is crucial to change the carbon filters regularly, which can be expensive (Lieze, 2021). In addition, the hood has less suction and therefore less odor reduction, and it makes more noise than a vented range hood.

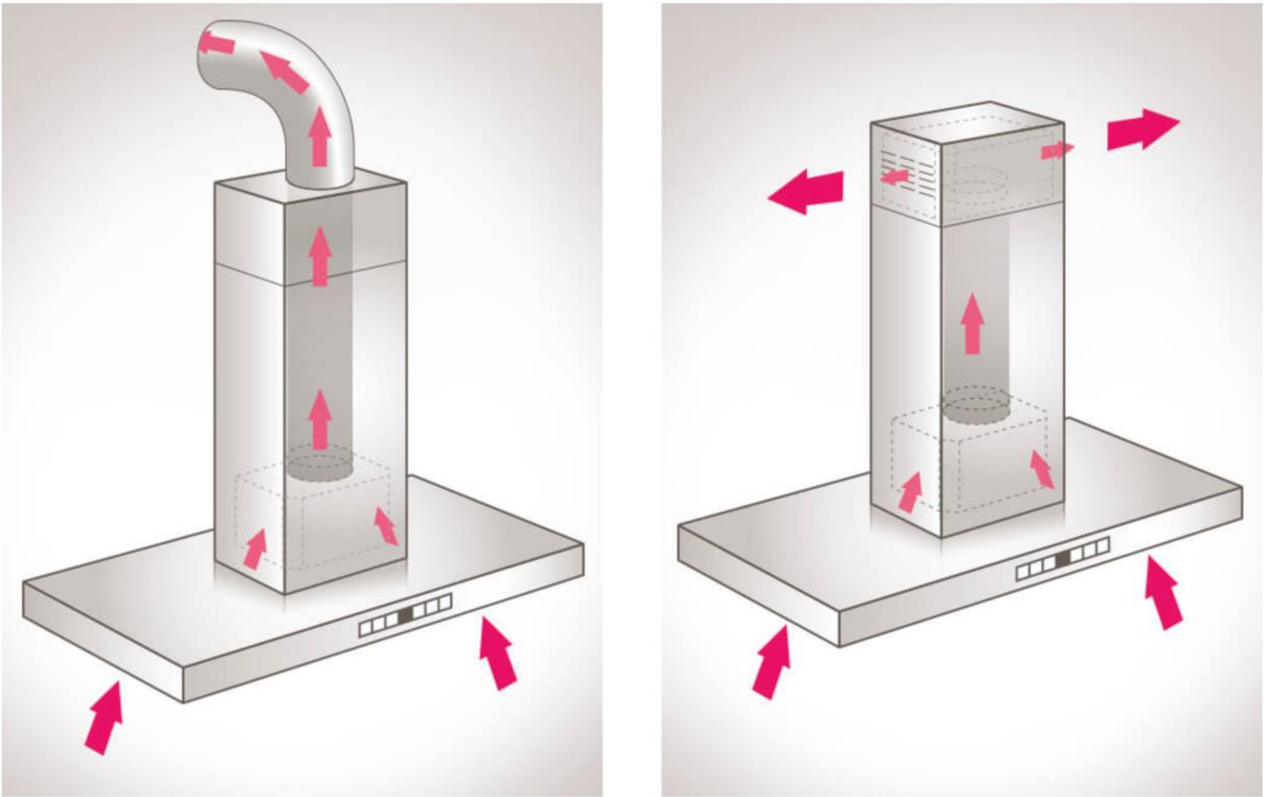


Figure 2 – An illustration of an extracting range hood (left) and a recirculation range hood (right). Image source: (Naber).

2.1.3 Filters in the range hoods

There are usually two types of filters in the range hood, depending on extracting or recirculating. Grease filter is always used regardless of which hood is applied. It captures and removes grease, smoke, and other debris from entering the ventilation system (Guardian, 2018). Without a grease filter there is a great risk of fire hazards. The carbon or charcoal filter is essential in recirculating hoods. As mentioned, the filter absorbs the particles, gasses and odor from cooking so that fresh air can be supplied back into the room again (Kitchinsider, 2022). Carbon filters come in various sizes and shapes to fit every range hood there is. The filter consists of black mesh, either in a single layer or multiple layers, and sometimes even in a honeycomb structure, with activated charcoal scattered throughout the mesh. Figure 3 is a picture of the different types of carbon filters. It is the activated charcoal that is extremely effective at absorption (Kitchinsider, 2022). Once the filter is saturated with oil and grease from cooking, it needs to be replaced. A normal filter lasts an average of 6-8 months, depending on the filter, how often the hood is used, and what type of food has been cooked. It also depends on the size of the filter. If the filter has a large surface area, it has more activated carbon and will thus absorb more grease. The filter cannot be washed and reused like a grease filter because of the activated carbon (Pick, 2020).

There are some factors that can influence the carbon filters' performance. The molecules that are absorbed by the carbon begin to move at high temperatures and can fall out again. As a result, as the temperature rises, the capture efficiency drops. Moisture can also decrease the CE by filling the pores in the carbon with water, reducing the surface area for other molecules to enter. Lastly, the air velocity can also have an impact. If the velocity is too high, the air will only flow right through the filter and almost nothing will be absorbed (Lederman, 2022).

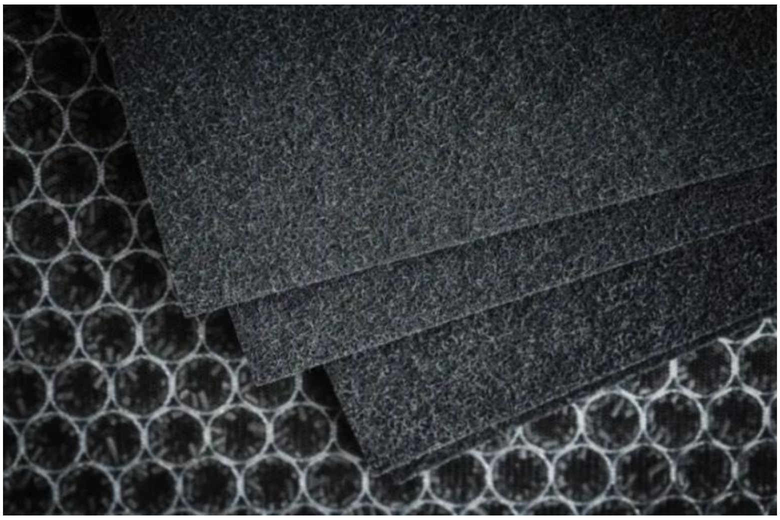


Figure 3 – Picture of carbon filters in honeycomb structure and layers. Image source: (Kitchinsider, 2022).

2.1.4 Test methods and test chamber set-up

To certify range hoods, it is important to conduct standardized test methods. The most implemented test method in Europe is NEK IEC 61591:2019, which includes hoods with extraction and recirculation, as well as downdraft systems (StandardNorge, 2019). In the US, the standardized method is the American Society for Testing and Materials (ASTM) standard E3087-18 (ASTM, 2018). This method works only on wall-mounted range hoods that exhausts air to the outside and does not apply to recirculating range hoods. The NS-EN 13141-3:2017 standard also only applies to wall-mounted range hoods with extraction, but without fans (StandardNorge, 2017).

To be able to implement the test methods, a test chamber is necessary. The test chamber often consists of a kitchen bench with a cooktop and a wall-mounted range hood with wall cupboards on each side. NEK IEC 61591:2019 has proposed a chamber that is often used as guidelines for several exposure studies in Europe (StandardNorge, 2019). For instance, the height between the cooktop and the range hood must be 600±10 mm on every cooking fume exhaust except the downdraft. Wall cabinets also need to be installed on each side of the range hood. The downdraft system has to be installed in accordance with the manufacturer's instructions, and wall cabinets are not installed. In recirculation mode, there must be an odor-reduction filter in addition to the regular grease filter. Figure 4 shows an illustration of the test chamber with a wall-mounted range hood in NEK IEC 61591:2019.

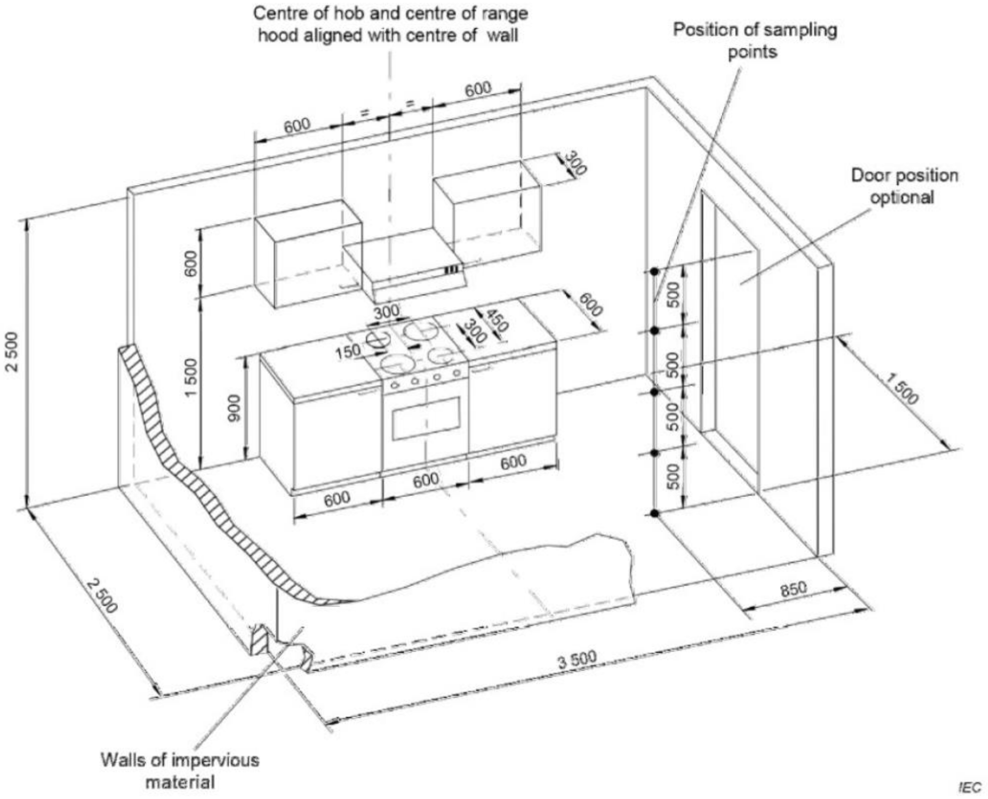


Figure 4 – Illustration of the test chamber from NEK IEC 61591:2019. Image source: (StandardNorge, 2019).

SINTEF also has some guidelines when it comes to the test chamber. To achieve the most efficient exhaust, the hood should have the same length and depth as the cooktop. It should not exceed a noise level of 45 dB, and the hood should not be more than 0,6 m above the cooktop. The higher the hood, the lower the efficacy.

2.2 Cooking emissions and capture efficiency

Cooking releases a lot of particles, such as PM, as well as moisture. These have a severe effect on indoor air quality and can cause diseases like asthma, cardiovascular disease, or pneumonia.

2.2.1 Particulate matter

Particulate matter (PM) is a generic term for both solid and liquid particles found in the air, of which many of them are hazardous (Fromme, 2019). PM size ranges from less than 1 micron to over 100 microns (Acharya, 2018). Some of these particles are too small for the naked eye to see but can cause serious health problems by inhaling them. Cooking emits a lot of PM, especially $PM_{2.5}$, which can be very critical for both acute and long-term exposure (O'Leary et al., 2019). The concentration and size of PM depend on what food is being cooked, the type of fuel, and which cooking oils are used. Temperature and the type of cooking are also factors. The health effects of cooking will therefore also vary according to these same factors. Hence, an adequate range hood is essential to avoid excessive amounts of PM exposure.

$PM_{2.5}$ and PM_{10} refer to particles with an aerodynamic diameter of 2.5 microns or less, and 10 microns or less, respectively. PM_{10} can penetrate deep inside the lungs, while $PM_{2.5}$ can penetrate the lung barrier and even enter the blood system, which is way more health-damaging (EPA, 2020; WHO, 2021a). If the aerodynamic diameter of the PM is 0.1 microns or less, it is called ultra-fine particles (UFP). The figure below demonstrates the sizes of $PM_{2.5}$ and PM_{10} compared to a straw of human hair and beach sand to get a perspective on how small it really is.

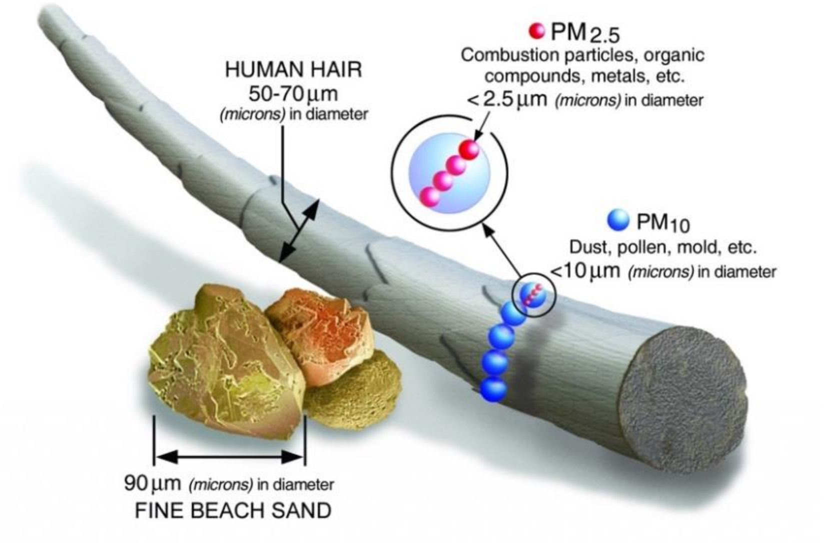


Figure 5 – Particulate matter, $PM_{2.5}$ and PM_{10}, compared to a straw of hair and beach sand. Image source: EPA.

There are several recommendations about acceptable PM concentration around the world. The recommendations are often divided into 24-hour mean, and annual levels. The Norwegian Institute of Public Health (NIPH) is in charge of these recommendations in Norway (Folkehelseinstituttet, 2017). For daily maximum exposure both NIPH and WHO recommend 15 µg/m³, which is lower compared to the US or Europe (EC, 2008; WHO, 2021a). While the yearly maximum values recommended by WHO is only 5 µg/m³. This is the lowest of all recommendations. The table below provides an overview of annual, and 24-hours mean guidelines from Norway, WHO, EU and USA.

Table 3 – Guidelines on annual and 24-hour mean from NIPH, WHO, EU and USA.

	Period	**PM_{10} [µg/m³]**	**$PM_{2.5}$ [µg/m³]**
NIPH	Yearly	20	8
	Daily	30	15
WHO	Yearly	15	5
	Daily	45	15*
EU	Yearly	40	25
	Daily	50**	-
USA	Yearly		15
	Daily	150***	35

* max 3-4 days per year
** max 35 days per year
***not to be exceeded more than once per year

2.2.2 Moisture from cooking

Moisture is one of the critical aspects of cooking and one of the reasons range hoods are mandatory in some countries. When cooking, the food emits a lot of particles and moisture. If the moisture is not extracted from the kitchen, it can increase the relative humidity (RH) in the room. High relative humidity can affect air pollution in ways that are harmful to humans (Rinkesh, 2022). It increases the amount of toxic particles in the air as well as causing dust mites. Bacterial organisms that can cause respiratory infections thrive in high RH and too low RH. The indoor RH should be around 30-50%, to not exceed this limit an adequate range hood is necessary (NACA, 2022). With recirculating hoods, the moisture is not extracted, which causes uncertainty as to whether additional ventilation or other measures are needed (Pick, 2020).

2.2.3 Capture efficiency

Capture efficiency is defined as "the percentage of emissions captured and vented to a control device" by the U.S. Environmental Protection Agency (EPA). CE is used in this thesis to figure out if recirculating hoods capture the same amount of particles as extracting hoods so that recirculation can compete with extracting in regular homes. Just because a range hood has a high airflow rate or operates quietly does not automatically imply that it has a high CE. As IAQ is becoming more critical in terms of people's health together with the growing urban population and more compact energy-efficient buildings, it is crucial that the range hood is operating in an efficient manner (ASHRAE, 2020). This means that the capture efficiency needs to be high enough to exhaust the cooking contaminants.

2.3 Literature review

To gather useful information about the topic and to find the gaps in this field of research, a literature review was conducted. Articles from a citation research method were reviewed and put in a matrix, see appendix A. The most relevant ones were picked out to be further investigated. These are listed in table 4.

Table 4 – The most relevant articles picked out to be further investigated.

Matrix of most relevant literature
O'Leary, C., Kluizenaar, Y., Jacobs, P., Borsboom, W., Hall, I., Jones, B., (2019), Investigating measurements of fine particle (PM2.5) emissions from the cooking of meals and mitigating exposure using a cooker hood. Indoor Air. https://doi.org/10.1111/ina.12542
Lunden, M. M., Delp, W. W., Singer, B. C, (2014) Capture efficiency of cooking-related fine and ultrafine particles by residential exhaust hoods. Indoor Air. https://doi.org/10.1111/ina.12118
Xie, W., Gao, J., Lv, L., Cao, C., Hou, Y., Wei, X., Zeng, L., (2021) Exhaust rate for range hood at cooking temperature near the smoke point of edible oil in residential kitchen. Journal of Building Engineering. https://doi.org/10.1016/j.jobe.2021.103545
Kang, K., Kim, H., Kim, D. D., Lee, Y. G., Kim, T., (2019) Characteristics of cooking-generated PM 10 and PM 2.5 in residential buildings with different cooking and ventilation types. Science of the total environment. https://doi.org/10.1016/j.scitotenv.2019.02.316
Singer, B. C., Delp, W. W., Apte, M. G., Price, P. N., (2011) Performance of Installed Cooking Exhaust Devices. Indoor Air. https://doi.org/10.1111/j.1600-0668.2011.00756.x
Meleika, S., Pate, M., Jacquesson, A., (2020) The influence of range hood mounting height on capture efficiency. Science and Technology for the Built Environment. https://doi.org/10.1080/23744731.2020.1863102
Jacobs, P., Borsboom, W., Kemp, R., (2016) PM2.5 in Dutch Dwellings due to Cooking. Environmental Science.
Jacobs, P., Cornelissen, E., (2017) Efficiency of recirculation hoods with regard to PM2.5 and NO2. Healthy Buildings Europe 2017(p.455-462). ISIAQ. ISBN: 978-83-7947-232-1.
Kah, O., Bräunlich K., Hartmann, T., Knaus, C., Broege, M., Bruns, A., (2020) Bewertung von Küchen-Dunstabzugssystemen in energieeffizienten Gebäuden. https://doi.org/10.1002/bapi.201900028

2.3.1 Type of range hood

Most of the articles reviewed operated with regular wall-mounted range hoods with extraction, such as O'Leary et al. (2019), Xie et al. (2021), Kang et al. (2019) and Meleika et al. (2020). This is the most common type of range hood and is therefore important to research. Singer et al. (2011) investigated several different types of range hoods, including downdraft, microwave over-the-range, under-cabinet systems, and collection hoods. In this way, they could compare them to each other to find the most sufficient hood. While Lunden et al. (2015) analyzed four different under-cabinet exhaust hoods that represented common geometries and ranges of airflow rates. Only a few examined range hoods with recirculation. Jacobs and Cornelissen (2017) and Jacobs et al. (2016) looked at wall-mounted hoods with recirculation in a kitchen lab and on site, respectively. Kah et al. (2020) looked into recirculating hoods, and the effect on carbon filters.

The type of range hood varies from house to house, which makes it difficult to compare data. The design of the kitchen, whether the cooktop is in a corner, on an island or next to a wall, also has an impact on the range hood's performance. However, a wall-mounted range hood is the most common and will therefore be used in this experiment in addition to a downdraft system. Table 5 shows an overview of the different hood types each article studied.

Table 5 – Different hood types in the reviewed literature.

Article	Type of range hood
O'Leary et al. 2019	Wall-mounted hood with extraction
Lunden et al. 2014	Four different under-cabinet exhaust hoods: Low-cost model, Energy Star qualified model, a premium hood and a combined microwave exhaust hood
Xie et al. 2021	Wall-mounted hood with extraction
Kang et al. 2019	Wall-mounted hood with extraction
Singer et al. 2011	Different types of above the range systems and downdraft
Meleika et al. 2020	Wall-mounted hood with extraction
Jacobs et al. 2016	Wall-mounted hood with both extracting and recirculating, as well as motorless
Jacobs and Cornelissen 2017	Wall-mounted hood with recirculation
Kah et al. 2020	Wall-mounted hood with recirculation

2.3.2 Capture efficiency and Indoor Air Quality

Indoor air pollution is a major health hazard and can cause severe diseases like lung cancer or cardiovascular disease. O'Leary et al. (2019) proved in their study that cooking emits a lot of $PM_{2.5}$, which is linked with adverse health effects. With the help of range hoods with high capture efficiency, the particles emitted can be drastically reduced. Xie et al. (2021) found that the CE of the hood can reach 99% if the airflow is above 700 m^3/h in a regular wall-mounted hood with extraction, while Meleika et al. (2020) measured CE values from 43.8-96.2% depending on mounting height. Singer et al. (2011) found that devices with a flat bottom (no capture hood) have a much lower CE, but the CE is substantially higher for back burner use. They also discovered that the maximum airflows in exhaust systems in Californian residences were 70% or lower than the values noted in the product literature in 10 out of 15 cases. This signifies that the range hood's CE is reduced significantly and the pollution from cooking can cause health issues.

In Kang et al. (2019)'s research, there were detected high levels of $PM_{2.5}$ and PM_{10} in Korean homes. Even though the concentration was decreased with the wall-mounted range hoods, the levels exceeded the recommendations by the Korea Ministry of Environment in 17 out of 30 buildings. Jacobs and Cornelissen (2017) found that the recirculating hood reduced the $PM_{2.5}$ concentrations by 30% with a carbon filter, and a fresh carbon filter reduced NO_2 by 60%. After a few weeks of cooking, the filter only reduced NO_2 by 20%, which implies that the filter must be replaced regularly to achieve good indoor air quality. When it comes to odor reduction, Kah et al. (2020) discovered that recirculating hoods with activated carbon filters combined with a residential ventilation are nearly comparable to standard exhaust systems. Although for the recirculating ones, it is crucial to change the filters regularly.

To ensure that people do not get large amounts of particles emitted from cooking into their bodies, an adequate range hood is essential. As seen from the assessed articles, the CE varies a lot from different hood types, mounting heights, and airflows. Even though the product description gives information on how much exhaust airflow and how high of a performance the hood has, it can vary depending on these factors. In other words, even if the product description says so, the CE is not always high enough to extract the required amount of particles.

In the case of recirculating range hoods, the big question is their performance in reducing exposure from cooking as the filter ages. This is a recent problem, which means there are few scientific studies about it. Further investigation is therefore needed. Humidity is also a big problem when it comes to recirculation. The hoods are not able to remove the moisture from cooking, and thus creates a need for additional ventilation. If users end up with a lot of extra ventilation, the energy use will increase and become higher than with an effective extracting system.

2.3.3 Methods in existing literature

Several studies used laboratory kitchens while others went on-site to measure and test different range hoods. In lab kitchens, it is easier to control the environment and ensure steady-state conditions, which is good in the case of reproducibility of the tests. On the other hand, cooking in real world environments is rarely done under steady-state conditions and can therefore deviate from the experimental tests.

O'Leary et al. (2019), Lunden et al. (2015), Xie et al. (2021), Jacobs and Cornelissen (2017), Meleika et al. (2020) and Kah et al. (2020) all used laboratory kitchens under controlled conditions. While Jacobs et al. (2016) and Singer et al. (2011) did on-site measurements in the Netherlands and California, respectively. Kang et al. (2019) chose to look at both a laboratory kitchen and 30 on-site residential kitchens. The laboratory experiments were done to evaluate the changes in fine particle concentration, particle decay rate constant, and the living/kitchen (L/K) ratio. Table 6 shows an overview of the different methods used in the assessed articles.

Table 6 – Different methods used in the reviewed literature.

Article	**Methodology**
O'Leary et al. 2019	Laboratory kitchen. PM2.5 measurements with OPC using ideal gases under steady state conditions. Four typical Dutch meals.
Lunden et al. 2014	Laboratory kitchen. Measured capture efficiency with both particle concentration and one with CO_2. Two different meals with two different pans.
Xie et al. 2021	Laboratory kitchen. Measured CE by heating oil and using tracer gas SF6
Kang et al. 2019	Field measurements performed in 30 residential buildings and a laboratory experiment. Broiling and frying fish and meat, measuring $PM_{2.5}$ and PM_{10}.
Singer et al. 2011	Field measurements in 15 California residences. Measured CE, CO_2 and airflow.
Meleika et al. 2020	Laboratory kitchen. ASTM-E3087.18 test method was used with tracer gas.
Jacobs et al. 2016	Field measurements in 9 dwellings. OPC measurements on different types of warm meals cooked by the residents.
Jacobs and Cornelissen 2017	Laboratory kitchen. Measured $PM_{2.5}$ and NO_2. Tested with recirculating hood with carbon filter, plasma hood and no hood. Frying burgers.
Kah et al. 2020	Laboratory kitchen. Measured odor reduction.

2.3.4 Recommendations from literature

From previous literature, a couple of recommendations are proposed to ensure the most efficient use of range hoods, see table 7 for an overview. O'Leary et al. (2019) recommends a range hood with good coverage of all burners and a high airflow rate. Meleika et al. (2020) suggests using lower mounting heights to increase CE. Singer et al. (2011) recommends using back burners and capture hood instead of other types, such as above-the-cooktop devices with flat bottoms. They also discovered that to attain 75% CE, a flow rate of 342 m^3/h was necessary, while Xie et al. (2021) found in their study that the CE can reach 99% if the exhaust airflow rate (EAR) is above 700 m^3/h and would therefore recommend an EAR this high. Kah et al. (2020) and Jacobs and Cornelissen (2017) both recommend changing the carbon filter regularly to achieve a decent CE on recirculating range hoods.

As seen in these assessed articles, there is a variety within the recommendations, and it is hard to compare results between them. This is mostly because of different test scenarios and different hood types. When it comes to recirculating hoods, very little existing literature was found, and more research is needed to make recommendations other than changing the filter regularly.

Table 7 – Recommendations from the reviewed literature.

Article	**Recommendations**
O'Leary et al. 2019	Good coverage of all burners at a high airflow rate.
Lunden et al. 2014	CE measured for burner produced CO_2 is not predictive for cooking-generated particles under all conditions but can be used to identify devices with CE over 80% for both.
Xie et al. 2021	Recommend above 700 m^3/h EAR
Kang et al. 2019	Use both natural ventilation and range hood simultaneously.
Singer et al. 2011	Minimum flowrate of 95 l/s (342 m^3/h) is necessary to achieve 75% CE. Back burners and capture hood is recommended
Meleika et al. 2020	Lower mounting heights were found to increase CE, and therefore recommended.
Jacobs et al. 2016	Motorized hood with a high exhaust flow
Jacobs and Cornelissen 2017	It is recommended to add a particulate filter to recirculation hoods and to apply them preferably in combination with electrical cooking
Kah et al. 2020	Recommended to replace or regenerate the filters regularly in accordance with the manufacturer's recommendations.

3 Method

3.1 Test facilities

The test chamber for this project is located at the SINTEF Community in Oslo, Norway. The tests were performed during the period March-April 2022. The following subchapters describe the set-up and conditions of the test chamber.

3.1.1 Test chamber

The test chamber is built according to the NEK IEC 61591:2019 standard for methods for measuring performance. SINTEF's chamber is slightly larger than the standard because it is supposed to simulate an open kitchen-living room solution that is common in newer apartments today. The chamber has a length of 6.2 m, a width of 4.8 m and a height of 2.7 m. This equals a volume of 80.3 m^3. Figure 6 shows an illustration of the test chamber and figure 7 of the kitchen set-ups.

To be able to test both the wall-mounted range hood and the downdraft system repeatedly one after the other without having to rebuild the entire lab several times, it was decided to have the wall-mounted hood on one wall and the downdraft system on another. This is because of the time limit and efficiency in the lab. This can have a negative effect on the comparison of the results from both rigs, but it is the most efficient way.

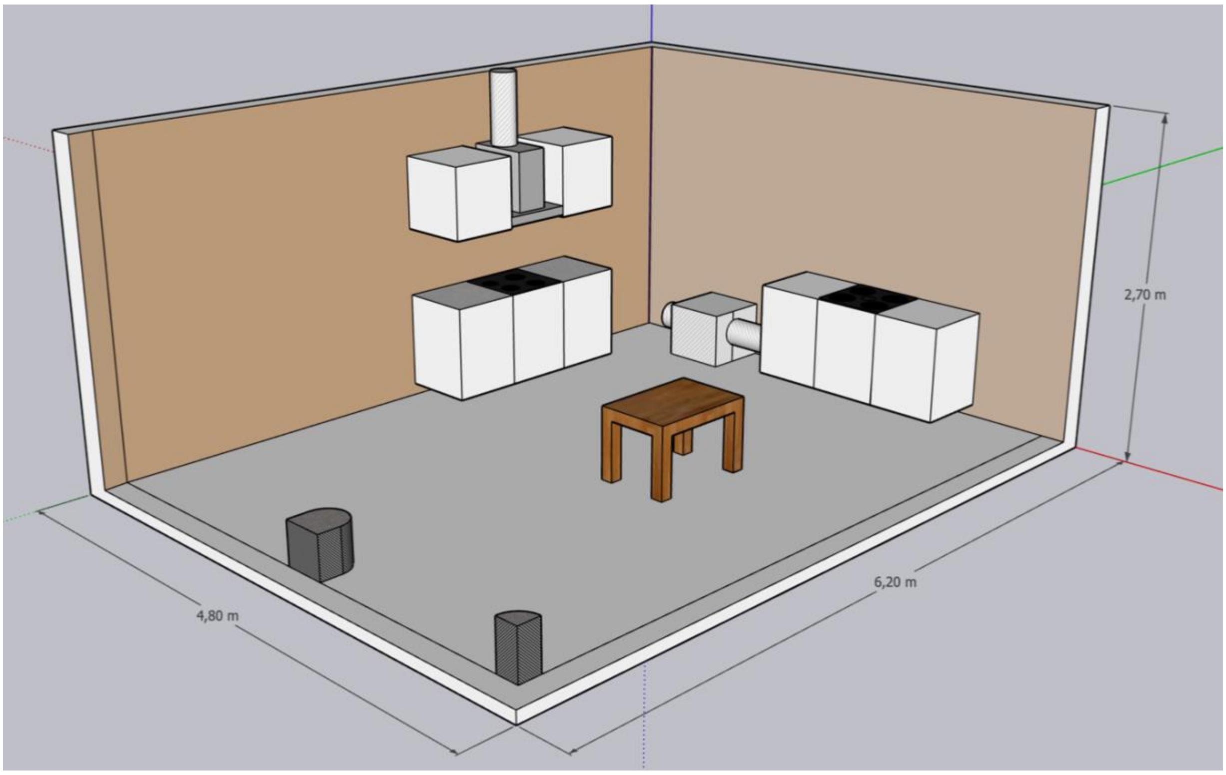


Figure 6 – An illustration of the test chamber at SINTEF Community.

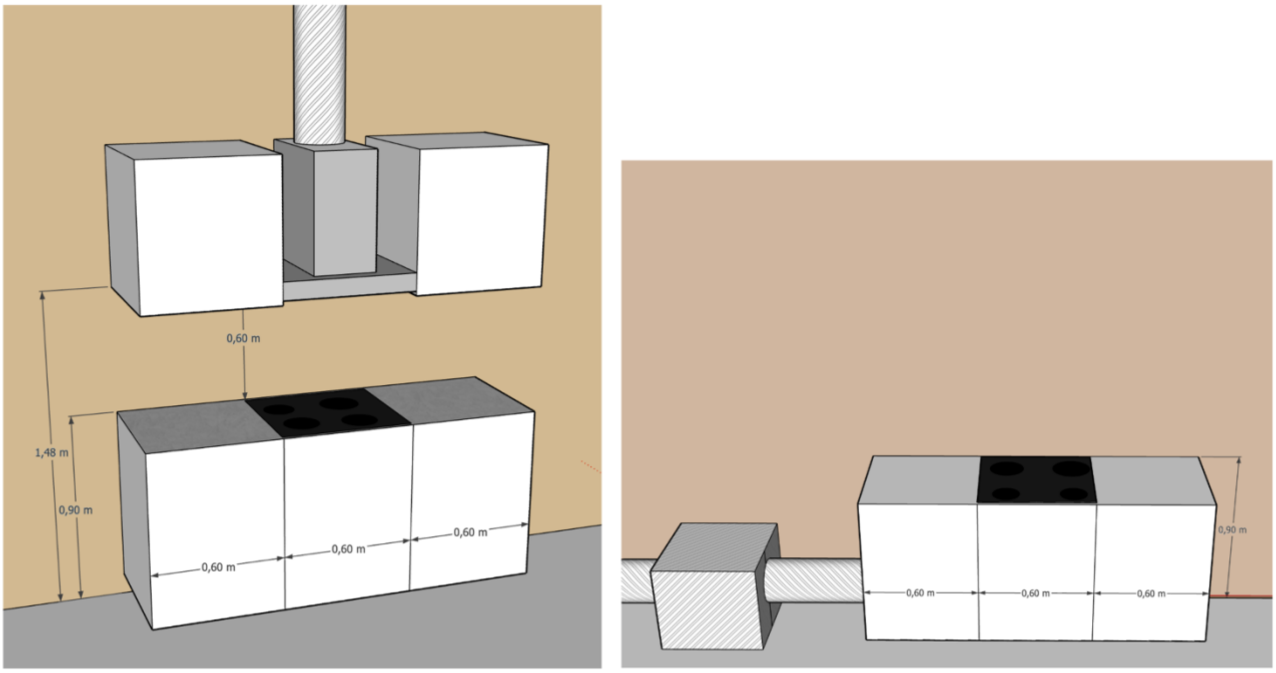


Figure 7 – An illustration of the two range hoods in the test chamber. Wall-mounted range hood (left) and downdraft (right).

The figure above shows each of the hoods in extraction mode, where the air is extracted above the ceiling and out. As seen on the right side, the downdraft system needs to extract the air out of the cabinet, at knee height, before it is ducted up above the ceiling. There is also a plenum box connected to the downdraft system, which is there to reset the pressure during extraction mode.

3.1.2 Range hoods

In SINTEF's test chamber, there is one kitchen set-up with a standard Siemens wall-mounted range hood and one with a Bora Pure downdraft. The hoods can be used for both extraction and recirculation. From last year's experiments of different installation heights, 54 cm and 70 cm, it was decided that for these experiments it would be used a height of 60 cm over the cooktop on the wall-mounted range hood. With this height, the results will be comparable to most range hoods. The Siemens wall-mounted hood has three power levels and one booster function. The Bora downdraft has nine power levels, one neutral function and one booster function. From last year's airflow measurements of the standard wall-mounted hood and this year's measurements of the downdraft, the different levels have the following airflows:

Table 8 – Exhaust airflow rates at the different levels for each of the range hoods (Jutulstad, 2021).

	Standard
Level 1	183 m^3/h
Level 2	286 m^3/h
Level 3	362 m^3/h
Boost	496 m^3/h

	Downdraft
Neutral	101,9 m^3/h
Level 1	143,4 m^3/h
Level 2	182,3 m^3/h
Level 3	216,1 m^3/h
Level 4	255,1 m^3/h
Level 5	293,9 m^3/h
Level 6	355,3 m^3/h
Level 7	390,6 m^3/h
Level 8	426,2 m^3/h
Level 9	459,7 m^3/h
Boost	530,4 m^3/h

To be able to compare the results from both setups, more similar airflow rates were required. To achieve this a damper was added to the ventilation ducts so that the airflows could be regulated to 108, 250 and 350 m^3/h. This way, the airflow rates were controlled under every experiment on both hoods.

Tests on noise levels for both set-ups at each power level of the hood were conducted to see the difference between the set-ups and be able to compare them. The tests were conducted with a Nor140 Norsonic instrument measuring at 1,2 meter above the floor and 1 m away from the range hood. The measurements were done over a period of 30 seconds. For average range hoods the noise level is around 60-70 decibels (dB). As a guide, 60 dB is the level where noise starts to be a nuisance to a conversation (Neutratest, 2022). Although, SINTEF recommends that range hoods should not exceed 45 dB. The set-ups in these experiments are therefore well within the comfortable range of noise, as seen in the tables below, but only some are within SINTEF's recommendations. The test chamber used in these experiments has a lot of hard surfaces compared to a regular open kitchen-living room where there are couches, pillows and curtains to muffle the sound. This means that the results from the tests could show a higher trend than what it would be in real life. See appendix E for detailed measurements of noise level.

Table 9 – Noise levels in dB for the Standard hood with extraction and recirculation mode.

Power Level	**1**	**2**	**3**	**Boost**
L_A Standard Extracting (dB)	47,1	56,8	61	63,7
L_A Standard Recirculating (dB)	49,1	55,8	60	-

Table 10 – Noise levels in dB for the Downdraft system with extraction and recirculation mode.

Power Level	**Neutral**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Boost**
L_A Downdraft Extracting	45,3	45,9	46,2	47,9	50,2	52,1	55,8	57,3	58,9	60,9	63,5
L_A Downdraft Recirculating	44,6	44,9	45,9	48,3	50,5	53,2	57,2	59,1	60,8	62,4	65,7

When the range hoods were set in recirculation mode, carbon filters were used. The Siemens range hood had a double layered carbon filter with the measures of 23x18,5 cm, while the Bora Pure's filter was a single layer in a long rectangular shape (43x13 cm). See figure 8 for a picture of the two filters. The different sizes and layers can make them harder to compare to each other.

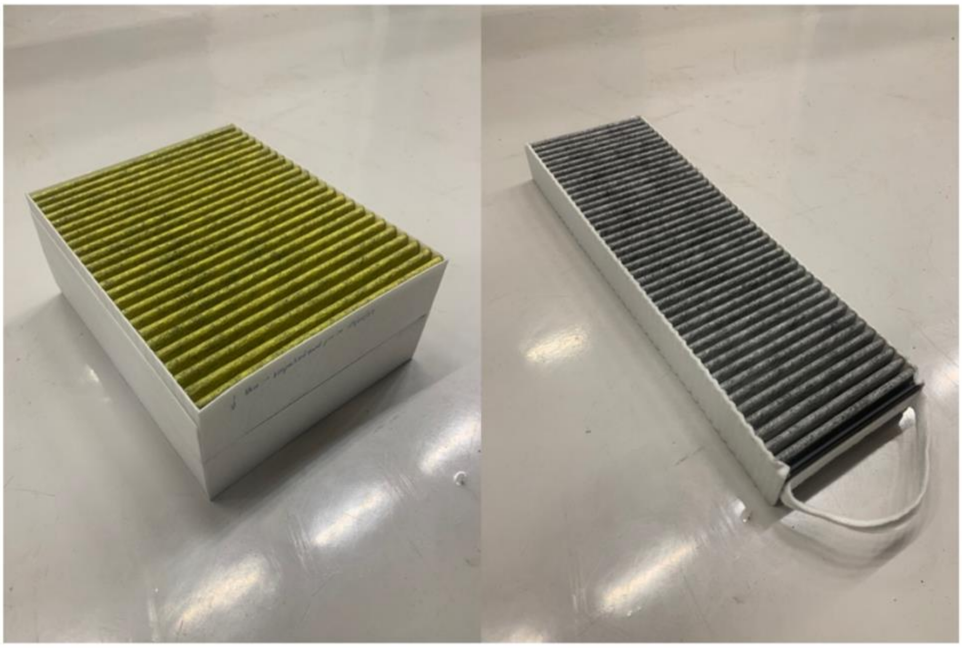
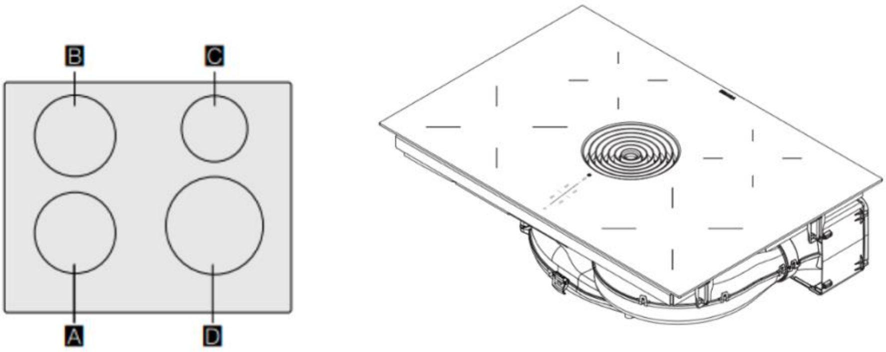


Figure 8 – A picture of the two carbon filters applied in these experiments. Siemens (left) and Bora Pure (right).

3.1.3 Cooktops

The cooktops are from the same manufacturers as the hoods: Siemens and Bora. Both cooktops use induction and have four cooking plates in different sizes and power levels. Figure 9 shows an illustration of each of the cooktops with their respective product data. The Siemens cooktop has nine power levels with mid-channels between the levels. In addition, there is a boost function for every plate. The Bora Pure cooktop also includes nine power levels and a "power function", however it is missing the mid-channels. During the experiments, cooktop A and D was used on the Siemens cooktop, and on the Bora Pure cooktop the front burners were used.



		Level 9	Boost
A/B	Ø 180	1800 W	3100 W
C	Ø 145	1400 W	2200 W
D	Ø 210	2200 W	3700 W

		Level 9	Power
Front	Ø 210 mm	2300 W	3000 W
Back	Ø 175 mm	1400 W	2100 W

Figure 9 – An illustration of each cooktop with the associated dimensions and power. Siemens cooktop (left) and Bora Pure (right) Image source: (Bora, 2021; Siemens, 2021).

To make sure that the cooking procedure was carried out in the same manner for both cooking tops, a pre-test on pan temperature was done. This was to ensure that the temperature in the pan was the same even though the power of the cooktops were different. Initially, a power effect test should have been done, but due to covid-restrictions, time-limit and some difficulties with the instruments, the power measurements had to be cancelled. The pan temperature test was therefore done by adding 200 ml of oil into the pan and then following the cooking procedure. Cooktop A was turned on level 9 for one minute and then turned down to 7 for seven and a half minutes. A thermo-couple in the pan measured and logged the temperatures. The same test was then run on the downdraft system but on a lower level since the power on this cooktop is higher than on the standard. To check if the levels were ok, a second test on the standard was done with half a level lower. Figure 10 shows the results from the tests where one can see that level 9 and 7 for the standard and level 8 and 6 for the downdraft system has the most similar temperatures.

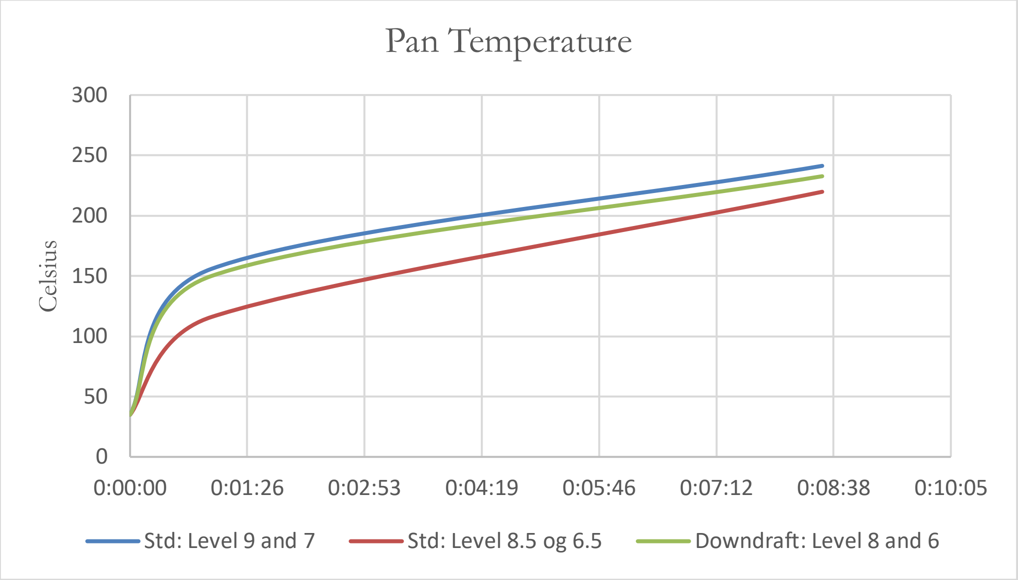


Figure 10 – Pan temperature for the standard cooktop and the downdraft cooktop.

3.1.4 Utensils

For the cooking experiments, two different types of pans were used, one smaller and one slightly bigger, measuring 24 and 28 cm, respectively. They are both made with aluminium and Tefal Titanium Pro non-stick coating, which has proven to emit less particles than steel pans since the food does not stick that easily to the pan (O'Leary et al., 2019). Two plastic spatulas were used to mix the food. To measure the weight of the food, a *Soehnle pagecompact 300* kitchen weight was used. *Funktion* measuring spoons were used for measuring oil in ml and salt and pepper in tbs.

Figure 11 – A picture of the utensils used in the experiments.

3.1.5 Instruments and placements

To be able to compare the results of the wall-mounted range hood and the downdraft system, it is important to use the same measuring points. Location 1 is placed in front of the cooktop, 20 cm from the bench, to simulate the person cooking the food. The instruments are placed at breathing height for an average Norwegian person, at 154 cm. This location was chosen because it shows how much a person is exposed to during cooking compared to other people in the room. Location 1 is the only one that will be moved between the wall-mounted and downdraft experiments. The second location is in the middle of the two range hoods, approximately in the middle of the room, where one would typically have a dining table. The instruments are placed at a height of 110 cm, which is assumed to be the breathing height of the people sitting around the table. Location 3 is located in the ceiling by the primary exhaust. This is to measure the particle concentration in the air before it is extracted from the room. Figure 12 shows the three locations from above, and figure 13 shows the locations from the side with the different heights.

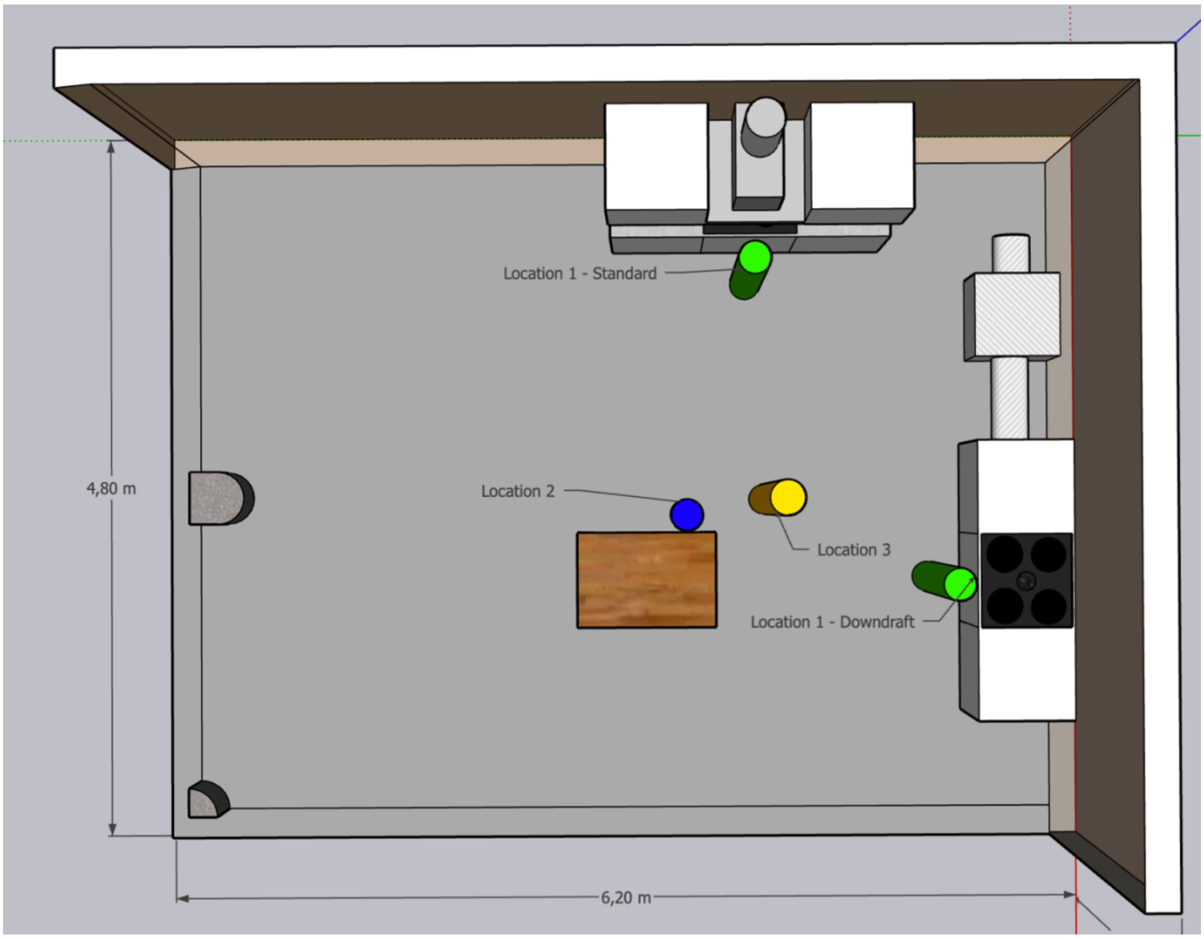


Figure 12 – An overview of the three locations for measuring. Location 1, the green poles, switch positions between the standard hood and the downdraft, the other two are the same for both experiments.

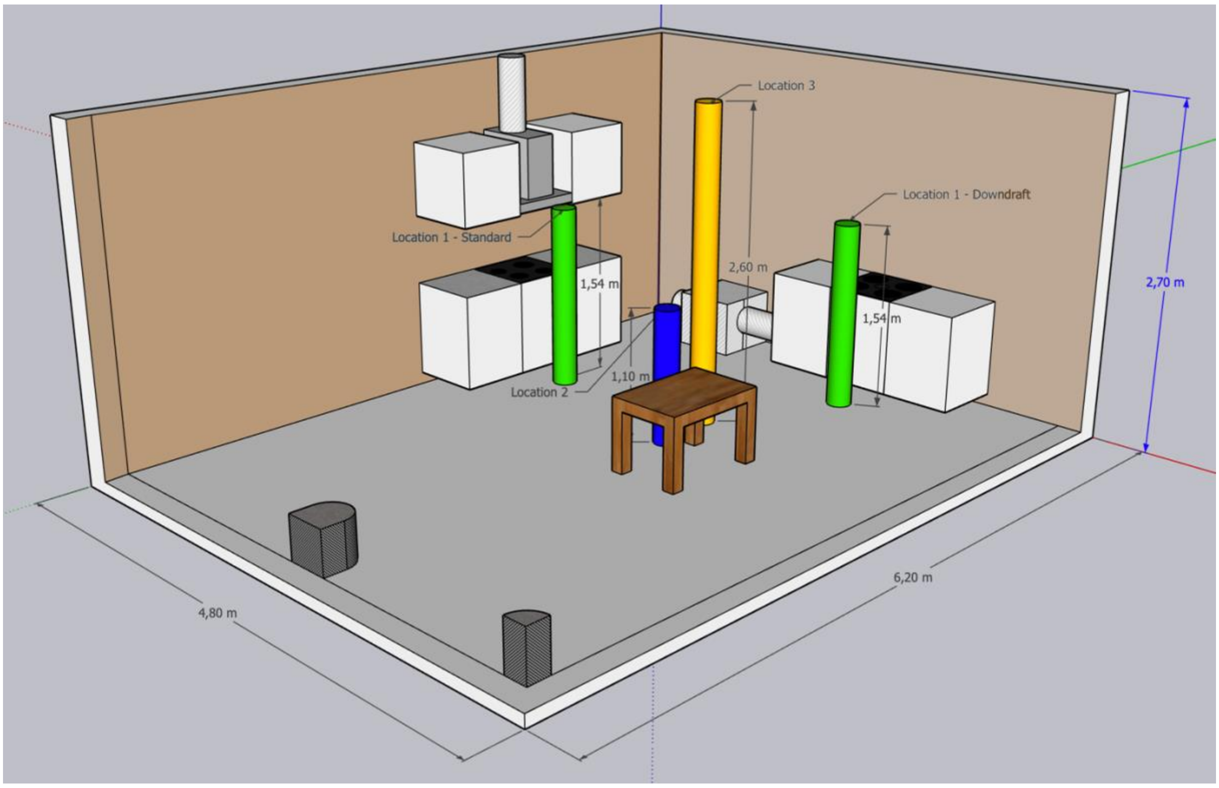


Figure 13 – An illustration of the instruments' location heights.

The main instruments used for measurements were Grimm 11-D in location 1 and Grimm 1.108 in location 2. These are optical particle counters and count particles in 31 and 15 bins, respectively. The 11-D model counts particles in the size of 0,253 microns to >35 microns, while the 1.108 model only counts from 0,3-20 microns. In this thesis the focus is on the particles with a diameter of 2.5 microns and less, the others will not be taken into account. The AeroTrak in location 3 is another important measurement for capture efficiency calculations. This instrument counts only in three bins meaning that it is less accurate than the Grimms. The AeroTrak is also placed in location 1 and 2 as a backup in case something happened to the Grimms. Table 11 shows a summary of the different instruments and at which locations they are placed. For more detailed information about the instruments, see appendix B.

Table 11 – A summary of instruments and their respective locations.

Instrument	Parameter	Location
AeroTrak	Particle counter [particles/liter]	1, 2, 3
Grimm	Particle counter [particles/liter]	1, 2
Thermocouple type T	Temperature [°C]	Inside chamber, air supply, air exhaust, outside chamber
DPT-CTRL 2500-D	Airflow [m^3/h]	Supply and exhaust air
Rotronic	Relative humidity (%), CO_2 [ppm] and Temperature [°C]	2
MetOne	Particle counter [particles/liter]	Supply air
Swema 3000	Flow rate and pressure	Pressure between the chamber and the hall

Grimm 11-D was completely new and calibrated by the manufacturer before the beginning of these experiments. Grimm 1.108 was too old for the manufacturer to calibrate and had not been calibrated since 2015. This also applied to the AeroTraks that were last calibrated in 2017. The DPT-Ctrl were reset and tested before the experiments, and the BAAS-measure points were calibrated last year, which is assumed to be acceptable. The Swema, Metone, Rotronic and Thermocouples were neither newly calibrated, however this was not critical because they were only used to check the environmental conditions.

3.1.6 Ventilation set-up

The experiments were performed under controlled ventilation conditions with a room temperature of 21±1.5 °C and an overpressure of 0,5±0,2 Pa to ensure that the chamber did not absorb particles from the hall. The test chamber's layout and the placement of the range hoods are comparable to the standard NEK IEC 61591. The ventilation was not connected to anything other than the chamber and was controlled using GK-cloud, see appendix C. A picture of the ventilation unit on top of the roof can be seen in figure 14. The test-chamber had displacement ventilation where the air was supplied into the room at floor height and extracted at ceiling height. To manage balanced ventilation without too much over or under pressure, the supply air had to be carefully regulated after the exhaust flowrate. The supply air was filtered to make sure the air from the outside was clean. The air was supplied by two air diffusers placed on both sides of the door to simulate a realistic apartment.

The exhaust extracted air from a primary exhaust in the ceiling and an additional exhaust, the range hood. The additional exhaust was rebuilt between the experiments on the standard wall-mounted range hood and the downdraft system. The primary exhaust operated at 36 m^3/h, which is the minimum requirement of TEK17. A differential pressure regulator with transmitter output measured and logged the flowrates for each test, see appendix D.

Figure 14 – The ventilation set-up up on the roof.

For the experiments in extraction mode, the range hoods were ducted up above the ceiling and out to the hall. The range hoods in recirculation mode were ducted into the room with a carbon filter. For the standard wall-mounted hood, the recirculated air got blown back into the room at ceiling height, while the downdraft blew the air back at floor height, as seen in figure 15. This can, of course, have an impact on airflow in the room and hence the results, but it was done for the purpose of real-life simulation, where it is most common with these set-ups for each hood. The reason the ducts are further out from the hood than what it would be in real-life is because of the need for control during the experiments. To be able to regulate the airflows and measure them, a damper and a measurement station is required. These take up a lot of space on the ducts before the filter, as one can see in figure 15.

Figure 15 – Both Standard hood (left) and Downdraft system (right) in recirculation mode.

Before the experiments were conducted, SINTEF received two new filters for the ventilation unit, F9 and Nano wave. To find which was better for our experiments, a pre-test was done by measuring the particle concentration before and after the filter for each of the filters, as well as the old F8 filter that was already there. From the tests it was found that no matter how high the particle concentration was outside, the F9 glass fiber filter was the one with the lowest particle concentration after the filter, see figure 16. This results in cleaner air inside the lab and was therefore chosen. The capture efficiency for the F9 and Nano wave filter were 90% and 87%, respectively.

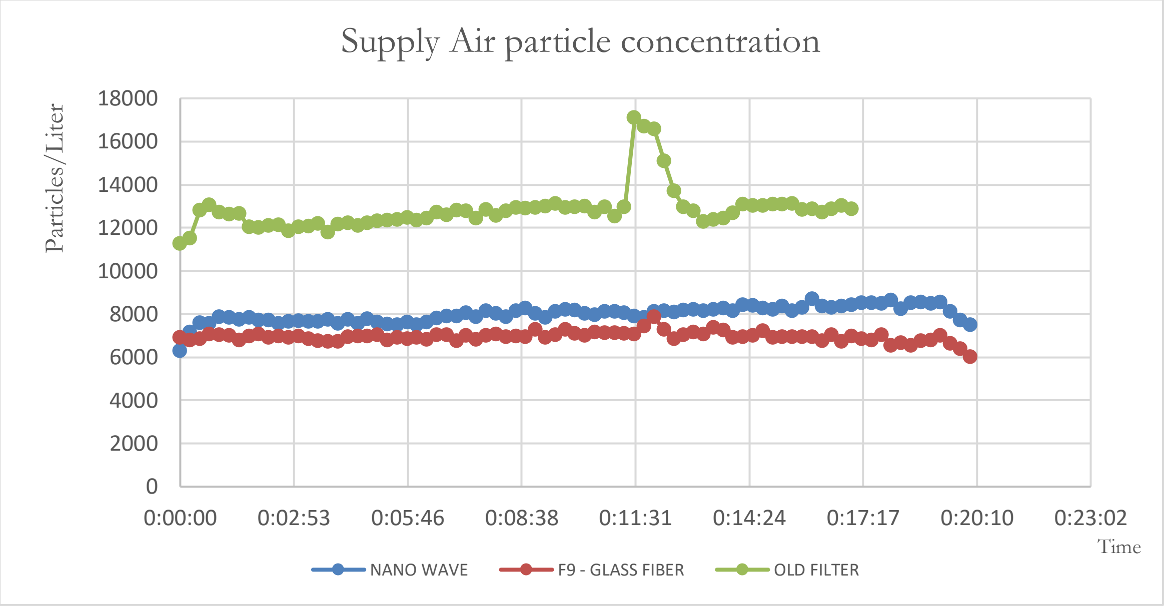


Figure 16 – The particle concentration after the air has been filtered through F9 and Nano wave filter.

3.2 Experiments

The experiments in this project were set up to specifically answer the research questions. They were conducted during March-April in 2022 together with Øystein Eliassen who also wrote a thesis for SINTEF's project "Healthy Energy-efficient Urban Home Ventilation" with a different approach.

3.2.1 Assumptions and limitations

There are some limitations to the experiments and therefore a few assumptions were made. The limitations and assumptions are listed below.

- The number of particles per litre was only measured in the range from 0.3 microns to 25 microns due to the instruments available. Because this thesis is mainly concerned with $PM_{2.5}$ exposure, only data regarding particulates with dimensions from 0.3 to 2.5 microns was examined.
- These experiments only performed with salmon and wok mix(frozen rice and vegetables) and will therefore not be comparable to other dishes.
- The measurements are done in three specific locations and is therefore not valid for other locations in the room.
- Only one type of downdraft system and one type of wall-mounted hood was tested. This means that these results do not apply to other brands or other types of hoods.
- The carbon filters for the wall-mounted range hood and the downdraft system are different in size. The wall-mounted hood's filter has a double layer of carbon whereas the downdraft system's filter has a longer surface area but only one layer. This can have an influence on how much is absorbed and thereby have an effect on the performance of the hood.
- To make a minimal amount of disturbance during the experiments the cook only moves when mixing the food. This is not similar to a real-life cooking process with a lot of movement, but it is done to ensure reproducibility and being able to compare each experiment to each other.

3.2.2 Meal and procedure

The meal cooked for these experiments was fried salmon with wok mix. From Jutulstad's master thesis survey about what Norwegians mostly cook for dinner, fish was a commonly prepared meal (Jutulstad, 2021). Furthermore, fish emit a lot of particles and are therefore an excellent choice for this type of experiment (Jutulstad, 2021). The meal is portioned for two adults since the test chamber is designed for two people. The meal consists of four salmon filets, about 500 g, and 500 g of wok mix, which is whole grain rice and vegetables mixed. The fish was seasoned with 0,75 g pepper and 1,5 g salt before it was added to the pan. The nutrition content of the meal is shown in table 12. For each experiment, 5 ml of canola oil was added to each pan since this type of oil is shown to have a high smoke-point and thereby lower emission rates (Torkmahalleh et al., 2012).

Table 12 – Nutrition content of fried salmon with wok mix.

Nutrtion value	**Salmon pr.100 g**	**Wok mix pr.100g**	**Meal (1000 g)**
Energy	932 kJ/224 kcal	421 kJ/100 kcal	6765 kJ/1620 kcal
Fat/ of which saturated	16 g/ 3,0 g	0,7 g/ 0,1 g	83,5 g/ 15,5 g
Carbohydrates/ of which sugars	0 g/ 0 g	18,4 g/ 1,6 g	92 g/ 8 g
Fiber	0 g	3,0 g	15 g
Protein	20 g	3,4 g	117 g
Salt	0,12 g	<0,05 g	0,85 g

The fish was bought from the same producer, Fiskeriet, to maintain consistency. The size of the fish fillets had an impact on the way it was cooked and thus the emission rate. This was taken into consideration in the shop when the fish was purchased to make sure they were about the same size and thickness.

To ensure reproducibility, a strict procedure had to be followed for every experiment. The procedure is shown in Table 13.

Table 13 – Cooking procedure for each experiment.

Description	**Start time**
Turn on instruments to measure background concentration, measure all ingredients, place on kitchen bench, add oil	-00:05:00
Season fish with salt and pepper	-00:01:00
Turn on cooktop A for small pan, setting 9 (8)*, turn on hood, wait 1 min	00:00:00
Turn heat down to 7 (6)* on cooktop A, add salmon skin side down	00:01:00
Press the salmon down with the spatula, then fry fish for total of 7 min skin side down	00:01:30
Change locations of the fillets (move them around in the pan)	00:03:00
Turn fillets over (skin side up), fry for 1.5 minutes	00:08:00
Remove salmon from pan, put on a plate	00:09:30
Turn on cooktop D for big pan, setting 8 (7)*, wait 1 min	00:10:00
Add wok mix, mix every minute	00:11:00
Turn off cooktop, turn off hood, transfer wok mix to a plate, and move the meal to location 3	00:16:00
Sit down by dining table	00:17:00
Stop intruments and increase ventilation before next experiment	01:08:00

*( ) is the power level for downdraft system

3.2.3 Experiments on extracting

Experiments on extracting were done on both the standard wall-mounted range hood and the downdraft system. The same meal was cooked with the same procedure to ensure comparability and reproducibility. The primary exhaust was 36 m^3/h for every experiment. The additional exhaust was 0, 108, 250, and 350 m^3/h for both hoods, and an additional 500 m^3/h for the downdraft. The same exhaust airflow rates were chosen to see the difference in capture efficiency and exposure between the hoods. The downdraft system was also tested at Bora Pure's maximum airflow rate of 500 m^3/h because it is known from the literature that downdraft systems need a higher airflow rate to achieve as high capture efficiencies as the standard wall-mounted range hood. The experiment with 0 m^3/h was done to find the concentration of particles emitted from the food without any additional exhaust other than the 36 m^3/h primary ventilation. 108 m^3/h was chosen to evaluate if TEK17's minimum requirements are sufficient. Due to SINTEF's recommendations, 250 m^3/h was tested. The largest airflow, 350 m^3/h, is higher than what regular wall-mounted range hoods usually work with but had to be tested for comparison to the downdraft, which operates on very high airflows.

The purpose of the experiment was to find capture efficiency and the exposure to the cook, location 1, and the people sitting by the dining table, location 2. In addition, the relative humidity and temperature were measured. Table 14 shows an overview of the different experiments conducted.

Table 14 – An overview of the different experiments in extraction mode.

Set-up	Expermiment	Additional ventilation [m^3/h]	Measurement time	Replicates
Standard Extracting	SE_0	0	1h 13 min	3
	SE_108	108	1h 13 min	3
	SE_250	250	1h 13 min	3
	SE_350	350	1h 13 min	3
Downdraft Extracting	DE_108	108	1h 13 min	3
	DE_250	250	1h 13 min	3
	DE_350	350	1h 13 min	3
	DE_500	500	1h 13 min	3

Explanation: SE_108 – Standard Extracting with airflow of 108 m^3/h
DE_250 – Downdraft Extracting with airflow of 250 m^3/h

It was decided that the order of the experiments would be “randomized”, but each day followed the order:

- High airflow – 500/350 m^3/h
- Medium airflow - 350/250 m^3/h
- Low airflow - 250/108 m^3/h
- Zero-test

The random order was done taking into account the varied background concentration from day to day. This way, if the background concentration was incredibly high one day, it would not affect all the repetitions of one airflow, but rather one repetition for each airflow. The high, medium, low order each day was used so that the concentration would not increase after every experiment. With the highest airflow rate at the beginning of the day made it possible to have a shorter time to air out the chamber between the experiments so that we could fit more experiments into one day. The zero-tests were therefore done at the end of the day. In appendix G one can see an overview of every experiment in the right order and which date they were conducted.

3.2.4 Experiments on recirculating

Data from recirculating hoods was also needed for the purpose of comparing them to extracting hoods. The same type of experiment was done on the same set-ups but this time with recirculating the air through a carbon filter. The exact same airflows were tested for comparison with extracting, see table 15.

The focus in these experiments was on capture efficiency, the exposure, if the carbon filter absorbed enough particles to ensure a healthy indoor climate, and the humidity levels in the room, since the air extracted from cooking has a high moisture content and is being recirculated and supplied back into the room.

Table 15 – An overview of the different experiments in recirculation mode.

Set-up	Expermiment	Additional ventilation [m³/h]	Measurement time	Replicates
Standard Recirculating	SR_108	108	1h 13 min	3
	SR_250	250	1h 13 min	3
	SR_350	350	1h 13 min	3
Downdraft Recirculating	DR_0	0	1h 13 min	3
	DR_108	108	1h 13 min	3
	DR_250	250	1h 13 min	3
	DR_350	350	1h 13 min	3
	DR_500	500	1h 13 min	3

3.2.5 Cleaning routine in test-chamber

To prevent the instruments from counting particles that has nothing to do with the cooking experiment, the chamber needed to be regularly cleaned. As one setup was done at a time, the routine became to clean before every setup. The floor was then washed with water and soap, and every horizontal surface was cleaned with a cloth. The grease filters were also cleaned once during the experimental period. Since the fish and oil caused a lot of grease around the pans, the cooktop and the bench were cleaned with water and soap after every experiment. Pans and spatulas were also cleaned with dish soap between each experiment. Due to the low number of experiments done on the recirculating hoods there was no need to change the carbon filter during this period.

3.3 Data analysis technique

In this experimental study, the data from the particle counters and the humidity level were primarily analysed. These gave an indication of the exposure from cooking and the indoor air quality in the rest of the room where people could be staying.

The data from the instruments were transferred to the computer using the associated software. The raw data was then transferred to Excel, where it was sorted and processed. Excel was used to create graphs and tables to help with the numbers and to demonstrate the differences between the experiments. If there were large deviations in the repeated experiments, the temperature and airflow measurements were checked to see if there were any changes that could have caused the deviation.

3.3.1 Converting raw data to $PM_{2.5}$

The raw data from the Grimms come in number of particles per m³. To get more accessible values that is easier to understand in terms of health effects, they are converted to $PM_{2.5}$. The Grimm 11-D automatically calculates the $PM_{2.5}$ values when transferring the data from the instruments to the computer. To convert the data from the older Grimm (1.108) to $PM_{2.5}$, Peter G. Schild had already developed an excel sheet. For more detailed information about this excel sheet, see appendix H. Simplified, the volume of each particle was calculated using the formula for the volume of a sphere and the particle density, here 1.65 kg/m³, and the particle count. To get the mass concentrations of $PM_{2.5}$ the mass of the particles in each bin was added together and the particle mass concentration was calculated. When using this excel sheet it is assumed that the particles are spherical, hence volume of a sphere.

To calculate the particle mass concentration [µg/m³] equation 3.1 was applied.

$$M_i = \sum_i \frac{\pi}{6} \rho \overline{d_\iota}^3 N_i \tag{3.1}$$

ρ particle density [kg/m³]

d_i particle diameter in each bin [m]

N_i particle count in each bin [particles/m³]

The equivalent particle diameter within each size bin can be calculated using equation 3.2, where a and b denote the bin limits.

$$\overline{d_\iota}^3 N_i = \int_{d_{i,a}}^{d_{i,b}} \frac{N_i}{d_{i,b}-d_{i,a}} x^3 dx \qquad \overline{d_\iota} = [\frac{{d_{i,b}}^4 - {d_{i,a}}^4}{4(d_{i,b}-d_{i,a})}]^{\frac{1}{3}} \tag{3.2}$$

Lastly, equation 3.3 is used to get the mass concentration $PM_{2.5}$.

$$PM_{2.5} = \sum_{i=0}^{2.5} M_i \tag{3.3}$$

3.3.2 Comparing PM2.5 concentration to WHO's recommendations

To be able to compare the $PM_{2.5}$ results from the experiments to the World Health Organization's yearly and daily maximum values, the formula below was used to transfer the average values from each experiment to a daily average. The formula takes the average background exposure of $PM_{2.5}$ plus the average $PM_{2.5}$ of the test multiplied by the experiment time divided by 24 hours.

$$\overline{PM}_{daily} = \overline{PM}_{background} + \overline{PM}_{2.5} * \frac{1.2}{24} \tag{3.4}$$

A worst- and best-case scenario was done of the average $PM_{background}$ since this will vary a lot from where the building is placed. The worst-case scenario used "Spikersuppa's" yearly average PM values from Oslo's statistics, assuming that the ventilation unit has no filter (OsloKommune, 2021). The best-case scenario took the background concentration in the test chamber where a F9 filter was used in the ventilation unit.

3.3.3 Uncertainty by standard deviation

To figure out the uncertainty in the results, the relative standard deviation is calculated. This is done by gathering all the data for each test into one excel sheet. To begin, the average results ($\bar{x}$) must be calculated by adding the individual results and dividing them by the number of samples (n), as shown in equation 3.5.

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \cdots x_n}{n} \tag{3.5}$$

Standard deviation is then calculated by the formula below:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{3.6}$$

The relative standard deviation (RSD) is a coefficient of variation which determines whether the standard deviation of a collection of data is small or large compared to the average (Indeed, 2021). This means that the RSDs inform you how precise your results' average is. The RSD can be calculated using equation 3.7 to make the deviation easier to assess and compare:

$$RSD = 100 * \frac{\sigma}{\bar{x}} \tag{3.7}$$

3.3.4 Capture efficiency calculations

Capture efficiency can be calculated in a number of different ways, and there are several standards providing different equations. For this study, an excel sheet was developed by Peter G. Schild to calculate the capture efficiency. For more detailed information about the program, see appendix I. The calculation is very similar to NEK IEC 61591:2019 but Peter integrates the particle concentration measured from the time when cooking begins until infinity. The equation is therefore a little bit different, see equation 3.8. Unlike the standards, where the primary goal is to assess the effectiveness of the range hood, the focus in this research is on exposure as well. The exposure for the chef and those in the open kitchen-living room is thus determined by the capture efficiency.

$$CE = \left(1 - \frac{\Sigma C_{on}}{\Sigma C_{off}}\right) \times 100\% \tag{3.8}$$

$\sum C$ is the total of all logged concentration values and can be calculated by equation 3.9.

$$\Sigma C = \left[\sum_{i=1}^{N} c_i\right] + \Sigma C_{tail} \tag{3.9}$$

In Peters macro-enabled excel sheet the capture efficiency can be calculated at any location in the room. In this thesis location 3(by the primary exhaust in the ceiling) was chosen. This is considered to be the most representative location for the enclosure as a whole. All the measurements from the AeroTrak in location 3 are compared to the zero-tests at the same location. It compares each possible combination of all three repetitions from each airflow and all five zero-tests, and the result is an average of these combinations.

The excel sheet also considers the variation in background concentration and manipulates the data so that each experiment start with the same background. In appendix I one can read the explanation of background concentration correction. The excel sheet assumes identical conditions for flow rate, hood height, filter configuration and so on. This makes it important that the repeated tests are consistent and completed in the same way.

Uncertainty in the capture efficiency is also calculated in this excel program. All five repetitions of the zero-tests are set up against the three repetitions of each airflow. The standard deviation is then calculated by the equations in chapter 3.3.3 for each of the combinations and an average for all together.

4 Results

4.1 Test chamber conditions

Test chamber conditions such as temperature, humidity and CO_2 were measured during each experiment. The average for each test can be seen in the table below, as well as the maximum and minimum values. Within each test the temperature only fluctuated by ±1°C, the relative humidity by ±5% and the CO_2 by ±180 ppm. As you can see from the table, the temperature is stable between each experiment. The relative humidity was unfortunately harder to keep the same because of some problems with the humidifier in the ventilation unit. Because of Covid-19 restrictions and time-limit, the manufacturer of the unit was not able to fix this in time. The relative humidity stayed mostly between 13-25% with some peaks above and some under.

Table 16 – An overview of the average, maximum and minimum values of temperature, relative humidity and CO_2 conditions for each experiment.

Experiment	Temperature [°C]			CO_2 [ppm]			RH [%]		
	Average	Max	Min	Average	Max	Min	Average	Max	Min
	Zero-tests								
D_0_1	21,3	21,3	21,1	549	597	486	29,8	32,0	27,7
D_0_2	21,3	21,4	21,2	539	598	490	19,7	22,4	18,4
D_0_3	22,9	22,9	22,8	520	555	501	25,3	26,3	24,0
D_0_4	22,9	23,0	22,9	456	525	419	24,1	25,6	22,5
D_0_5	21,3	21,5	20,8	485	506	429	14,6	15,8	13,3
S_0_1	23,3	23,5	23,1	489	536	468	23,6	25,2	22,8
S_0_2	22,9	23,1	22,7	475	498	456	20,1	21,3	19,0
S_0_3	22,4	22,5	22,3	571	602	549	19,9	21,1	18,0
S_0_4	23,4	23,5	23,0	492	528	447	12,7	14,7	11,0
S_0_5	22,6	22,9	21,8	475	524	417	27,2	29,8	25,5
	Downdraft Extracting								
DE_108_1	22,8	22,8	22,7	518	555	480	20,5	21,6	19,3
DE_108_2	23,1	23,2	23,0	495	583	457	28,7	29,2	27,6
DE_108_3	23,5	23,6	23,4	495	566	461	25,4	25,9	24,6
DE_250_2	22,9	23,1	22,7	506	568	451	27,4	28,7	25,7
DE_250_3	23,4	23,4	23,2	486	531	421	24,8	25,6	23,5
DE_250_4	23,5	23,6	23,2	446	528	412	13,1	13,6	12,0
DE_350_1	22,4	22,5	22,2	480	539	428	18,8	19,6	17,7
DE_350_2	22,6	22,7	22,4	468	545	425	25,3	25,8	24,6
DE_350_3	23,1	23,2	22,9	449	537	406	24,4	25,1	23,4
DE_500_4	23,1	23,3	22,8	440	499	395	13,0	14,2	11,9
DE_500_5	23,6	23,7	23,3	448	493	391	12,1	13,0	10,5
DE_500_6	22,9	23,0	22,6	452	556	406	13,0	14,5	11,7
	Downdraft Recirculating								
DR_108_1	21,1	21,2	20,9	470	507	440	21,7	23,4	20,3
DR_108_3	22,8	22,8	22,7	506	569	478	24,7	25,6	23,5
DR_108_4	22,8	22,8	22,7	528	646	467	23,9	24,9	23,0
DR_250_2	21,2	21,3	21,1	509	566	459	19,6	21,4	18,3
DR_250_3	22,6	22,8	22,5	542	600	500	23,9	24,9	22,4

DR_250_4	23,1	23,2	23,0	532	624	467	23,4	24,8	21,7
DR_350_3	22,5	22,6	22,4	532	591	489	19,8	21,0	18,9
DR_350_4	22,2	22,3	21,8	494	514	470	22,5	23,7	21,3
DR_350_5	23,0	23,2	22,9	551	603	503	23,6	24,7	22,4
DR_500_2	20,8	21,0	20,5	506	544	465	22,9	24,7	20,7
DR_500_3	20,9	21,1	20,6	541	587	500	19,6	21,6	17,3
DR_500_4	22,3	22,5	22,1	558	601	523	25,2	26,2	24,2
	Standard Extracting								
SE_108_2	23,0	23,1	22,9	485	546	465	23,2	34,1	22,2
SE_108_3	22,8	22,9	22,6	456	481	431	21,3	21,9	20,6
SE_108_4	22,0	22,1	21,9	543	644	516	18,8	19,5	17,9
SE_250_2	22,5	22,7	22,2	494	537	461	24,5	25,6	23,5
SE_250_3	22,6	22,8	22,4	466	501	438	25,6	26,7	24,3
SE_250_4	21,6	21,8	21,1	534	557	499	19,3	20,0	18,1
SE_350_3	22,9	23,1	22,6	479	514	437	24,7	25,3	23,6
SE_350_4	23,0	23,2	22,6	463	493	428	23,1	23,8	22,4
SE_350_5	22,2	22,4	21,8	453	494	427	25,8	27,1	24,9
	Standard Recirculating								
SR_108_1	23,6	23,8	23,4	518	575	483	8,5	11,3	7,4
SR_108_2	23,7	23,8	23,4	501	538	470	12,9	14,5	11,9
SR_108_3	23,2	23,4	23,0	475	538	441	12,6	15,3	11,3
SR_250_1	23,3	23,6	22,8	552	578	526	11,1	12,8	9,8
SR_250_2	23,6	23,7	23,2	463	486	441	12,8	15,2	11,7
SR_250_3	23,1	23,3	22,8	499	531	464	13,4	16,2	12,0
SR_350_1	22,8	23,1	22,2	474	505	455	13,7	15,9	12,1
SR_350_2	23,4	23,6	23,1	509	556	464	14,0	17,1	12,5
SR_350_3	22,8	23,0	22,4	500	562	449	13,2	15,5	11,7

4.2 The zero-experiment

To be able to calculate capture efficiency there was a need for zero-tests. These are experiments done in the exact same procedure as every other test, but without any range hood on. This will also give an expression of how much $PM_{2.5}$ is produced from cooking when there is no hood on, and thereby show the significance of range hoods. As the literature has shown, it is the particles of size 2.5 microns and less that are the most dangerous, and $PM_{2.5}$ is comparable to the recommendations from for example WHO.

Figure 17 shows the $PM_{2.5}$ values for all repetitions of the zero-test on the standard wall-mounted hood on location 1, where the cook stands, and on location 2, where the dining table is placed. The relative standard deviation (RSD) is 52,5% with a maximum 189 $\mu g/m^3$ and a minimum of 0,1 $\mu g/m^3$ for location 1 (the cook) and 54,3% for location 2 (dining table) with a maximum and minimum of 38,7 and 0,02 $\mu g/m^3$, respectively.

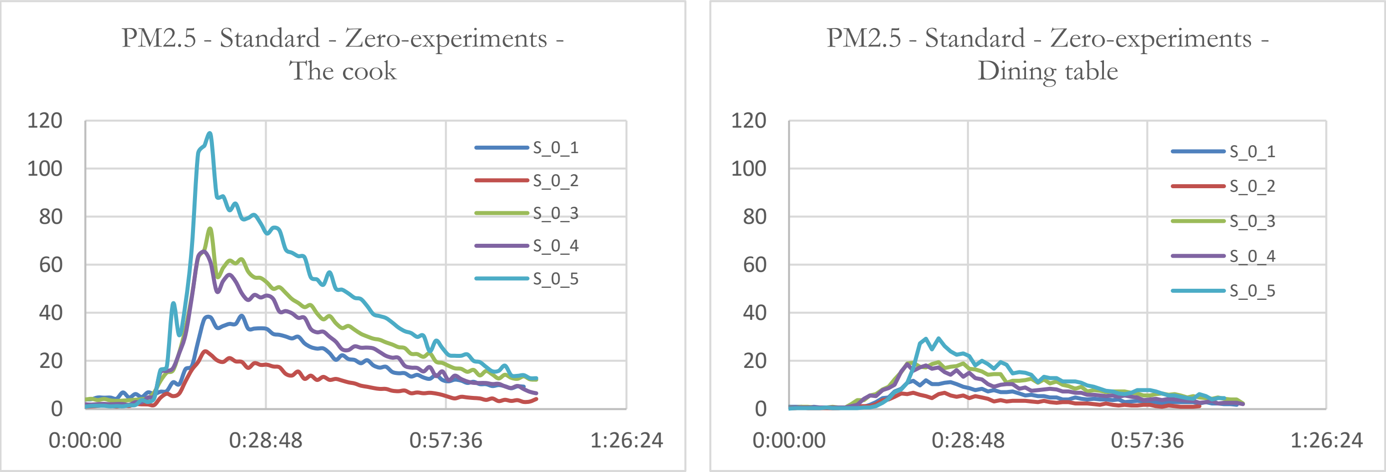


Figure 17 – PM$_{2,5}$ values for all repetitions of the zero-test on the standard hood for location 1(left) and location 2(right).

Figure 18 shows the PM$_{2.5}$ values for all repetitions of the zero-test on the downdraft system on both location 1 and 2. The relative standard deviation (RSD) is 29,5% with a maximum of 72,9 µg/m^3 and a minimum of 0,1 µg/m^3 for location 1 (the cook) and 63% for location 2 (dining table) with a maximum and minimum of 24 µg/m^3 and 0,005 µg/m^3, respectively.

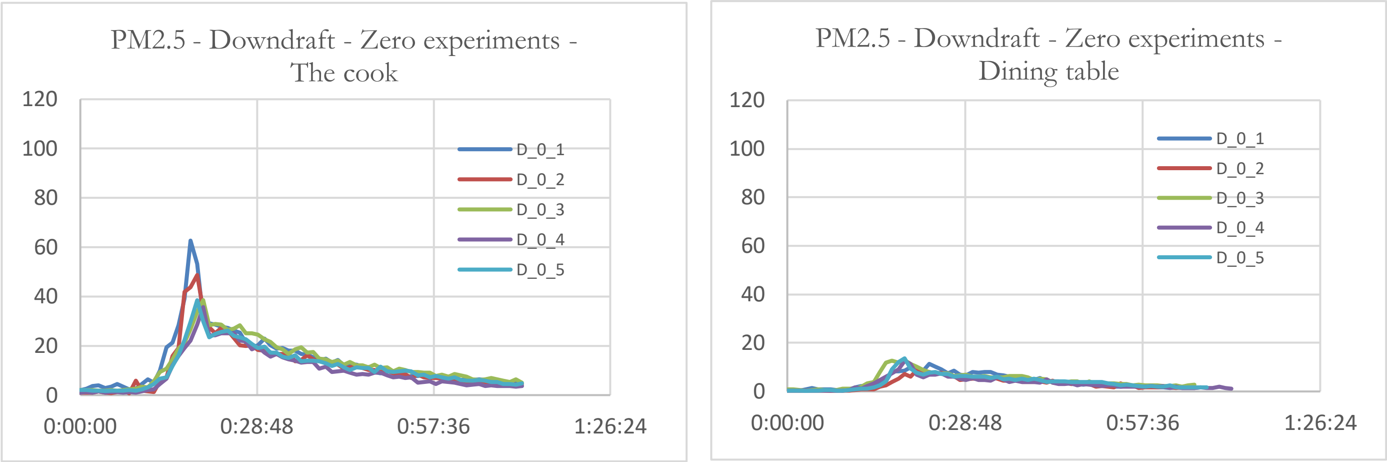


Figure 18 – PM$_{2,5}$ values for all repetitions of the zero-test on the downdraft system for location 1(left) and location 2(right).

4.3 Standard hood – Extraction vs Recirculation

4.3.1 Exposure

The figures below represent the PM$_{2.5}$ concentration at different airflow rates when using extracting and recirculating mode on the standard wall-mounted hood. The blue and green curve represents the hood in extraction mode for location 1, the cook, and location 2, the dining table, respectively. The red and purple curve shows the hood in recirculation mode at the same locations. The curves are an average of the three repetitions done for each airflow. In appendix F one can see all the repetitions for each airflow.

Figure 19 shows the PM$_{2.5}$ concentration when using an airflow rate at 108 m^3/h. As one can see, the exposure for the cook when using recirculation has the highest peak at 74 µg/m^3, while the lowest peak, 4 µg/m^3, is when using extraction.

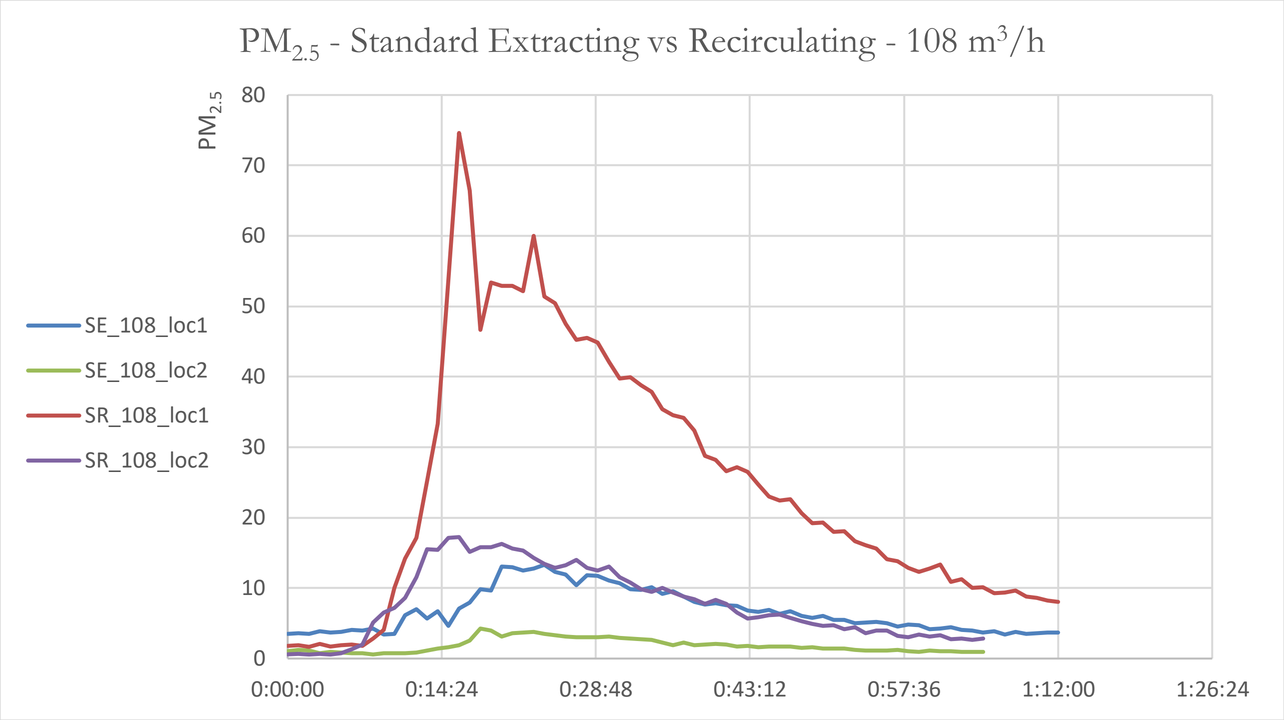


Figure 19 – $PM_{2.5}$ concentration for both standard recirculating and extracting with an airflow rate at 108 m^3/h.

Figure 20 shows the $PM_{2.5}$ concentration when using an airflow rate at 250 m^3/h. The highest peak is still recirculating in location 1, but at 68 μg/m^3, and the lowest is extracting in location 2 at 2,7 μg/m^3.

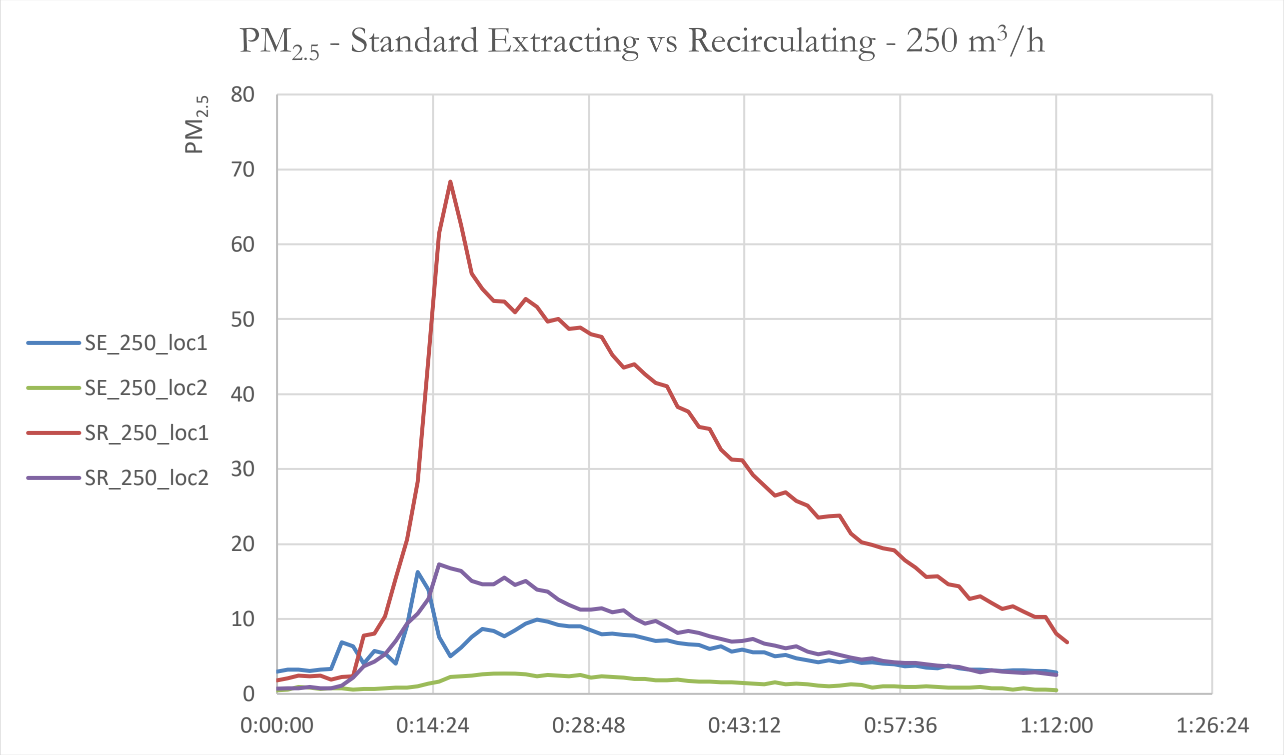


Figure 20 - $PM_{2.5}$ concentration for both standard recirculating and extracting with an airflow rate at 250 m^3/h.

Lastly, figure 21 also shows the $PM_{2.5}$ concentration but with an airflow rate at 350 m^3/h. The highest peak is still the same curve but at 48 μg/m^3. The lowest curve stays almost flat at 1 μg/m^3 throughout the experiments.

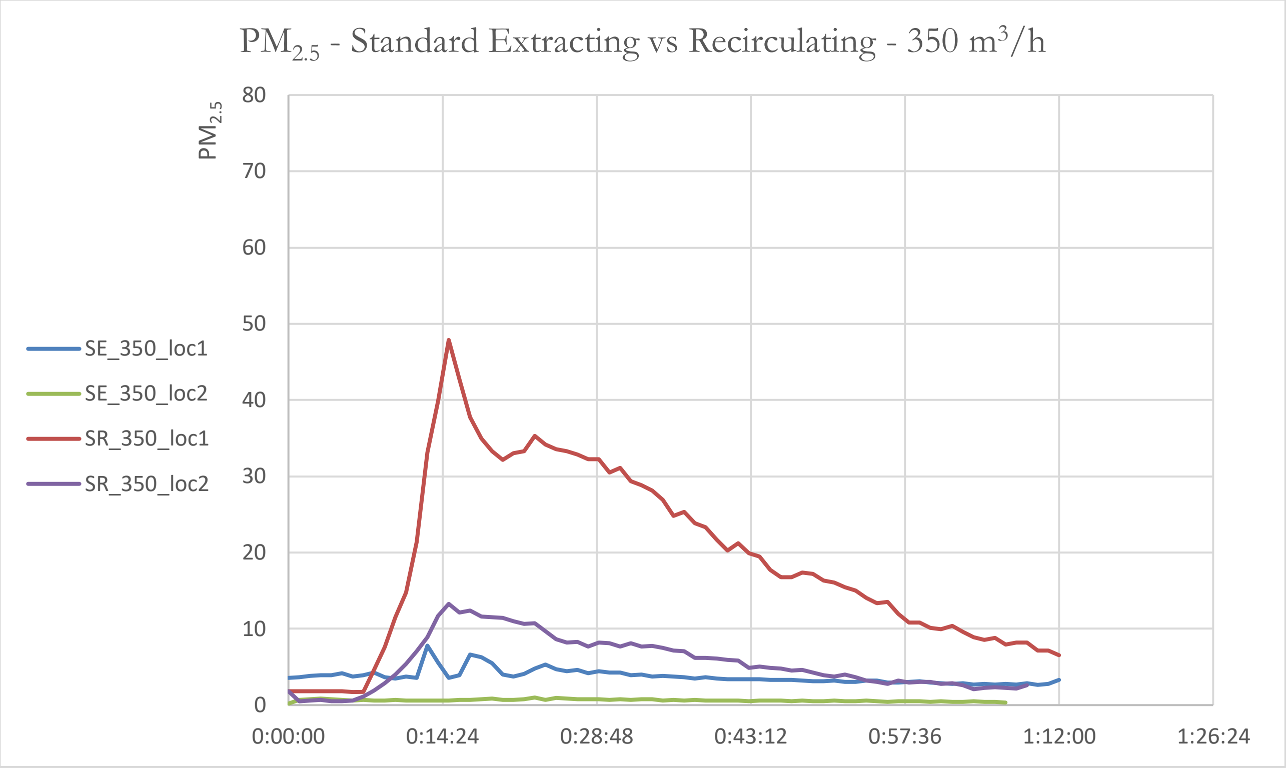


Figure 21 - PM$_{2.5}$ concentration for both standard recirculating and extracting with an airflow rate at 350 m^3/h.

The emissions increase over the first 16 minutes before declining, as seen in the figures. This corresponds to a minute after the fish is done cooking, which is what gives out the most particles.

The table below shows an overview of the relative standard deviation between all repetitions of each airflow, as well as the maximum and minimum values.

Table 17 – An overview of the relative standard deviation and maximum and minimum values between all repetitions of each airflow for the Standard range hood.

	SE_108		**SE_250**		**SE_350**	
	Grimm1	**Grimm2**	**Grimm1**	**Grimm2**	**Grimm1**	**Grimm2**
Average %RSD	45,7	44,0	57,1	64,5	45,6	56,9
max [µg/m³]	93,80	12,54	218,90	7,71	99,20	3,60
min [µg/m³]	0,30	0,05	0,60	0,05	0,60	0,05
	SR_108		**SR_250**		**SR_350**	
	Grimm1	**Grimm2**	**Grimm1**	**Grimm2**	**Grimm1**	**Grimm2**
Average %RSD	17,9	95,9	28,1	32,5	42,2	73,4
max [µg/m³]	100,10	31,18	102,70	33,03	95,40	22,21
min [µg/m³]	0,60	0,12	0,60	0,07	0,20	0,04

4.3.2 Capture Efficiency

For the standard wall-mounted hood, the capture efficiency was calculated by Peter Schild's excel sheet. The figure below presents a histogram of the average capture efficiency for both extracting and recirculating for each of the three airflows tested.

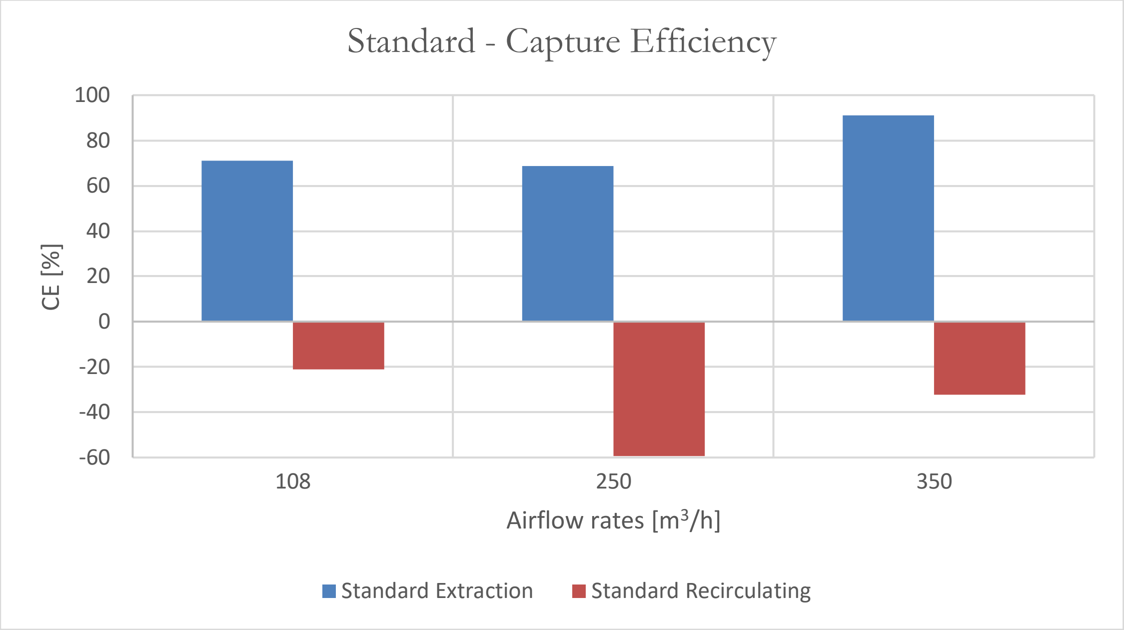


Figure 22 – Capture efficiency for the standard hood with both extraction(blue) and recirculation(red) for each airflow.

The highest average CE, 91,2 %, is with extraction at 350 m^3/h, while the lowest CE is recirculating at 250 m^3/h. Table 18 shows an overview over the average CE for each airflow, the calculated relative standard deviation and the maximum and minimum values of CE. The RSD is significantly lower with extraction than recirculating.

Table 18 – An overview of the average capture efficiencies and the related relative standard deviations with maximum and minimum values for each airflow for the standard hood.

Airflow [m³/h]	Mean [%]	RSD [%]	Max [%]	Min [%]
Standard Extracting				
108	71,1	20,1	86,6	35
250	68,6	40,1	93,4	-6
350	91,2	4,9	96,6	81,7
Standard Recirculating				
108	-21	259,5	38,6	-134,3
250	-59,3	133,7	30,6	-250
350	-32,2	233,2	47,8	-231,9

4.4 Downdraft system – Extraction vs Recirculating

4.4.1 Exposure

The figures below indicate the $PM_{2.5}$ concentration at the various tested airflow rates while using the downdraft system in extracting and recirculating mode. The hood in extraction mode for location 1 (the cook) and location 2 (dining table) is represented by the blue and green curves, respectively. The red and purple curves represent recirculation mode in location 1 and 2, respectively. The curves are an average of the three repetitions done for each airflow.

For airflow rate 108 m^3/h one can see in figure 23 that the red and blue curves are similar and have a peak at 23 $\mu g/m^3$ and 18 $\mu g/m^3$, respectively. Although, one should notice the different start values, which indicate that the background values are very different for those two experiments. The lowest peak is the same curve as for the standard tests but at 5,99 $\mu g/m^3$.

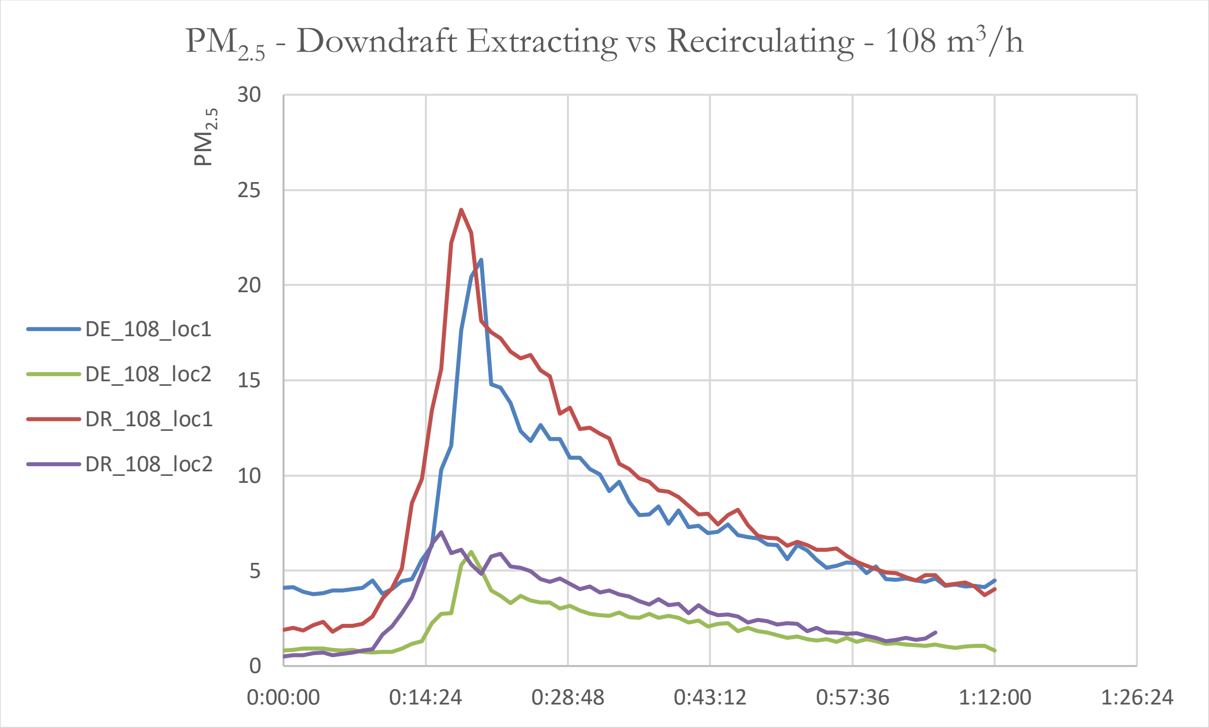


Figure 23 - $PM_{2,5}$ concentration for both downdraft recirculating and extracting with an airflow rate at 108 m^3/h.

For downdraft with an airflow rate at 250 m^3/h, see figure 24, the curves have the same trend as the standard hood where location 1 in recirculation mode has the highest peak, 27 $\mu g/m^3$, while the others are way smaller. The lowest peak is less than 0,5 $\mu g/m^3$ at location 2 for extracting.

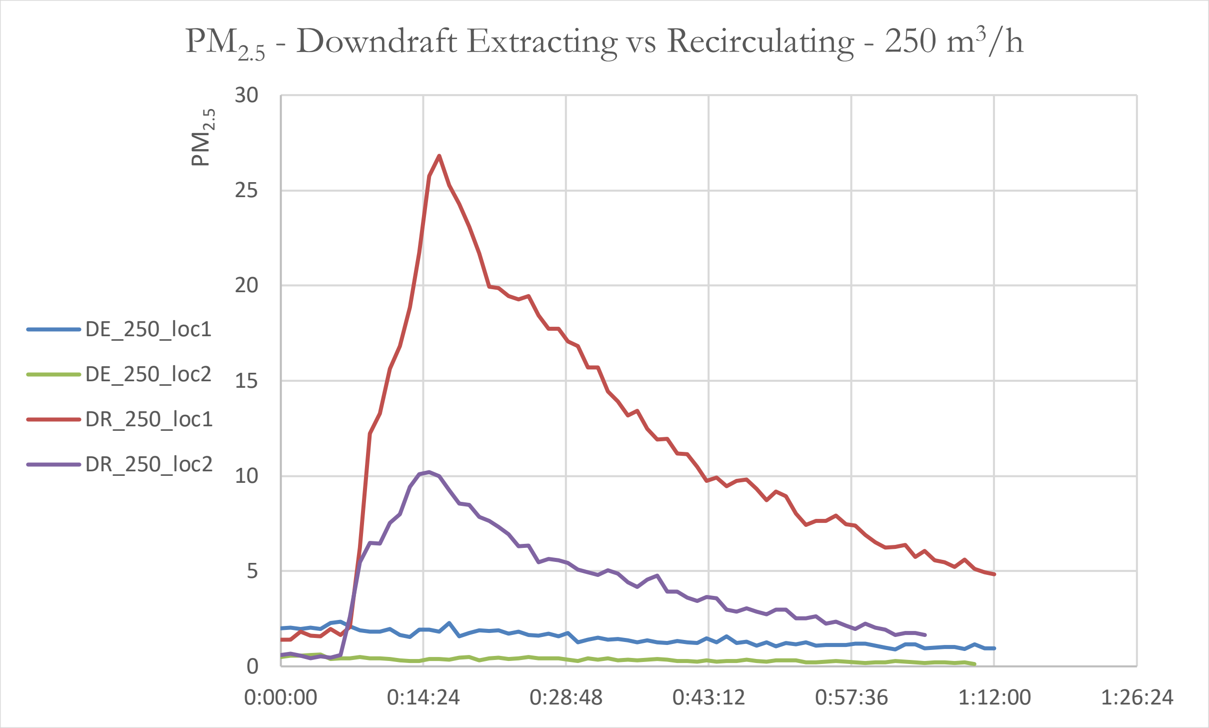


Figure 24 - PM$_{2,5}$ concentration for both downdraft recirculating and extracting with an airflow rate at 250 m^3/h.

As seen in figure 25, the highest peak at airflow 350 m^3/h is 20 µg/m^3, which again is the downdraft in recirculation mode at location 1. While the lowest is almost exactly the same as for the 250 m^3/h tests, less than 0,5 µg/m^3.

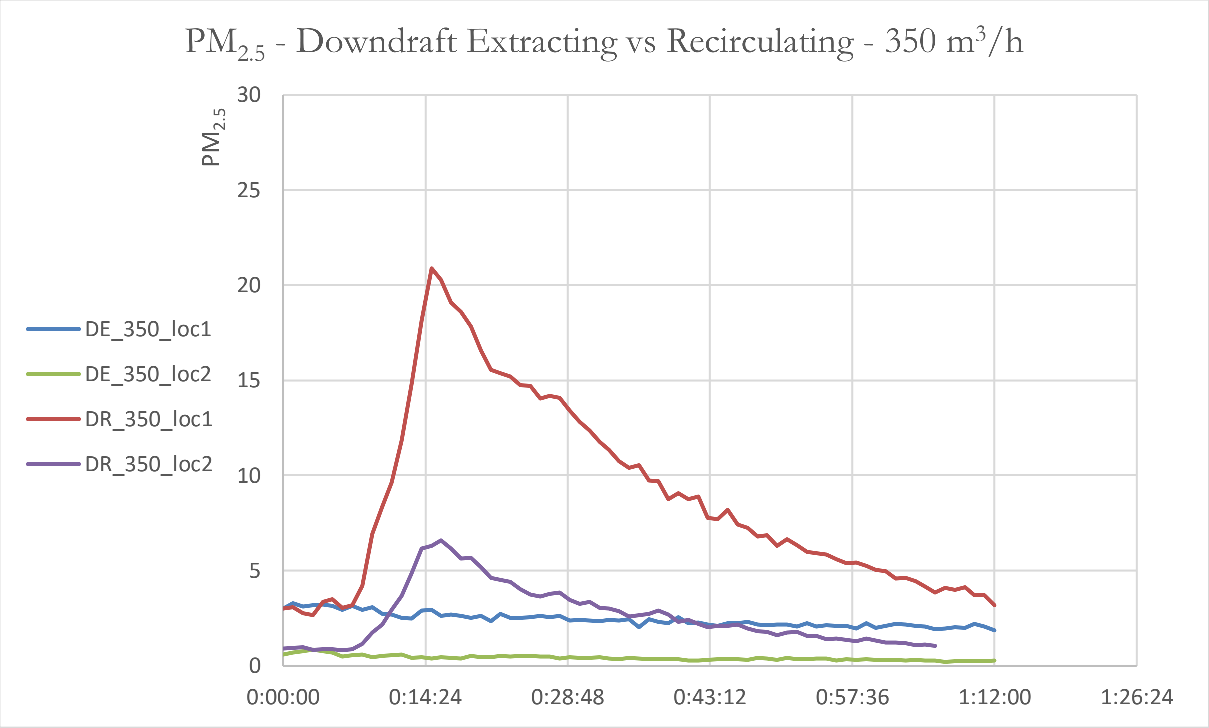


Figure 25 - PM$_{2,5}$ concentration for both downdraft recirculating and extracting with an airflow rate at 350 m^3/h.

For the highest airflow, the highest peak is 11,5 µg/m^3, which makes the other curves extremely small, see figure 26. The green curve, which is downdraft extracting at location 2 (dining table), does not even go over 0,3 µg/m^3.

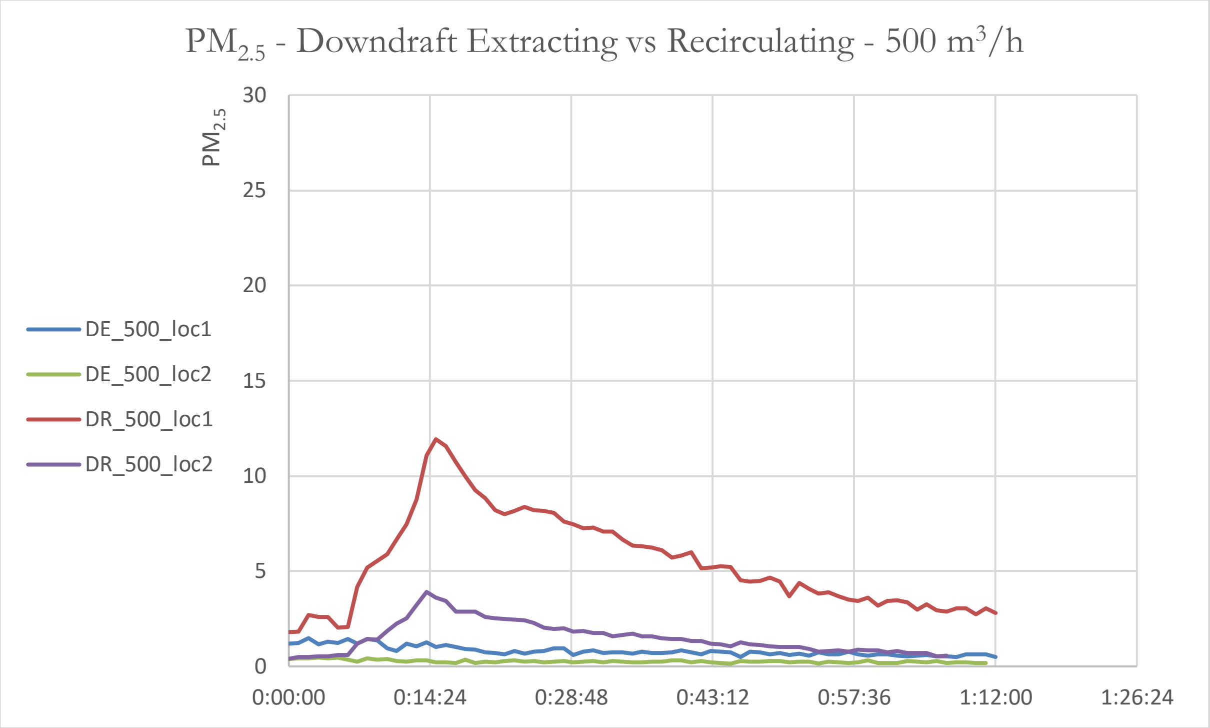


Figure 26 - PM$_{2.5}$ concentration for both downdraft recirculating and extracting with an airflow rate at 500 m^3/h.

As seen in the figures, some of the location 2 curves end earlier than the location 1 curves. This is because the old Grimm was slowly getting worse and quitting on us every now and then. The results from the old Grimm is therefore not that reliable, but is used to indicate the exposure one could possibly get by sitting at the dining table while someone is cooking food.

The table below shows an overview of the relative standard deviation between the three repetitions of each airflow, and the maximum and minimum values in µg/m³ for the downdraft system.

Table 19 – An overview of the relative standard deviation and maximum and minimum values between all repetitions of each airflow for the Downdraft system.

	DE_108		**DE_250**		**DE_350**		**DE_500**	
	Grimm1	**Grimm2**	**Grimm1**	**Grimm2**	**Grimm1**	**Grimm2**	**Grimm1**	**Grimm2**
Average %RSD	44,4	44,8	89,4	78,3	68,6	65,4	60,4	75,9
max [µg/m³]	42,7	22,3	9,2	2,7	7,4	2,1	4,1	2,1
min [µg/m³]	0,2	0,0	0,0	0,0	0,1	0,0	0,0	0,0
	DR_108		**DR_250**		**DR_350**		**DR_500**	
	Grimm1	**Grimm2**	**Grimm1**	**Grimm2**	**Grimm1**	**Grimm2**	**Grimm1**	**Grimm2**
Average %RSD	28,2	38,8	35,1	37,5	35,1	39,4	39,3	38,7
max [µg/m³]	53,3	14,2	42,0	18,2	32,8	10,7	18,7	7,2
min [µg/m³]	0,1	0,0	0,1	0,0	1,1	0,2	0,5	0,1

4.4.2 Capture Efficiency

Capture efficiency calculations were done for the downdraft in both extraction and recirculation mode. The figure below presents the average capture efficiency for all repetitions of each airflow.

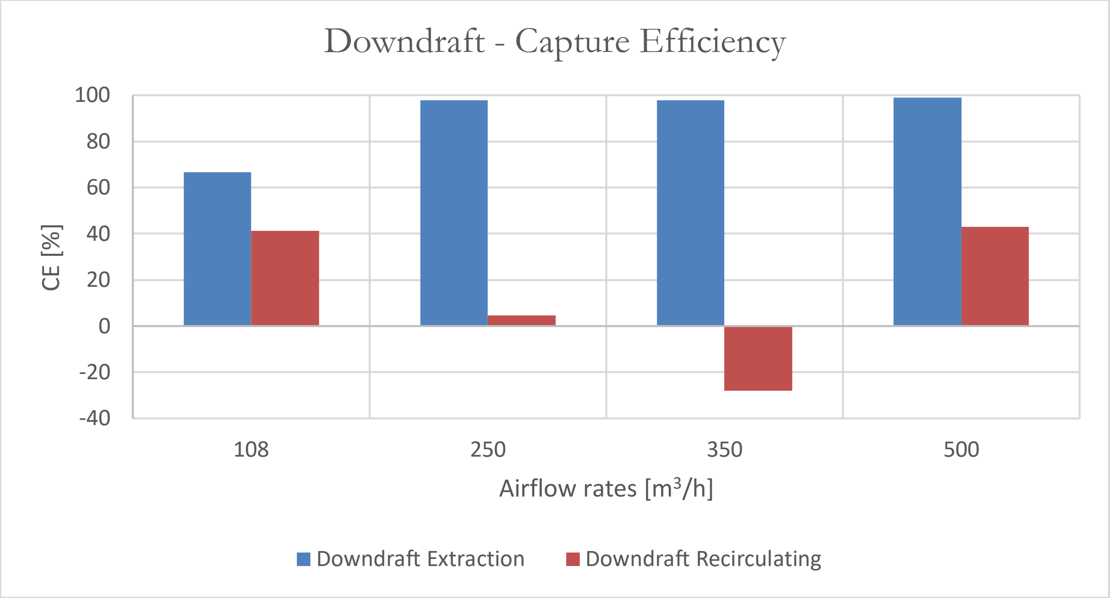


Figure 27 - Capture efficiency for the downdraft with both extraction and recirculation for each airflow.

As seen in the figure, the highest CE at 98,9 % is achieved when using extraction and the highest airflow. However, 250 and 350 m³/h have almost equally high CE. The table below shows an overview of the average CE, the RSD and the maximum and minimum percentages of CE for all repetitions for each airflow.

Table 20 - An overview of the average capture efficiencies and the related relative standard deviations with maximum and minimum values for each airflow for the downdraft system.

Airflow [m³/h]	**Mean [%]**	**RSD [%]**	**Max [%]**	**Min [%]**
Downdraft Extraction				
108	66,5	18,9	84,8	45,2
250	97,7	1,5	99,1	94,9
350	97,9	0,8	99,1	96,6
500	98,9	0,2	99,2	98,4
Downdraft Recirculating				
108	41,3	22,0	53,9	20,2
250	4,7	908,5	52,4	-79,7
350	-28,1	232,4	62,5	-125,6
500	43	66,0	76,50%	-12,6

4.5 Comparing PM2.5 to WHO's recommendations

To compare the results from the experiments to the World Health Organization's recommendations of maximum daily and yearly exposure to PM$_{2.5}$, formula 3.4 was used. The results are given in table 21.

Table 21 – Daily exposure of PM2.5 for worst- and best-case scenario for both Standard and Downdraft.

		Worst case [µg/m^3]		Best case [µg/m^3]	
Standard [m^3/h]		**The cook**	**Dining Table**	**The cook**	**Dining Table**
	0	10,18	9,33	1,18	0,33
Extracting	**108**	9,34	9,09	0,34	0,09
	250	9,29	9,07	0,29	0,07
	350	9,19	9,03	0,19	0,03
Recirculating	**108**	10,24	9,39	1,24	0,39
	250	10,39	9,36	1,39	0,36
	350	9,95	9,28	0,95	0,28
Downdraft [m^3/h]					
	0	9,60	9,19	0,60	0,19
Extracting	**108**	9,37	9,10	0,37	0,10
	250	9,08	9,02	0,08	0,02
	350	9,12	9,02	0,12	0,02
	500	9,04	9,02	0,04	0,02
Recircualting	**108**	9,42	9,15	0,42	0,15
	250	9,57	9,22	0,57	0,22
	350	9,44	9,13	0,44	0,13
	500	9,28	9,08	0,28	0,08

The maximum exposure for worst-case scenario in location 1 is 10,39 µg/m^3 when using standard recirculating hood with an airflow rate at 250 m^3/h. The highest exposure for location 2 is 9,39 µg/m^3 when standard recirculating at 108 m^3/h is being used. For best-case scenario the values are incredibly low with a maximum of 1,39 µg/m^3 in location 1 and 0,39 µg/m^3 in location 2 for the same experiments as the worst-case scenario, respectively.

4.6 Relative Humidity

Figure 28 and 29 shows the relative humidity during a number of experiments with recirculating and extracting mode. The experiments in the figures are chosen randomly but at least one for each airflow. Not every single experiment is shown because they are all very similar, just at different levels because of the defect humidifier. The graphs are shown to give a perspective of how the relative humidity changes throughout the experiment.

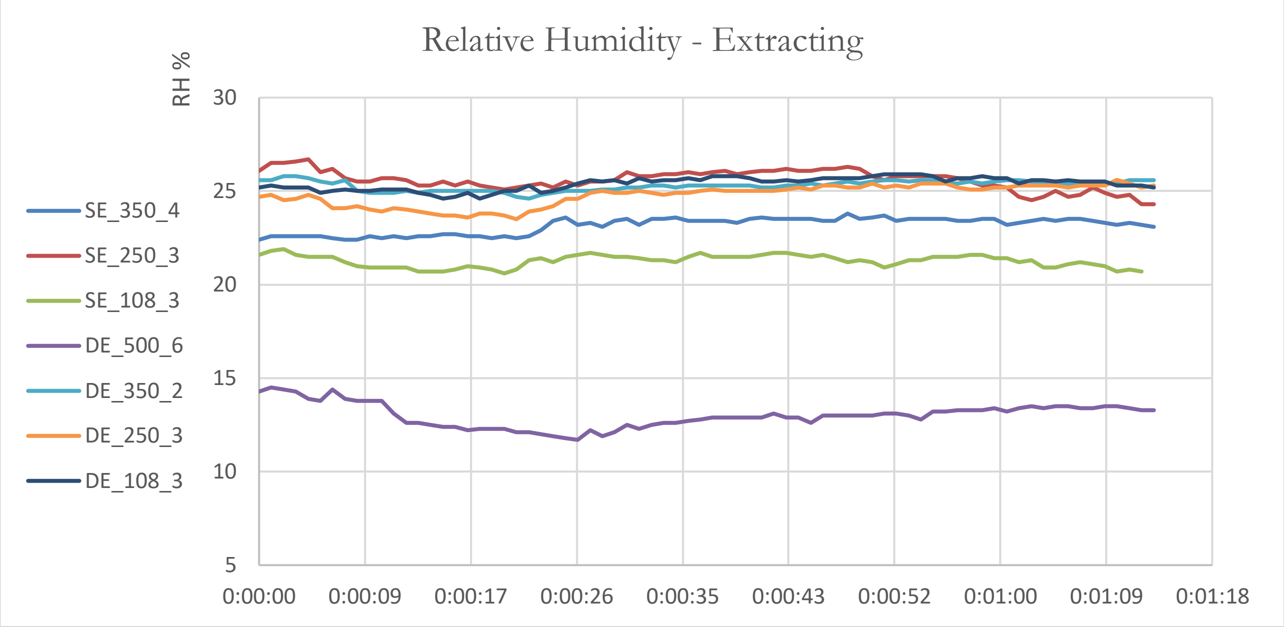


Figure 28 - Relative humidity changes throughout the extracting experiments.

With extracting, the curve is almost flat throughout the experiments, as seen in figure 28. It only fluctuates about ±2%.

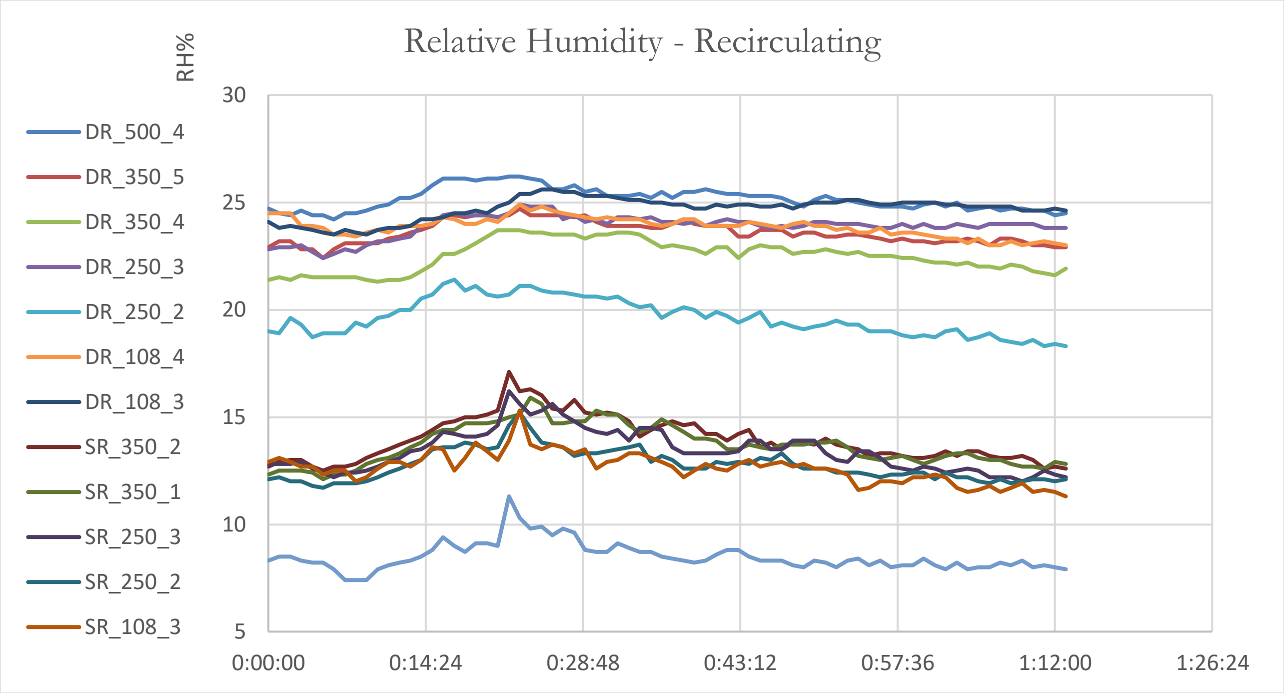


Figure 29 - Relative humidity changes throughout the recirculating experiments.

With recirculation mode one can see a little peak after about 22 minutes, which is right when the cooking is done. The peak is higher for the standard recirculating experiments than for the downdraft recirculating experiments. Although, the peak is only maximum 5% over the start values.

5 Discussion

5.1 Zero-Experiments

The zero-experiment for standard shows higher values of $PM_{2.5}$ than the zero-experiment for downdraft, as seen in the figures in chapter 4.2. This is presumably because of the higher temperatures in the pans on the Siemens cooktop as will be discussed in 5.6.4 Pan temperature. As the graphs indicate, the standard emits a lot more particles than the downdraft, which ideally should emit an equal number of particles. This needs to be taken into consideration when looking at the values of the standard versus the downdraft.

5.2 Extracting vs Recirculating in terms of exposure

5.2.1 Standard hood - exposure

As can be seen from the findings, extracting the air to the outside is significantly superior to recirculating it. Even at the lowest airflows, recirculating shows values that are three to four times higher than extracting. The difference just gets larger with higher airflows.

The graphs clearly show that location 1 where the cook is standing making the food is undoubtedly the most exposed location. This emphasizes the importance of properly functioning range hoods so that the cook does not inhale all the harmful $PM_{2.5}$ particles, putting him or her at risk of getting severe health problems like cardiovascular disease.

One thing worth noticing is that the average zero-test has lower $PM_{2.5}$ values than both 108 and 250 m³/h recirculating experiments, see figure below, which does not make much sense. During the recirculating experiments it was noticed a change in the airflow from the cooking. It seemed like the recirculated air that came back into the room hit the wall and created an under pressure dragging the cooking fumes towards the left. This means that only some of the smoke from cooking actually went through the hood and got cleaned by the filter, which could explain the extremely high values. To ensure this theory, a smoke test was done to see more clearly if the smoke got dragged to the left, which it did. Other ways to mount the recirculating ducts were discussed but since this is an experiment where full control over airflows is needed, this was the only way we could fit both a measuring station and a damper before the carbon filter. This is therefore not like an ideal recirculating range hood which makes the results doubtful. Another reason the recirculating-system have a higher particle concentration than the zero-test may be because the air from the hood that hits the wall goes straight down to the floor and swirls up the particles lying on the floor. This can increase the number of particles the instruments count. That being the case, the results show higher values of $PM_{2.5}$ than what the cooking is actually emitting.

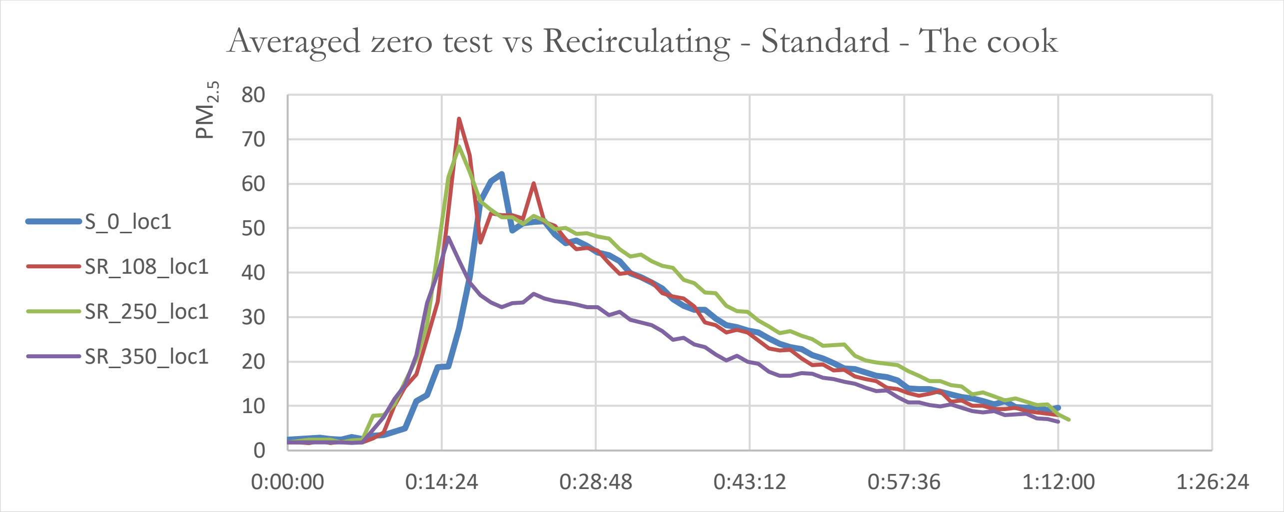


Figure 30 – Averaged zero-test (the bold blue curve) compared to recirculating experiments for the standard hood in location 1.

5.2.2 Downdraft system - exposure

The downdraft experiments on extracting and recirculating resulted in generally lower values for extracting, but on the lowest airflow, 108 m³/h, some of the recirculating experiments were better than extracting. As mentioned before, the higher the velocity of the air through the filter, the less particles get absorbed by the carbon filter. The air velocity at 108 m³/h is low enough for the filter to capture the most and therefore clean the air before it goes back to the room. At 250, 350 and 500 m³/h the air velocity may be too high for the coal to work its full effect. This is not the case for the standard range hood though, which may indicate that the downdraft's carbon filter is better than the standard's. This may be due to larger surface area, or more active carbon inside the pockets. Since the filters are different in size, shape, and weight it is hard to compare them to one another.

Some of the downdraft extracting experiments, especially the higher airflows, end with lower concentration than it started with. This means that the extracting on the downdraft is powerful enough to not only drag out the particles emitted from cooking but also the general particle concentration in the room, which explains the extremely low concentrations at the end.

The way downdraft recirculating was mounted in this lab is almost identical to what could have been in a normal kitchen. It is just placed a little bit further out so that the measurement station and the damper could fit before the filter. One thing that was noticed during the experimental period was that the air from the recirculating hood was not evenly distributed over the carbon filter since the circular duct was attached to the left side of the rectangular filter. This can have a negative effect on the filter's efficiency. The circular duct should be placed in the middle to make the air spread more evenly.

The method applied in this thesis was not ideal for recirculating experiments. The method does not separate the particles emitted from cooking and the particles that are naturally in the room. Thus, it does not give an indication of whether the hood actually works well with recirculation, but it does give an indication of how much one can be exposed to. For future experiments on recirculating hoods, another method should be considered. Furthermore, for safer results, additional repetitions are required. The results from this thesis are only an indication of how much one can be exposed to by cooking this meal.

5.3 Extracting vs Recirculating in terms of capture efficiency

5.3.1 Standard hood - CE

The capture efficiencies for the standard range hood varies a lot between the airflows and especially between extracting and recirculating. As seen in the figure in chapter 4.3.2, the recirculating bars are on the negative side of zero meaning they all have negative capture efficiencies. This is a consequence of only taking the average of the zero-tests and experiments. From table 18 in the same chapter one can see that the maximum values from all of the repetitions for all three airflows are positive, which means that some of the repetitions within each airflow actually have a positive CE. With RSD values between 133,7-259,5%, as seen in the table, one can tell that there is a huge variation between the repetitions of the recirculating experiments. Extracting on the other hand has RSD values less than 40%, which implies that the repetitions are closer to the average. For an airflow rate at 350 m³/h the capture efficiency is 91,2% and the RSD is 4,9%. This signifies that the CE will be around 91,2% no matter what repetition is done.

One thing that was noticed when analyzing the data is that the CE for 108 m³/h with extraction is higher than for 250 m³/h. It was therefore looked more closely into the repetitions of SE_250. Here it was found that one of the repetitions had extremely high values compared to the other two repetitions. A decision was made to try to exclude this repetition and see what happened. As thought, the CE for 250 m³/h went up to 83,3% and the RSD decreased. This corresponds with the fact that CE should ascend when increasing the airflow. However, it was decided to keep the high repetition so that the data would be less manipulated.

As the previous literature mentioned, the best way to increase the capture efficiency is to have a range hood that covers the entire cooktop and has a capture hood. Our siemens hood did neither cover the cooktop nor have a capture jet/hood, which may be because of the slightly low CEs.

5.3.2 Downdraft system - CE

Capture efficiencies for the downdraft system also varies a lot between extracting and recirculating. However, for the experiments on extracting the capture efficiencies are quite similar. As the table in chapter 4.4.2 shows, airflow rates 250, 350 and 500 m^3/h all have CEs above 97% with extremely small RSDs. This could indicate that a flow rate of more than 250 m^3/h is unnecessary, which is surprising considering earlier assumptions that downdraft required high flow rates. However, the lowest airflow tested, 108 m^3/h, only has a CE of 66,5% which signifies that downdraft systems with extraction do not operate optimal on such low airflows.

The recirculating experiments had a large range of capture efficiencies. What comes as a surprise to many is that it does not follow the same ascending curve when you increase the airflow as the extracting experiments does. The lowest and the highest airflow have the largest capture efficiencies at 41,3 and 43%, respectively. This emphasizes what was mentioned earlier about the carbon filter and how the air velocity through the filter has a huge effect on the efficiency. Although, one could think that with an airflow rate of 500 m^3/h the velocity would be too high for anything to be absorbed, but with this high flow rate, the air in the room will go through the filter more than once throughout the experiment period, which means that the filter filters the air several times. The capture efficiencies for airflows of 250 and 350 m^3/h are 4,7% and -28,1%, respectively. The relative standard deviations are also exceedingly high (908 and 232 percent, respectively), making the findings doubtful.

5.4 Relative humidity

The humidifier on the ventilation unit did not work, and because of covid-19 and the time-limit, we could not wait for the manufacturer to come and fix it. Because of this, there was little control over the relative humidity in the lab during and between each experiment, which is why every experiment starts with a different percentage. The relative humidity in the lab was still measured for every experiment to see the change in moisture content in the air during cooking. Initially the thought was to keep the humidity generally around 30% since this is what we usually want inside, but the maximum RH was around 25%. As seen in figure 29, there is a small peak in the recirculating experiments just when the cooking is done before it slowly goes back to “normal”. While in the extracting experiments, the curve is almost completely flat throughout the experiment.

In addition, the primary exhaust will remove some of the humidity. If it wasn’t for this, the moisture content from the food may have had a greater importance when using recirculating hoods. Residences with recirculating hoods without primary exhaust may be more affected by the moisture from cooking than others.

Although there is a difference between the recirculating and the extracting, the peaks in the recirculating experiments are so minimal that it has no effect on the indoor climate and cannot be a cause for mold or other fungus. Hence, recirculating range hoods work well when it comes to moisture with this type of cooking. Boiling for instance could cause more moisture and would possibly make a greater importance.

5.5 Recommendations and TEK17

To get a better understanding of what all these numbers mean, I compared them to the recommendations from World Health Organization. The table in chapter 4.5 show the estimated daily and yearly values of $PM_{2.5}$ exposure from cooking with a best- and worst-case scenario for background PM. As one can see from the table, all values are within the recommendations of the maximum daily exposure of 15 µg/m^3, no matter the background concentration. On the contrary, the values for worst-case scenario all exceed the yearly recommendations of maximum 5 µg/m^3 exposure of $PM_{2.5}$. This gives only an indication of how much we are exposed to when cooking this exact meal. Although, in reality no one would cook the same meal 365 days per year.

What's important to remember when looking at these $PM_{2.5}$ values is that the type of particles is more crucial than the amount. This is not taken into consideration in the thesis but is recommended to look further into.

TEK17 should change its requirements from 108 m^3/h to a minimum capture efficiency to ensure good performance of the hoods. This way, it is easier to make sure that recirculating hoods work as well as extracting hoods, and there is no need to differentiate between the two. When it comes to moisture, the recirculating experiments showed only a little peak that is small enough to neglect.

5.6 Uncertainties

5.6.1 Instruments

Although the instruments have been calibrated, some are a little outdated. The new Grimm 11-D was considered to be the most trustworthy since it had been newly calibrated. The older Grimm (1.108) had not been calibrated since 2015 and it was slowly starting to quit on us during the experiments. There was some trouble starting it before some experiments and sometimes it quit in the middle of an experiment. Since it is outdated and have not been calibrated in a long time, the results from it are not 100% trustworthy and only an indication of how much one can be exposed to. The AeroTraks were neither newly calibrated, but the data seemed to be reasonable. Because of these outdated calibrations there are some uncertainties that must be considered when analyzing the data.

5.6.2 Manipulating the data

When calculating capture efficiency, the background levels for each test were manipulated so that the experiments had the same starting point. For the $PM_{2.5}$ calculations, the background was not manipulated that way, which is why the graphs do not start at the same point. It was decided not to do this manipulation because when extracting the average background value from the tests, some values came out negative. Because negative $PM_{2.5}$ levels are not possible, we would have to adjust them to zero, which would be too much manipulation for my preference. To see the variation in background particle concentration, the RSDs were calculated, see chapter 5.6.3.

At the beginning of the experimental period, the instruments had different time and date. This made it harder to compare the results from each instrument because the time did not match. In addition, the old Grimm didn't sample every 6 seconds as the setting said it would, but rather every 4-10 seconds. Hence, sometimes when taking the average of the three repetitions, some had fewer samples than others, which makes some of the location 2 graphs end before the actual experiment ended.

5.6.3 Relative Standard Deviation

Relative standard deviations were calculated for each experiment to see the grade of uncertainty in the repeatability. The RSD from $PM_{2.5}$ values varied between 17,9-95,9%. This means that some of the experiments have high uncertainties as experiments with greater RSDs are more uncertain than tests with lower RSDs. This is crucial to remember while assessing the results.

To ensure that the temperature conditions for each experiment were about the same, RSD has been calculated for room temperature, supply air temperature and exhaust temperature. The test chamber temperature had a relative standard deviation of 3,43%, the supply air temperature had 4,2% and the primary exhaust temperature had 2,9%. These are all very low values which indicates that the temperature conditions were stable throughout the entire experimental period.

As mentioned in the chapter above, the RSDs for background particle concentration were calculated to see the variation. The RSD for the standard hood with airflow rate of 108 m^3/h was 45,3%, for 250 m^3/h it was 41% and for 350 m^3/h it was 39,1%. This means that there are some variations, but nothing that is extremely out of control. For the downdraft system, an airflow rate of 108 m^3/h had an RSD of 51,6%, 250 m^3/h had 63,1%, 350 m^3/h had 44,3% and 500 m^3/h had 61,5%. These are somewhat larger than for the standard, meaning that there is more variation between the repetitions on the downdraft system.

5.6.4 Pan temperature

Pre-tests of the pan temperature was done to ensure the same temperature for both cooktops. However, when the cooking was done during the experiments, the fish was fried a little bit more on the Siemens cooktop than on the Bora Pure cooktop. The same case was for the wok mix. For that reason, an infrared thermometer was used to measure the temperatures in the pans before adding the fish and before adding the wok mix into the pans. This thermometer showed a 29,5 °C difference in average pan temperature on Siemens vs Bora Pure cooktop. The pre-test on the other hand only had a 5 °C difference after a minute, and 10 °C difference after 9,5 minutes. The minimum and maximum temperatures of the cooktops are also shown in table 22, with Bora Pure having a larger deviation from average than Siemens. This may be because the induction does not always provide a constant power output, but alternates on and off.

With the pre-test it was found which levels on the different cooktops were the most similar ones, but the temperature difference is still large and should be considered when looking at the results.

Table 22 – An overview of pan temperature measured with the infrared thermometer, for both Bora Pure and Siemens cooktops.

		Temp pan before fish [°C]	Temp pan before wok mix [°C]
Bora Pure	**Average**	157,0	95,1
	Max	195,4	138
	Min	123,8	67,2
Siemens	**Average**	186,5	111,2
	Max	198	160
	Min	174	98,8

5.6.5 Other weaknesses

Throughout this semester, a few weaknesses were discovered. Some were taken care of and strengthened, but some could not be fixed and are therefore listed as weaknesses to the experiments. These can cause some uncertainties in the results and have been considered when the data was analyzed.

- The primary supply airflow rate at 36 m^3/h was hard to keep constant. It fluctuated a lot, but the average through the experiments were 36 m^3/h with an RSD of 16,7 %.
- Adjusting the supply air when the range hood was turned on/off to avoid under or over pressure was hard to make identical for every experiment because it was done manually by adjusting the valve on the air handling unit until the pressure was around 0,5±0,2 Pa. This gives some uncertainty in the reproducibility

of the experiments but since the rough adjustment was done at the same time for each experiment and only the fine-tuning took a few minutes it is considered negligible.

- The supply airflow rate measured by the DPT-Ctrl differed by around ±5 m^3/h from the flow rate measured by the Swema3000. This was small enough to ignore.
- The cooktops have induction, which cannot produce a constant Watt. The temperature was therefore hard to keep identical for each experiment.
- The intake of supply air is placed in an unfortunate location outside. It is placed on the wall at a low altitude close to the road. This can cause poorer quality of supply air during rush hour, which can explain the different background concentrations each day.
- Although the fish is bought from the same brand and weights the same, it can contain different amounts of fat, water and salt. These factors can affect the particle concentration emitted from the fish when cooking.
- Covid-19 has caused some issues along the way. Due to corona sickness in the lab, a couple of instruments were missing in the beginning, which delayed some of the experiments. Power-measurements were unfortunately not done in time.
- Since the experiments are done by people there is a human error that causes uncertainties. Even though the experiments followed a strict procedure, it was completed by two people who cannot, no matter how strict the procedure is, do the exact same movements.

6 Conclusions

In this thesis, several experiments were conducted for two types of range hoods, a standard wall-mounted hood and a downdraft system, to assess whether recirculating hoods would perform as good as, or better than, extracting hoods. Experiments were done with airflow rates of 108, 250 and 350 m^3/h on both hoods, and an additional 500 m^3/h were tested on the downdraft, while cooking a typical Norwegian meal: fish and wok mix. Optical particle counters were used to measure particles at different locations to assess the exposure during cooking and to calculate the capture efficiency of the range hoods. The results only apply to these specific range hoods and this exact meal.

The results indicate that both range hoods with extracting the air outside perform better than recirculating solutions in terms of exposure and capture efficiency.

- Recirculation showed $PM_{2.5}$ values that are 3-19 times higher than extracting at the same airflow rates.
- The highest average $PM_{2.5}$ concentration was found to be 10,39 $\mu g/m^3$ at location 1 when using the standard hood with recirculating, which was well below the WHOS's recommendation of daily maximum value of 15 $\mu g/m^3$.
- Recirculation worked better on the downdraft system than on the standard hood. This can be because of different surface area on the filters, or different amount of activated carbon in the filters.
- The carbon filter on the downdraft system worked better on the lowest airflow, 108 m^3/h, presumably because of the low velocity through the filter. This way the activated carbon had more time to absorb more particles.
- The 500 m^3/h recirculation tests on the downdraft system were equally as good as the 108 m^3/h tests, which can be strange to many since the velocity through the filter is extremely high. However, at 500 m^3/h the air will go through the filter several times during the experiment and thereby be "cleaned" more than once.
- The calculated capture efficiencies (CE) for range hoods in extracting mode were up to 98%, while in recirculating mode, the CEs were lower than 43% and some even resulted in negative values. This gives an indication of how much worse recirculating hoods are than extracting hoods.
    - From the results one can see that there is a difference between the standard hood and the downdraft, where the downdraft system shows much higher CEs on extracting. This difference can be due to higher pan temperature on the standard cooktop which presumably results in more emitted particles. These are therefore not directly comparable to each other.
- Moisture content was also a concerning problem when recirculating the air. From the relative humidity measurements, it was discovered a slightly increase in RH during cooking in the recirculating experiments. This increase of 5% was small enough to not impact the indoor air quality and thus not cause any problems.
- Taking all of this into account, the results indicate a need for an additional requirement of minimum capture efficiency as an indicator for the range hoods' performance, in addition to the requirements of extract airflow rate by TEK17. More research on carbon filters is recommended before recirculation becomes common in regular homes.

7 Further Works

Several experiments and adaptions are left for the future to investigate due to lack of time and instruments.

- It would be interesting to look more into the carbon filters over time to see how long they will last before the efficiency decreases and the change of filters is needed. This was not possible to do in this thesis because of the time limit and number of experiments that were done. One should also test different types of carbon filters for the same hood to see which factors has the largest impact on the efficiency.
- Another aspect of these recirculating experiments that would be interesting to look at is odor. Will the carbon filter extract enough odor? This is an important factor since people usually do not want their entire apartment to smell like fish several hours after they are done cooking.
- There is also a need to develop a better method for recirculating range hoods since the airflows from the recirculated air disturbs the flow in the room so that particles laying on the floor gets swirled up.

When it comes to adaptions there are some that needs to be reconsidered in future experiments.

- For the experiments conducted in this thesis, an overpressure of 0,5±0,2 Pa was used to make sure that the lab did not attract particles from the hall. This is not ideal to compare to the real world. For future experiments, one should reconsider this and maybe keep the ventilation balanced so that the pressure is equal to zero.
- Relative humidity is another feature that should be fully controlled for future experiments.
- More importantly, all instruments should be calibrated. If they are too old to be calibrated, one should consider getting new instruments.

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Appendices

Appendix A – Literature research

A.1 Literature research method

To find relevant literature with good quality it is essential to implement a good research method. There are several main search methods like scoping, systematic, snowball method and citation searching. In this study the citation searching was applied to find relevant research in this field. Citation searching uses a key article and looks at the referenced articles as well as newer articles that have cited the key article to find relevant literature. A few articles were handed out by SINTEF in the beginning of the semester. These became the key articles. In addition, a second search had to be done to find more literature about recirculating hoods, but the search only ended up with two relevant articles which reinforces the importance of this study. In table 2 there is an overview of the most relevant literature.

A.2 Collecting the data

In order to collect literature with good quality it was necessary to filter out less important articles or articles that did not match this study's subject. The found literature was put in an excel sheet and then categorized in different colors, see table 1. Green-colored articles were the most relevant, yellow-colored articles were slightly relevant but not that important, and lastly orange-colored articles were not relevant for this study. The green articles were then read and the most relevant were put in a review matrix, see table 2, for further investigation as seen in chapter 2.3.

Table 1: Color categorized articles

Color Categorized Articles - Title
Investigating measurements of fine particle ($PM_{2.5}$) emissions from the cooking of meals and mitigating exposure using a cooker hood
Long-term evaluation of a low-cost air sensor network for monitoring indoor and outdoor air quality at the community scale
Capture efficiency of cooking-related fine and ultrafine particles by residential exhaust hoods
Comparing extracting and recirculating residential kitchen range hoods for the use in high energy efficient housing
Measurement of Ultrafine Particles and Other Air Pollutants Emitted by Cooking Activities
Characteristics of cooking-generated PM 10 and $PM_{2.5}$ in residential buildings with different cooking and ventilation types
Modelling uncertainty in the relative risk of exposure to the SARS-CoV-2 virus by airborne aerosol transmission in well mixed indoor air
$PM_{2.5}$ in Dutch Dwellings due to Cooking
Indoor thermal environment and air quality in Chinese-style residential kitchens
Effect of indoor and outdoor sources on indoor particle concentrations in South Korean residential buildings
Efficiency of recirculation hoods with regard to $PM_{2.5}$ and NO_2
Size segregated PM and its chemical composition emitted from heated corn oil.
A review of data requirements and model performance
The influence of range hood mounting height on capture efficiency
A method to esti-mate the chronic health impact of air pollutants in U.S. Residences
Health effects of particulate air pollution: a review of epidemiological evidence.
A pre and post evaluation of indoor air quality, ventilation, and thermal comfort in retrofitted co-operative social housing
Performance of Installed Cooking Exhaust Devices
Effect of Occupant Activity on Indoor Particle Concentrations in Korean Residential Buildings

Indoor aerosols: from personal exposure to risk assessment
Contribution from indoor sources to particle number and mass concentrations in residential houses
Personal, indoor, and outdoor exposures to $PM_{2.5}$ and its components for groups of cardiovascular patients in Amsterdam and Helsinki
Exhaust rate for range hood at cooking temperature near the smoke point of edible oil in residential kitchen
The risk of lung cancer among cooking adults: a meta-analysis of 23 observational studies
Emissions and indoor concentrations of particulate matter and its specific chemical components from cooking: a review
Assessing the Effect of Reactive Oxygen Species and Volatile Organic Compound Profiles Coming from Certain Types of Chinese Cooking on the Toxicity of Human Bronchial Epithelial Cells
Quantifying trace elements in the emitted particulate matter during cooking and health risk assessment
Risk factors for primary lung cancer among non-smoking women in Taiwan
Review of factors impacting emission/concentration of cooking generated particulate matter.
Indoor air quality: residential cooking exposures
Particle dose estimation from frying in residential settings
What's wrong with the National Ambient Air Quality Standard (NAAQS) for Fine Particulate Matter ($PM_{2.5}$)?
Particle emission factors during cooking activities
Bewertung von Küchen-Dunstabzugssystemen in energieeffizienten Gebäuden
$PM_{2.5}$ and ultrafine particles emitted during heating of commercial cooking oils
A new computer model for the simulation of particulate matter formation from heated cooking oils using Aspen Plus

Table 2: Literature review matrix

Matrix of most relevant literature
O'Leary, C., Kluizenaar, Y., Jacobs, P., Borsboom, W., Hall, I., Jones, B., (2019), Investigating measurements of fine particle (PM2.5) emissions from the cooking of meals and mitigating exposure using a cooker hood. Indoor Air. https://doi.org/10.1111/ina.12542
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Appendix B – Instruments information

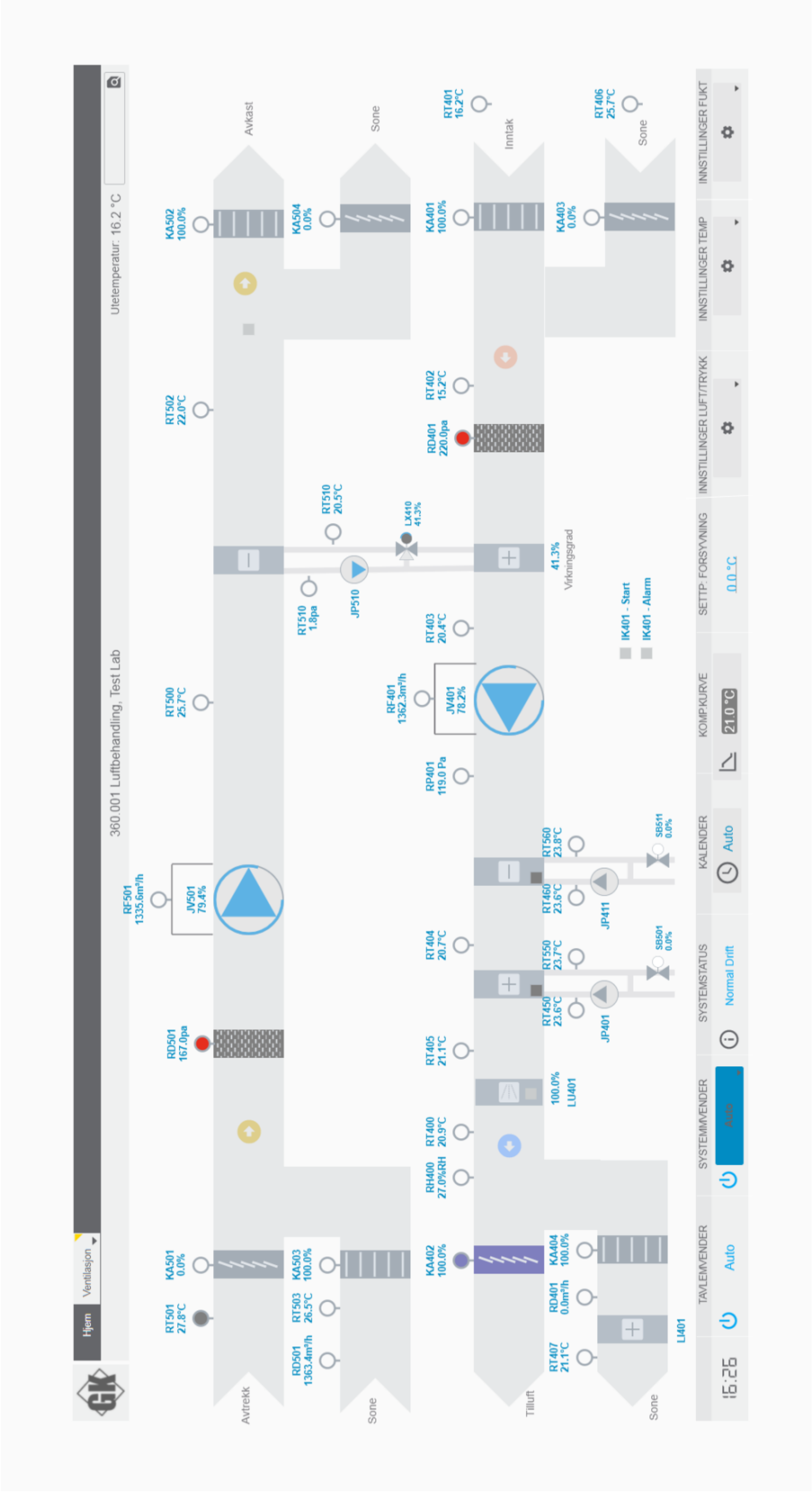
Table 3: Detailed information about each instrument used during experiments.

Instrument	Parameters	Size range	Accuracy	Operating conditions	Measurement principle
AeroTrak: Handheld airborne particle counter Model 9303	Measures particles/litre in three bins: 0.3, 2.5, 5	Particle size: 0.3-25 um	Counting efficiency: 50% at 0.3 um and 100% at >0.45 um	5-35 °C, 20-95% non-condensing RH	Not publicly available
Grimm: Portable dust monitor 1.108	PM1, PM2.5, PM10 measuring in particles/litre in 15 bins	Particle size: 0.3-20 um	Reproducability: +/- 3%	0-40 °C, <95% non-condensing RH	The sample air is led directly into the measuring cell via the aerosol inlet or other custom-designed air inlets. The particles in the sample air are being detected by light scattering inside the measuring cell. The scattering light pulse of every single particle is being counted and the intensity of its scattering light signal classified to a certain particle size
Grimm: Portable Aerosol Spectrometer, model 11-D	TSP, PM10, PM4, PM2.5, PM1, PMcoarse measuring in particles/litre or um/m3 in 31 bins	Particle size: 0.253-35.15 um	Reproducability: more than 95% at 500 nm	4-40 °C, <95% non-condensing RH	A laser diode is focused onto the measuring cell and directed into a light trap at the end of the measuing field. When a particle passes through the laser beam, it is illuminated. This reults in scattered light that is directed to a receiver diode. Each electrical signal is counted and classified into 31 size channels.
Rotronic CP11	Relative humidity CO2 Temperature	0.1-99.95% 0-9999ppm -20-60 °C	* ±3.0%(10~95%@25 °C), ±5% (other). *+(30ppm+5% of reading)@0~5000ppm *+0.3 C@5~40 C	0-50 °C for CO2, -20-60 °C for rest/ non condensing	Non dispersive infrared (NDIR) with automatic baseline correction (ABC) is used to measure different paramters

Thermocouples type K and T	Temperature, °C	Type K: -270 to 1260 °C Type T: -270 to 370 °C	Type K: Standard +/- 2.2 °C or +/- 0.75% Type T: Standard +/- 1.0°C or +/- 0.75% (whichever is greater)	Operating temperature is the same as the size range	Two wired legs are welded together at on end, creating a joint junction able to measure the temperature.
Air handling controller **DPT-CTRL**-2500-D	Air flow rate (m3/h)	0-2500 Pa	Pressure <125 Pa = 1% +/- 2Pa. Pressure > 125 Pa = 1 % +/- 1 Pa	Temp: -20-50 °C 0-95% RH non-condensing	Multifunctional PID controller with differential pressure or air flow transmitter for building automation systems
804 4 Channel Handheld Particle Counter **MetOne**	Particles/litre in 7 differe	0.3-10 um	± 10%, to calibration aerosol	0° to +50°C	A 4-channel portable particle counter that counts particles 0.3 microns to 10.0 microns. Completely self-contained with its own internal battery and sample pump
Swema 3000	Temperature, humidity, differential pressure, air velocity and flow	-	Measurement uncertainty at 23°C ±5°C: Barometer: ±2,5 hPa Temperature: ±0,3°C at -10...70°C With sensor: ±2,5°C	Barometer: 600-1200 hPa Temperature: -270-1372 °C	An ideal professional tool for ventilation testing, adjusting and balancing (TAB) and includes telescopic anemometers, air density compensation and measuring programs according to EN 16211 and 12599.

Appendix C – GK-Cloud

Figure 1: A screenshot of GK-Cloud, the program used to control the ventilation unit.



Appendix D – Airflows and temperature

D.1 – Supply air

Table 4: An overview of the supply air flows and the temperature for the supply air.

	Supply Air Temp [°C]			Supply Air flow [m^3/h]		
Experiment	**Average**	**Max**	**Min**	**Average**	**Max**	**Min**
Downdraft Extracting						
DE_108_1	23,1821183	24,2	22,5	134,153161	237,37	74,445
DE_108_2	23,5701893	24,6	22,7	159,741525	258,79	115,01
DE_108_3	24,0301815	25,1	23,2	146,554911	262,255	76,685
DE_250_2	23,0276039	23,8	22,5	82,8390359	387,73	-7,99687
DE_250_3	23,8133077	24,7	23,2	195,91498	421,75	99,295
DE_250_4	24,0250138	24,8	23,5	197,176117	397,845	122,01
DE_350_1	22,9239174	23,8	22,3	200,202036	518,35	72,905
DE_350_2	23,0671685	23,9	22,5	202,358974	513,765	76,895
DE_350_3	23,7082538	24,5	23	218,107802	535,185	118,79
DE_500_4	23,7901277	24,4	22,9	251,165956	645,19	118,44
DE_500_5	24,2063567	25	23,6	265,750184	679,805	122,01
DE_500_6	23,4350432	24,4	22,6	262,455157	681,485	119
Downdraft Recirculating						
DR_108_1	20,5690127	20,7	20,4	146,465285	169,8	130,3
DR_108_3	22,0737086	22,3	21,9	119,391082	139,265	76,685
DR_108_4	22,3621735	22,6	22	129,483285	139,055	118,055
DR_250_3	22,797292	23,8	21,9	145,945073	397,635	73,325
DR_250_4	22,4203856	22,7	22	119,749189	137,165	85,75
DR_350_3	21,9578639	22,2	21,7	116,311437	144,06	44,065
DR_350_4	22,092189	22,4	21,8	121,464666	141,75	84,35
DR_350_5	22,5137827	23,2	22	136,687714	234,5	76,895
DR_500_2	20,5580159	20,8	20,2	77,2479509	81,325	71,475
DR_500_4	22,2185878	22,5	22	127,621332	147,07	103,11
Standard Extracting						
SE_108_2	23,7738957	24,2	22,5	134,153161	237,37	74,445
SE_108_3	23,395712	24,6	22,7	159,741525	258,79	115,01
SE_108_4	22,7983533	25,1	23,2	146,557666	262,255	76,685
SE_250_2	23,720569	23,8	22,5	82,8042836	387,73	-7,99687
SE_250_3	23,6290364	24,7	23,2	195,919974	421,75	99,295
SE_250_4	22,7972893	24,8	23,5	197,172467	397,845	122,01
SE_350_3	23,8326861	23,8	22,3	200,201321	518,35	72,905
SE_350_4	23,8554155	23,9	22,5	202,358974	513,765	76,895
Standard Recirculating						
SR_108_1	22,2116472	22,5	22	133,321887	147,07	97,58
SR_108_2	21,9963884	22,2	21,8	120,543933	154,735	77,455
SR_108_3	21,5031574	21,7	21,4	120,33384	208,25	84,56

SR_250_1	21,7997474	22,1	21,4	126,679555	147,07	109,62
SR_250_2	22,035567	22,3	21,8	123,95171	210	86,1
SR_350_1	22,0459028	22,2	21,9	121,17253	147,315	96,04
SR_350_2	21,9317947	22,1	21,8	118,28138	139,265	76,125
SR_350_3	21,5675531	21,8	21,4	124,721042	147,28	76,895

D.2 - Exhaust

Table 5: An overview of the primary exhaust air flows and the temperatures for the primary exhaust.

Experiment	**Primary Exhaust Temp [°C]**			**Primary Exhaust flowrate [m^3/h]**		
	Average	**Max**	**Min**	**Average**	**Max**	**Min**
Downdraft Extracting						
DE_108_1	23,0989224	23,5	22,7	30,9046644	47,39	9,24
DE_108_2	23,4309775	24	22,8	40,8414982	48,545	27,02
DE_108_3	23,8469495	24,2	23,5	41,2481973	55,02	26,845
DE_250_2	22,9653667	23,1	22,8	37,7129578	51,625	27,825
DE_250_3	23,663013	23,9	23,4	44,7831528	57,54	32,235
DE_250_4	23,81878	24	23,5	43,7840209	56,385	31,99
DE_350_1	22,7004974	22,9	22,4	33,7616506	55,44	14
DE_350_2	22,8554216	22,8554216	22,8554216	23,0671685	23,0671685	23,0671685
DE_350_3	23,4480827	23,8	23,1	41,4747937	53,095	28,77
DE_500_4	23,5106114	23,8	23,1	41,519109	61,355	26,845
DE_500_5	23,9115298	24,2	23,6	43,6039165	74,76	30,66
DE_500_6	23,1220354	23,4	22,8	41,3625891	75,565	27,02
Downdraft Recirculating						
DR_108_1	21,2959216	21,6	21	-	-	-
DR_108_3	23,0023694	23,5	22,5	37,1986274	49,14	17,815
DR_108_4	23,0131586	23,2	22,8	30,7497838	36,085	26,285
DR_250_3	21,326608	21,7	21	24,5798113	36,435	-0,91
DR_250_4	23,1867412	23,5	22,9	33,2201736	43,155	25,865
DR_350_3	22,8379803	23,3	22,4	26,4694418	46,795	-0,945
DR_350_4	22,4728357	22,7	22	33,3396338	50,26	18,41
DR_350_5	23,169966	23,8	22,6	33,4264839	49,14	3,29
DR_500_2	20,8568383	21,2	20,4	-	-	-
DR_500_4	22,5143144	22,8	22	34,503867	44,485	18,62
Standard Extracting						
SE_108_2	23,0989224	23,5	22,7	30,9046644	47,39	9,24
SE_108_3	23,4309775	24	22,8	40,8414982	48,545	27,02
SE_108_4	23,846956	24,2	23,5	41,2482836	55,02	26,845
SE_250_2	22,9653179	23,1	22,8	37,709263	51,625	27,825
SE_250_3	23,6630104	23,9	23,4	44,7830776	57,54	32,235
SE_250_4	23,81878	24	23,5	43,7840209	56,385	31,99
SE_350_3	22,7004953	22,9	22,4	33,7618323	55,44	14
SE_350_4	22,8554216	22,8554216	22,8554216	23,0671685	23,0671685	23,0671685

Standard Recirculating						
SR_108_1	23,1857107	23,6	22,8	36,2688652	45,08	25,9
SR_108_2	23,2840694	23,8	22,7	35,3018129	47,18	15,12
SR_108_3	22,7236459	23,2	22,3	39,4584262	47,565	28,21
SR_250_1	22,9207069	23,2	22,4	32,1921794	43,925	19,74
SR_250_2	23,0975572	23,6	22,6	30,7218575	39,69	18,795
SR_350_1	22,6064097	22,8	22,4	32,4944302	40,075	26,67
SR_350_2	22,9555352	23,4	22,5	36,514797	47,775	9,8
SR_350_3	22,3925029	22,7	22	36,162306	48,545	10,955

Appendix E – Noise Levels

E.1 – Downdraft Recirculating

Table 6 – Detailed table of the measured noise levels for Downdraft Recirculating.

Downdraft Recirculating										
	Neutral		**Level 1**		**Level 2**		**Level 3**		**Level 4**	
Frequency	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$
50	30,9	0,6	32,9	2,6	32	1,7	33,8	3,5	34,4	4,1
63	32	5,8	33,6	7,4	33,5	7,3	34,6	8,4	36,2	10
80	41,1	18,7	41,2	18,8	41,2	18,8	42,6	20,2	42,3	19,9
100	34,5	15,4	33,4	14,3	33,4	14,3	36,3	17,2	37,3	18,2
125	38,1	21,9	39,8	23,6	38,6	22,4	46,4	30,2	48,2	32
160	34	20,8	34,9	21,7	37,1	23,9	39	25,8	41,2	28
200	40,5	29,7	40,8	30	41,7	30,9	43,4	32,6	44,9	34,1
250	43,5	34,8	43,7	35	43,8	35,1	45,9	37,2	45,8	37,1
315	43,6	37	43,9	37,3	44,4	37,8	46,2	39,6	46,5	39,9
400	35,6	30,8	36,9	32,1	38,3	33,5	40,9	36,1	43,6	38,8
500	35,6	32,4	36,1	32,9	38,1	34,9	40,2	37	42,1	38,9
630	42,9	41	42,9	41	43,5	41,6	45,4	43,5	46,6	44,7
800	35,4	34,6	35,9	35,1	37,4	36,6	40,3	39,5	43,8	43
1000	26,2	26,2	27,8	27,8	31,4	31,4	35,8	35,8	39,8	39,8
1250	21,6	22,2	23,5	24,1	28	28,6	33,2	33,8	37,4	38
1600	19,6	20,6	21,3	22,3	25,4	26,4	30,9	31,9	35,8	36,8
2000	15,5	16,7	18,5	19,7	23,8	25	29,3	30,5	34,1	35,3
2500	19,2	20,5	19,2	20,5	21,1	22,4	25,1	26,4	29,5	30,8
3150	16	17,2	15,8	17	17,5	18,7	21,8	23	26,4	27,6
4000	6,8	7,8	7,5	8,5	11,8	12,8	18,7	19,7	24,6	25,6
5000	6,6	7,2	6,9	7,5	9,7	10,3	16,3	16,9	22,6	23,2
6300	8,4	8,3	8,3	8,2	9	8,9	12,6	12,5	18,3	18,2
8000	6,4	5,3	6,4	5,3	6,7	5,6	8,9	7,8	14	12,9
10000	6,8	4,3	6,9	4,4	6,9	4,4	7,5	5	10	7,5
L_A		**44,6**		**44,9**		**45,9**		**48,3**		**50,5**

Downdraft Recirculating											
Level 5		**Level 6**		**Level 7**		**Level 8**		**Level 9**		**BOOST**	
$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$
35,6	5,3	36,4	6,1	37,2	6,9	38,9	8,6	40,3	10	42,1	11,8
36,6	10,4	38,4	12,2	42,1	15,9	41,1	14,9	42,7	16,5	45,8	19,6
43,9	21,5	43,4	21	45	22,6	47,2	24,8	50,9	28,5	48,4	26
38	18,9	40,4	21,3	47,2	28,1	45,7	26,6	46,4	27,3	53,1	34
41,7	25,5	44,8	28,6	46,2	30	47,2	31	48,8	32,6	54	37,8

43,4	30,2	46,6	33,4	48,7	35,5	50,5	37,3	52,1	38,9	54,1	40,9
46,5	35,7	49	38,2	50,8	40	52,3	41,5	54,2	43,4	56,5	45,7
48,2	39,5	50,3	41,6	51,6	42,9	53	44,3	54,7	46	58	49,3
48,2	41,6	50,2	43,6	52,3	45,7	53,4	46,8	54,3	47,7	57,2	50,6
46,1	41,3	49,1	44,3	50,5	45,7	52,4	47,6	54,5	49,7	57,1	52,3
44,9	41,7	48	44,8	49,8	46,6	51,6	48,4	52,6	49,4	55,9	52,7
47,9	46	50,6	48,7	52,4	50,5	53,9	52	54,9	53	56,8	54,9
47,7	46,9	51,6	50,8	51,9	51,1	53,7	52,9	55,3	54,5	58	57,2
43,8	43,8	50,2	50,2	52,5	52,5	53,5	53,5	54,3	54,3	56,9	56,9
40,9	41,5	45,6	46,2	48,5	49,1	51	51,6	53,6	54,2	58,2	58,8
39,3	40,3	43,8	44,8	46,4	47,4	48,8	49,8	50,7	51,7	54,6	55,6
38,2	39,4	42,9	44,1	45,5	46,7	47,9	49,1	49,7	50,9	53,1	54,3
33,8	35,1	38,9	40,2	41,6	42,9	44,2	45,5	46,2	47,5	50,4	51,7
30,7	31,9	36	37,2	39	40,2	41,7	42,9	43,9	45,1	47,5	48,7
29,3	30,3	34,9	35,9	38	39	40,9	41,9	43	44	47	48
27,9	28,5	33,9	34,5	37	37,6	40	40,6	42,2	42,8	46,4	47
23,9	23,8	30,6	30,5	34,2	34,1	37,4	37,3	39,8	39,7	44,2	44,1
19,7	18,6	26,9	25,8	30,9	29,8	34,5	33,4	37,3	36,2	42,2	41,1
14,5	12	21,7	19,2	26	23,5	30,2	27,7	33,3	30,8	39,3	36,8
	53,2		**57,2**		**59,1**		**60,8**		**62,4**		**65,7**

E.2 – Downdraft Extracting

Table 7 – Detailed table of the measured noise levels for Downdraft Extracting.

Downdraft Extracting										
	Neutral		**Level 1**		**Level 2**		**Level 3**		**Level 4**	
Frequency	**$L_{p,t}$**	**$L_{p,t,A}$**	**$L_{p,t}$**	**$L_{p,t,A}$**	**$L_{p,t}$**	**$L_{p,t,A}$**	**$L_{p,t}$**	**$L_{p,t,A}$**	**$L_{p,t}$**	**$L_{p,t,A}$**
50	30,9	0,6	31,7	1,4	32,1	1,8	32,6	2,3	33,7	3,4
63	31,8	5,6	33,3	7,1	34,7	8,5	36,2	10	37,9	11,7
80	41,5	19,1	42,1	19,7	42,1	19,7	42,8	20,4	43,3	20,9
100	35,2	16,1	35,8	16,7	34	14,9	35,8	16,7	36,6	17,5
125	38,2	22	41,4	25,2	39,8	23,6	46,7	30,5	48,2	32
160	33,8	20,6	35	21,8	36,6	23,4	39,1	25,9	41	27,8
200	40,7	29,9	41,2	30,4	42,2	31,4	42,5	31,7	44	33,2
250	43,5	34,8	45,6	36,9	44,7	36	45	36,3	46	37,3
315	43,7	37,1	44,8	38,2	44,5	37,9	45,6	39	46,7	40,1
400	35,7	30,9	36,6	31,8	37,2	32,4	38,8	34	41,7	36,9
500	36,4	33,2	36,4	33,2	37	33,8	38,4	35,2	39,1	35,9
630	44,1	42,2	44,3	42,4	44,3	42,4	45,6	43,7	47,3	45,4
800	36,1	35,3	36,5	35,7	37,3	36,5	39,3	38,5	42,3	41,5
1000	26,3	26,3	27,9	27,9	31,5	31,5	35,7	35,7	39,9	39,9
1250	21,5	22,1	23,4	24	27,8	28,4	32,7	33,3	36,9	37,5
1600	19,1	20,1	21,2	22,2	25,9	26,9	31,5	32,5	35,9	36,9

2000	15,7	16,9	18,9	20,1	24,7	25,9	30	31,2	34,7	35,9
2500	19,2	20,5	19,3	20,6	21,3	22,6	25,1	26,4	29,4	30,7
3150	15,1	16,3	15,1	16,3	17,1	18,3	21,7	22,9	26,3	27,5
4000	6,7	7,7	7,6	8,6	12,5	13,5	19,4	20,4	25,3	26,3
5000	6,9	7,5	7,2	7,8	10,5	11,1	17,2	17,8	23,5	24,1
6300	8,2	8,1	8,3	8,2	9,3	9,2	13,4	13,3	19,3	19,2
8000	6,4	5,3	6,4	5,3	6,8	5,7	9,6	8,5	15,1	14
10000	6,6	4,1	6,6	4,1	6,7	4,2	7,5	5	10,6	8,1
L_A		**45,3**		**45,9**		**46,2**		**47,9**		**50,2**

Downdraft Extracting											
Level 5		**Level 6**		**Level 7**		**Level 8**		**Level 9**		**BOOST**	
$L_{p,t}$	**$L_{p,t,A}$**	**$L_{p,t}$**	**$L_{p,t,A}$**	**$L_{p,t}$**	**$L_{p,t,A}$**	**$L_{p,t}$**	**$L_{p,t,A}$**	**$L_{p,t}$**	**$L_{p,t,A}$**	**$L_{p,t}$**	**$L_{p,t,A}$**
38,4	8,1	36,3	6	38,1	7,8	39,5	9,2	41,2	10,9	42,9	12,6
39,9	13,7	48,2	22	45,6	19,4	46,4	20,2	48,6	22,4	51,8	25,6
45,1	22,7	46,3	23,9	47,2	24,8	52,2	29,8	58,8	36,4	52,6	30,2
39,2	20,1	43,5	24,4	44,5	25,4	45	25,9	46,4	27,3	53,4	34,3
43,5	27,3	46,7	30,5	47,6	31,4	49,1	32,9	50,6	34,4	54,9	38,7
43,7	30,5	46,7	33,5	48,9	35,7	50,8	37,6	53,5	40,3	54	40,8
45,6	34,8	48,2	37,4	49,9	39,1	51,2	40,4	52,9	42,1	55,3	44,5
47,1	38,4	48,6	39,9	49,8	41,1	51,6	42,9	52,9	44,2	55	46,3
47,6	41	50,2	43,6	51,2	44,6	52,7	46,1	54,2	47,6	56,6	50
42,6	37,8	44,6	39,8	44,7	39,9	47	42,2	51,1	46,3	51,6	46,8
41	37,8	43	39,8	44	40,8	45,3	42,1	46,3	43,1	49,7	46,5
47,3	45,4	49,2	47,3	50,8	48,9	51,5	49,6	52,5	50,6	53,9	52
45,5	44,7	49,2	48,4	49,5	48,7	50,8	50	52,6	51,8	55,2	54,4
43,3	43,3	48,9	48,9	50,3	50,3	51,5	51,5	53,1	53,1	55,4	55,4
40,3	40,9	44,8	45,4	47,2	47,8	49,4	50	52,1	52,7	54,9	55,5
39,5	40,5	43,6	44,6	45,9	46,9	47,9	48,9	50	51	53,2	54,2
38,6	39,8	43,2	44,4	45,6	46,8	47,5	48,7	49,5	50,7	52,7	53,9
33,8	35,1	38,7	40	41,3	42,6	43,4	44,7	45,5	46,8	48,8	50,1
30,7	31,9	36,1	37,3	39	40,2	41,3	42,5	43,5	44,7	46,9	48,1
30,1	31,1	35,6	36,6	38,6	39,6	41	42	43,4	44,4	47	48
28,7	29,3	34,6	35,2	37,7	38,3	40,3	40,9	42,8	43,4	46,7	47,3
24,9	24,8	31,5	31,4	34,9	34,8	37,7	37,6	40,4	40,3	44,6	44,5
20,8	19,7	27,9	26,8	31,8	30,7	35,1	34	38,1	37	42,8	41,7
15,7	13,2	23	20,5	27,2	24,7	30,9	28,4	34,5	32	40,1	37,6
	52,1		**55,8**		**57,3**		**58,9**		**60,9**		**63,5**

E.3 – Standard Recirculating

Table 8 – Detailed table of the measured noise levels for Standard Recirculating.

Standard Recirculating						
	Level 1		Level 2		Level 3	
Frequency	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$
50	41,2	10,9	47,5	17,2	48,5	18,2
63	40,9	14,7	48,6	22,4	53	26,8
80	36,9	14,5	44	21,6	47,6	25,2
100	38,3	19,2	46,8	27,7	50,8	31,7
125	45,1	28,9	58	41,8	62,1	45,9
160	39,8	26,6	50,4	37,2	55,6	42,4
200	43,1	32,3	53,1	42,3	58,9	48,1
250	45,8	37,1	51,7	43	56,5	47,8
315	44,2	37,6	50,2	43,6	54,8	48,2
400	40	35,2	45,8	41	49,7	44,9
500	39,9	36,7	47	43,8	50,8	47,6
630	47,7	45,8	50,8	48,9	53,6	51,7
800	40,3	39,5	46,9	46,1	50,8	50
1000	37,3	37,3	45,8	45,8	49,6	49,6
1250	34,2	34,8	44,4	45	48,3	48,9
1600	31,6	32,6	43,7	44,7	48,3	49,3
2000	28,8	30	41,5	42,7	46,9	48,1
2500	27	28,3	39,9	41,2	45,5	46,8
3150	23	24,2	36,4	37,6	42,1	43,3
4000	18,7	19,7	33,7	34,7	39,6	40,6
5000	15,2	15,8	29,3	29,9	36,2	36,8
6300	12,4	12,3	25,6	25,5	32,5	32,4
8000	8,2	7,1	22	20,9	29,2	28,1
10000	14,2	11,7	19,1	16,6	25,6	23,1
L_A		**49,1**		**55,8**		**60**

E.4 – Standard Extracting

Table 9 – Detailed table of the measured noise levels for Standard Extracting.

Standard Extracting								
	Level 1		**Level 2**		**Level 3**		**BOOST**	
Frequency	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$	$L_{p,t}$	$L_{p,t,A}$
50	38,6	8,3	52,1	21,8	55,9	25,6	58	27,7
63	34,3	8,1	46,5	20,3	50,9	24,7	54,2	28
80	38,3	15,9	47,4	25	50,9	28,5	54,9	32,5
100	40,1	21	55,8	36,7	60	40,9	62,9	43,8
125	38,2	22	54,8	38,6	59,7	43,5	62,8	46,6
160	38,1	24,9	52,7	39,5	57,4	44,2	60,8	47,6
200	40,2	29,4	53,3	42,5	59,5	48,7	62,2	51,4
250	41,9	33,2	54,1	45,4	57,4	48,7	62	53,3
315	41,1	34,5	52,3	45,7	55,3	48,7	58,2	51,6
400	37,5	32,7	45,6	40,8	49	44,2	51,9	47,1
500	37,9	34,7	47,1	43,9	50,6	47,4	53,4	50,2
630	46,7	44,8	51,1	49,2	54,2	52,3	55,4	53,5
800	37,8	37	46,7	45,9	50,4	49,6	52,6	51,8
1000	33,1	33,1	46,3	46,3	50,2	50,2	52,7	52,7
1250	29,3	29,9	44,7	45,3	49,1	49,7	52	52,6
1600	27,3	28,3	45,6	46,6	50	51	52,3	53,3
2000	24,3	25,5	43,7	44,9	48,8	50	51,5	52,7
2500	23,6	24,9	42,8	44,1	48,4	49,7	51,1	52,4
3150	20,2	21,4	40,2	41,4	46,2	47,4	49,2	50,4
4000	14,7	15,7	38,3	39,3	44,4	45,4	47,8	48,8
5000	11,5	12,1	34,7	35,3	41,2	41,8	44,4	45
6300	10,6	10,5	30,9	30,8	37,5	37,4	41,1	41
8000	7,3	6,2	28	26,9	35	33,9	38,6	37,5
10000	16,6	14,1	23,8	21,3	31,1	28,6	35	32,5
L_A		**47,1**		**56,8**		**61**		**63,7**

Appendix F – $PM_{2.5}$ graphs for each repetition conducted

The following graphs shows the $PM_{2.5}$ values for all the three repetitions conducted within each airflow for both location 1, the cook, and location 2, the dining table. F.1 and F.2 show standard extracting and standard recirculating, respectively. F.3 and F.4 show downdraft extracting and downdraft recirculating, respectively.

F.1 – Standard Extracting

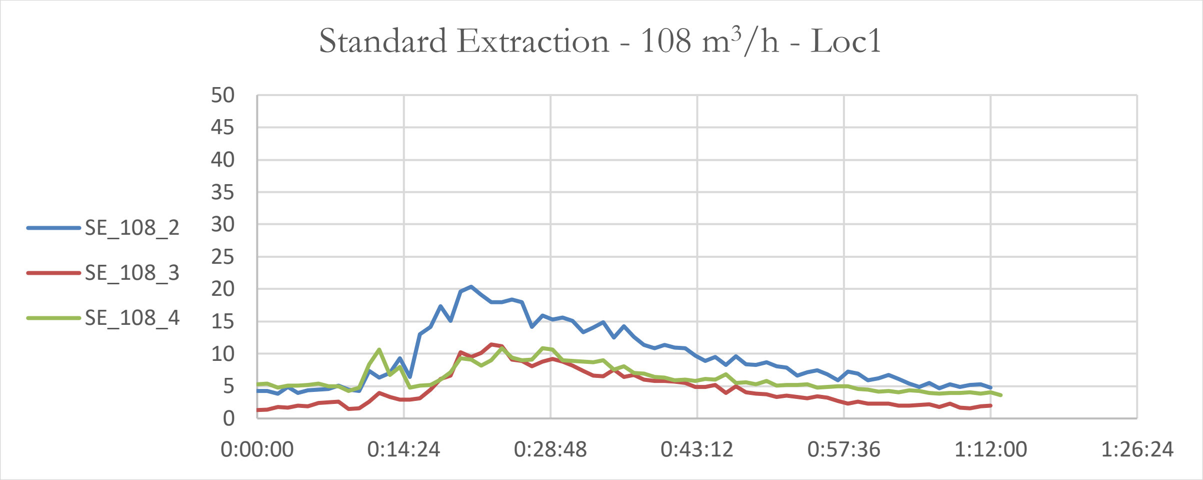


Figure 2 – All repetitions of airflow rate 108 m³/h for location 1 on the Standard Extracting.

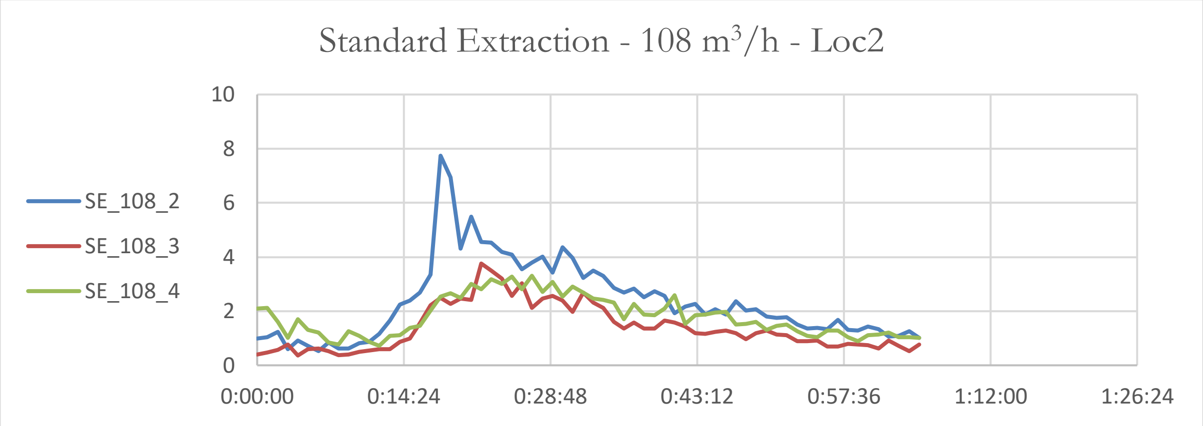


Figure 3 – All repetitions of airflow rate 108 m³/h for location 2 on the Standard Extracting.

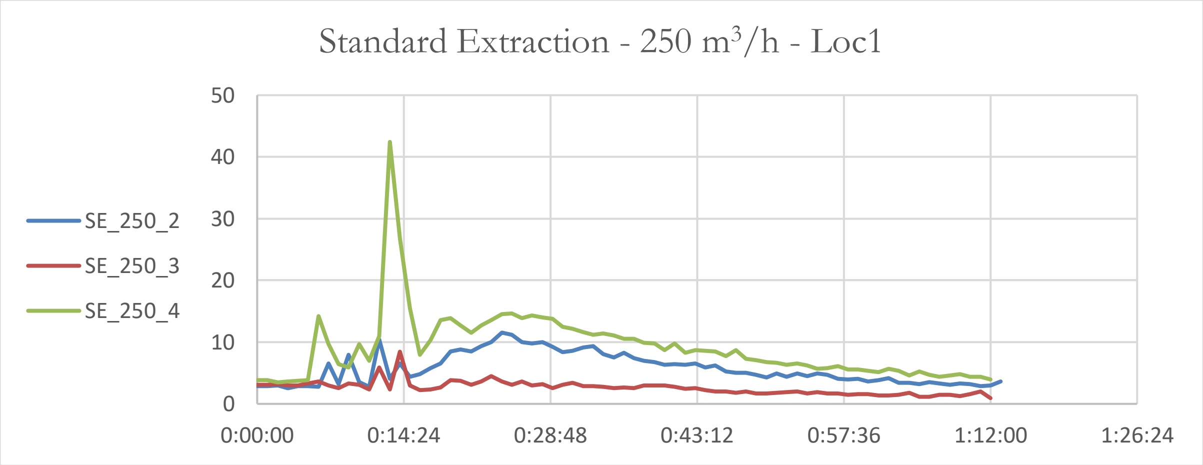


Figure 4 – All repetitions of airflow rate 250 m³/h for location 1 on the Standard Extracting.

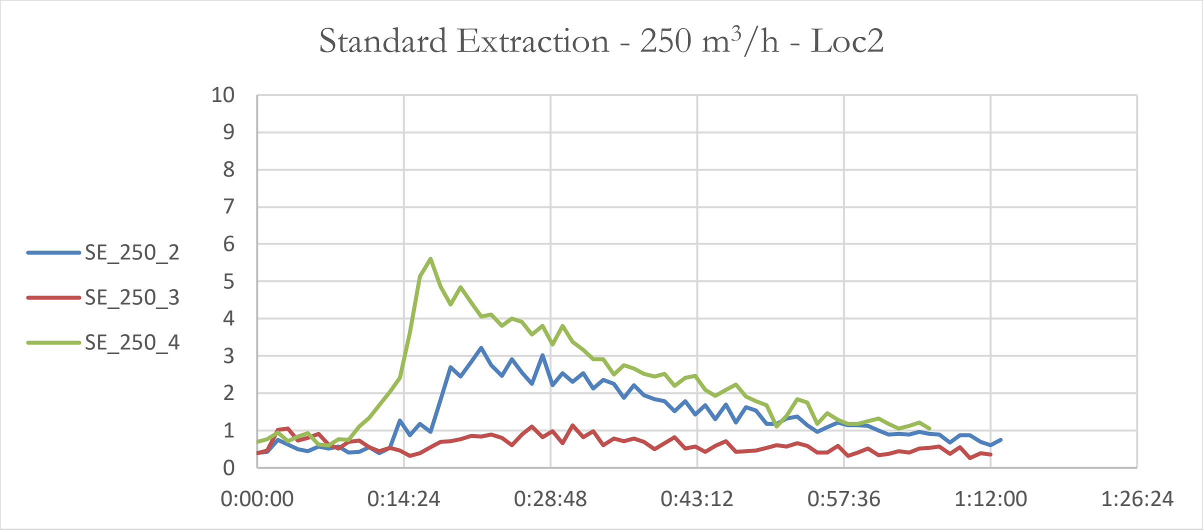


Figure 5 – All repetitions of airflow rate 250 m^3/h for location 2 on the Standard Extracting.

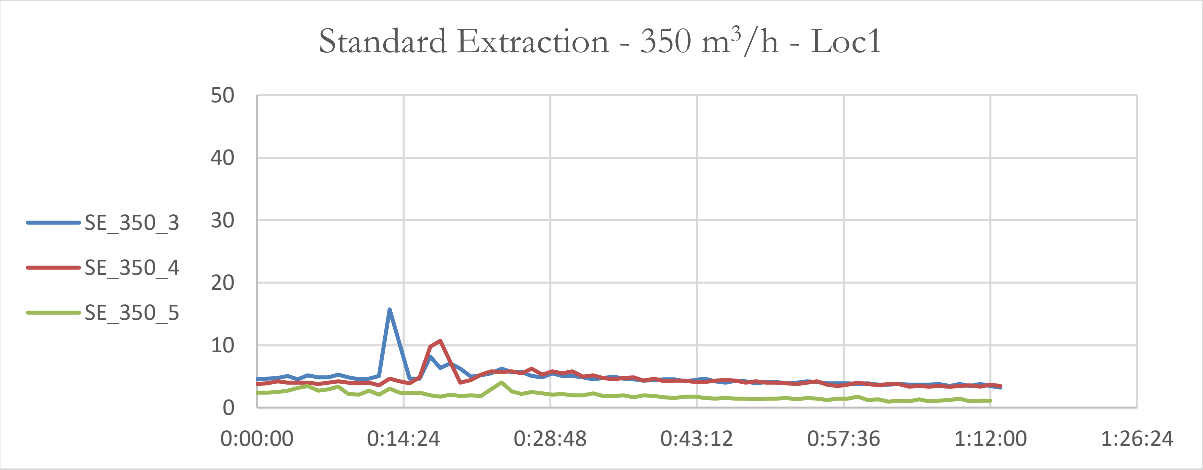


Figure 6 – All repetitions of airflow rate 350 m^3/h for location 1 on the Standard Extracting.

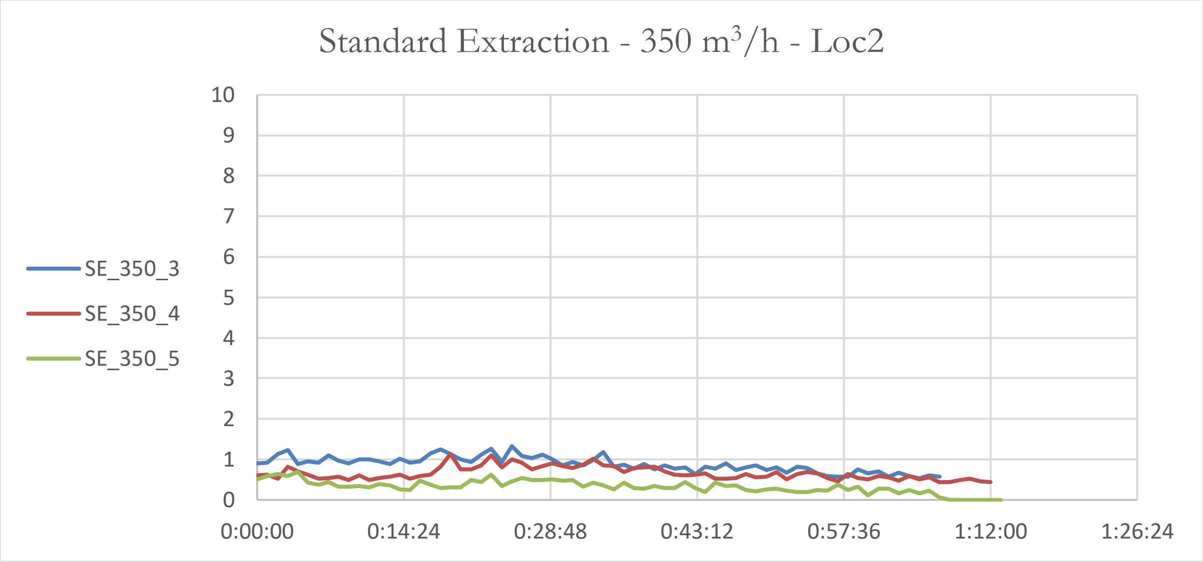


Figure 7 – All repetitions of airflow rate 350 m^3/h for location 2 on the Standard Extracting.

F.2 – Standard Recirculating

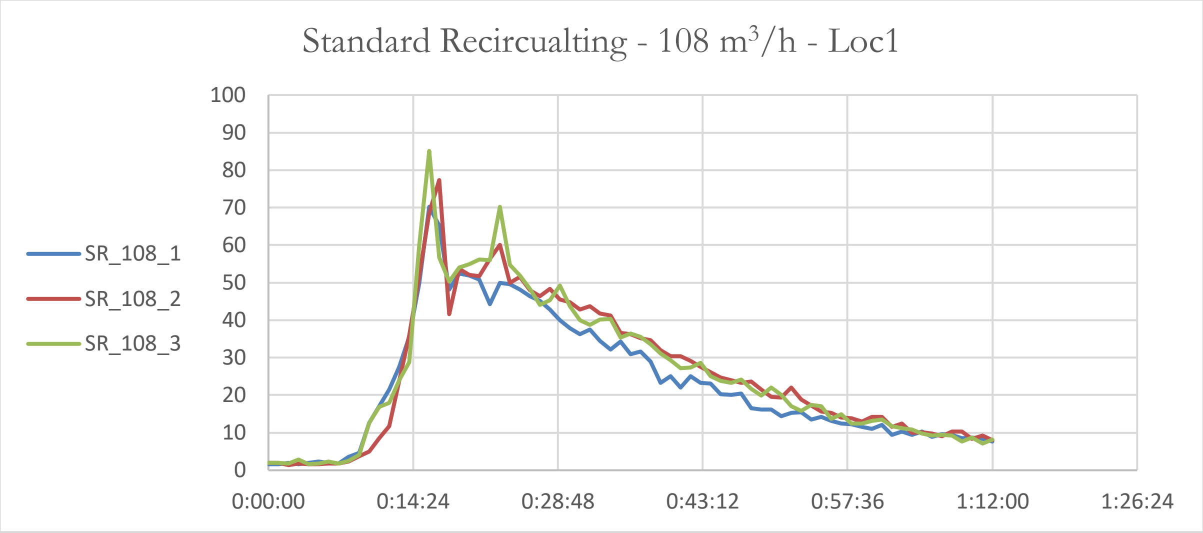


Figure 8 – All repetitions of airflow rate 108 m³/h for location 1 on the Standard Recirculating.

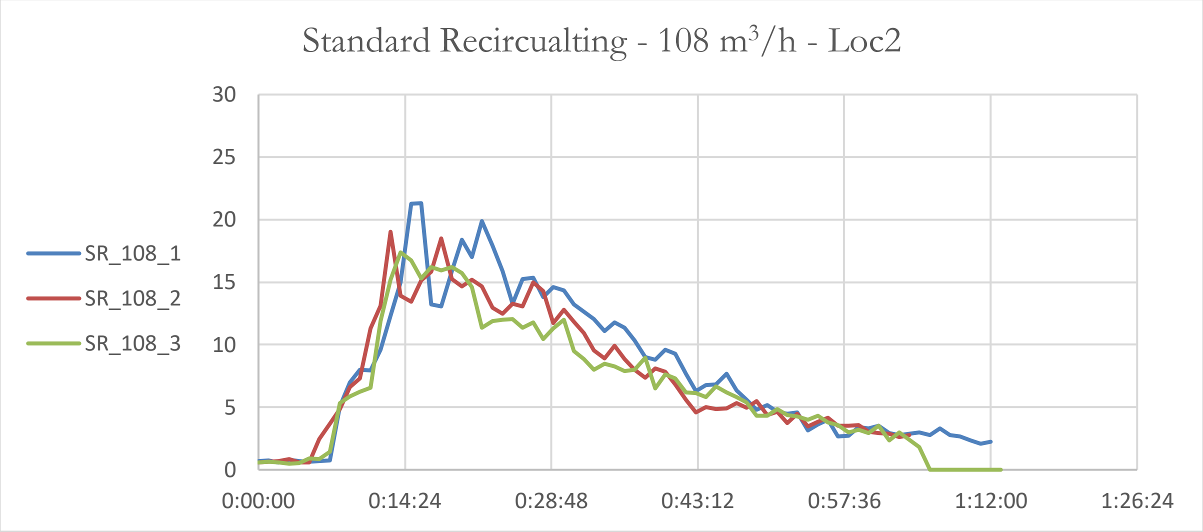


Figure 9 – All repetitions of airflow rate 108 m³/h for location 2 on the Standard Recirculating.

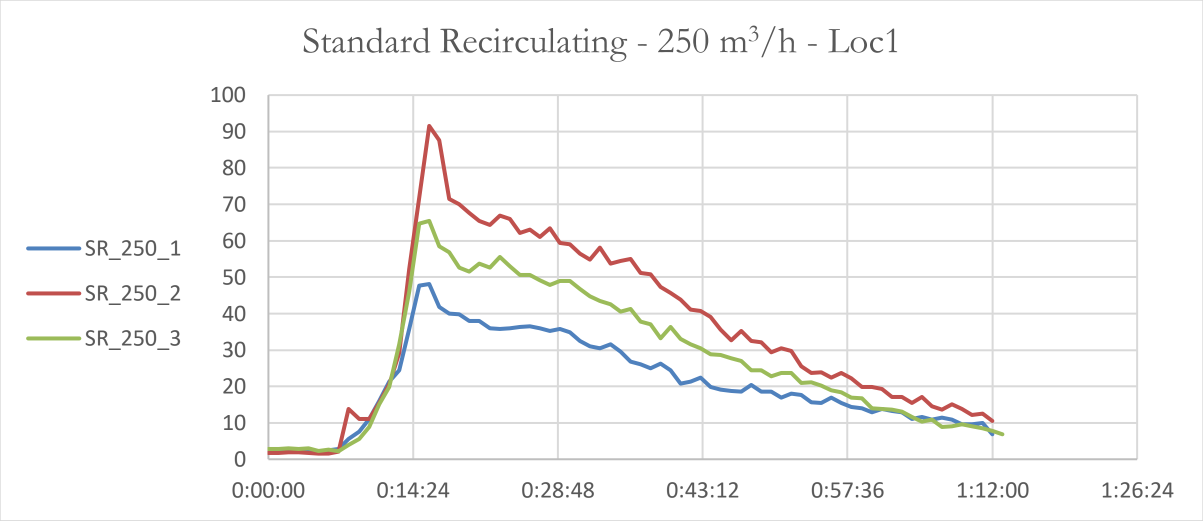


Figure 10 – All repetitions of airflow rate 250 m³/h for location 1 on the Standard Recirculating.

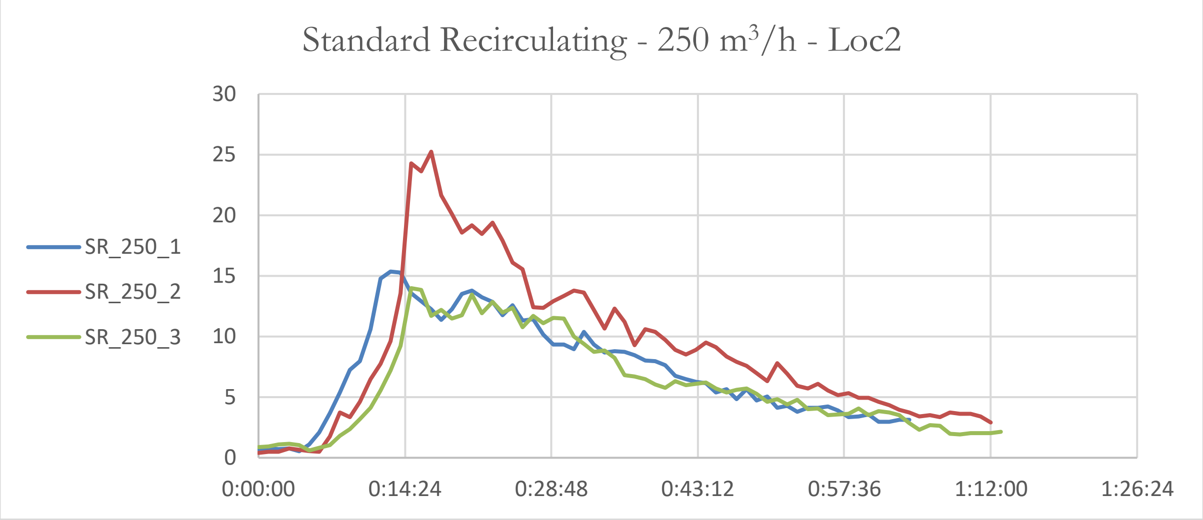


Figure 11 – All repetitions of airflow rate 250 m³/h for location 2 on the Standard Recirculating.

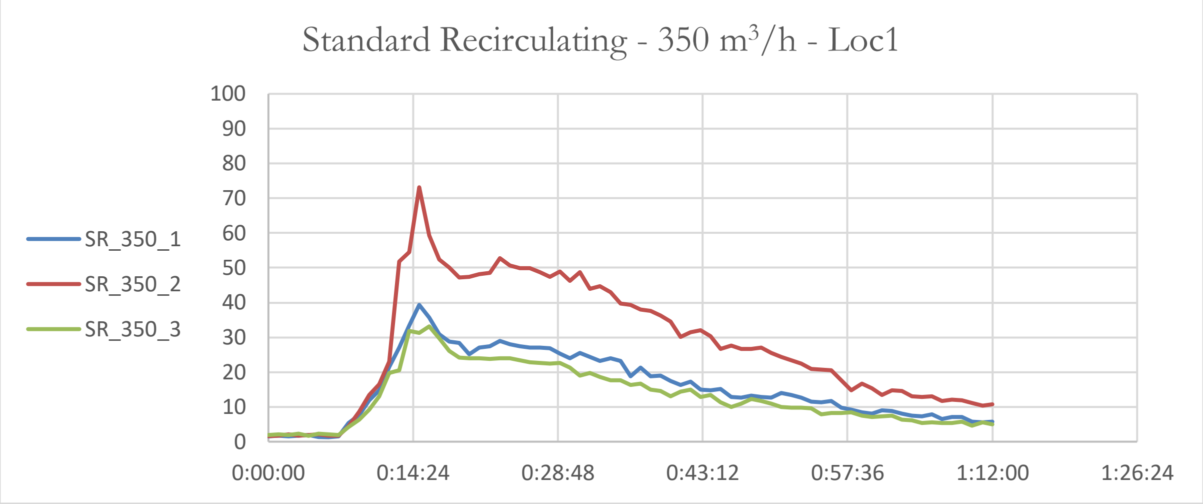


Figure 12 – All repetitions of airflow rate 350 m³/h for location 1 on the Standard Recirculating.

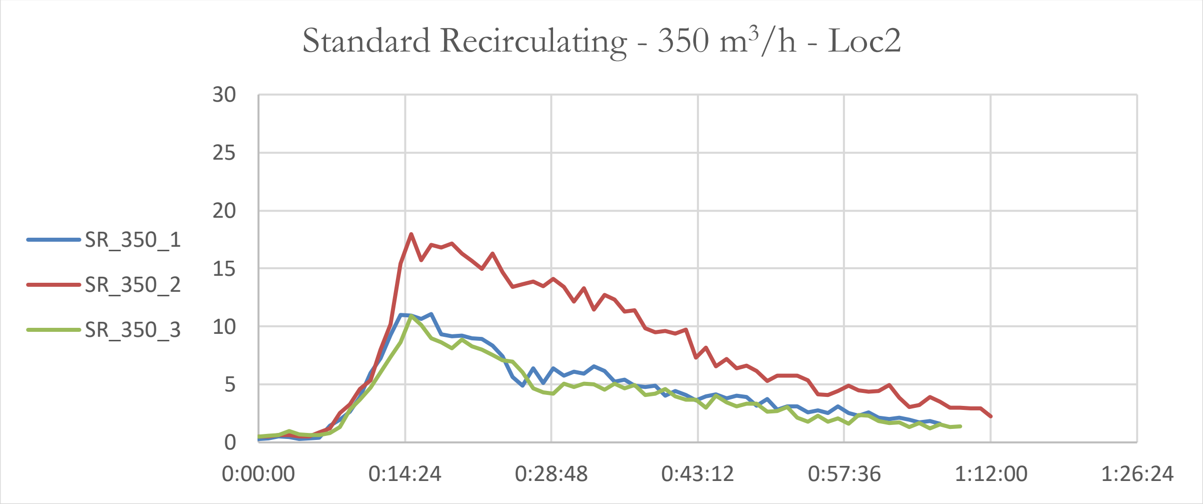


Figure 13 – All repetitions of airflow rate 350 m³/h for location 2 on the Standard Recirculating.

F.3 – Downdraft Extracting

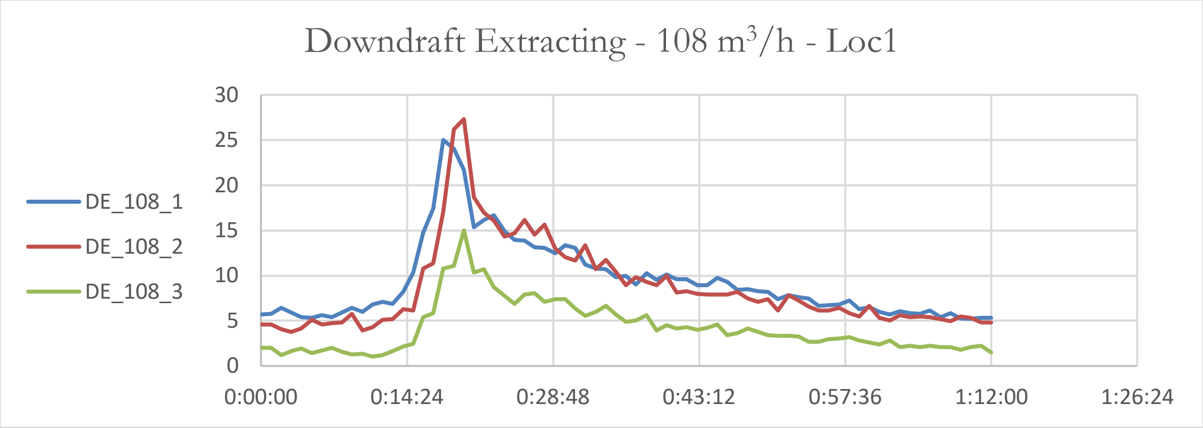


Figure 14 – All repetitions of airflow rate 108 m^3/h for location 1 on the Downdraft Extracting.

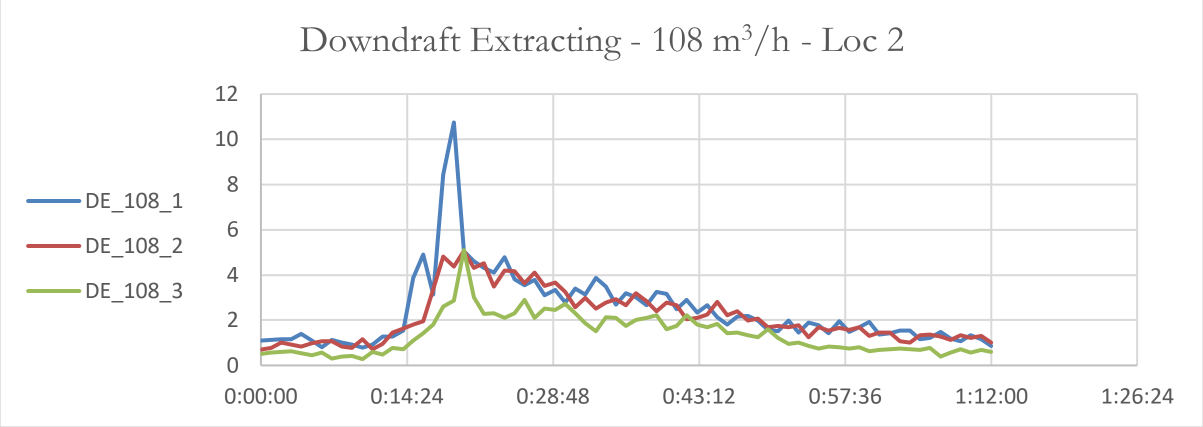


Figure 15 – All repetitions of airflow rate 108 m^3/h for location 2 on the Downdraft Extracting.

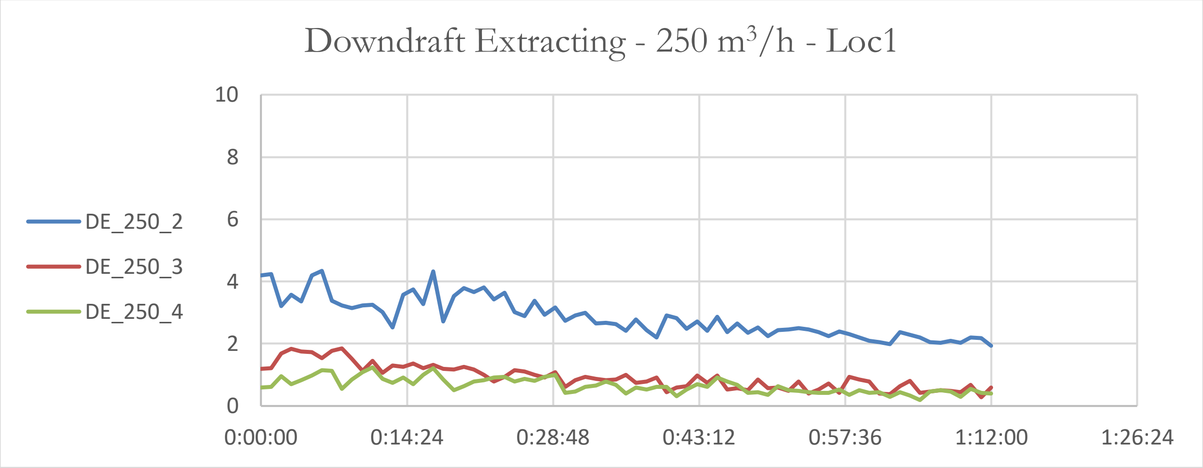


Figure 16 – All repetitions of airflow rate 250 m^3/h for location 1 on the Downdraft Extracting.

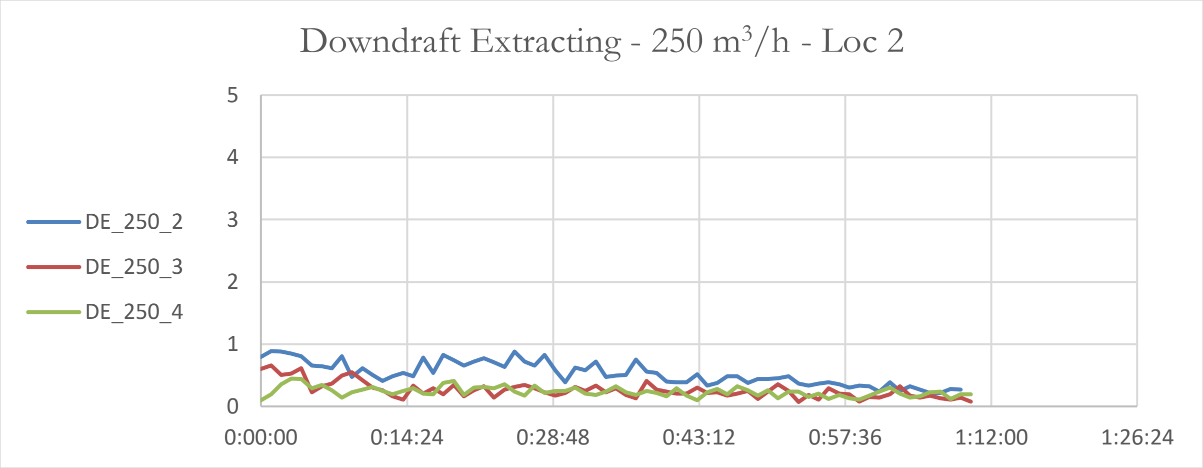


Figure 17 – All repetitions of airflow rate 250 m³/h for location 2 on the Downdraft Extracting.

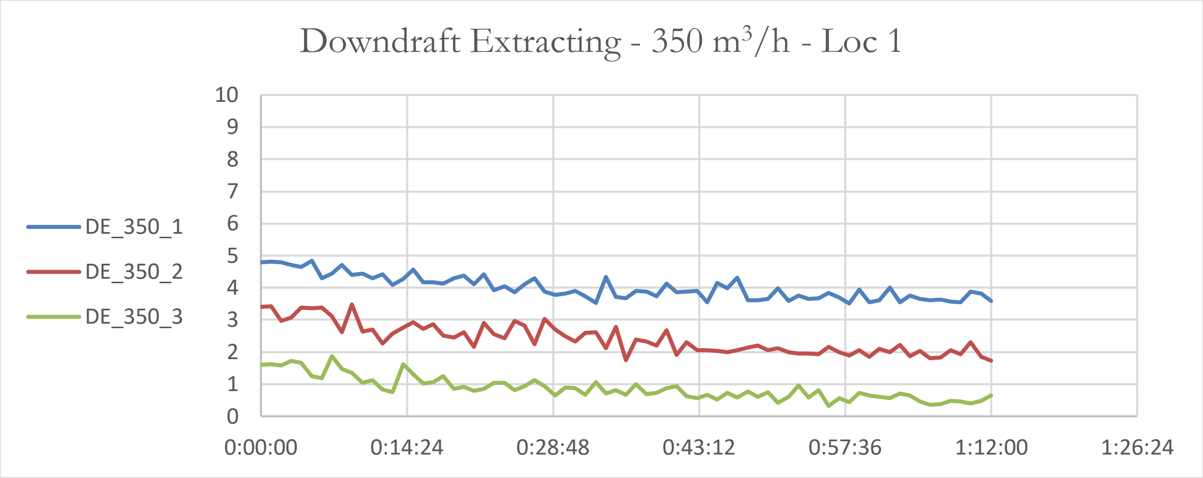


Figure 18 – All repetitions of airflow rate 350 m³/h for location 1 on the Downdraft Extracting.

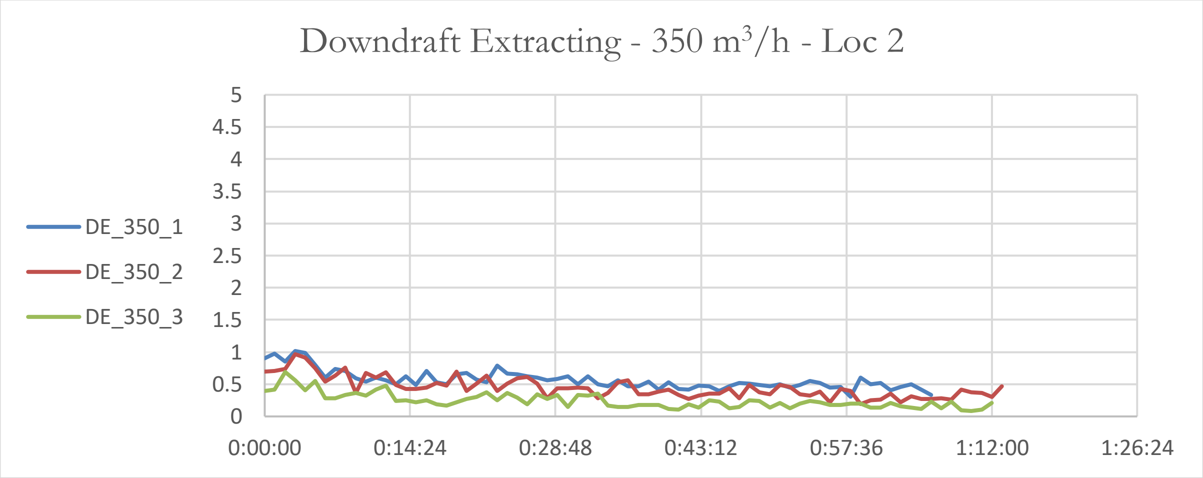


Figure 19 – All repetitions of airflow rate 350 m³/h for location 2 on the Downdraft Extracting.

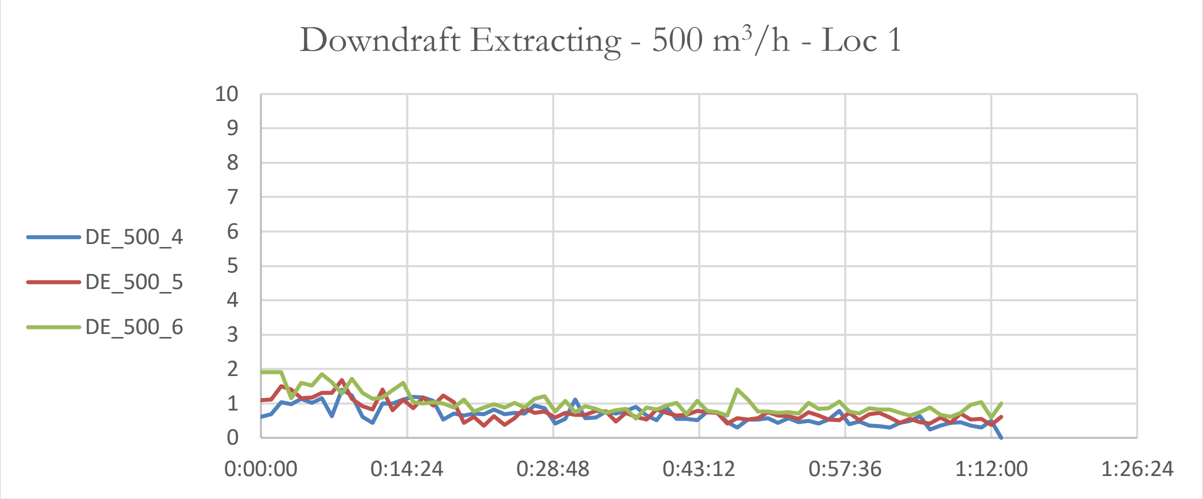


Figure 20 – All repetitions of airflow rate 500 m³/h for location 1 on the Downdraft Extracting.

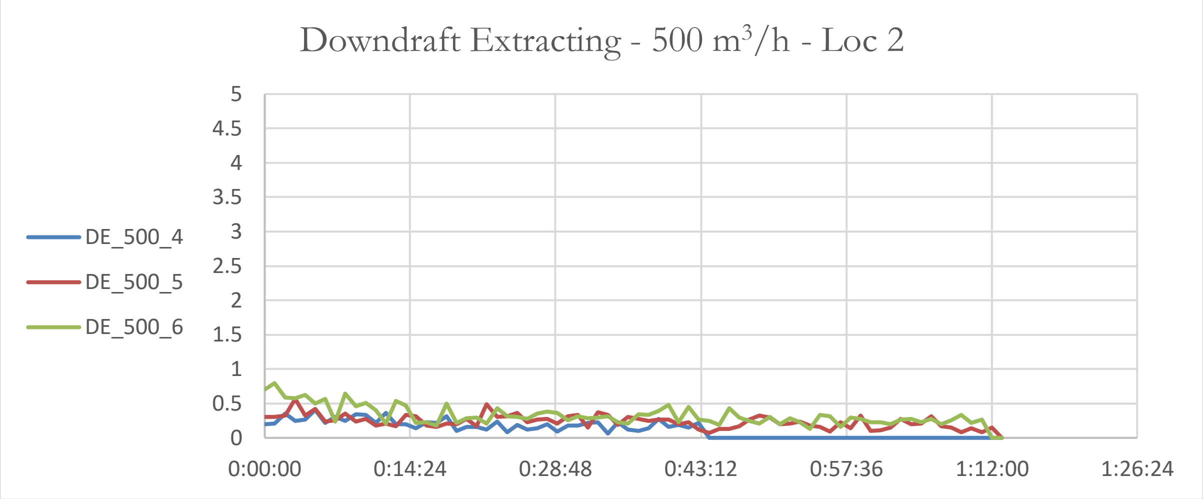


Figure 21 – All repetitions of airflow rate 500 m³/h for location 2 on the Downdraft Extracting.

F.4 – Downdraft Recirculating

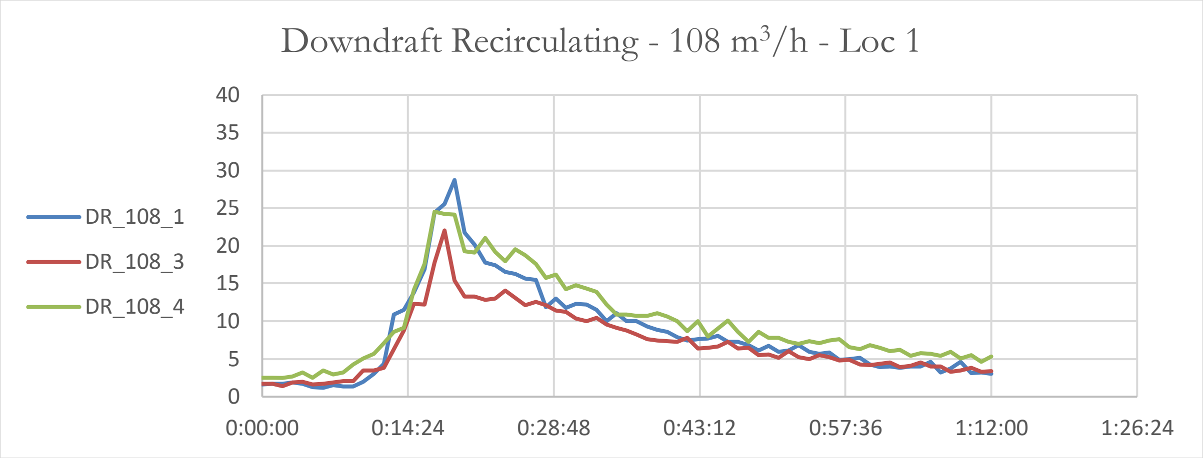


Figure 22 – All repetitions of airflow rate 108 m^3/h for location 1 on the Downdraft Recirculating.

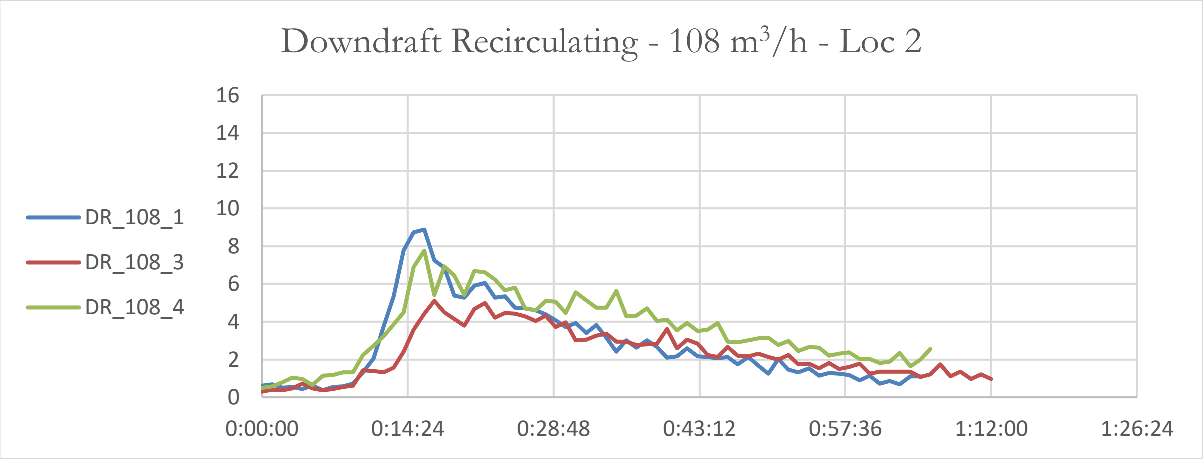


Figure 23 – All repetitions of airflow rate 108 m^3/h for location 2 on the Downdraft Recirculating.

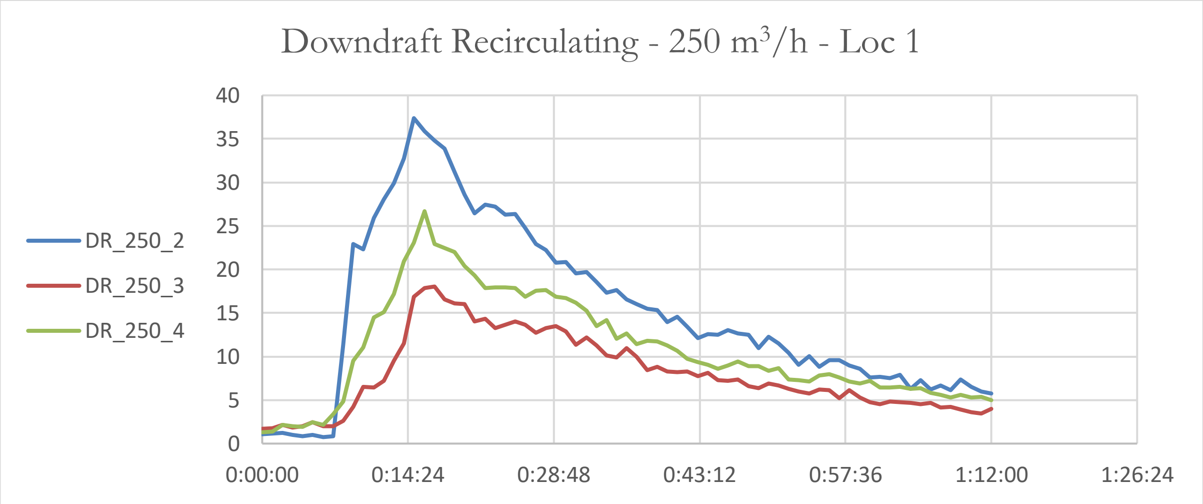


Figure 24 – All repetitions of airflow rate 250 m^3/h for location 1 on the Downdraft Recirculating.

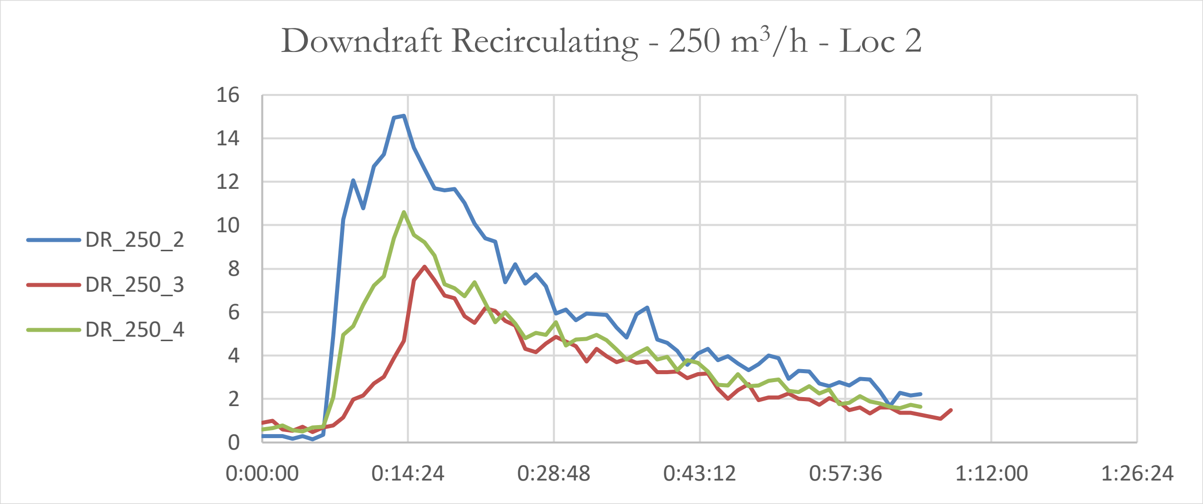


Figure 25 – All repetitions of airflow rate 250 m^3/h for location 2 on the Downdraft Recirculating.

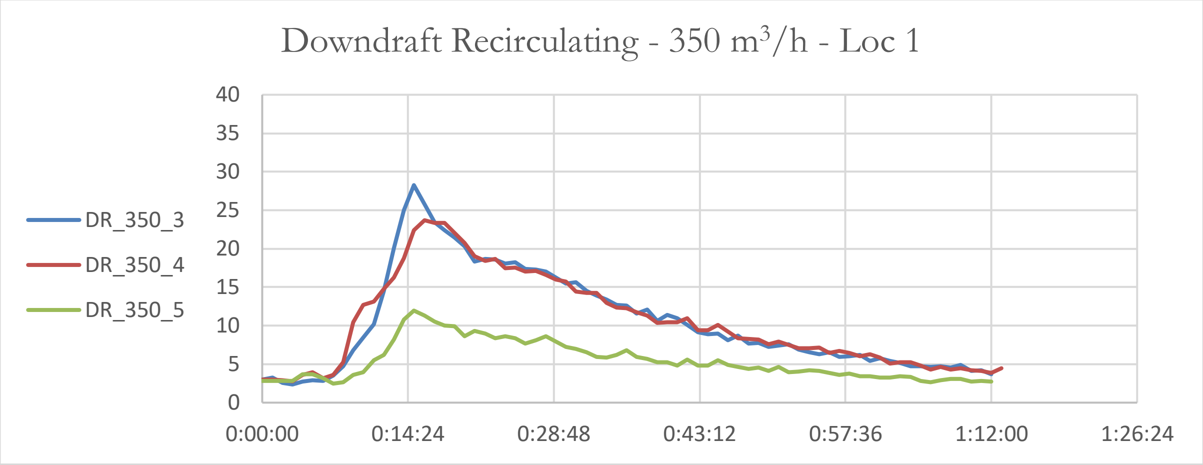


Figure 26 – All repetitions of airflow rate 350 m^3/h for location 1 on the Downdraft Recirculating.

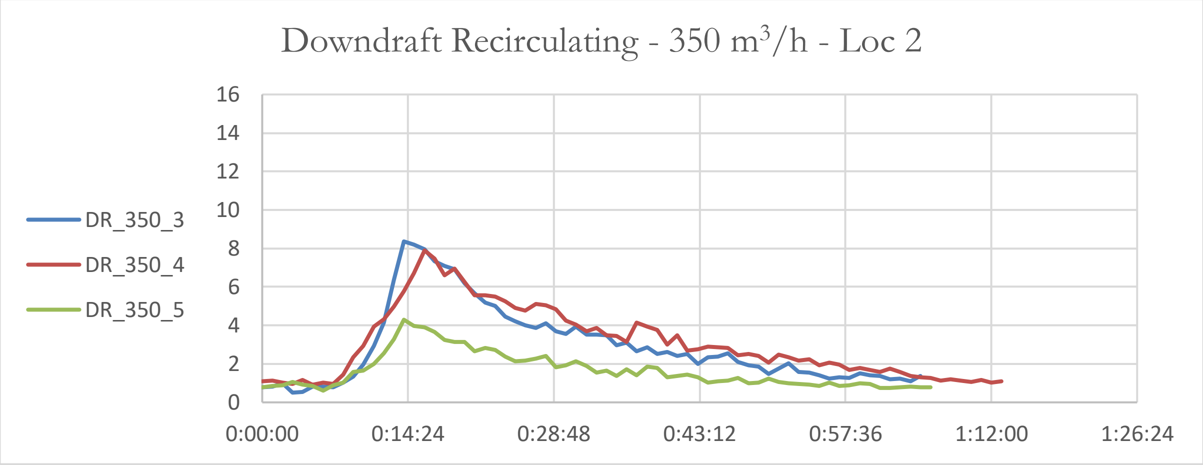


Figure 27 – All repetitions of airflow rate 350 m^3/h for location 2 on the Downdraft Recirculating.

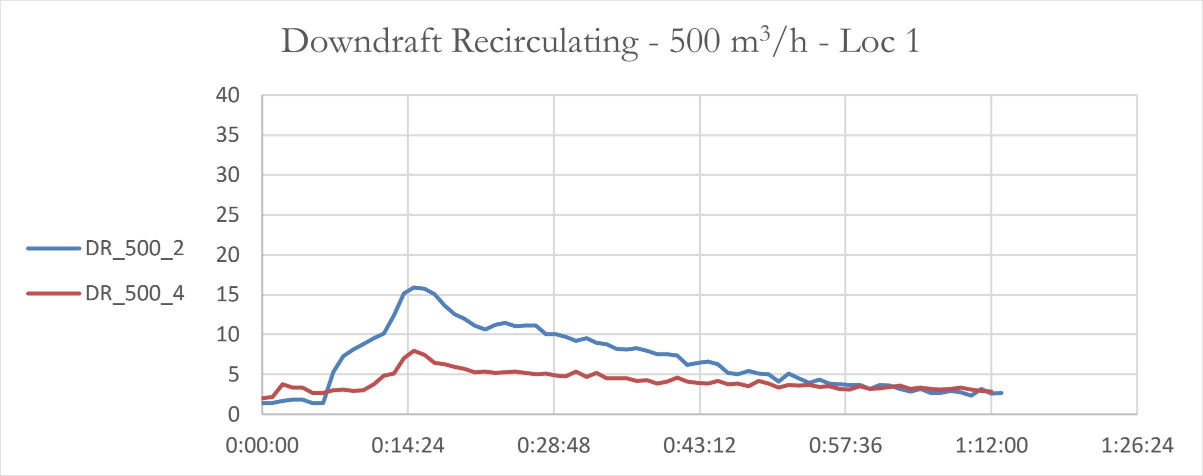


Figure 28 – All repetitions of airflow rate 500 m^3/h for location 1 on the Downdraft Recirculating.

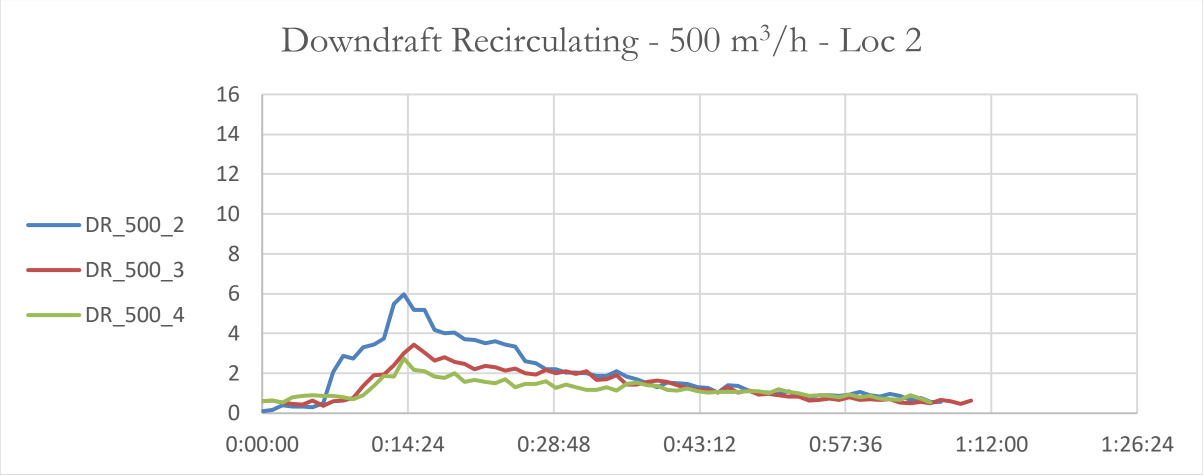


Figure 29 – All repetitions of airflow rate 500 m^3/h for location 2 on the Downdraft Recirculating.

Appendix G – Experiments conducted sorted after date

Table 10: An overview of every experiment conducted sorted after date. The OK/NOT OK column shows which experiments that were failed and had to be redone.

Date	Experiment	OK/NOT OK
25.feb	DR_500_2	OK
01.mar	DR_0_1	OK
02.mar	DR_108_1	OK
02.mar	DR_350_1	NOT OK
02.mar	DR_250_1	NOT OK
03.mar	DR_500_3	OK
03.mar	DR_250_2	OK
03.mar	DR_0_2	OK
09.mar	DR_350_2	NOT OK
09.mar	DR_350_3	OK
09.mar	DR_108_2	NOT OK
10.mar	DR_350_4	OK
10.mar	DR_250_3	OK
10.mar	DR_108_3	OK
10.mar	DR_0_3	OK
11.mar	DR_500_4	OK
11.mar	DR_350_5	OK
11.mar	DR_250_4	OK
11.mar	DR_108_4	OK
15.mar	SE_350_1	NOT OK
15.mar	SE_250_1	NOT OK
15.mar	SE_108_1	NOT OK
16.mar	SE_350_2	NOT OK
16.mar	SE_350_3	OK
17.mar	SE_350_4	OK
17.mar	SE_250_2	OK
17.mar	SE_108_2	OK
17.mar	SE_0_1	OK
18.mar	SE_350_5	OK
18.mar	SE_250_3	OK
18.mar	SE_108_3	OK
18.mar	SE_0_2	OK
21.mar	SE_250_4	OK
21.mar	SE_108_4	OK
21.mar	SE_0_3	OK
23.mar	DE_500_1	NOT OK
23.mar	DE_350_1	OK
23.mar	DE_250_1	NOT OK
23.mar	DE_108_1	OK
24.mar	DE_500_2	NOT OK

24.mar	DE_350_2	OK
24.mar	DE_250_2	OK
24.mar	DE_108_2	OK
25.mar	DE_500_3	NOT OK
25.mar	DE_350_3	OK
25.mar	DE_250_3	OK
25.mar	DE_108_3	OK
28.mar	DE_500_4	OK
28.mar	DE_500_5	OK
28.mar	DE_250_4	OK
29.mar	DE_500_6	OK
29.mar	DE_180_1	OK
29.mar	DE_180_2	OK
30.mar	SR_250_1	OK
30.mar	SR_108_1	OK
31.mar	SR_350_1	OK
31.mar	SR_350_2	OK
31.mar	SR_250_2	OK
31.mar	SR_108_2	OK
01.apr	SR_350_3	OK
01.apr	SR_250_3	OK
01.apr	SR_108_3	OK
01.apr	SR_0_1	OK
04.apr	SR_0_2	OK
05.apr	DR_0_4	OK
05.apr	DR_0_5	OK

Appendix H – Particulate Matter explanation by Peter G. Schild

Note on the equations used in Visual Basic code to calculate PM2.5 and PM10

Author: Peter G. Schild, OsloMet, 2022

The equations and software documented in this appendix can convert the output from optical particle counters (particles per unit volume) to mass concentration [µg/m³] by means of a user-specified assumed particle density [kg/m³]. Particle counters do not measure particle mass directly. However, some particle counters can output gravimetric PM concentrations [µg/m³], but their software simply estimates the mass using equations similar to the ones given in this appendix. Such software is generally factory-preset with an assumed particle density [kg/m³].

This software was developed from first principles. As cursory review if the literature showed that studies either do not document the exact calculation method, or use inferior or incorrect calculations. For examples of the latter, see [3, 8].

Christian Junge in 1955 [2] famously claimed that the relationship between particle number and particle diameter for natural aerosol particles fits a power law (a straight line when plotted on a log-log chart), see Fig.1 below. In fact, the particle size distribution for a specific particle species can be better described with a log-normal distribution, as observed by Kottler in 1950 [9], and that the distribution in natural aerosols is in fact often bimodal or multimodal, due to aerosol coagulation/accumulation phenomena, as observed by Dallevalle *et. al* in 1951 [10], or from different sources. Such a multimodal log-normal distribution gives the “bumpy” appearance to Fig.1. This illustrates the importance that optical particle counters should resolving particle sizes in as many “bins” (i.e. particle size ranges) as possible.

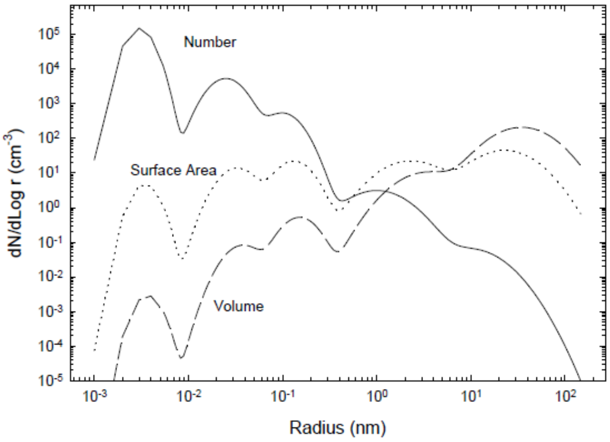


Fig.1 Illustration of typical distribution of particle number as a function of particle size in natural aerosols.

Because one cannot be sure of the particle size distribution within a specific bin in a multimodal distribution, one cannot easily infer the true volume-weighted mean diameter of particles in each bin. Therefore a pragmatic assumption is to assume that the median diameter in each bin is a geometric mean:

$$\overline{D_{12}} = D_1\sqrt{\frac{D_2}{D_1}} = \sqrt{D_1 D_2} \qquad (1)$$

The mean particle mass in each bin range is then estimated as follows:

$$\bar{V}_{12} = \frac{1}{6}\pi\,\overline{D_{12}}^{3} \qquad (2)$$

Finally the mass concentration PM [µg/m^3] is calculated by summating the mass of particles in each bin (i.e. particle count in that range multiplied by the mean volume, and particle density) as follows:

$$PM_{2.5} = \sum_{i=1}^{n-1} \left[N_{i,i+1} \cdot \rho \cdot \bar{V}_{i,i+1} \right] + N_{n-1,n} \cdot \rho \cdot \bar{V}_{n-1,n} \cdot \frac{2.5 \times 10^{-6} - D_{n-1}}{D_n - D_{n-1}} \qquad (3)$$

Where counter i=1 to n encompasses only those bins with a lower diameter of D_i < 2.5 µm.

The right-hand term in the above equation accounts for the fact that the last bin, has a mixture of particles smaller and larger than 2.5 µm, i.e. it has an upper diameter D_n > 2.5 µm.

The volume of particles smaller than the lowest measureable diameter is assumed to be negligible, i.e. $\bar{V}_{0,1} \approx 0$.

Assumptions

- For the equations above, it is assumed that the particle counter has been correctly factory-calibrated such that it has 100% counting efficiency (sensitivity) in each particle size range that it measures.
- Particles are assumed to be spherical. For real, non-spherical particles, it is assumed that the particle count output from the particle counter is the same as for spherical particles with equal mass.

Density input data

Most particle counters that have gravimetric output, seem to be factory-preset with an assumed particle density of approximately 1.65 kg/m^3. This is the typical density of "Arizona Road Dust" or equivalent dust specified in Standard ISO 12103-1 [1], which is used to test the efficiency of air filters in ventilation systems. Many particle-counter studies therefore use this density [3, 4, 5, 6, 7, 8] . It is well known that particles of different sizes and sources have different densities, especially the differences in particulate matter from indoor and outdoor sources, however this requires a time-consuming gravimetric calibration using a teflon air filter in the particle counter's outlet air stream.
For these reasons, the spreadsheet is using a provisional density of $\rho_{\text{fine}} = \rho_{\text{coarse}}$ = 1.65 kg/m^3.

Nomenclature

N_{ij}	Number of particles in size range D_i to D_j [particles/m^3]
V	Volume of a single particle [m^3]
V_{ij}	Total volume of particles in size range D_i to D_j [m^3]
V_{0j}	Cumulative volume of particles in size range zero to D_j [m^3]
D_i	Particle diameter i [m]
ρ	Particle density [kg/m^3]

References

[1] International Standard ISO 12103-1:2016 *"Road vehicles — Test contaminants for filter evaluation — Part 1: Arizona test dust"*

[2] C. Junge. "The size distribution and aging of natural aerosols as determined from electrical and optical data on the atmosphere." *Journal of Atmospheric Sciences,* Vol.12, No.1 (1955): pp.13-25. https://doi.org/10.1175/1520-0469(1955)012<0013:TSDAAO>2.0.CO;2

[3] W.R. Chan, F. Noris, *"Side-by-Side Comparison of Particle Count and Mass Concentration Measurements in a Residence"*. Lawrence Berkeley National Laboratory, document LBNL – 5327E, December 21, 2011

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Appendix I – Capture Efficiency explanation by Peter G. Schild

Note on the equations used in Visual Basic code to calculate kitchen hood capture efficiency

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The equations and software documented in this appendix are used to calculate the capture efficiency for real cooking fumes in kitchen hoods, under more realistic conditions than existing laboratory test standards. The method can be applied to assess exposure to any quantitative property of cooking fumes, either aerosols (e.g. PM1, PM2.5) or gases (e.g. PAH, water vapour).

There exist 3 known laboratory test standards in Europe:

- Swedish standard SS 433 0501:1981 *"Cooker fans and hoods – Performance testing"* (withdrawn): This laboratory test employs N_2O tracer gas emitted for 10 minutes from a perforated flat cylinder placed directly on the hob, after which the cooker hood is switched off and mixing fans are operated in the room to produce a uniform concentration of tracer gas in the room. A moving 500x1000 mm plate in front of the bob produces air turbulence disturbances representing the cook. The term "*uppfångningsförmåga*" is used for capture efficiency.
- International standard IEC 61591:2019 *"Cooking fume extractors - Methods for measuring performance"*: This laboratory test employs solvent methyl-ethyl- ketone (also known as MEK or Butanone) evaporating from the frying pan, after which the cooker hood is switched off and mixing fans are operated in the room to produce a uniform concentration of MEK vapour in the room. The term "*odour reduction factor* (O_f)" is used for capture efficiency.
- European standard CEN 13141-3:2017 *"Ventilation for buildings - Performance testing of components/products for residential ventilation - Part 3: Range hoods for residential use without fan"*: This standard employs an laboratory rig that is identical to IEC 61591, but has a specific clause concerning the test for the *"odour extraction factor"* instead of making reference to IEC 61591.

Common to all these standards is that the capture efficiency (or equivalent term) is calculated with the following universal equation:

$$CE = \left(1 - \frac{\langle c \rangle_{on}}{\langle c \rangle_{off}}\right) \times 100\% \qquad (1)$$

All three of the above-mentioned laboratory standards effectively measure the total amount of odour remaining in the kitchen at the exact time when the odour emission is ceases (after approx 10 minutes of emission). This is achieved by effectively "stopping time" by switching off the kitchen hood and operating circulation fans in the room in order to measure a uniform concentration of vapour $\langle c \rangle$ in the room.

The more realistic test method presented employed in this document does not "stop time", but measures the exponential decay of concentration in the room for a long period after the kitchen hood is switched off. The concentration of fumes is then integrated over time from the start of cooking until infinity:

$$CE = \left(1 - \frac{\Sigma C_{on}}{\Sigma C_{off}}\right) \times 100\% \qquad (2)$$

Where ΣC is simply the sum of all logged values of concentration (logged at uniform intervals):

$$\Sigma C = \left[\sum_{i=1}^{N} c_i\right] + \Sigma C_{tail} \tag{3}$$

The additional term (ΣC_{tail}) extrapolates the concentration trend from the end of the logging period until time $t = \infty$. This term is almost negligible, but is included here for scientific rigor.

$$\Sigma C_{tail} \approx c(0) \cdot \mathrm{EXP}\left(\frac{N}{\tau_i}\right) \tag{4}$$

This approach of integrating concentration over time, and adding an extrapolated tail term, is inspired by age-of-air tracer gas tests for ventilation efficiency, such as described in Nordtest Method NT VVS 047:1985 *"Buildings – Ventilating air – Mean age of air"*.

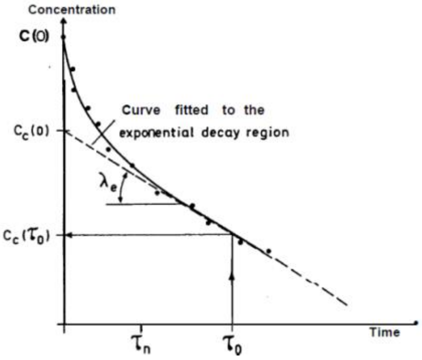

Fig.1 Illustration of typical tracer gas decay curve, showing extrapolated exponential decay trend. (Source NT VVS 047)

Choice of location and integration time

This capture efficiency can be measured at any location of choice in the kitchen, e.g. near the cooker (to assess cook exposure) at the dining table, or in the living room. However, the location that is most representative for the enclosure as a whole is the ventilation extract terminal for ground-ventilation of the kitchen.

Furthermore, it is possible to calculate the capture efficiency for exposure of occupants who are not in the kitchen for the entire period ($0 \leq t \leq \infty$). For direct comparison with IEC standard, the integration period should start at the time when the cooking ends and the hood is switched off. This is equivalent to the exposure for a "guest" who enters the kitchen just when the meal is ready. To assess the total exposure for the cook, then the whole time series from time t=0 should be integrated. As such, the IEC standard is inferior to the method explained here.

Correcting for background concentration

It is essential that the measured concentrations are corrected for background concentrations from other sources, such as the concentration in the supply air (due to recirculation in the air handling unit), and other sources in the room. This is done by an algorithm that estimates and subtracts the background concentration as follows:

1. The initial background concentration is logged for 10 minutes before cooking commences. The *median* value is calculated. See the dashed red line in Fig.2 (left) below.

2. The background concentration achieves a new steady-state value after cooking, due to operation of the hood during cooking. This background concentration is fitted simultaneously with the exponential decay curve (starting after cooking has ended). This involves fitting three parameters simultaneously, using a method inspired by Kendall-Theil-Sen (KTS) regression[1]:

   Step 1: For each value of background concentration (c_{bck}) the median time constant (τ_i) is fitted by KTS-regression, based on all combinations of pairs of logged values of corrected concentration that are separated by at least half of the whole logging period. Each individual estimate of τ_{ij} is calculated according to Equation 5 below, where *i* and *j* are two specific log indices.

   Step 2: Given the median time constant (τ_i) calculated above, the extrapolated initial concentration is fitted by KTS-regression, based on all logged values of concentration in the period after cooking. Each individual estimate of $c(0)$ is calculated based on one logged value of c_i according to Equation 6 below.

   Step 3: Steps 1 and 2 above are repeated with an exhaustive search of trial values of constant background concentration (c_{bck}) from zero $c_{\mathrm{bck}} = 0$ to the highest measured concentration during the test. The final choice of (c_{bck}) is the one that gives the best fit of the exponential decay curve (red line in Fig.2) by minimizing the cost function in Equation 6. The addition term +500 in the cost function accounts for the resolution (uncertainty) in the particle counter.

3. Lastly the intermediate values of background concentration during cooking is simple assumed to be linear, as illustrated between time *t* = 00:10 to *t* = 00:23 in Fig.2 below. This linear trend is acceptable assumption, as it is very short compared to the rest of the whole experiment.

$$\tau_{ij} = -\frac{i-j}{\mathrm{LN}\left(\frac{c_i}{c_j}\right)} \tag{5}$$

$$c(0)_i = \frac{c_i}{\mathrm{EXP}\left(-\frac{i}{\tau_i}\right)} \tag{6}$$

$$cost\ \ function\ = \sum_{i}^{N} \left| \mathrm{LN}\left(\frac{c(0) \cdot \mathrm{EXP}\left(-\frac{i}{\tau_i}\right) + 500}{c_i + 500} \right) \right| \tag{7}$$

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[1] https://en.wikipedia.org/wiki/Theil-Sen_estimator

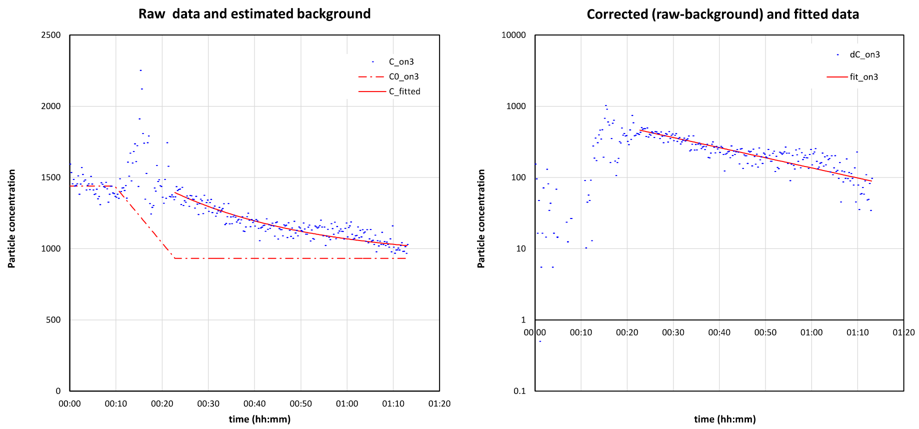

Fig.2 ***Left****: Uncorrected particle concentration. The fitted background concentration is the dashed red line. The whole red line is the fitted exponential concentration decay curve, starting after cooking. The cooking period is from t = 00:10 to t = 00:23.*
Right*: Particle concentration corrected for background concentration (plotted with logarithminc y-axis, thus showing the exponential decay curve as a straight red line.*

Nomenclature

c_{on}	Concentration of odour measured during a test with the kitchen hood operated (for the first 10 minutes). Concentration is corrected for background concentration.
c_{off}	Concentration of odour measured during a test with the kitchen hood inoperative (switched off during the whole test). Concentration is corrected for background concentration.
ΣC	Sum of concentrations in time series from tome t = 0 to time t = ∞. The concentrations are corrected for background concentration.
N	Number of logged values in the time series.
τ_i	Equivalent time constant (time series log counter) for exponential decay. Note that this is dimensionless, not in seconds.
$c(0)$	Extrapolated concentration at time t = 0, assuming exponential decay curve, see Fig.1. Concentration is corrected for background concentration.