CLASSIFICATION:
Open

OSLO METROPOLITAN UNIVERSITY
STORBYUNIVERSITETET

Department of Civil Engineering and Energy Technology – Energy and Environment
Postal address: P.O.box 4 St. Olavs plass, N-0130 Oslo, Norway
Visiting address: Pilestredet 35, Oslo
Website: www.oslomet.no

MASTER'S THESIS

TITLE: # Test facility and capture efficiency for a wall-mounted range hood in an open plan kitchen - living room	SUBMISSION DATE: 30.06.21 NO OF PAGES & APPENDICES: 96
AUTHORS: Zahra Amgais Fulsebakke	SUPERVISOR: Peter Schild Kari Thunshelle

DONE IN COLLABORATION WITH: SINTEF	CONTACT PERSON: Kari Thunshelle

ABSTRACT:

Challenges within kitchen ventilation are prevalent in today's airtight and low-energy buildings, especially apartments with open plan kitchen-living rooms. This master thesis is a part of the Research project Healthy Energy-efficient Urban Home Ventilation. Laboratory experiments is conducted to investigate the exposure and the performance of a wall-mounted range hood related to real cooking. The results of this work are preliminary data and a new developed test method aimed for further advanced exposure studies.

KEYWORDS
Capture efficiency Ventilation Rang hood

Preface

This thesis was written during the spring of 2021 for the Department of Civil Engineering and Energy Technology at Oslo Metropolitan University. The master thesis is a part of the Research project Healthy Energy-efficient Urban Home Ventilation. The project aims to establish knowledge and recommend robust ventilation solutions for private homes in an urban environment.

I would like to thank my supervisors Kari Thunshelle and Peter Schild, for their excellent guidance and support during the process. Your knowledge is invaluable.

I would also like to thank Bjørn Ludvigsen, who has assisted in the lab whenever needed and added value to this project.

Lastly, a big thank you to my lab partner and friend Adele Jutulstad for her positive and optimistic attitude throughout the entire project. I also benefitted from debating issues with you. You have been the best companion I could wish for

Zahra Amgaisi Fulsebakke

Master in Energy and Environment in Buildings

30.06.2021

Summary

Cooking activities are a significant source of indoor air pollutants. Therefore, good exhaust performance is essential to control and remove contamination and further provide a good indoor climate. Challenges within kitchen ventilation are prevalent in today's airtight and low-energy buildings, especially apartments with open floor plans. A kitchen hood with satisfactory efficiency is required installed in all residential buildings. No efficiency requirements or sufficient exhaust air is set, only a minimum requirement of additional ventilations. The requirements are only for the minimum additional ventilation during cooking of 108 m^3/h, in total 144 m^3/h considering primary ventilation of 36 m^3/h

This thesis investigates the exposure during a cooking activity where oil is heated. A large part of this study has been set up and operating a suitable test facility designed to measure the exposure. Furthermore, developing a calculation method to evaluate the performance effectiveness of wall-mounted range hood. After completing the test facility, 9 test combinations were performed for a wall-mounted range hood in two different mounting heights, a total of 27 tests. All experiments are repeated regarding collecting credible data to provide an initial understanding of CE and its uncertainty and repeatability. For the same reason, most experimental conditions were carefully regulated, recorded, and analyzed to ensure the same and stable conditions for all test combinations.

A realistic method of calculating the capture efficiency CE related to particles generated by the cooking has been developed. The method is an indirect approach by comparing particle concentration when the range hood was used to the concentration measured with the hood switched off. To evaluate the effect of the period CE is calculated based on, CE was calculated for a period during cooking and a period post-experiment. There was also a need to account for the increment in the background emission during the test day.
Based on preliminary data, CE has been ranged from 72%-97% for all tested combinations of airflow rates and two mounting hights of the hood. The mean relative standard deviation (RSD) was 26% (8.5%-66%) when calculation during the experiments, of which the RSD of particle concentration across replicated experiments constituted an RSD of 24 % (2.7%-65.1). CE based on calculations during experiments was lower than CE based on the period after the end of the experiment. The CE based on post-experiment period had a mean RSD of 29% (9.4%-64%), of which 28% (8.9% to 63%) was related to particle variability.
In the majority, increasing the airflow rate improved the CE with no significant impact on RSD (0.8%-1.4%). The influence of increasing the flow rate from 321 m^3/h to 395 m^3/h had no considerable effect when on CE when the range hood is mounted in a high of 70 cm. A slight of a negative impact on 54 cm. implying there might be is a maximum flowrate beyond which the CE may begin to decrease for some reasons (still need to be investigated, plum?

An average CE across the experiment combinations of airflow rate (144 m^3/h to 321 m^3/h) and hood mounting hights is estimated from 91%, with the hood is mounted 54 cm above the cooktop and 88% when 70 cm—indicating an improvement of a lower mounting hight of 3%.

The results show an improvement of 15 % when increasing the airflow rate from the minimum requirements of 144 m^3/h to 219 m^3/h (hood mounted at 54 cm above the cooktop). However, the improvement is insignificant when increasing to 321 m^3/h.

The result of this work is based on a preliminary amount of data and a newly developed test method aimed at the purpose of the Urban ventilation project. It is observed that the variability in particle concentration across replicated experiments dominated the uncertainty and constituted a mean RSD of CE calculations. The results may be initial and may also change as the amount of data/replicated experiments increases and the uncertainty of particle measurements decreases. However, the selected experiment facility and design was considered suitable due to a significant uncertainty

Contents

Figure list

Table list

Acronyms

MEK	Methyl-ethyl ketone
AHU	Air Handling Unit
CE	Capture efficiency
CPC	Cumulative particle count (pt/liter)
OPC	Optical particle counter
APC	Airborne particle counter
UPC	Ultrafine particle counter
SD	Standard deviation
RSD	Relative standard deviation
PM	Particulate Matter
Pnc	Particle number concentration
TEK17	Norwegian Directive of Technical Requirements

1. Introduction

1.1 Background for the study

Cooking activities are a significant source of indoor air pollutants and may be responsible for various respiratory health effects. A range hood is required in residential kitchens to control the odor generated. Today's requirements for kitchen ventilation in Norway are for the absolute minimum exhaust air for primary and additional ventilation. The extract should have sufficient capture efficiency to remove airborne contaminants from the kitchen. The Norwegian Directive of Technical Requirements TEK 17 does not specify any efficiency requirements or sufficient exhaust airflow. Therefore, the minimum requirements are not necessarily sufficient to meet the functional need.

The challenges within kitchen ventilation are significant in today's modern, airtight, and low-energy buildings, especially apartments with an open kitchen plan with a living room. This results in greater demands for the ventilation to achieve a good indoor climate simultaneously as the solutions desire to be energy efficient. The URBAN ventilation research project investigates the challenges and solutions regarding energy-efficient ventilation systems that also take the good indoor climate and thermal comfort into consideration. The study aims to develop new recommendations for urban building ventilation systems in Norway. Furthermore, this master thesis contributes to initial experiments of a test procedure for more advanced exposure studies.

One main objective of this study is to evaluate suitable laboratory test methods for more realistic evaluation of kitchen hood performance. A test setup was designed and adapted to the purpose of this study concerning standard tests and calculating methods of evaluating a range hood performance. A residential wall-mounted range hood is tested in two different mounting heights with varying rates of airflow are applied to investigate the effectiveness of kitchen ventilation in an open plan solution kitchen-living room of 80 m3. Moreover, a method of calculating the capture efficiency related to particles generated by the cooking event procedure-of in which oil is heated- is to be developed and evaluated concerning uncertainty and repeatability.

A concrete and specified list of the work purposes and questions are listed below

1.2 Research purpose and questions

1- Evaluation of the test facility, design, and procedure suitability
2- Assessment of collected data applied to calculations and its repeatability
3- Evaluation of calculation method of capture efficiency based on measurements of emissions during cooking, and their uncertainty
4- What impact does the distance between the rangehood and the cooktop have on CE?
5- Based on CE calculations, what is a reasonable airflow rate for a wall-mounted range hood for best results?
6- Evaluation of the requirement for the minimum exhaust air concerning capture efficiency and particles emission
7- What is the impact of the range hood mounting height and jet velocity generated by cooking on the design of the exhaust flow rate?
8- Based on convection flow rate/vertical velocity in the plum generated by cooking, what is the sufficient exhaust flow rate for a range hood mounted in the tested heights for best emissions capture?

2. Theory and literature review

This chapter presents relevant information concerning kitchen ventilation. Data extraction and reporting are geared to illuminate themes applied in the method and further discuss the report. The section will review subjects below

- The requirements and recommendations for kitchen ventilation in Norway and other countries
- The most common kitchen design for modern apartments and the recommended ventilation design
- The standard laboratory test methods and facility for evaluating range hood in residences?
- Methods of calculating and evaluating the effectiveness of rang hoods.
- A review of previous studies was carried out concerning range hood effectiveness.

2.1 Requirements and recommendations

Kitchen ventilation systems are essential in residential ventilation to remove contaminations generated while cooking. A range hood is required in all Norwegian residential kitchens to control pollutants from cooking, and the required exhausted airflow rates for range hoods are specified in "§13 indoor air quality" in the Norwegian Directive of Technical Requirements TEK17
TEK17 requires that housing units must have ventilation that ensures an average fresh air supply of at least 1.2 m^3/hm^2 and that bedrooms must be supplied with a minimum of 26 m^3/h per bed. The additional exhaust airflow through the kitchen should be placed and designed to remove contamination and moisture generated by cooking and other activities in a satisfactory efficient manner. The regulations do not specify any efficiency requirements but mention that unfortunate design and placement of the cook-top and the exhaust may lead to increased exhaust volume.[2]. Table 1 is an overview of the requirements.

Table 1: Pre-accepted performance for exhaust air volume in housing according to TEK17[3]

Room	Primary ventilation (m^2/h)	Additional ventilation (m^2/h)
Kitchen	36	108
Bedroom	54	108
Bathroom	36	36
Laundry room	36	72

The standard does also set requirements for minimum exhaust volumes, shown in Figure 1. For a kitchen, the absolute minimum requirements are 36 m^3/h as primary ventilation and 108 m^3/h as additional ventilation when cooking [2]. It should be noted that TEK 17 does not say anything about the sufficient amount of ventilation air. These minimum requirements are not necessarily sufficient to meet the functional needs [4]. SINTEF Building Research Design Guides recommends a minimum fresh air supply of 1.44 m^3/hm^2 and that the kitchen ventilation should increases when cooking by 250 m^3/h. Those recommendations are experiences based [4].

2.1.1 Airflow rate for range hood

Most range hoods (with building fans) ran on 70 L/s, while many in the market today run at an airflow of 540-720 m^3/h [5]. There are two types of residential range hoods: recirculating and extracting. Recirculating range hoods discharge air back into the room and do not remove all the emitted particles. They also require extra maintenance to change/regenerate filters and have various performances, from excellent to useless products. The minimum airflow recommended by professional staff for the recirculating hood is 300-440 m^3/h [5].
The other type of range hoods exhaust kitchen contaminants directly to the outside and are a more effective method of source control for cooking-related contaminants. A laboratory done by Røros in Norway showed that duct out/ extract is 35% better than recirculation in the performed tests [6]

2.1.2 Requirements in other countries

Residential ventilation standards usually don't have specific requirements on the kitchen range hood. As TEK 17, they typically have general kitchen ventilation requirements. The requirements In Sweden are removed from the standard, while they in Denmark require at least 20l/s (72 m3/h), 144 m3/h additional when cooking, and 75% ORF " odor Reduction factor" (Tests by EN 61591 or EN 13141-3)[7]. In the Netherlands are the minimum requirements 100,8 m³/h. The ASHRAE Standard 62.2 requires either an intermittent ventilation rate of 50 L/s (180 m³/h) or a continuous air exchange rate of 5 Air Changes per Hour (ACH) for the kitchen [3]. The guideline from the Home Ventilating Institute (HVI) requires a minimum airflow of 170 m3/h (47 l/s) for a typical US range width of 76 cm [7, 8].

2.2 Standards

Highlights from standards related to laboratory testing methods of kitchen hoods performance are summarized in Table 2 and reviewed. [1, 9, 10]

Table 2: Standards for test methods of kitchen hoods.

Standard	Disturbance/ Tracer substance	Type of hood	Test Air flow
IEC 61591:2019	No Solution of (312 ± 1.5) g. Of which (12 ± 0.1) g MEK and (300 ± 1) g of distilled water Within (1800 ± 10) s (30 min)	Extract and recirculation. Down-draft Only build in or dedicated roof fan	The highest continuous setting for regular use (manufacture's instruction) Max and normal
EN 13141-3:2017	Yes Solution of 100g. Of which (12 ± 0.1) g MEK and (300 ± 1) g of distilled water Within 10 min	Extract only Without build in or dedicated roof fan	The highest continuous setting for regular use
Energy label	No No control of odor reduction (should include exposure?)	Recirculation hoods not included (no internal exhaust fan outlet)	Airflow higher than Scandinavian level (test 0-800m3/h
ASTM-E3087.18	No CO_2 injection rate less than 0.5% of this airflow	Extract only Wall-mounted range hoods	One or more air inlets with a max of 200 L/s. Min exhaust airflow 50 L/s

IEC 61591:2019

NEK IEC 61591:2019 [11] European standard for test methods of the performance for Cooking fume extractors and can be applied to extracting or recirculating range hoods, depending on what is tested. The standard includes fan performance, grease absorption, and odor extraction. The standard does not allow for any conditioning of the cooking fume extractor, and all settings are tested in accordance with the manufacturer's instructions.
The grease absorption factor G_{FE} is defined as a percentage of grease retained within a grease filter and calculated in percent as follows:

$$G_{FE} = \frac{w_g}{w_r + w_t + w_g} \qquad (1)$$

W_g is the mas of oil, in g, including all detachable parts

W_r is the mass of oil, in g, retained in the airways of the cooking fume extractor and oil retained in ducting used in the chamber

W_t is the mass of oil, in g, retained in the absolute filter

Fluid dynamic efficiency FDE_{hood} is only possible for cooking fume extractor in extraction mode and calculated with the following formula:

$$FDE_{hood} = \frac{Q_{BEP} \cdot \Delta p_{BEP}}{3600 \cdot p_{BEP}} \times 100 \qquad (2)$$

Q_{BEP} is the numerical value of the airflow at the best efficiency point, expressed in m^3/h

Δp_{BEP} is the numerical value of the different static pressure at the best efficiency point, expressed in Pa

P_{BEP} is the numerical value of the electric power at the best efficiency point, expressed in W

The method is used to assess the effectiveness of an odor reduction filter and is not applicable for range hood operating in extraction mode, as the filters are not used in this mode.
For the measurements of *Odour reduction factor* O_f, the air in the test room is mixed with a room ventilator, and the MEK concentration is measured in a certain position in the room at four different heights. The concentration of MEK for both conditions-without and with the operating C_1 and the hood operating C_2.- is measured at the end of the dripping period of 30 min. This method has been early used for testing the carbon filter and gives an unrealistically high odor reduction factor. [7]
O_f is defined as the capability of the cooking fume extractor to reduce odors and calculated in percent as follows:

$$O_f = \frac{C_1 - C_2}{C_1} \times 100 \qquad (3)$$

C_1 is the concentration of MEK at the end of the application period without the range hood operating.

C_2 is the concentration of methyl-ethyl ketone at the end of the application period with the range hood operating

NS-EN 13141-3:2017

The test method in NS-EN 13141-3:2017 is very similar to NEK IEC 61591:2019 (O_f). Otherwise, the standard does also cover residential cooking hoods without build-in fans. The method also requires the use of a "disturbing element" in front of the hood when performing the odor extraction test. This disturbing element is to be moved periodically left and right to simulate air movements produced by a person to simulate a real situation with air movement in the kitchen. Furthermore, the application period and the MEK solution are reduced, as shown in Table 3. The concentration of MEK without and with the operating (C_1) is measured at the end of the application period in both standards. For C_2, the hood is switched off, and the ventilating opening is closed after the application period ends. Then a fan positioned on the center of the floor is operated. The measurements are taken when the value has stabilized [9]. O_f is calculated by the same formula (3).

ASTM-E3087.18

The American Society of Testing and Materials (ASTM) has developed a methodology and testing procedure, ASTM-E3087.18. for measuring the capture efficiency CE of residential, wall-mounted range hoods. CE is defined as the fraction of contaminants emitted during cooking proses that are exhausted directly to the outside via the hood. CE is measured under specific conditions that permit accurate comparison of range hoods. The test is developed for electric stoves that have a burner power output that seems to be between gas and induction. The method uses two tracer gas emitter elements which emit 1000 W each and enable a surface temperature of 200 ^{0}C. The power output is representative during the heating-up phase for cooking on gas but not when considering induction cooking, where the power consumption is often lower due to higher efficiency.
[10]

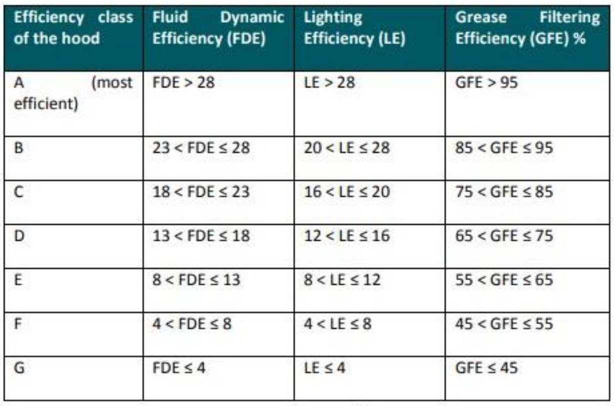
CE can be determined by the equation below:

$$CE = \frac{(C_{exhaust} - C_{chamber})}{(C_{exhaust} - C_{inlet})} \times 100 \tag{4}$$

The steady-state tracer gas concentrations of CO_2 are measured in three locations in this test method: inside the test chamber (Cc), at the test chamber inlet (Ci), and in the exhaust ducting/exhaust (Ce).

Energy label

There are multiple testing criteria and rating standards to evaluate the airflow, noise, and other important parameters. All range hoods are required tested and delivered with an Energy star label according to “International Electrotechnical Commission” CEI/ICE 61591 and EN 60704. The Energy label addresses energy efficiency by requiring the fan efficacy to be ≥ 0.21 Wh/m3, measures the rate of flowrate, pressure, and electricity power at the best efficiency point but doesn’t include the exposure (control of odor reduction) or capture efficiency. The parameter that er tested includes Energy efficiency index (EEI), fluid dynamic efficiency (FDE), lighting efficiency (LE), grease filtering efficiency (GFE), and noise. According to CEI/IEC 61591:1997 and EN 60704. The Energy label is just a comparison of the hoods and does not say anything about odor reduction level/efficiency, and the airflow is significantly higher than the inlet air can handle. The hoods are Energy ranges from A to F, as shown in Figure 1.



Efficiency class of the hood	Fluid Dynamic Efficiency (FDE)	Lighting Efficiency (LE)	Grease Filtering Efficiency (GFE) %
A (most efficient)	FDE > 28	LE > 28	GFE > 95
B	23 < FDE ≤ 28	20 < LE ≤ 28	85 < GFE ≤ 95
C	18 < FDE ≤ 23	16 < LE ≤ 20	75 < GFE ≤ 85
D	13 < FDE ≤ 18	12 < LE ≤ 16	65 < GFE ≤ 75
E	8 < FDE ≤ 13	8 < LE ≤ 12	55 < GFE ≤ 65
F	4 < FDE ≤ 8	4 < LE ≤ 8	45 < GFE ≤ 55
G	FDE ≤ 4	LE ≤ 4	GFE ≤ 45

Figure 1: Energy label ranging

2.2.1 Standard test facility and conditions

The recommended test room facilities and conditions are summarized in Table 3

Table 3: Recommended laboratory conditions

Terms	IEC 61591:2019 for O_f	ASTM E3087-18	NS-EN 13141-3:2017
Test room volum (m^3)	22±2	>21	22±2
Type of hood	Range hood 600 ±10 mm, centrally above the hob, wall cabinets mounted on both sides	Range hood along with one of the longer walls. 0,75 mm wide. Cabinetry mounted to the ceiling and extended down vertically	Range hood along with one of the longer walls. Centrally, 600 mm above the hob
Pressure	The absolute air pressure shall be between 913hPa and 1063 hPa	Less than 2,5 ACH at 50 Pa leakage. The air inlets sized so that the max exhaust for the hood depressurizes the room by less than 5 Pa	Not stated
Equipment	Outer bottom dim 200±20mm. The thickness of the bottom 7±1 mm. Height 125±20. Height of the hob element and cookware > 205mm.	Electrical heating elements dim 200±20 mm	Pan dim 200±20 mm. cooper base and a height of 45±2
Equipment placement on the hob	Front left-hand cooking zone. Matching the size of the zone. Centrally positioned	For 0,61m wide hood; two emitter/pan elements with the center of emitters 500 mm from the back wall and 150 mm to the left and right of the centerline of the hood	On the front left-hand hob element with the same base dim
Temperature	Room temp 23±2 The bottom of the cookware maintained of 250±5 °C	Room temp at the same location as $C_{chamber}$.15-30 °C ±5 °C during the test. Heating elements maintain T of the top plate of the tracer gas 160 ±10 °C Tracer gas introduced through emitters and stable up to 400 °C	170±5 °C in the base of the pan, 40 mm from its side

2.3 Kitchen layout

The capture ability of a kitchen hood depends on the airflow amount, design, placement in relation to the wall, and height between the cook-top ad the hood. When it comes to the design, an island kitchen hood requires a higher exhaust airflow compared to a wall-mounted one. Overhang/fold-down screen improves the exhaust performance of the hood. SINTEF Building Research Design Guides also point that reaching a satisfying contaminants capture requires a higher amount of exhaust air than the recommendations in TEK17. The kitchen hood shall be at least as wide as the cook-top and with a minimum distance of 600 mm (650 when gas burner), as seen in Figure 2 [12].

Figure 3 shows an illustration of the test room according to NEK IEC 61591:2019 when measuring O_f

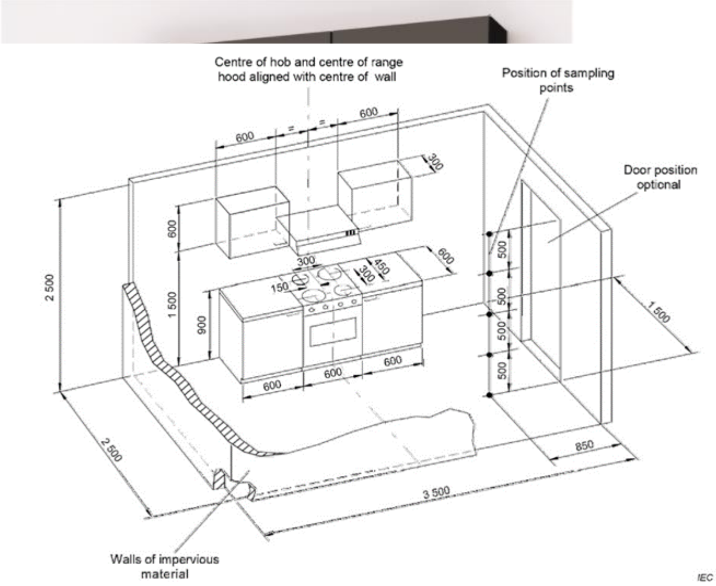
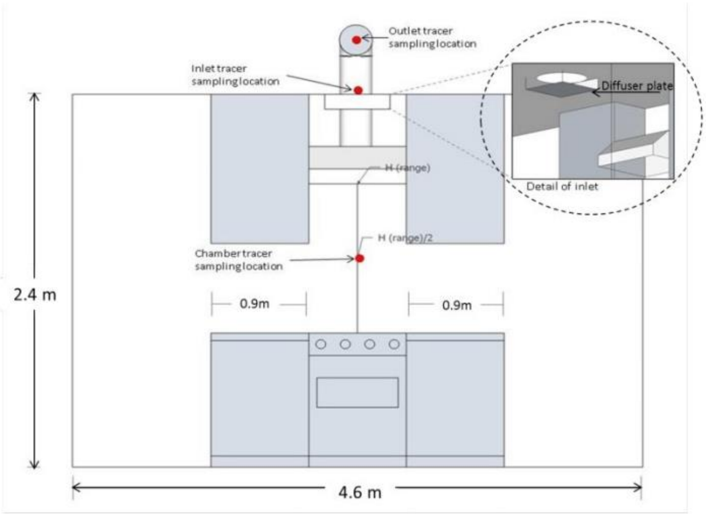


Figure 3: Example of a test room according to NEK IEC 61591:2019 [1]

Figure 4 is an illustration of the laboratory test room according to ASTM E3087-18 when measuring CE



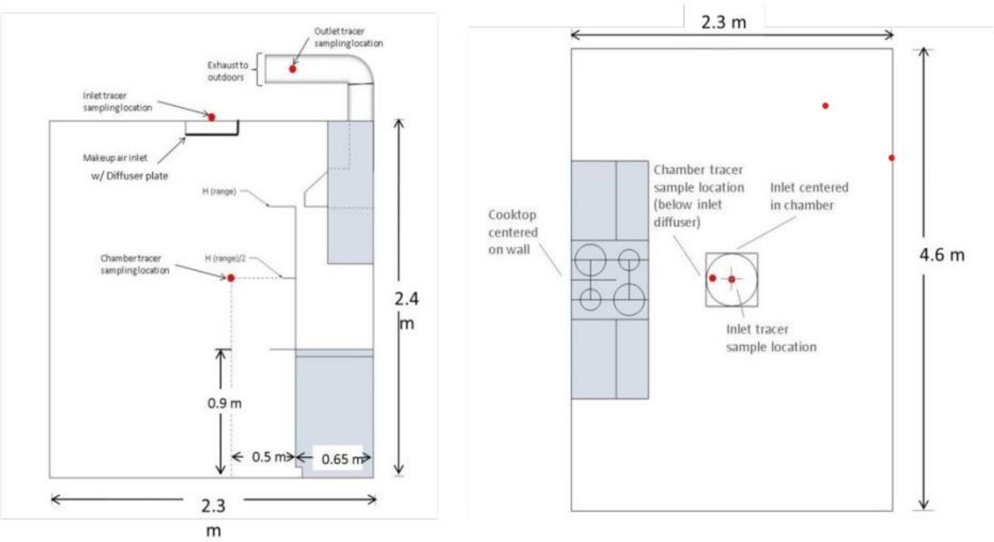
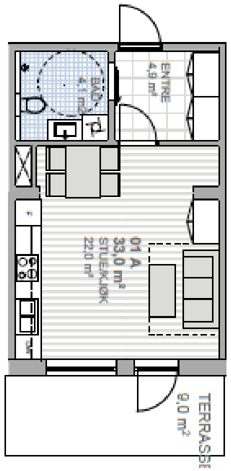
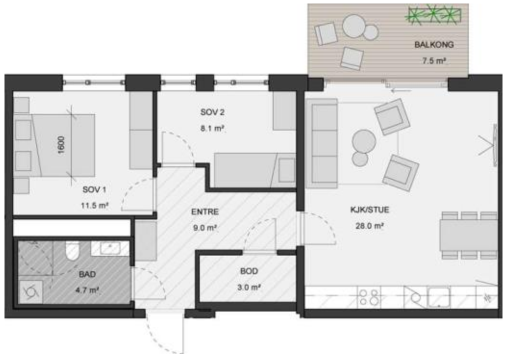


Figure 4: Test chamber according to ASTM standard [13]

2.3.1 Apartment architecture

In order to achieve more area-efficient apartments in Norway, the apartments are being built smaller and more and more compact. All from studio apartments 18-34 m2 to 4-rooms apartments 66-97 m2. Some examples of the plan solutions are shown in the table below. As seen in the table, the common solution seems to be an open plan solution (kitchen/living room). Some of the common floor plan solutions are shown in Figure 5, rewired by Karina Denizou [13]

Table 4: Examples of floor plan design for modern apartments in Norway

Studio: 33 m^2 (living./bed/kitchen 22 m^2)	2-rooms: 52 m^2 (living./kitchen 24 m^2)	3-rooms: 68/86 m^2 (living. 28/40 m^2)	4-rooms: 92 m^2 (living. 39 m^2)
		 	
Kitchen in living room Cook-top to the inner wall	L-kitchen in living room Cook-top to wall	Kitchen/L-kitchen in living room Cook-top to wall	L-kitchen in niche in living room Cook-top to wall
	Kitchen not a passage room	Kitchen not a passage room	Part of kitchen as passage room

2.4 Apartment ventilation

The supply air shall be supplied to rooms with the least pollutions as living rooms and bedrooms, and extracted from the rooms with the least pollution, like bathrooms and kitchens, to prevent leading contaminations to rooms with high demands [14]. Figures 5 show a typical apartment ventilation outline with an open plan kitchen and living room solution.
The three main principles of ventilation include balanced ventilation, natural ventilation, and mechanical exhaust ventilation. Balanced and mechanical ventilation is the most common and satisfying solution regarding TEK17 energy requirements [14].

Figure 5: Example of ventilation airflow through apartments with balanced ventilation [1, 2]

- Balanced ventilation: the air supply and exhaust er almost equal with the possibility to recover the heat from the exhaust air. The system requires additional ventilation when the kitchen and bathrooms are used.
- Mechanical ventilation: the system is based on exhaust fans with the possibility of a god regulation of the exhaust air amount.

There are two general design methods for balanced ventilation in apartment buildings: individual and central systems. When an individual system, each apartment has its own AHU (Air Handling Units). At the same time, all the apartments are connected to the same AHU when central system. The exhaust from the kitchen hoods is recommended designed with a separate exhaust duct that leads to the outside [12]. Figure 6 illustrates this.

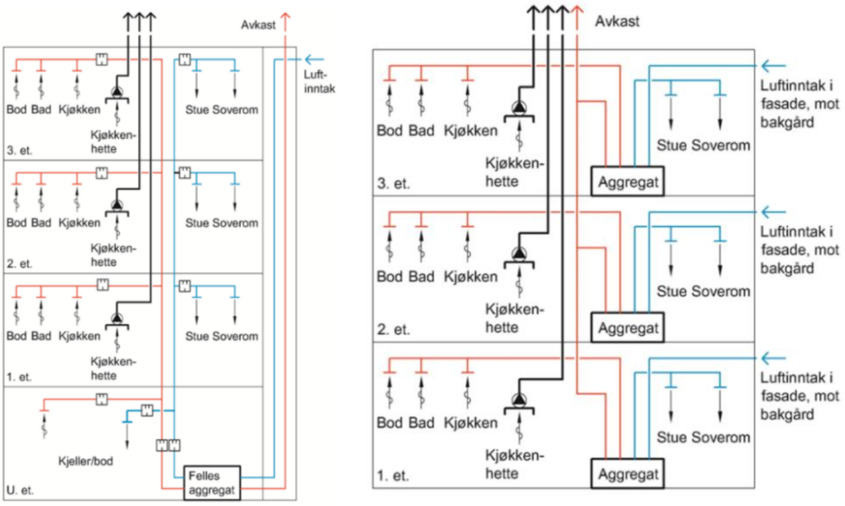


Figure 6: Principle sketch of apartment building with balanced ventilation. [3]

2.5 Cooking emissions

Cooking techniques such as frying, roasting, grilling, baking, smoking, boiling, and steaming contribute to pollutant emissions and are affected by the type of fuel, raw food composition, type of cooking oil, and cooking temperature- hood perform

Several studies show that particle emissions from cooking are primarily in the fine and ultrafine size ranges both in terms of particle mass concentration and particle number concentration. Particles are mainly concentrated in a range of 0,01-0,5 µm. The mass ratios of the particle sizes are shown in Table 5 [15-18].

Table 5: The mass ratio and ratio of number of fine particles during the cooking process

Cooking style	Items	Mass ratio	References
Laboratory kitchen (oil heating)	$PM_{0.1-5.0}/PM10$	≈1.0	Gao et al., 2013[16]
Laboratory kitchen (frying chips)	$PM_{0.1}/PM_{10}$ $PM_{0.1-1}/PM_{10}$ $PM_{0.1-2.5}/PM_{10}$	0.09 0.67 0.24	Buonanno et al., 2009[15]
Cooking style	Items	Amount ratio	References
Laboratory kitchen (oil heating)	$PM_{0.01-0.1}/PM_{0.01-0.5}$	0.76-0.99	Torkmahalleh et al., 2012[18]
Laboratory kitchen (oil heating)	$PM_{0.3}/PM_{1}$	0.84-0.9	Zhao et al., 2019[17]

2.5.1 Edible oil and cooking temperature

Differences in the composition of the oils affect their fume temperature. The semivolatile compounds emitted from oil condense and form an aerosol phase; consequently, the particle emissions occur [15]. Therefore, the composition of the oil further affects the particle emission rate. Soybean oil, safflower oil, canola oil, and peanut oil are known to be quite low-particle emitters compared with corn, coconut, and olive oils due to the higher smoke point temperature [18]. The smoke point is the temperature at which oil begins to smoke continuously. A general recommendation is that the higher the smoke point is, the better suited a fat is for frying. Fats with smoke points below 200 °C are not suitable[19]

Another study looking into emotions composition from heating by Harinageswara Rao Katragadda et al., 2009 compared the impact of heating oil with different smoke points on the emission of volatile organic compounds[19]. The tests were conducted on four types of oil at four different temperatures: 180 °C (deep-frying optimum), 210, 240, and 270 (temperature above the maximum smoke point). A smoke point for Canola oil was found to be 238±°C

Proper control of the oil temperature reduces indoor emissions of aldehydes during frying. Therefore, it is recommended to use the lowest possible temperature for reaching the desired cooking during deep-frying operations. In this study, Canola oil was the oil generating the lowest amount of potentially toxic chemicals. The emission of indoor air pollutants was mainly related to the smoke point of the oils being heated although. The formation of aldehydes and volatile rate was found to be constant with time and depends primely on oil temperature but also on the fatty acid composition of the oil.

These findings are consistent with the studies of (Torkmahalleh et al, 2012)[18]

looking to PM2.5 and ultrafine particles emitted during heating of 200 ml commercial cooking oils at 197 C. The results of this study showed that olive oil, corn oils, and coconut oil generated higher PM2.5 concentrations while peanut, safflower, soybean, and canola oil result in the lowest generation of particles, for both mass and number. The study results indicate that it is possible to considerably reduce the exposure to PM and UFP (Ultra Fine Particles) emitted by cooking sources by selecting oils with higher smoke temperatures as well as reducing the surface area of the oil

Numerous previous studies that investigate CE and the factors that have an impact on it are reviewed to brighten the subject and provide guidance on further work. Not everyone is reviewed in detail. A summary of the main findings has listed a table further down.

Lunden et al. in 2015 [20]

A central study of capture efficiency by Lunden et al. compared CE for cooking-generated particles and CE for burners produced CO_2. [20] . Capture efficiencies (CE) were determined for four under-cabinet exhaust hoods under carefully controlled conditions in an experimental room. CE for burner pollutants was determined directly by comparing the CO2 mass flow through the exhaust hood to the CO2 produced at the burner. CE for cooking particles was determined indirectly by comparing particle concentrations in the room when a hood was in use to concentrations measured during the same cooking activity with no hood installed. CE was calculated for particle measurements in different size bins. Two cooking procedures were tested: Pan-frying hamburger on medium heat on the back burner and a stir-fry of green beans on high heat on the front burner

The study indicates that CO2-based CEs measured for combustion pollutants are not predictive of CEs for cooking-generated particles under all conditions, but they may be suitable to identify devices with CEs above 80% for both burner exhaust gases and cooking-related particles. The study dos also affirm that the CE of the exhaust hood is higher for the back burners compared to the front burners. Figures below show the results for airflow (183-496 m^3/h). Capture efficiency for particles was calculated from the time when cooking began to when the particle concentration returned to the background, of the total of 25 min, of which 15 minutes is a post-recording period.

Singer et al,.2012 [16 [21]

A study by Singer et al.,.2012 conducted one-site CE tests for residential kitchen hoods in a laboratory and in the field. The tests were conducted with pots of boiling water on a gas cooktop. Fifteen different range hoods that were already installed and used in homes were tested. *The field [22]* and seven different range hoods for *laboratory tests[21]*. Both tests showed a large range of CE, from 17%–100% for the laboratory tests. The performance was largely dependent on the heating element used, airflow, and range hood geometries. Higher airflow generally led to higher CE. For wall-mount hoods, the performance depended largely on the airflow rate and the heating elements used. The lowest CE was for flat-bottomed hoods when front burners were used, while CE was much higher for the back-heating elements near the wall. The more of the front heating elements that were covered by the hood, the better the plume is captured.

Ventkook [23]

A laboratory study of Ventkook [23] for range hood performance-tested four representative Dutch meals on induction cook tops with a range hood installed on the wall. The CE was ranged 93.1%-99,6%. PM2.5 measurements were taken with an optical counter (GRIMM) and placed 2m from the hobs at one point in the room (with kitchen hood on and off). When the hood was switched off, a desk fan in the room was operated to mix the air and ensure a uniform concentration of PM. The primary ventilation was operating on 75m3/h. The measurement and calculation method are not specified and seem to be for exposure/odor reduction factor O_f than CE according to ASTM. The results are shown in the table below.

Table 6: Results from Ventkook study testing CE for different meals [23]

Meal	PM emissions (mg)	Capture efficiency (%)
Chicken, green beans, boiled potatoes	21.7	93.1
Chicken, green beans, fried potatoes	19.1	95.4
Pasta bolognese (back hob)	46.3	99.6
Noodles wooked with chicken and vegetables (back hob)	52.2	97.1
Average per meal	34.8	96.3

Cooking fuel, oil, temperature, method, and hood style are some of the parameters that have a major influence on the source strength of contaminants emitted by cooking. Table 7 shows some of the findings whit focus on parameters that are reported to have an impact on CE. Some of the studies are reviews; others are based on experiments.

Note that the CE referred to is based on CO_2 as a tracer gas.

Table 7: Highlights of findings on capture efficiency

Kim, Walker, Delp, “Development of a standard capture efficiency test method for residential kitchen ventilation, 2018 [24]	
CE, airflow and hood geometry	CO_2-CE improves with higher airflow and lower mounting. CE with two front and one back emitter configurations and mounting height of 61cm were ranged respectively from 74%– 92%. 74% for air flow of 180 m^3/h and 270 m^3/h. CE increased from 91%-95% for another hood model where the mounting height was increased from 61-91 cm with the same airflow of 464 m^3/h. Repeatability uncertainties typically±0.5% CE, with±1.4% CE at worst.
Disturbance	High make-up air from the air inlet produced a high-velocity air jet that might change the airflow patterns in the room and causing a great variability in the measurements
Han, Li, Kosonen, “Hood performance and capture efficiency of kitchens: A review, 2019. [25]	
Airflow and hood geometry	CE varies considerably depending on disturbing airflow, hood style and geometric features, distance from the cooking surfaces to the hood, the overhang and rear gap, the presence and size of side panels, cooking appliance diversity, food, and cooking processes, as well as the exhaust airflow rates.
Disturbance	The influence of disturbing airflow varies with its velocity and direction, cooking appliance type, and hood type and size. Makeup air introduced close to the exhaust hood has a detrimental effect on the capture hood performance. The convection load-based design is recommended to calculate the exhaust airflow, as it is the most accurate design method, which considers heat loads and empirical knowledge.
Meleika, Hicks, Pate, Sweeney, “The design, construction and evaluation of a test chamber for measuring rangehood capture efficiency [26] co2	
CE airflow and hood geometry	CO_2-CE increased as the flow through the range hood increased for most cases. For some, flow rates beyond a certain threshold result in no impact or a negative impact on CE. CE was 63,5 % (SD of 1.44%) for a hood-mounted in 51 cm, airflow of 214 m^3/h, and left and right electric burners operating
Disturbance	Three factors influenced the tests: prescribed steady-state time, inlet filter selection, and cabinet height.
Borsboom, Gids, Walker, Jacobs, “Assessment of Range Hoods based on Exposure,” 2018. [27] review	
Disturbance	If the focus is on exposure, the effect of disturbances must be taken into account. The flow field for capturing cooking plumes can be disturbed by the presence of cooks as they move around with their bodies and arms. This can reduce the efficiency by roughly 30%. The cook’s arm blocks an effective area of 0.075 m^2
Li, Delsante, Symons, “Residential Kitchen Range Hoods – Buoyancy-Capture Principle and Capture Efficiency Revisited, 1997. [28] review	
Airflow and hood geometry	identified two important parameters which influence the capture efficiency of a range hood, the exhaust flow rate and horizontal dimensions of the hood and their link with the buoyancy capture principle.

The most range hoods on the market usually run at an air flow of 540-720 m^3/h. The manufacturer’s recommendation is a minimal air flow of 165-220 m^3/h to get an acceptable function for the range hoods.

Tests in the laboratory done by Røros in Norway looked to disturbance influence on O_f for different range hoods in the Nordic. Minimum airflow 108, 140, 165 m^3/h was tested to maintain an ORF of 75% with disturbance and higher without disturbance for the range hood with a fold-down screen. See figure below. The tests dos also show that using MEK (Methyl-ethyl Ketone) as tracer gas does not represent a real-life cooking situation and that it takes 24 min after ending cooking to get back to the normal/typical air concentration in the room[29].

2.6 Calculations of exhaust air flow

Convection load method
The cooking process does not only emit large amounts of harmful gases but also releases a significant amount of heat, which produces an upward heat plume. A thermal plume generated by cooking processes is contained in the hood, which is directly related to the exhaust airflow rate. Therefore, the heat load should be considered for control of pollutants when designing the exhaust airflow rate for kitchen hoods. The most accurate kitchen ventilation design method should be based on the heat load of the appliances. Several methods for calculating the exhaust airflow rate were presented in a review by Ou Han et al.,2019 [25]. The convection load-based design was found to be the most accurate design method. The method considers many factors that exist in the actual cooking event, including convective heat output, the area of the appliance, the distance between the hood and appliance, and the general ventilation.
A theoretical calculation of the amount of air carried in a convective plume over a cooking appliance at a certain height is achievable using a generic theory of thermal plumes. This chapter presents different equations found in the literature for calculating different conditions in the plume.

Eimunud Skåret [30]
Free convection currents

A heat source causes air movement because the emitted heat heats the air near the source that will flow vertically, as illustrated in Figure 8. Replacement air is then drawn in towards the heat source, and heat-driven flow occurs. The convective power output is decisive and has a great influence on volume flow and speed. All convective heat from a heat source will be conserved in the convection current.

For point sources (axisymmetric flow), the Equations for Central-velocity, Central temperature, and airflow, when normal temperatures, are given:

$$U_m = 1{,}28 \cdot \left(\frac{\dot{Q}_k}{y + y_p}\right)^{\frac{1}{3}} \tag{5}$$

$$\Delta T_m = 20{,}9 \cdot \dot{Q}_k^{\frac{2}{3}} \cdot (y + y_p)^{-\frac{5}{3}} \tag{6}$$

$$\Delta T_m = 20{,}9 \cdot \dot{Q}_k^{\frac{2}{3}} \cdot (y + y_p)^{-\frac{5}{3}} \tag{7}$$

$$y_p = \frac{{}^{d}\!/_{2}}{C_b} \tag{8}$$

U_m	Central velocity [m/s]
	Power, the convective heat output of the cooking appliance [kW]
y	Height above the heat source [m]
y_p	Distance from the source to the convection pole imaginary point source [m]
d	Heat source diameter
C_b	Proportionality factor, 0.235
ΔT_m	difference between the central temperature of the jet and the ambient temperature
q_{vk}	volume flow [m³/s]

$$v_y = 0{,}13 \cdot \varphi_{conv}^{\frac{1}{3}} \cdot (y + d)^{-\frac{1}{3}} \tag{9}$$

Danvak [31]
The equations below can be used for natural convection over a concentrated heat source:

$$\Delta t_y = 0{,}45 \cdot \varphi_{conv}^{\frac{2}{3}} \cdot (y + d)^{-\frac{5}{3}} \tag{10}$$

$$q_{Vy} = 0{,}005 \cdot \varphi_{conv}{}^{\frac{1}{3}} \cdot (y + d)^{\frac{5}{3}} \tag{11}$$

v_y	Central velocity in distance y (m/s)
φ	Power, the convective heat output of the cooking appliance [W]
Y	Height above the heat source (m)
d	Diameter of the heat source (m)
Δt_y	Difference between the central temperature of the jet and the ambient temperature K
q_{Vy}	Volume flow (m^3/s)

Leif Ingmar Stensaas: Ventilasjonsteknikk [32]:
For a given distance x from the floor, x will have the following airflow and velocity when pollutants are transported upward because of a convection flow

$$w_c = C_1 \left(\frac{P_k}{x}\right)^{\frac{1}{3}} \tag{12}$$

$$L = C_2 \cdot P_k{}^{\frac{1}{3}} \cdot x^{\frac{5}{3}} \tag{13}$$

w_c	Central air velocity for the jet in a dictance x(m/s)
L	Air volume/airflow (m^3/s)
P_k	Power output (W)
C_1, C_2	Constants; C_1=1-2, C_2=0,05-0,15 typical value for C_2=0,06

VDI: German Kitchen Standard VDI [33]

The standard can be used when an accurate calculation of exhaust airflow rate is required. The calculations according to German VDI are based on heat loads and empirical knowledge.

$$q_v = k_e \cdot (z + 1{,}7D_h)^{\frac{5}{3}} \cdot (\varphi_{conv} \cdot \varphi)^{\frac{1}{3}} \cdot k_r \cdot k_s \tag{14}$$

K_e = empirical coefficien; 0.005 for a generic hood

Z_m the distance between the local exhaust hood and cooking surface (m)
D_h= hydraulic diameter (m)
$_{conv}$= convective heat output of the cooking appliance block (W)

Φ= simultaneous factor (normally 0.5–0.8, meaning that only 50%–80% of the appliances are used at any one time)
k_r = reduction factor of the installation location (free k_r =1, near-wall k_r =0.63 or in the corner k_r 0.43)
k_s = spillage coefficient that considers the effect of the air distribution system. Obtaining 85% and 90% pollutant removal efficiency leads to a spillage coefficient of 1.2 and 1.5 using the centralized capture jet concept [34]
Vena Contraction is the point in a stream where the kinetic energy is at the maximum and pressure energy at minimum as the diameter of stream is at the minimum. The phenomena occur because the fluid streamlines are not able to abruptly change direction. The coefficient of contraction is defined as the ratio between the area of the jet at the vena contracta and the area of the orifice. The typical coefficient value is often given as 0.611 for a sharp orifice.

3. Methods

3.1 Test facility design and construction

The following subsections will describe the design and construction of the test room located at SINTEF community ventilation lab

3.1.1 Test room

All standards refer to a test room corresponding to an ordinary kitchen with a volume of 22 m^3, as the focus is on the calculations of the effectiveness (Chap.2.2). The facility design for this work is built up as an open floor plan (kitchen and living room area) corresponding to the most common floor plan solutions in modern urban apartments in Norway, as shown in Chap 2.3, as the focus is exposure and capture efficiency. Therefore, the test room design for the experiments exceeds the standard recommendations. The airtight chamber is increased to 80.3 m^3. A schematic of the laboratory layout with belonging dimensions is shown in Figures 7 and 8; Figure 8 illustrates the kitchen setup according to the standards in chap. 2.3

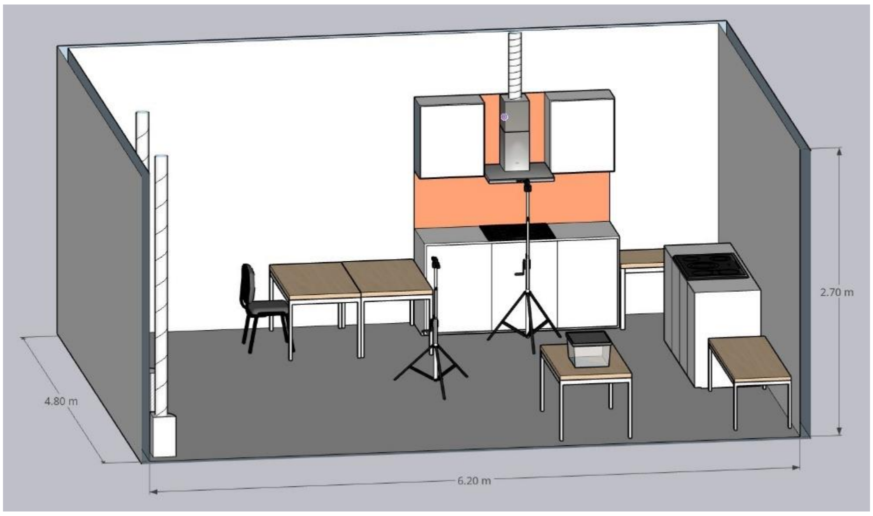


Figure 8: A sketch of the test room

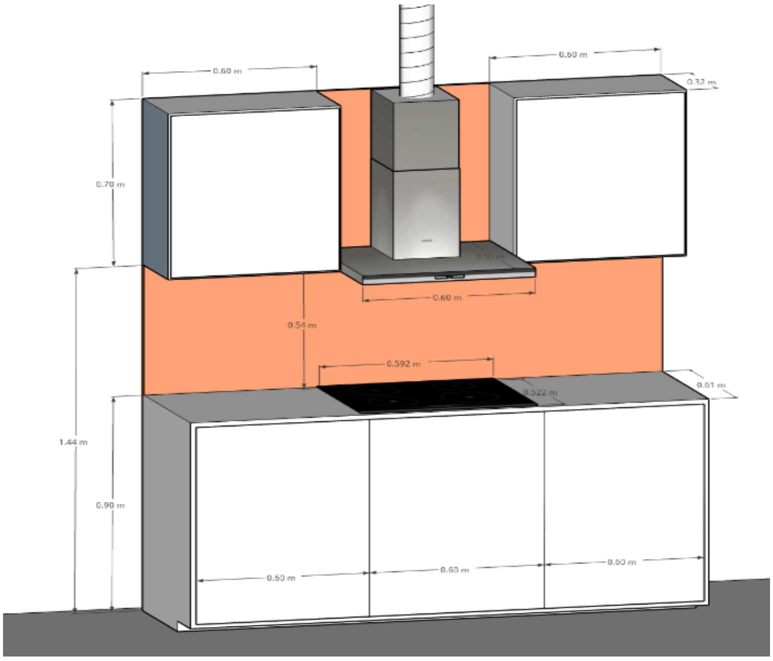


Figure 7: Sketch of kitchen installation

3.1.2 Laboratory conditions

With regard to recommended test room conditions in Chap 2.2, the desired conditions during the experiments are shown in Table 8.

Table 8: Test room conditions

Test room air temperature (°C)	22 ± 0.5
Air inlet Air temperature (°C)	22 ± 1
Test hall Air temperature (°C)	21 ±0.5
Pressure test rom/hall (Pa)	0± 0.2

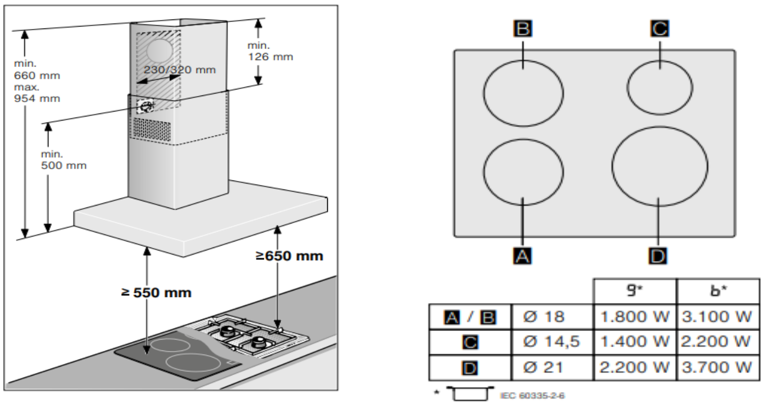
3.1.3 Kitchen setup

A type of cooktop has an impact on energy consumption and emissions from cooking. The selections are different depending on the user's desire and purpose. For commercial kitchens, gas stoves are more common. Moreover, in many countries' biomass is the primary source of heat for cooking; in some others, electric stoves and gas stoves are more common. In the transition towards an energy-neutral built environment, induction cooking has been more common in Norway and other countries. Therefore, an

Figure 9: Experiment setup: range hood, cooktop, and equipment

The induction cooktop shown in Figure 9 is selected in this study as it is dedicated to modern apartments. An Induction cooktop from Simens shown Fre (h:51 x b:592 x d:522 mm) with four cooking zones is selected for the experiments. The cook top has 17 power steps include mid-channels between each main power levels. There are nine main power levels and one boost function. Level 1 is the minimum level with a power of 1000 [W] and level 9 maximum level 3700 [W].) Figure 10 shows the various sizes and power for all cooking zones. For the experiments, only zone D is used. The cooktop does also has an energy consumption indication. A function that shows the total energy use during the last cooking session. The cook-top is installed in accordance with the manufacturer's instructions.
Range hood
A standard wall-mounted range hood from the same manufacture as the hob (Simens) has been selected. The hood can be used for both exhaust and recirculation. The hood has 3 power levels, one intensive level, and a booster function. The hood is installed at the same height as the cupboards 54 cm above the

cook top and moved upward to 70 cm above for the other conducted tests. Appendix A shows some of the product fiches related to airflow. Figure 11 shows the applied Renge hood and cooktop



		9*	b*
A / B	Ø 18	1.800 W	3.100 W
C	Ø 14,5	1.400 W	2.200 W
D	Ø 21	2.200 W	3.700 W

Figure 10: Test cook top and rang hood

A simple survey was executed to assess the mounting heights of kitchen hoods by different suppliers. Most kitchen providers we have interviewed over the phone have emphasizes that they install downdraft for the most part. When wall mounted hood is installed, the mounting heights are normally in the same height as the cabinets. The mounting height varied when the hood was free-standing installed (no cabinets on the side). In the experimental setup, the range hood was mounted 54 cm above the cook top (as the cabinets) and 70 cm.

Table 11 shows the highlights from the conversations with the suppliers.

Table 9: Mounting heights survey

Kitchen Suppliers	Lower height [cm]	Max height [cm]	Comments
Kvik	56	70	If integrated with wall cabinets down to 46 cm
Sigdal	51.4	70	If integrated with wall cabinets down to 51.4 cm
Designa	54	65	f integrated with wall cabinets 54 cm. Cabinets mounted on 54 cm. For the most 60-65
Drømmekjøkken	56	70	If integrated with wall cabinets down to 50 cm. For the most 65-70 cm
Rotpunkt	50	70	Suppose integrated with wall cabinets 50 cm. The largest cabinets are mounted on 50 cm, then -13 cm for each shorter variant. For the most 63-70
Bulthaup	60	70	For the most 60-65 cm. Downdraft installed in 9/10 Kitchens.
Byggmaker Brobekk /Norema forhandler	50	75	If integrated with wall cabinets down to 50-51 cm. For the most 65 cm

3.1.4 Instruments and measurement points

Sampling points

The objective of the current study is to evaluate particle-based CE that is relevant to actual cooking activities. Therefore, the measuring points recommended in standards reviewed in Chap 2.3 were deemed unsuasible as the particle loss in the duct and the hood would bias the concentration measured in the exhaust and consequently bias the CE calculations. This is further discussed in Chap 3.7. Thence the mean measurement point determined in the middle of the room (point 2) 1.25 m above the floor. The selected position is also in terms of keeping distance from both supply and exhaust air. The concentration is also recorded in two other points for two reasons. Firstly, to be able to evaluate the achievement of a consistent concentration in the room. Secondly, the test room is used in parallel for other experiments looking to exposure in different locations in the room. Figures 12 and 13 shows a setup with the range hood mounted in a high of 70 cm above the cooktop

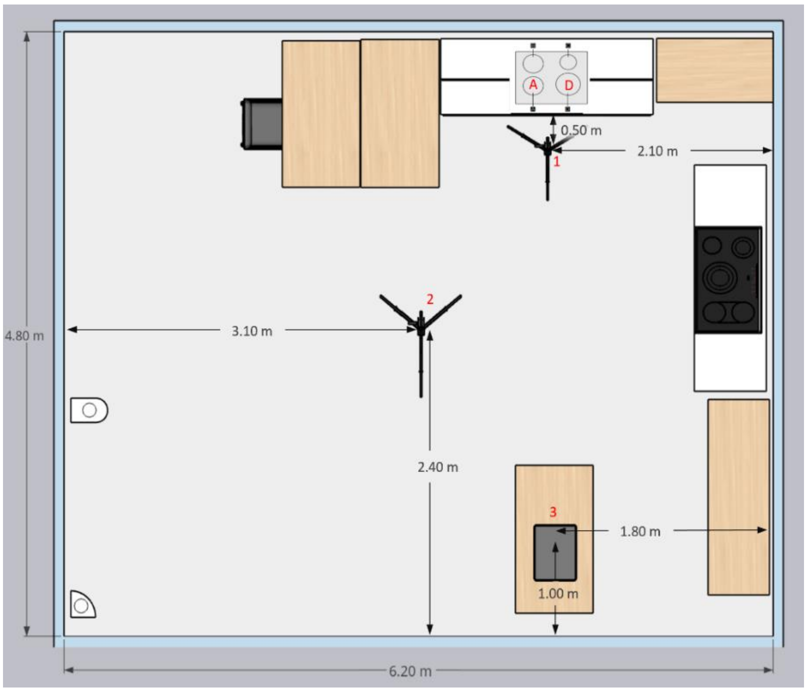


Figure 12: A top view of sampling points in the test room

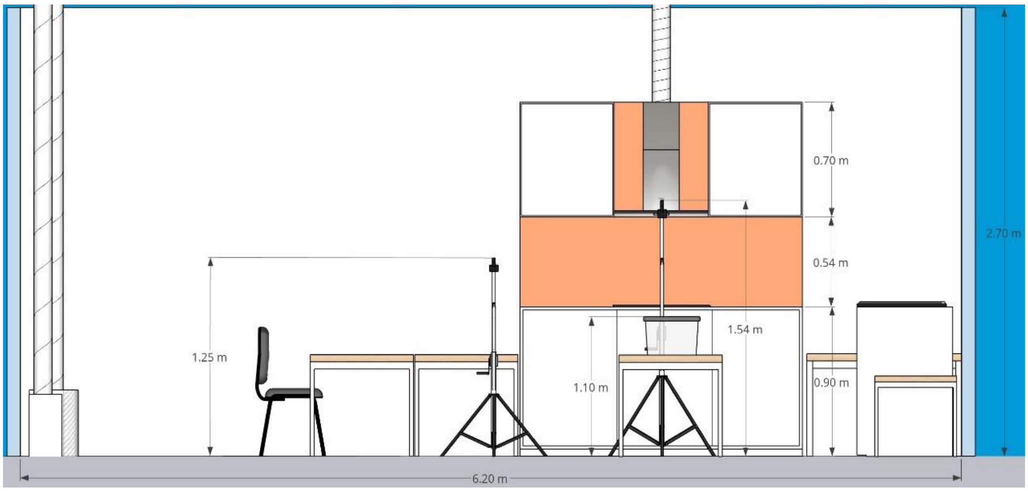


Figure 11; Front view of the sampling points

3.1.5 Instruments and recording frequency

The particle concentration was measured and recorded every minute with different instruments. As shown in Table 10, the air temperature and other parameters were also measured and recorded. A thermocouple of type K was placed in the center of the pan and was recording every 5 seconds to monitor the temperature of the heated oil manage to regulate the power quickly as the temperature increased rapidly. Table 10 shows an overview of the instruments, the measured parameters, and sampling locations. More details related to instruments are attached in Appendix B. Figure 13 is a picture of the instruments positioned in location 3 in the test room

Table 10: Measuring instruments and sampling points

Instruments	Parameter	Sampling point
APC-Aerotrak: Handheld Airborne Particle Counter Model 9303	Three particle size at the same time 0,3/0,5/5µm	1-Breathing height in front of the cooktop 2-Middle of room 3-Sitting height
OPC-Grimm: Portable Dust Monitor 1.108	0.30 µm to 20 µm. PM1, PM2.5, PM10,	2-Middle of room
UPC-P-Track: Ultrafine Particle Counter Model 8525	Particle Concentration: 0 to 5 x 10‘5 particles/cm3	2-Middle of room
Thermocouples type T	Air temperature [°C]	Supply and exhaust air, test room and hall, plum
Thermocouples type K	Cooking temperature [°C]	center of the pan-Oil
Air Handling Controller DPT-CTRL 2500-D	Airflow [m^3/h]	Supply and exhaust air
Q-TRACK: Pluss IAQ Monitor. Air velocity Probe Model 8552/8554	Air velocity [m^3/h] and temperature [°C] for the plum	10, 20, 30, 40 cm above the heated oil
Controller DPT-	Pressure [Pa]	Across the room and the hall

Figure 13: Instruments in sampling point 2

3.1.6 Ventilation setup

Most of the reviewed studies (Chap.2.5) indicate that supply air introduced close to the exhaust hood has a disturbing effect on the measurements of exposure due to a high-velocity air jet that changes the airflow patterns in the room. Displacement ventilation is considered beneficial to ensure low air velocity near the hood and to avoid interference with thermal plumes.

Figure 15 shows an individual balanced ventilation system corresponding to the recommendations mentioned in Chp 2.4 that was delivered by GK and regulated in GK-cloud. Otherwise, the ventilation unit supplied the test room only, and the exhaust air was led separately and was not connected to the AHU. The scheme was mounted on the roof and supplied the room with particle-free air through a Hepa filter. A schematic of the ventilation system in Gk-cloud is attached in Appendix C

Figure 14: Installed AHU system

3.1.7 Air supply

Figure 16 shows the two supply air diffusers of type Trox Siv inn 2000 that were placed on the floor on each side of the entrance to the test room.

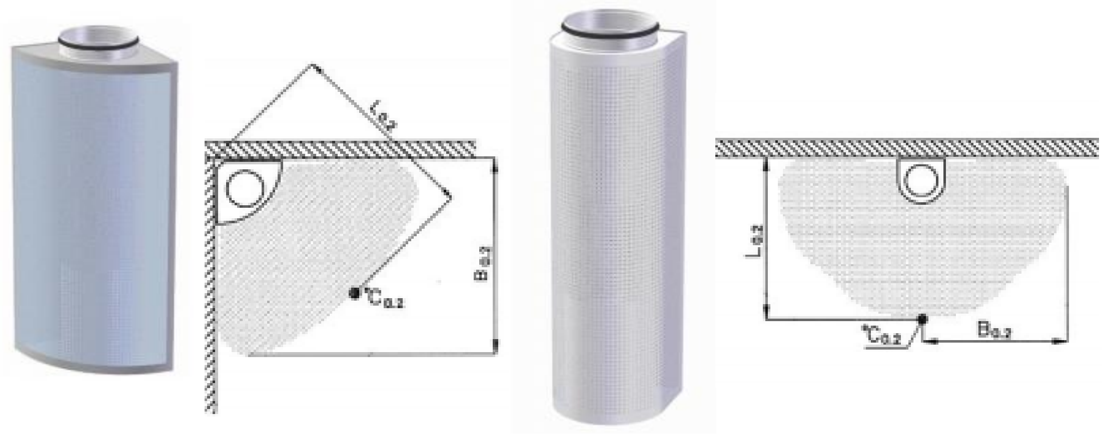


Figure 15: Siv-inn 2000 1/4R placed in the corner and 1/2R placed on the right side of the door

Supply air was measured and recorded for each test by an Air Handling Controller DPT-CTRL 2500-D. Both diffusers were equipped with a manual sliding damper and connected to the ventilation unit by a duct of 160 cm through the roof.

3.1.8 Exhaust air

The built-in hood fan provided exhaust air, and frequency-controlled in-line fans are shown in Figure 16. The exhaust air was extracted from the room to the test hall, as shown in figure 17, and not connected to the ventilation system. The flowrate was measured and recorded for each test by an Air Handling Controller DPT-CTRL 2500-D

Figure 16: In-line-auxiliary fans

For the primary exhaust, an exhaust valve/unit of type LØV-R-KSO-160 was mounted on the ceiling, all most in the center of the room, and connected to a duct of 160-cm-diameter that leads to the roof.

3.2 Experimental setup

3.2.1 Ventilation setup

The rang hood was wall-mounted and connected to a duct of 160-cm-diameter immersed from the ceiling. As mentioned above, the exhaust was provided by the build tin hood fan for the experiments with the hood on, and to different additional auxiliary in-line fans when the hood was switched off, and for the condition with airflow of 144 m^3/h.
The room was operated at the same primary/background exhaust ventilation of 36 m3/h for all the experiments except for Test A-1 (with primary ventilation only), as we did not succeed in measuring and regulate the air flow to 36 m3/h. The airflow was increased/double (72 m3/h) for that reason and to avoid saturating the instrument due to high particle concentration. The table above shows the airflow and ACH "Air Change per Hour" for the different tests. The pressure across the test room and the test hall was monitored and recorded. The supply of air was increased by the amount of flow through the hood in use to maintain a stable pressure difference in the room. The setup is shown in Table 11

Table 11: Test airflow and ACH

Test	Hood Setting	Primary exhaust (m^3/h)	Additional exhaust (m^3/h)	Tot. exhaust (m^3/h)	Supply air 1 (m^3/h)	Supply air 2 (m^3/h)	Tot. air supply (m^3/h)	ACH (1/h)
A1	OFF	72	0	72	71	closed	72	0,9
A2 and A3	Auxiliary fan	36	108	144	108	closed	144	1,8
B1, B4, C1 and C4	level 1	36	182	218	113	106	219	2,7
B2, B5, C2 and C5	level 2	36	285	321	164	158	322	4,0
B3, B6 C3 and C6	level 3	36	359	395	204	194	398	4,9

3.3 Calibrations and pre-tests

3.3.1 Thermocouples calibration

The thermocouples used in the experiments were calibrated using a Hart Scientific 9105 Calibrator. The temperature tested were 140, 80, 40, 22, and 10 °C. The results show the highest deviation when testing Type T against 140 °C: -2,8 °C for supply air, and +0,8 °C for the hood exhaust air when testing against 80 °C, a condition that would not appear. The deviation is +0,7 °C and + 0,3 °C when testing against 22 °C. The calibration is considered valid due to small deviations.

Table 12: Thermocouple calibration

Logger outside test-hall										
Type T (°C)	140	SD	80	SD	40	SD	22	SD	10	SD
Test-hall	137,5	2,5	80,6	0,6	39,7	0,3	22	0	10	0
Exhaust hood	137,9	2,1	80,8	0,8	39,2	0,8	22,3	0,3	9,9	0,1
Primary exhaust	137,6	2,4	80,6	0,6	39,4	0,6	22,4	0,4	10,3	0,3
Supply air	137,2	2,8	80,7	0,7	40,5	0,5	22,7	0,7	10,5	0,5

Logger inside test-room										
Type T (°C)	140	SD	80	SD	40	SD	22	SD	10	SD
Plum-right-D	137,8	2,2	78,8	1,2	39,6	0,4	21,9	0,1	10	0
Test-room	138,8	1,2	79	1	39,2	0,8	21,5	0,5	9,9	0,1
Type K (°C)	140	0	80	0		40	22	0	10	0
Cook-top-D	140,3	0,3	79,2	0,8	39,5	0,5	22,3	0,3	10,6	0,6

3.3.2 Airflow regulation

The ventilation system had a maximum capacity of 4500 (m3/h), which turned out to be difficult to regulate to small airflow amounts in order to achieve balanced ventilation for all tests; an equal amount of supply air and exhaust. The flow rate was precisely regulated. Firstly, by an automatic Butterfly flat Dish Damper in GK-cloud, then manually with a Blade/Slide damper for each duct that leads to the diffusers. The flow rate was first measured by Seema 3000. A regulation-setting table for all test categories was developed. The instrument was unstable for the smallest airflow amounts and was not able to record during the experiments. The regulating dampers are shown in Figure 19

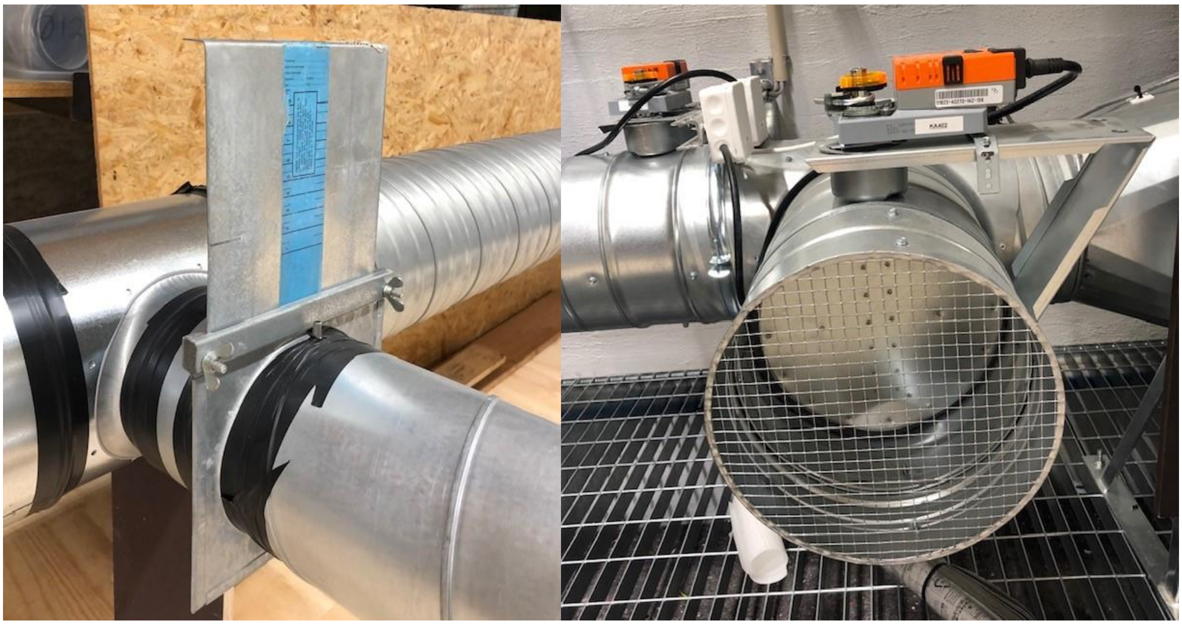


Figure 17: Sliding damper and Butterfly flat Dish Damper user to regulate the airflow

We sought to make new measurement and regulation settings with a new instrument, Air Handling Controller DPT-CTRL 2500-D, that could record through the entire experiment. The table below shows the regulating settings for the different experiments.

Table 13: Airflow regulation

Hood Setting	Supply air GK-cloud		Air diffuser 1 (corner)		Air diffuser 2		Total air supply (m3/h)
	Sett-Point (m3/h)	KA402 Damper (%)	Damper (%)	DPT-CTRL-2500-D (m3/h)	Damper (%)	DPT-CTRL-2500-D (m3/h)	
OFF	300	70	20	71	closed	0	71
Auxiliary fan	400	50	open	142	closed	0	142
level 1	400	45	open	113	open	106	219
level 2	400	17	open	164	open	158	322
level 3	460	0	open	204	open	194	398

3.3.3 Pre-tests

Axial fans

For test A-1 with primary ventilation only, two household axial desk fans were operated in the room to achieve good mixing of the air and reduce directional airflow around the hood. Preliminary tests were taken in three positions in the room to evaluate the placement of the fans and mixing conditions. The fans were operating at maximum setting and placed on each side of the cooktop 0,6 and 0,9 m above the floor, as seen in figure 20.

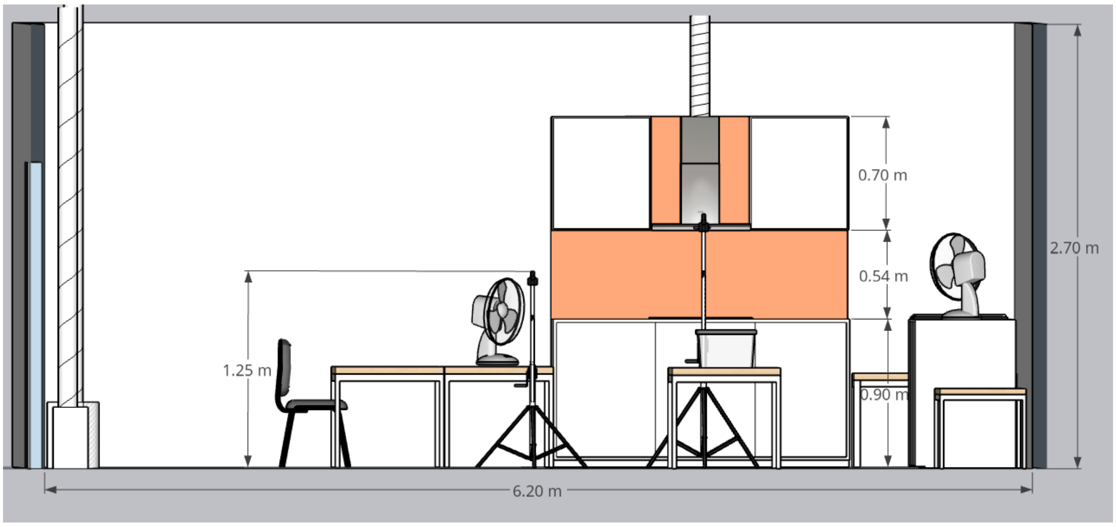


Figure 18: Sketch of test room during test A-1 with desk fans

Figure 21 shows that the chosen placement and settings improved a consistent concentration in the different locations. The measurements were taken with Aerotrak.

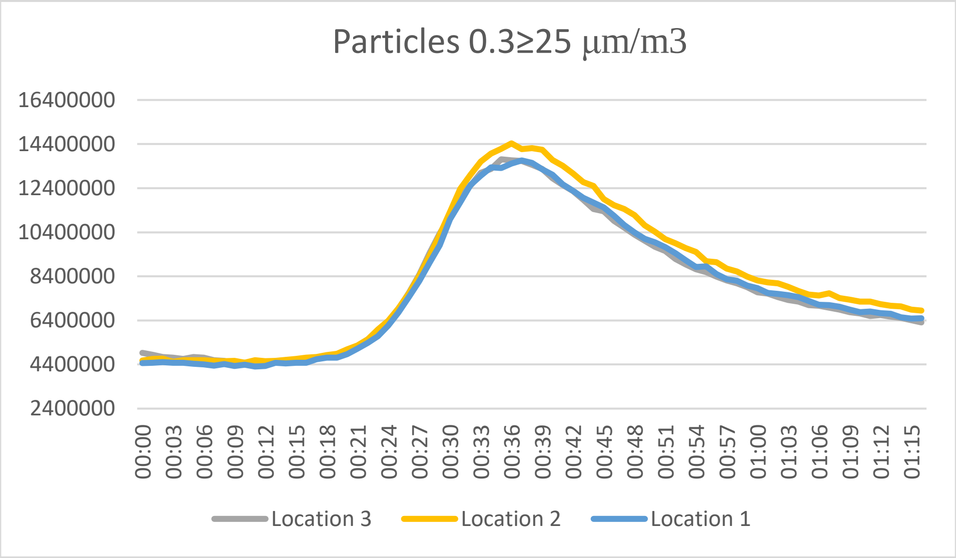


Figure 19: Particle concentration in the test room with no hood operating

3.3.4 Cooking event

As reviewed, some of the important parameters that should be controlled to achieve a good performance assessment for all experiments includes the power input into the cooking appliance, thus the surface temperature and the disturbance. The measurements for CE related to cooking particles depend on the cooking procedure being suitably repeatable. Both standards and studies review in chap 2.2 and 2.6 pointed out that movements created by a cook create disturbances and lead to measurement instability. Different cooking events/dishes have been considered: boiling water, real cooking meals, CO_2 tracer gas, and heating oil. Using CO2 as inter tracer has been considered and deemed unsuitable for those experiments as the object of this work is evaluating CE for particles relevant to the actual cooking activity. Challenges for accomplishing a consistent plum from test to test in a standardized, replicable way for experiments are reported for the use of boiling water. Boiling water removes about 40%–65% of the heating energy from the plume and needs to be carefully controlled. (Kosonen et al. 2006b)

They are considering the findings, heating oil for as the deep-frying cooking event was chosen to attempt to generate a reproducible quantity of pollutants through execution of a tightly controlled cooking protocol. This cooking event was also considered to be a "simple" process that does not require or create much disturbance around the instruments. High cooking -the temperature is to be avoided. As previously mentioned in Chap 2.5, high cooking temperatures lead to higher contamination. In the cooking process, the oil temperature should not be higher than the smoke point. For that reason, 200ml of Canola oil (smoke point >210 °C) was used. More details about the procedure in Chap 3.2.5.

3.3.5 Cooking equipment

Cooking equipment and the bottom of the pan can affect the result of cooking and thus the test results. To efficiently cooking and save energy, Simens recommends using pots and pans with a flat bottom and in materials that distribute the heat evenly in the cooking vessel, e.g., boilers with sandwich bottom in stainless steel.

Table 14: Cooking equipment's and conditions

Particles generation	200 ml Canola Oil
Cooking zone	Front right zone
Kitchen utensil	Tefal frying pan 28cm Ingenio resource; made with aluminum and Tefal Titanium Pro non-stick coating
Cooking power level	8 and 5
Cooking Temperature [°C]	180 ± 5
Cooking power [W]	885/464

Figure 20: Test equipment; pan with the heated oil

3.3.6 Oil temperature

As reviewed in Chap 2.5, proper control of the oil temperature reduces indoor emissions of aldehydes during frying. Therefore, it is recommended to use the lowest possible temperature for reaching the desired cooking during deep-frying operations. Canola oil was the oil generating the lowest amount of potentially toxic chemicals. The recommended frying temperature for oil is 180 °C. The standards recommendation in NS-EN 13141-3:2017 for the cooking temperature during the test 170 ± 5 °C. Attaining and maintaining a stable temperature of around 180 for oil has been proven to be difficult. Different power levels and heating time were tested before a procedure was developed by heating the oil on level 8 (885 W) for approx. 3,5 min to 191 °C and turning the heat down to level 5 (464 W), we managed to maintain the temperature between 180-185 °C during the rest of the experiment. A profile of the heated oil is shown in Figure 23

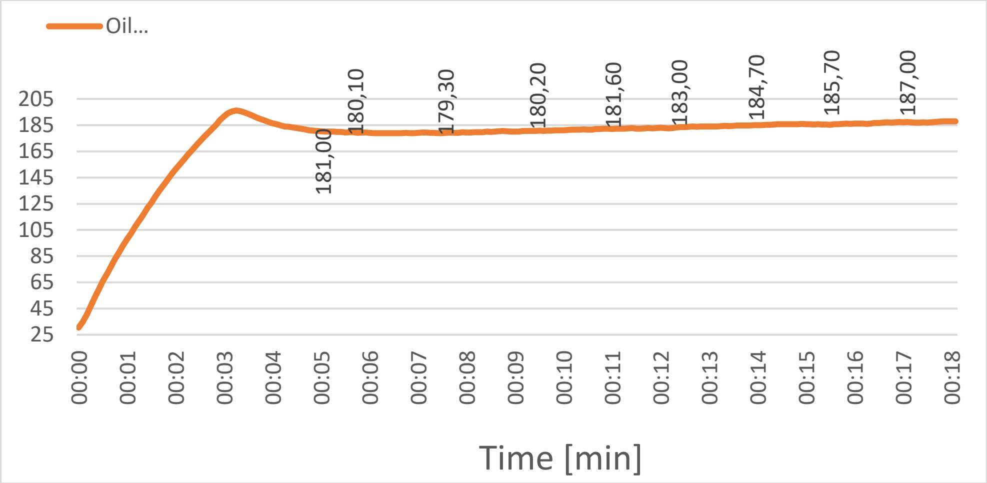


Figure 21: Temperature profile for the heated oil

Cooking procedure.

The oil was heated on the right front zone in a pan. The cooking zoon was firstly operated on level 8 (885 W), then turned down to level 5 (464 W) after approx. 3.5 min. To minimize activity-based air movement that may affect the measurements, the researcher moves away from the cooktop after the power regulation and sits on the chair illustrated in the sketch until the experiment time expires. The power is then maintained for another 16,5 minutes so that the entire test period lasts for 20 minutes before the heat switches off. The frying pan was covered with a lid, the door opened, and the researcher leaves the room. For safety reasons, the pan with the hot oil was not moved from the cooktop.

For each experiment: the pan was cleaned, washed with soap to remove any residual oil. The pan was then cooled down, the thermoelement and "fresh" oil were weighed and added. Table 15 shows an overview of the cooking procedure.

Table 15: Cooking procedure

Steps and description	Start time
1- Test-0. All instruments on	00:00:00
2- The power turns on Level 8	00:20:00
3- The power turned down to level 5	00:23:30
4- The reassurer walks away from the cook top	00:23:30
5- Log for total 20 min	00:40:30
6- Turn off the power	00:40:30
7- Read the energy consumption	00:40:30
8- Cool down and cover the pan after 30 sec	00:41:00
9- The door opens. Researcher leaves the lab	00:41:30
10- log for 30 min more	01:11:30
11- Enter the test room and stop instruments	01:11:30
Expt-end	01:11:30
Ventilate the test room and prepare for the next expt.	

3.4 Air velocity in the plum

The air velocity and temperature in 4 heights are measured and recorded at the center of the pan by a velocity monitor connected to a tracker. The height over the oil was measured to the center of the instrument, where it was installed in a stable position. The instrument was set at a recording interval of 10 secund for a measuring period of 2 minutes. The output was an average value over the sampling period. The instrument has been validated against another instrument. Figure 24 shows the experiment setup

Figure 22: Measurement setup for air velocity and temperature in the plum

3.5 Experimental Schedule

The experiments were conducted in May 2021 and arranged in three categories.
Nine test combinations were performed and repeated in regard to collecting credible data and provide an initial understanding of the repeatability. The original test plan included two identical tests per combination due to the lack of time. In the case where the variation between different replicated experiments of the same conditions was large, the laboratory test conditions are to be evaluated. In the worst case, when abnormal measurements the experiment has been repeated, for whatever reason. For most of the combinations, several tests have been performed to ensure credible results with low deviations. in a total of 27 experiments. As shown in Table 16
Before the start of every experiment, a zero-test of the Airotrak was performed. The particle filter for the GRIMM was changed four times during the experiment period. A zero-test has also been performed for the P-track. The fat filter has been cleaned when the hood notified the need.
To ensure stable conditions before every experiment, the range hood was switched on, airflow for both supply and exhaust air was regulated for each ongoing experiment, and all instruments started recording as Test-0 before every experiment for at least 10 min.
The time it takes before the particle concentration in room decreases was also of interest. Therefore, the instruments continue to log for 30 minutes after the researcher leaves the room.

Table 16: Experiment schedule

Test type	Nr of expt.	Conditions	Height above the cook top
Test-0:	Background emissions before every expr with the same conditions as the upcoming experiment		
Test A:	Rang hoof off or performed by an auxiliary fan to regulate the exhaust flow rate to 108 m^3/h		
Test A-1	3	The building hood fan off. Primary ventilation only	54
Test A-2	2	The build-in hood fan off. An auxiliary fan in use. Primary ventilation and the minimum required additional ventilation	54
Test A-3	2	The building hood fan off. An auxiliary fan in use. Primary ventilation and the minimum required additional ventilation	70
Test-B	Range hood in use on different levels and two mounting heights		
Test B-1	3	Range hood on level 1	54
Test B-2	4	Range hood on level 2	54
Test B-3	3	Range hood on level 3	54
Test B-4	3	Range hood on level 1	70
Test B-5	4	Range hood on level 2	70

Test B-6	3	Range hood on level 3	70
Test- C	Central air velocity and temperature in the plum. 10, 20, 30, and 40 cm above the heated oil		
Test C-1	1	Similar to A2	54
Test C-2	1	Range hood on level 1	54
Test C-3	1	Range hood on level 2	54
Test C-4	1	Range hood on level 3	54
Test C-5	1	Similar to A3	70
Test C-6	1	Range hood on level 1	70
Test C-7	1	Range hood on level 2	70
Test C-8	1	Range hood on level 3	70

3.6 Capture efficiency

Several tests and calculating methods to evaluate different performance characteristics of a range hood have been reviewed in the literature (Chap 2.2), including the dynamic fluid efficiency FDE_{hood}, Odour reduction factor O_f, The grease absorption factor G_{FE} and capture efficiency CE. The O_f method in IEC 61591:2019 standard is pointed out to be intended to assess the effectiveness of rang hood operating in recirculating mode and were not applicable in this case. Further development of the same test method is made in NS-EN 13141-3:2017 standard is intended to range hoods in extraction mode. Tracer gas is used in all the tests. The standard test and calculation method recording ASTM also was found to be inconvenient because the particle loss in the duct and the hood would bias the concentration measured in the exhaust and consequently bias the CE calculations. A calculation method based on an indirect approach of O_f method NS-EN 13141-3:2017 (formula 3 Chap 2.2) has been developed by comparing particle concentration when the range hood was in use to the concentration measured with the hood switched off. Otherwise, there is a need to account for particles in the room that are not associated with the cooking activity. This is further described in the section below. Almost the same approach is used in a mentioned study by Lunden et al, [20], with some differences in test facility and conditions.

3.6.1 Background emissions

As mentioned above, there was also a need to account for particle concentrations in the room that are not associated with the current cooking activity. Therefore, every experiment started with-Test-0-measurements of the background emissions C_{bkg}. The particle concentration in the room that is related to an increase of particle concentration C_{bkg} caused by the experiment's execution during the test day is subtracted. Thus, the C_{bkg} is not subtracted in the cases where there has been no or a significant increase.

3.6.2 Calculation period and combinations

In the standard test methods (reviewed in Chap. 2.2), the concentration of MEK was measured at the end of the dripping period of 30 min for NEK IEC 61591:2019, and 10 min NS-EN 13141-3:2017 with all ventilation turned off, for both conditions-without and with the operating C_1 and the hood operating C_2-. Unlike our experiments, the heat was on for 20 min then turned off for a post-recording period of 30 minutes, as we were also interested in the time it takes before the concentration returns to start level. The recordings were taken every minute, meaning a total of 50 records. The hood was kept operating for the entire time.

As opposed to the standards where the mean purpose is an evaluation of the effectiveness of the range hood itself, the focus in our study is additionally the exposure. Therefore, two different CE calculations are contrived and includes. CE during the experiment to evaluate the exposure the user/cook is exposed to. And CE post-experiment-in somehow similar to the standards- to assess the effectiveness of the hood assumed that the user keeps the hood on.

Lunden et al, 2015. referred to in the review calculated CE as an average from the time when cooking begins to when the particle concentration returns to the background of a total of 25 min, of which 15 minutes is a post-recording period.

Therefore, an average CEs was calculated as:

- CE $_{\text{during expts.}}$: the last 10 minutes during the experiment (recordings 10-19), as the temperature of the heated oil has stabilized around 180 °C
- CE $_{\text{post expts}}$. : the first 10 minutes after the heat was turned off. (recordings 20-29),

Combinations

The two mentioned CEs above are calculated for 8 different conditions of airflow rate and a mounting height: 144 m^3/h, 221 m^3/h, 322 m^3/h, and 395 m^3/h with hood mounted 54 cm, then 70 cm above the cooktop

3.6.3 Calculation formulas

The total CE is calculated in the following steps and demonstrated for an of experiment combination.

Substractions of background emissions

For the single repeated experiment for expr B-1(1), an average particle concentration is calculated by integrating the particle concentration measured between the time mentioned above. The formula below shows the calculation formula for $\Delta C_{B-1(1)}$. The same calculation method is used for all other combinations and for the concentration with the hood of

$$\Delta C_{B-1(1)} = \int_{ty}^{tx} \left(C_{cook.} - C_{bkg}\right) dt \tag{15}$$

C_{ook}	the particle concentration measured when cooking with the hood operating
C_{bkg}	the increasement in background emissions during the test day

The average concentration for an experiment combination
An average ΔC_{B-1} based on all repeated experiments is then calculated by the equation below

$$\overline{\Delta C_{B-1}} = \overline{\left(C_{cook.} - C_{bkg}\right)} \tag{16}$$

CE for an experiment combination

For instance, CE for the experiment combination B-1, including all replicated experiments is calculated relative to the experiment when the hood is of (A-1) as shown in the formula below

$$CE_{B-1} = 1 - \frac{\overline{\left(C_{cook.with-hood} - C_{bkg}\right)}}{\overline{\left(C_{cook.no-hood} - C_{bkg}\right)}} = \frac{\overline{\Delta C_{B-1\,with-hood}}}{\overline{\Delta C_{A-1\,no-hood}}} \tag{17}$$

CE $_{B\text{-}1}$ Capture efficiency as average emissions over the measurement period for replicated experiments of the same conditions

$C_{.cook.with\text{-}hood}$	the particle concentration measured at the room with the hood operating
$C_{cook.\ no\text{-}hood}$	is the particle concentration measured at the room whit the hood off

3.6.4 CE for all combinations

And finely, an average CE $_{\text{tot. During expts.}}$ It is calculated across all 8 experiment combinations for the given measuring period above as shown in the equation below, likewise CE $_{\text{tot. Post expts.}}$

$$CE_{tot.} = \sum_{8}^{1} \overline{(CE_{A-2} + \cdots + CE_{B-1} + \cdots CE_{B-6})} \tag{18}$$

CE $_{\text{tot}}$ Capture efficiency as average emissions over the measurement period for all experiment combinations

3.7 Convection load calculation

The formulas mentioned in Chap. 3.2.4 are used for the calculations of Exhaust air flow

3.8 Uncertainty in calculations

The uncertainty in CE calculations is considered as a combination of uncertainty related to repeated measurements and uncertainty related to the OPC. Hence, total uncertainty U$_{\text{tot}}$ in CE was estimated using a combination method (in quadrature) for summing influential variances that may have an impact during all replicated experiments. The experimental conditions that have been recorded and included in the calculation are mentioned in section 3.1.2

$$U_{tot}(v) = \sqrt{U_{prt.}{}^2 + U_{ist}{}^2 + U_{temp.}{}^2 + \cdots U_n{}^2} \tag{19}$$

3.8.1 Uncertainty in replicate experiments

The mean value of all variables was firstly calculated by:

$$\bar{x} = \frac{1}{n} \sum_{i-1}^{n} x_i = \frac{x_1 + x_2 \ldots + x_n}{n} \tag{20}$$

Secondly, the standard deviation SD by:

$$S\,(x) = \frac{1}{n-1} \sum_{i-1}^{n} (x_i - \bar{x})^2 = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 \ldots + (x_n - \bar{x})^2}{n-1}} \tag{21}$$

The relative standard deviation (RSD) (%) is a standardized measure for the ratio of the SD relative to the mean displayed as present age (%). Calculated based on average value by the equation:

$$\overline{RSD} = \frac{\bar{S}}{\bar{X}} \times 100 \tag{22}$$

For the exponential variances as particle measurements and the heated temperature for the oil, a time-integrated mean value, SD, and RSD was suitable and applied.

Uncertainty in the concentration measured by the Grimm U$_{\text{inst.}}$
The given reproducibility: ±3% over the whole measuring range

Uncertainty in the airflow rate U_{air}

The same calculation method is shown above for an average flow rate over the measuring period and post-logging.
The standard deviation across replicate experiments was, in general, larger than instrument accuracy and flowrate standard deviation with a result of dominating the total uncertainty in CE.

3.9 Data extraction and management

As mentioned in Chap 3.1.4. several instruments have been used to record both particle concentration and other conditions. Data has been exported, sorted, and processed in Excel sheets several times in the order below.

1. Raw data is exported to datasheets from all instruments by the end of the test day using the associated software. All raw data from the same instrument is stored in folders belonging to the logging instrument. For example, <GRIMM test day 5-12.05>. If the memory is full, data has been transferred to a backup folder and deleted from the instrument.
2. Each experiment has a unique number (see Chap 3.3) which is stored according to when the associated data is obtained from step 1. For instance, A-1 (1) is the first test performed in test combination A-1. The sheet A-1 (1) is preceded with a description of the experiment, further a timed description of the entire test process followed by sheets for the recordings for each instrument. This includes GRIMM, Aerotrack, P-track, Hikoki logger in the test room and the test hall. This data is filtered to suit the exact time and a specific order for further work. Furthermore, all data for the repeated experiments of type (A-1: A-1(1), A-1(2), etc.) are placed in an associated folder A-1, B-1, etc.
3. Data for each combination, for example, A-1, have been obtained for processing and illustrations. The sheet is again preceded by a description of the experiment and includes: particle measurements for each test A-1 (1) performed with GRIMM, calculations of CE and RSD related to particle concentration, recorded airflow and oil temperature during the experiment, and ends with a brief overview of average values for the latter two conditions.
4. A new sheet is used for the graphs and calculation of mean RSDs for all experiments

Both CE and RSD calculation was of a time-integrated concentration, meaning calculated for every recording. For the CE calculation, a limitation between 0 and 1 was set.

4. Results

The results represented in this chapter are a selection of analyzed data. Illustrations for the rest of the test combinations are attached in order in Appendix D, while complete tables are attached in Appendix E

4.1 Experiment conditions and variability

4.1.1 Instrument variability

The results from the three instruments used to track particles generated during the experiments showed a trend variation and, in some instances, a recording challenge. Figure 24 shows an example of time-resolved measurements of the particle number concentration during two replicated experiments with the GRIMM ((pt/liter) 0,3≤D≤∞) and Aerotrak (0.3 µm > 25); in this case, with a correlation. In comparison, the particle concentration (pt/cc) during the same experiments recorded with a P-track (0.02 µm>1 µm) shows a correlation during one of the experiments (A-2(1)) and a different trend during the second one (A-2(2)). The experiment in Figure 25 is for the combination: airflow 142 m^3/h and a hood mounting high of 54 cm. Note that the traced particle rang different the figures is to illustrate the trend.

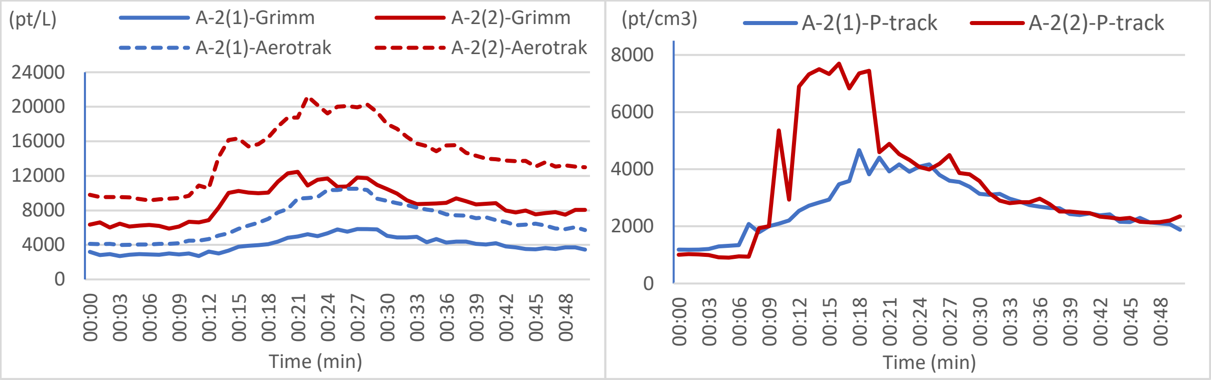


Figure 23:Instrument comparison 1: GRIMM, Aerotrak and P-track

The correlation trend for another experiment with a higher airflow rate is illustrated in the figures below and shows a larger variation with the different instruments. The figure below shows a good correlation across the experiments measured with the same instrument- GRIMM, whereas the variability with the Aerotrak and p- track is much higher. The P-track hade often a troubleshooting "LOW ALC" message during several experiments that may have affected the recording. Airflow rate 223 m3/h

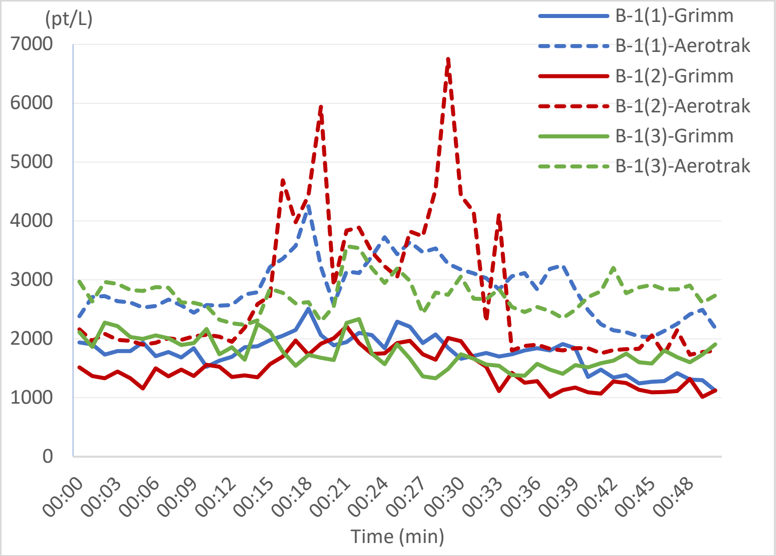


Figure 24: Instrument comparison 2: GRIMM and Aerotrak

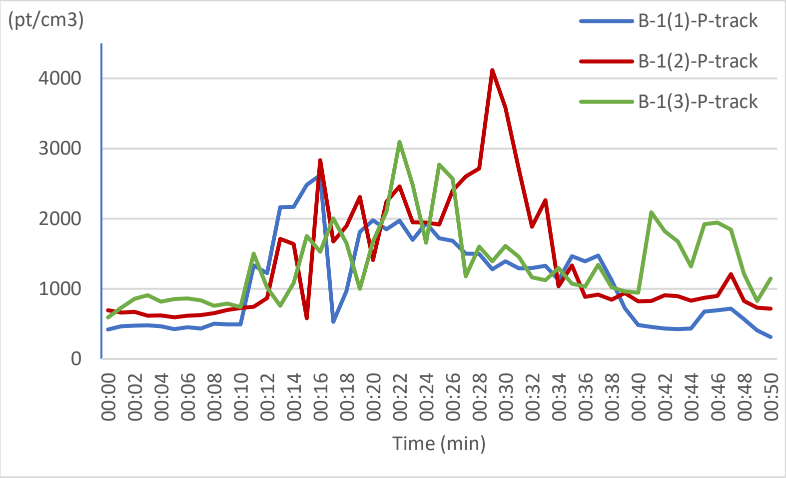


Figure 25: P-track measurement comparison 2

Further in the reported all illustrated and analyzed data of the particle measurements are particle number concentration based on the Grimm (pt/liter; 0,3≤D≤20) as the variability between the replicated experiments were lowest.

4.1.2 Experiment conditions

All experiment conditions that are have been recorded have been analyzed and evaluated before the inclusion of the experiment in further calculations of CE. In this section, only one of the conditions is illustrated.

Table 17 shows an example of the analyzed data in Appendix G. The conditions are through multiplicate experiments of the combinations B-1 where the range hood is mounted at the height of 54 cm and maintained on level 3 with an airflow rate of 395 m3/h. The related SD and RSD have been calculated for each experiment (replications) and across all experiments.

The mean RSDs across all experiments was ranged from 0.5% to 4.5%, the highest for the test hall temperature.

Table 17: Excerpt of measured test conditions and RSD

Expts.	Avg air temperature [°C]					Airflow [m3/h]	ΔPressure [Pa]	Oil temp.
	Test-room	Test-hall	Primary exhaust	Hood exhaust	Supply air	Tot. supply air	Test room/hall	Across experiments
B-3(1)	21,7	20,6	21,9	21,6	23,0	394,5	0,02	
B-3(2)	21,9	20,8	22,2	21,7	23,1	393,4	0,02	
B-3(3)	21,9	21,0	22,4	21,6	23,3	392,1	0,02	
B-3 avg.	21,8	20,8	22,2	21,6	23,1	393,3	0,02	
B- RSD (%)	0,22	9,92	0,08	0,42	0,03	0,1		1,3
Avg all expts.	22,8	21,6	23,2	22,1	24,8		-0,40	
SD all expts.	0,2	1,0	0,3	0,1	0,3	2,8	0,35	
RSD all expts. (%)	1,0	4,5	1,4	0,5	1,4	1,4		3,6

A profile example of the heated oil temperature during the same experiment as in table 17 is illustrated in figure 26. A good correlation across all repeated experiments is obtained, and a temperature of approx. °180 C after the heat was switched off.

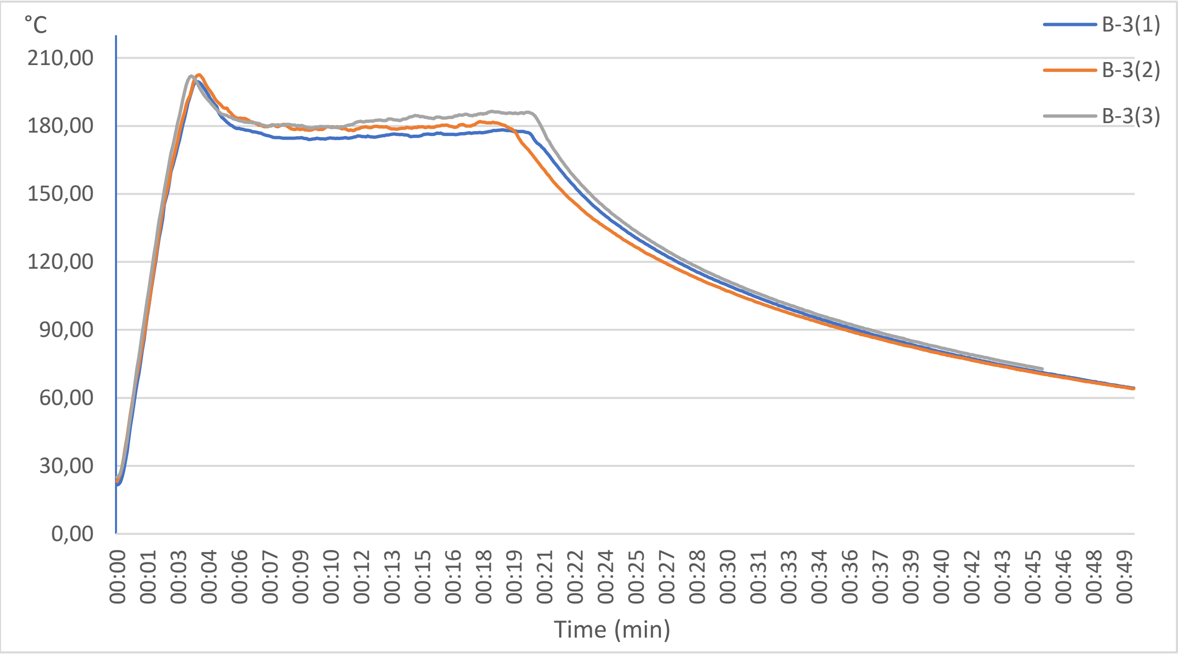


Figure 26: Temperature profile of the heated oil during expts. B-3. RSD 1.3%

A profile of the airflow rate showing the variability during repeated experiments B-1 is shown in Figure 27.

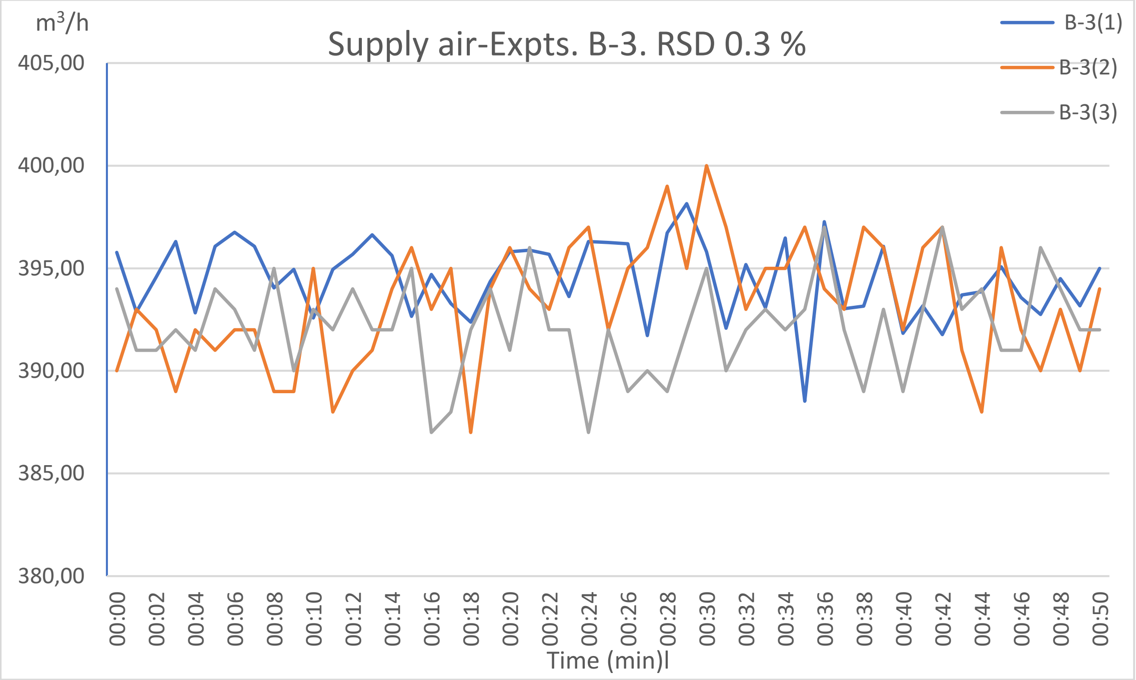


Figure 27: A profile of airflow rate during expts. B-1

4.2 Particle consentration

Time-resolved measurements of the particle number concentration measured by the GRIMM with hood off and for the different airflow rates are provided in figure 28. The hood is here mounted 54 cm above the cooktop. The concentration for each flowrate is an average of the replicated experiments. As expected, the concentration was highest when the hood was off and decreases with a higher airflow rate. For the highest hood level 3 with an airflow rate of 395 m3/h, the concentration increases again compared to 144 and 321 m3/h. The same trend has been shown with a hood mounted 70 cm above the cooktop.

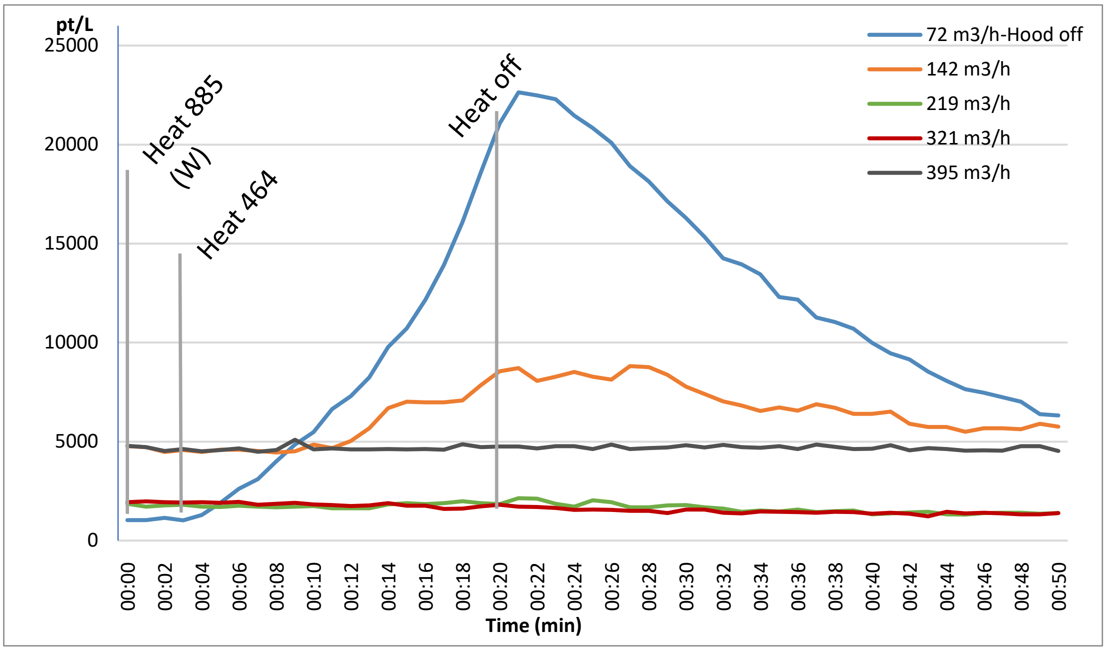


Figure 28: Particle number concentration for all combinations with the hood off and on 54 cm

Regarding investigating the particle concentration further, Figures 29 and 30 distinguish the combinations with low and high tested flow rates and, as the concentration difference was significant.
Figure 30 shows the time-resolved particle concentrations for the experiments with the hood switched off at a144 m³/h. As demonstrated with dashed lines, the particle concentration did not return to start conditions during the post-recording period of 30 min in any of the cases.

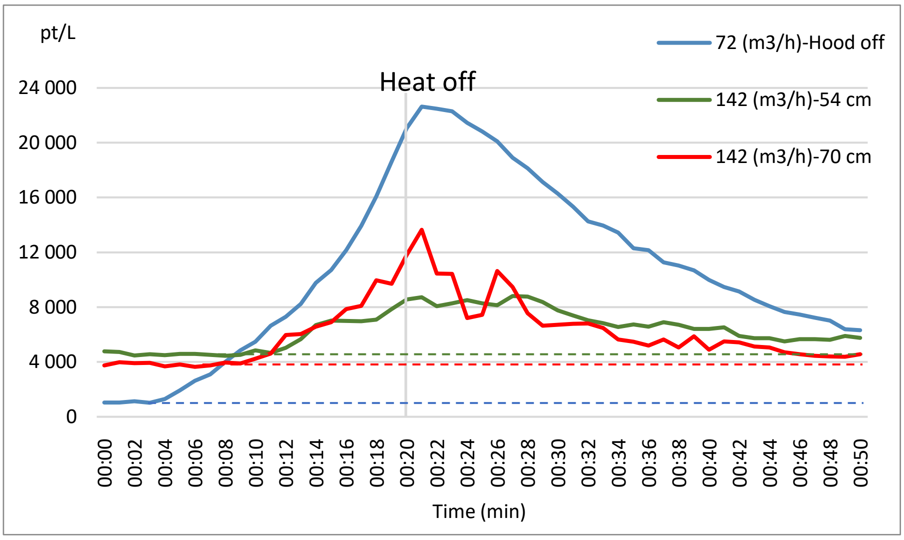


Figure 29: Particle concentration at the end of recording period compared to the start 1

For the experiments with range hood on level-1 219 (m³/h) shown in Figure 3, the particle concentration in the test room was back to start conditions 15 minutes after the heat is turned off for the hood installed 54 cm above the cooktop and 26 minutes when 70 cm. The particle concentration stable or decreasing for the higher airflow rates 321 and 395(m³/h) experiments.

Not that the concentration is an average of the replicated experiments

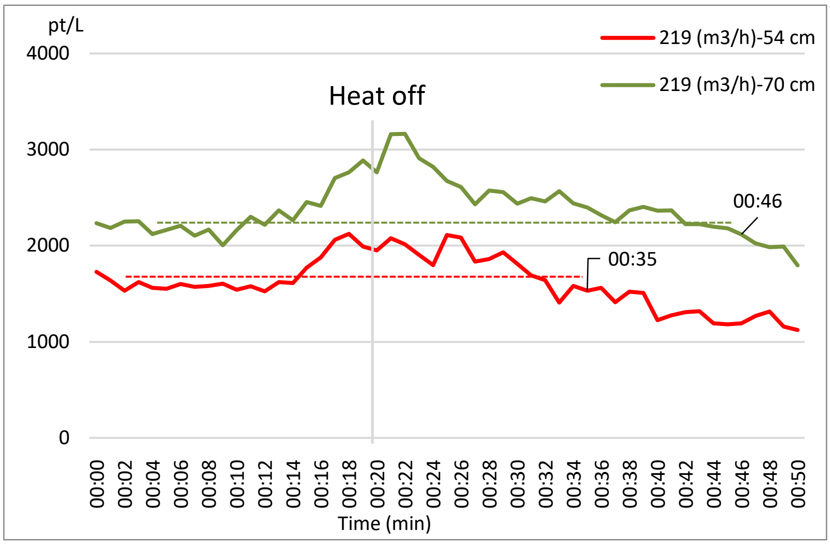


Figure 30: Particle concentration at the end of recording period compared to the start 2

4.2.1 Hood mounting height

The particle concentration across all the combinations of flowrate and mounting heigh is displayed in the Figure 30. For the same mounting height, a lower concentration is shown for higher flow rate increases. When comparing across the combinations of the mounting height, the concentration is higher for the hood mounted 70 cm above the cooktop compared to 54 cm. Expect the flow rate of 395 m3/h for both mounting heights that are increasing.

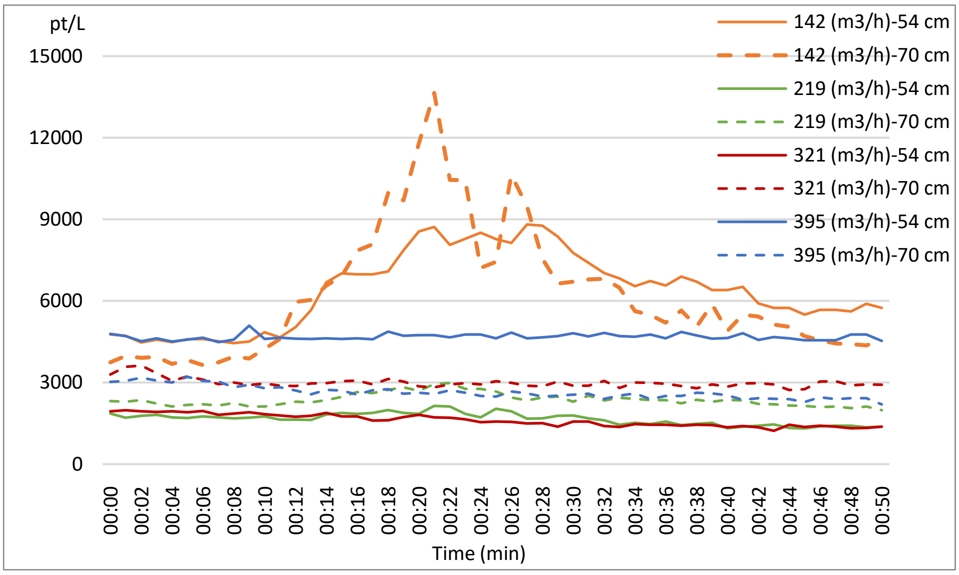


Figure 31: Compression of particle concentration for the tested mounting hights

4.2.2 Particle size ratio

Figure 31 illustrates a typical experimental result of four size-resolved number concentrations of particles. As shown, the particle emissions were predominately in the 0.3 to 0.5 µm size range, of which 0.3 µm is most significant. For the largest particle size (≥0.65 µm), there was no substantial response.

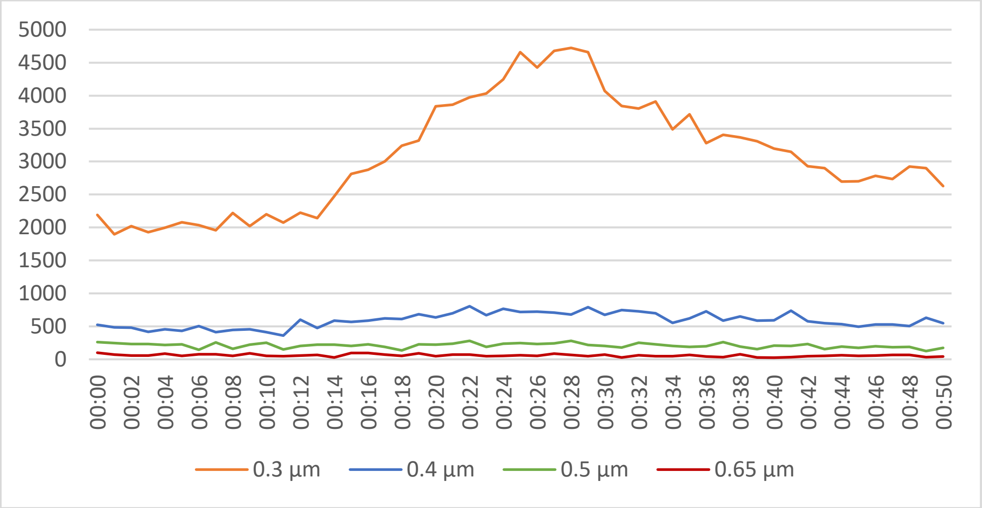


Figure 32: Particle size ratio. Expt. A2-(1)

4.2.3 Particle measurement repeatability

A considerable/significant variation in particle concentrations across several combinations is observed, despite precisely defined and executed experiment protocol. An example of the variability in measured particle concentration across replicated experiments with an airflow rate of 221 m3/h and a mounting height of 54 cm is demonstrated in Figures 31.

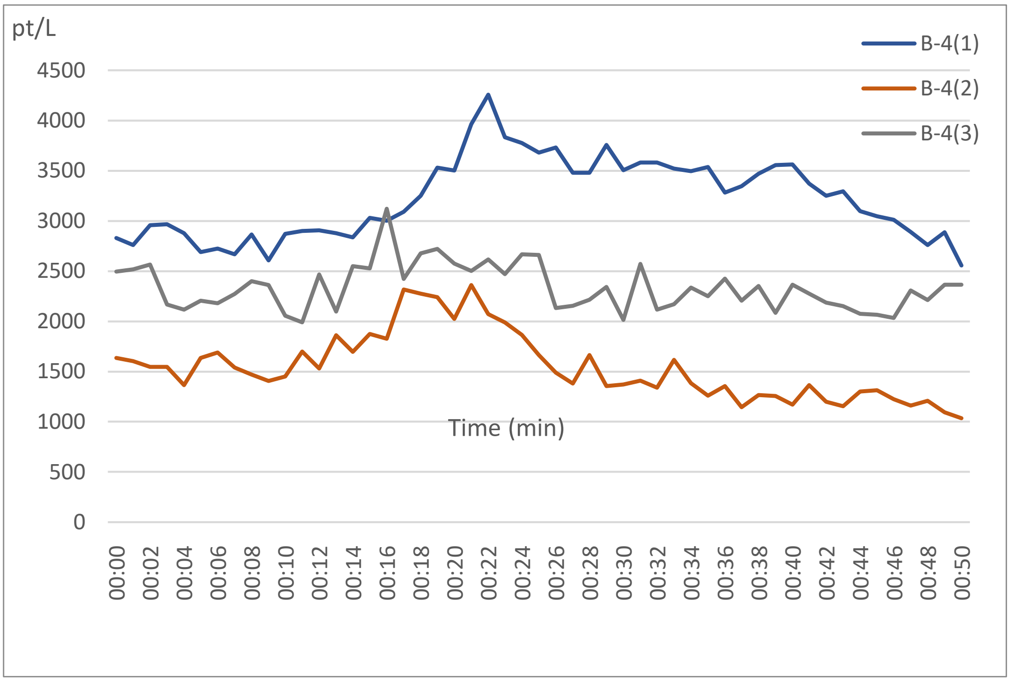


Figure 33: Particle concentration across replicated experiments B-4 with a flowrate of 221 m³/h. RSD 36.4 %

All the experiments conducted in a mounting height of 54 cm and 70 cm are illustrated in Figures 32 and 33, illustrating a core challenge in conducting performance assessments is experienced.

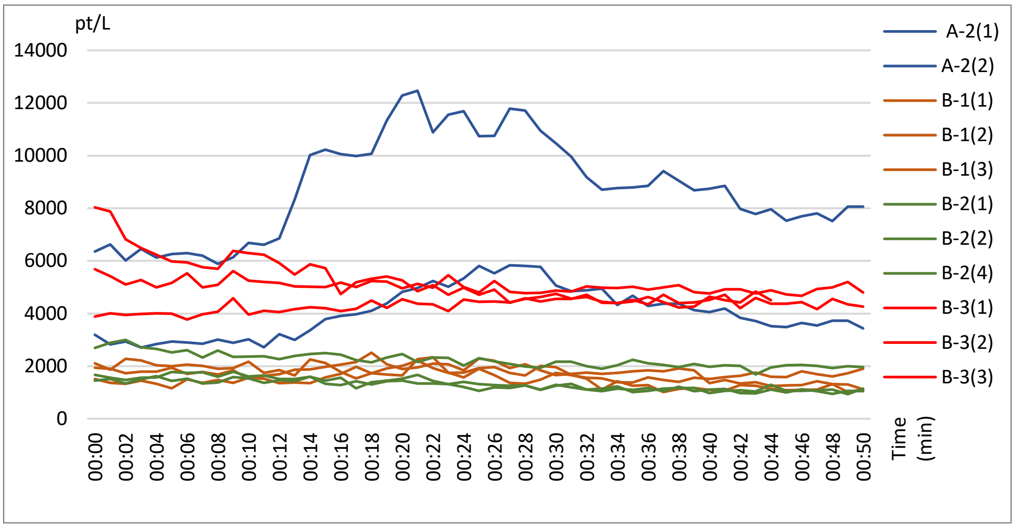


Figure 34: Particle measurement variability for expts. with a hood in a mounting hight of 54 cm

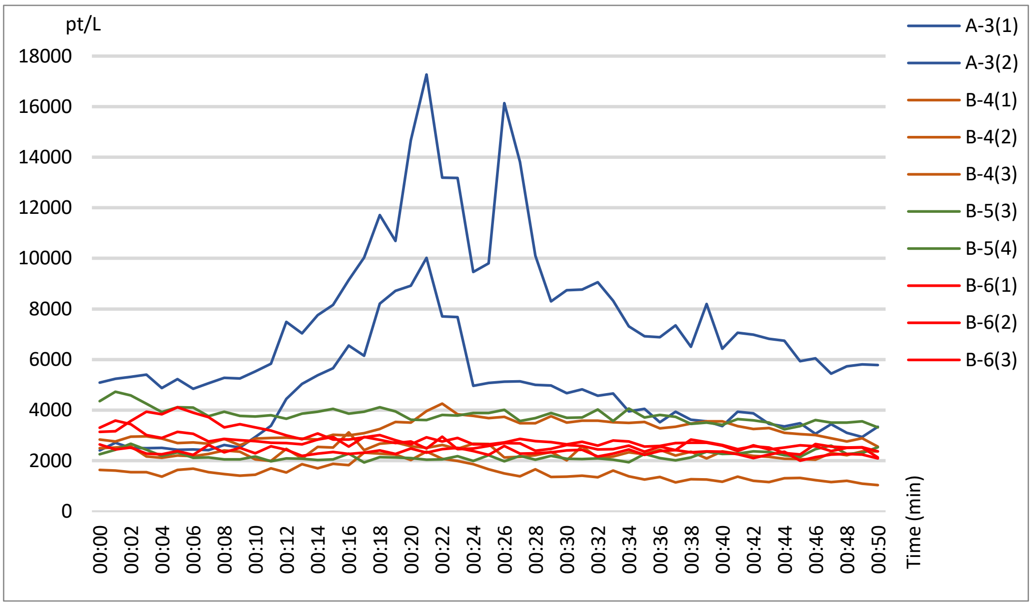


Figure 35: Particle measurement variability for expts. with a hood in a mounting hight of 70 cm

The relative standard deviations (RSDs) of the time-integrated particle concentration for all the combinations of hood mounting height and airflow rates are shown in Table 18. Particle-related RSD is ranged from approximately 11 % to 52%, with a mean of 29% across all combinations. The RSD when no-hood operating was 22 %. For the combinations with different airflow rates and the hood mounted 54 cm above the cooktop shown in Figure 32, the RSD was 28.7 %. A higher RSD is calculated of 31.9% of the hood mounted at the height of 70 cm, shown in Figure 33. An overall uncertainty that also includes several mentioned conditions in Chap 4.2 and instrument uncertainty is also calculated. Unsignificant impact by those conditions is to be observed; the variably of the particle measurements dominates the overall RSDs

Table 18:The RSD for particle concentration across all expt. combinations

Expts.	Nr of expert	Mounting hight (cm)	Avg. measured airflow (m3/h)	ACH (1/h)	Particle RSD (%)	Overall RSD (%)
A-1**	2	Hood off	72	0,9	22,2	24,20
A-2	2	54	151	1,8	52,4	52,62
B-1	3	54	224	2,7	17,4	17,58
B-2	3	54	325	4,0	34,2	35,01
B-3*	2	54	394	4,9	11	11,29
Avg. 54 cm					28,7	29,1
A-3	2	70	140	1,8	41,8	
B-4	3	70	222	2,7	36,4	37,75
B-5**	2	70	320	4,0	38,1	40,45
B-6	3	70	394	4,9	11,3	12,77
Avg. 70 cm					31,9	33,2
RSD All expts. (%)					29	30

*One- **Two experiments are excluded as the measured concentration was abnormal

4.3 Capture efficiency

4.3.1 Background emissions

For further calculations of CE, the particle concentration in the room that is related to an increase of particle concentration C_{bkg} caused by the execution of the experiment during the test day is subtracted. Furthermore, the order in which the experiments are performed was investigated may have an impact on the start concentration for the next experiment. For some of the experiments, the start concentration was higher at the start than through the experiment time, although the test room was well ventilated between all experiments. A table overview of experiment day, start time, measured particle concentration during Test-0 is developed to investigate experiment procedure parameters that may have affected the records. The full table in Appendix I. The average background concentration during Test-0 for the last experiments was 1.4 -2.0 times higher than the first one (highest 12.may). However, the time between the experiments had a minor impact.

Table 19: Excerpt of the evaluation of background emissions

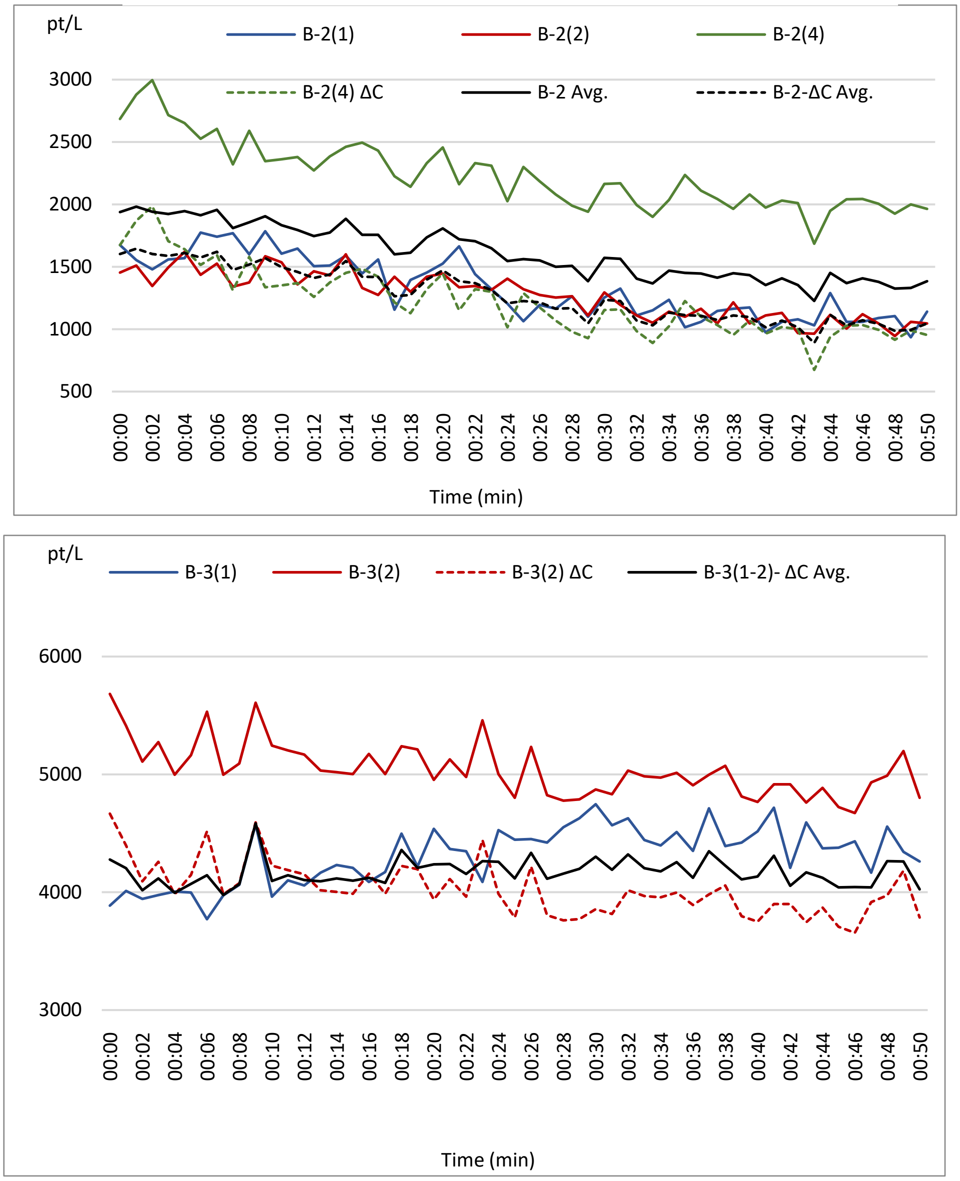
Test day	Record time Test-0	Time from previous expts.	Expt.	OPC-GRIMM (pt/litre)-Test-0-	Background Cons. Subtracted C_{bkg}
05.mai	12:38		A2-1	2721	0
07.mai	11:24		B3-1	3776	0
	14:42	02:07	B3-2	4792	1016
	16:55	01:33	B3-3	5053	1277
	18:51		A2-2	5248	1472

A decreasing or flat particle tendency is observed for experiments with airflow rate between 321-395 m3/h for both mounting hights, which demonstrate a core challenge in conducting performance assessment and calculations of the capture efficiency. Figure 35 and shows illustrations of experiments conducted 12. and 24. of May, where the particle concentration decreases during experiment B-2 and remains almost the same concentration in experiment B-3. An average concentration for a given

experiment, for instance, B-2- ΔC-Avg. (black dashed line) Figure 35 is used for the calculations of CE. This depicts an average concentration ΔC (C_{ook}-C_{bkg}) where the concentrations during cooking are adjusted with regard to background emissions and results in a lower concentration B-2-Avg. then the measured raw data B-2 ΔC-Avg. (black line).
For the shown experiments, only one repeated experiment has been adjusted: B-2 (4) in experiment B-2 and B-3(2) in B-3.
Note that the y-axes are adjusted and do not start from 0.

The time it takes before the particle concentrations return to the same range of background concentrations for both hood and no-hood conditions is demonstrated in figure 36. for the experiments with low airflow rate: the concentration did not return back to start conditions during post logging period of 30 min.

Figure 36: Measured particle and adjusted concentration ΔC for expts. B-2 and B-3



4.3.2 Capture efficiency results

Figure 37 shows the results for calculated CEs during the last10 min of the experiment and the first 10 minutes after the heat was switched. The CEs are ranged respectively from 72%-92% and 79%-97% and for all experiment combinations. The results show that CE generally increases with higher airflow and lower mounting height. Expect of increasing the airflow from 219 m³/h to 321 m³/h appeared to have no Effect impact on CE. The lowest CE calculated was for the experiment at 144 m³/h with a mounting height of 70 cm (72%). Moreover, the influence of increasing the flow rate from 321 m³/h to 395 m³/h had no significant impact when on CE when the range hood was mounted in a high of 70 cm and a slight of a negative effect on 70 cm. CE based on calculations during experiments was lower than CE based on the period after the end of the experiment.

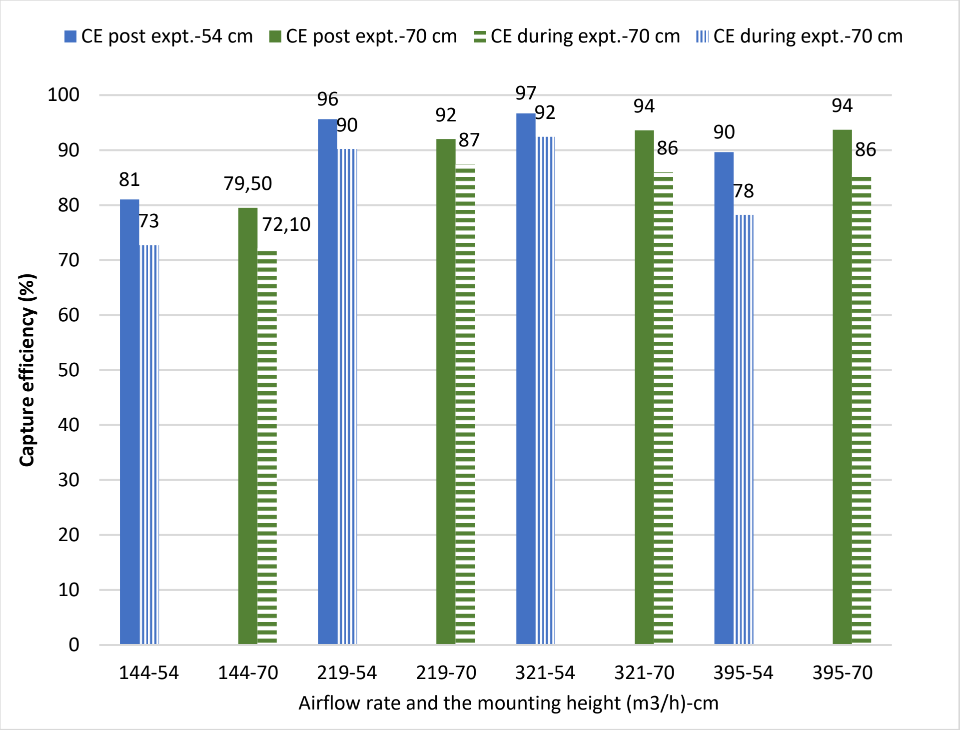


Figure 37: Capture efficiency results

4.3.3 Uncertainty in CE

Uncertainty in CE was calculated as described in Chap 3.9 with respect to all recorded variables that may have an impact. The table below shows the results for each combination of airflow rate and hood mounting height. Uncertainty in CEs calculated for 10 minutes period during the experiments was ranged from 3.4% to 66%, with a mean uncertainty of 26% across all combinations. A slight difference is found when CE was calculated after the end of the experiments: from 9.4% to 64% and a mean uncertainty of 29%. The RSD for measured particle concentration across replicate experiments is also shown in Table 20 to point out/emphasize the large impact on the total CE uncertainty. Hence, other variables become significant. The results are presented in Table 20

Table 20: Uncertainty in capture efficiency

Expts	CE uncertainty during expts. (%)		CE uncertainty post expts. (%)	
	Particle RSD	Utot	Particle RSD	Utot
A-1	10,8	14,1	12,6	15,5
A-2	49,9	50,2	42,1	42,3
A-3	7,5	8,5	32,9	33,2
B-1	15,7	16,3	12,5	13,8
B-2	30,1	30,2	32,3	32,5
B-3	2,7	3,4	8,9	9,4
B-4	24,9	26,9	38,2	39,5
B-5	65,1	66,0	63,0	64,0
B-6	12,7	13,9	8,3	10,3
All expts.	24	26	28	29

4.4 Calculations of exhaust air

Measured conditions and inserted parameters in the calculation used in this chapter are listed in the table and.

Table 21: Measured and inserted parameter for the calculations of exhaust air

Parameter	Inserted/ measured	Comments
Q_{hob} (W)	464	Measured power when level 5
Distance y (m)	0.1-0.4	Measurement point for central temperature and air velocity
Distanse y (m)	0,52	Distance from the heated oil to the hood when 54 cm above the cooktop
Distanse y (m)	0,68	Distance from the heated oil to the hood when 70 cm above the cooktop
Pan diameter (m)	0,28	Also for D_h
Room temperature	22.5 ±0.5	Measured in the test room
Oil temp	183.5±0.5	Measured in the center of the pan

4.4.1 Measurements of the jet velocity and temperature

The measurements of temperature and air velocities are taken at four different heights above the heated oil for the eight combinations of the hood settings and mounting hights listed in section 3.6. Appendix H Measurements taken for one of the conditions with the hood operating in 185 m^3/h at a mounting height of 54 cm are presented in Table 24. T_y is the measured central temperature at the distance y. As expected, the temperature decreases with a distance from the heated oil while the velocity increase. At a distance of 0.4 m, the velocity decreases again. In five of eight tests, the measured center velocity Um was increasing from the measuring point 0.3 m to 0.4 m above the oil.

Table 22: Measured central jet conditions

y	T_y	ΔT	U_m
m	C	K	m/s
0,1	45,7	23,2	0,10
0,2	39,7	17,2	0,35
0,3	37,5	15	0,37
0,4	38	15,5	0,34

4.4.2 Calculations jet velocity and temperature

The specificity of the various calculation methods reviewed in Chapter 3.8 is to be assessed for a comparison with the measured conditions and further evaluate the calculation methods. The results are presented in the same order as in chapter 3.8, where formulas are also shown
The formulas reviewed are used to calculate velocity, temperature, and air velocity in the jet. For instance, a required exhaust air for an optimal catchment of generated emission
Eimunud Skåret

The distance from the source to the convection pole imaginary point source y_p was calculated to 0.596 m using proportionality factor C_b of 0.235. ΔT is the difference between the central temperature of the jet and the ambient temperature. The results of Equations (6) to (9) are presented in Table 23 and show a decreasing central velocity U_m and temperature ΔT for an increasing height above the heat source (y). For instance, the calculated flowrate needed for maximum capture was 182 m^3/h for a hood mounted 0,52 m above the heat source and 227 m^3/h when 0,68 m.

Table 23: Calculation results of jet temperature, air velocity and exhaust airflow. Eimund skåret

y	ΔT	U_m	q_{vk}	
m	K	m/s	m^3/s	m^3/h
0,1	22,9	0,67	0,023	82,1
0,2	18,3	0,64	0,029	102,9
0,3	15,0	0,62	0,035	125,6
0,4	12,6	0,59	0,042	150,1
0,52	10,4	0,57	0,050	181,7
0,68	8,3	0,55	0,063	227,5

Danvak

The calculation results using Equations (10) to (12) are presented in Table 24. Similar to Eimund skåret, a decreasing temperature t_y and central velocity v_y is calculated for an increasing height above the heat source (y). The calculated flow rate was 96 m^3/h for a hood mounted 0,52 m above a heat source and 130 m^3/h when 0,68 m. The results are shown in Table 24

Table 24: Calculation results of jet temperature, air velocity and exhaust airflow. DANVAK

y	t_y	v_y	q_{vy}	
m	K	m/s	m^3/s	m^3/h
0,1	135	1,39	0,01	28
0,2	92	1,29	0,01	41
0,3	67	1,21	0,02	56
0,4	51	1,14	0,02	73
0,52	39	1,08	0,03	96
0,68	29	1,02	0,04	130

Leif Ingmar Stensaas: Ventilasjonsteknikk [32]:

In the calculations with Equations (14) to (15), the constants C_1 and C_2 were inserted as 1,5 and 0,06. The results are shown in Table 25. A very high central velocity of the jet is calculated and also here decreasing this the higher distance from the source. The calculated flowrate for the hood was 599 m^3/h for a hood mounted 0,52 m above a heat source and 879 m^3/h when 0,68 m.

Table 25: Calculation results of jet temperature, air velocity and exhaust airflow. Leif I. Stensaas

x	wc	L	L
m	m/s	m^3/s	m^3/h
0,1	25	0,010	36
0,2	20	0,032	114
0,3	17	0,062	225
0,4	16	0,101	363
0,52	14	0,166	599
0,68	13	0,244	879

VDI: German Kitchen Standard VDI [33]

For equation (16), listed terms are inserted for the calculations of the exhaust flow

- 0,28m as the hydraulic diameter D_h
- 0,25 simultaneous factor φ of the appliances used at any one time 0,25 as only one ¼ zones of the cooktop is used
- 0.63 as the reduction factor k_r of the installation location for a hood near a wall
- 1,5 as spillage coefficient k_s to obtaining 90% pollutant removal efficiency (k_s for 100% is not given)

The estimated needed exhaust airflow 255 m^3/h for a hood mounted 0,52 m above a heat source and 333 m^3/h when 0,68 m

5. Discussion

5.1 Test facility and method

The instrumentation part of the test facility has been essential to investigate to ensure suitable instruments that can withstand the emission of particles associated with an actual cooking process, thus provide stable measurements. The comparison results of the three instruments tested showed that the Grimm provided to be the most stable instrument. Measured data with this instrument was of that reason used for further analysis and calculations. Like the GRIMM, the Airotrak measures the particle number concentration. The results showed the same tendency but more variability when the airflow increased. The instrument that has shown the most significant variability among repeated tests was P-Track. A possible reason might be related to its operating range and conditions or a need for a better and continuous procedure before starting every experiment. For the Aerotrak, a zero-test was performed before every experiment. In contrast, no procedure was applied for the P-track. A zero-test was conducted now and then. Another suspected parameter is the instrument's sensitivity. The test room was operated with balanced displacement ventilation, resulting in a higher Air Change per Hour (ACH) when the flow rate increases. That may lead to a higher velocity jet and direction that changes the airflow pattern in the room. The same disturbance of airflow was pointed out/reported in other studies (Kim et al.,.2018) and (Han et al.,.2019). [24, 25].

5.2 Experiment measurements:

particle concentration, conditions, and variability

As mentioned, it has been challenging to conduct performance assessments of data. Therefore, an essential and significant part of the work has been analyzing the uncertainty of the experiments. This includes the repeatability associated with measured emissions and test conditions.

The tested exhaust air was 72 m^3/h as primary ventilation with the hood off, and four different levels with hood operating: 144 m^3/h, 221 m^3/h, 322 m^3/h, and 395 m^3/h.

The mean RSD associated with particle concentration across all experiments was 29.4%, ranged from 11.3% to 52.4%. For the experiment with the hood off, the RSD was 22.2%. A similar challenge in terms of variability in particulate emissions measurements was reported in a previous study (Lunden et al., 2014), where the RSD was 23% for no-hood condition and 10% to 50% with the hood operating.

The average total uncertainty related to both instruments used to measure particle concentration, frying temperature, and other laboratory conditions across all experiments was 30%, rated between 11.29% to 52.6%. The analysis shows that the uncertainty is dominated by the variations in measured particle concentration across similar experiments, while other sources/deviations become negligible, despite accurately developed and precisely conceived cooking process.

The relative uncertainty related to airflow rate has been 0.8% to 1.4%, with mean RSD compared to the variation in particle concentration. The uncertainty of the other laboratory conditions was also analyzed and considered inconsequential, meaning that the developed test facility and conditions applied were suasible.

The particle concentration did not return to start conditions during the post-recording period of 30 min during the two experiments with the lowest airflow, despite the fact that the hood was kept operating during the experiment with 144 m3/h. This demonstrates the long period of pollution an apartment would be exposed to with the minimum required exhaust and a need for better/higher air exchange.

The GRIMM measures particle number of concentration cumulatively in (pt/liter), meaning for exp. in size ration 0.3 µm, all particles with a diameter of 0.3 µm to infinity are measured ($0.3\ \mu m \leq D \leq \infty$). The size of the particle in a ratio of 0.3 µm is calculated by subtracted all other sizes. The results show that 0.3 µm is the most significant. This is also similar to the findings in other studies conducted in section 2..5

5.3 Capture efficiency: background emissions, CE and RSD

5.3.1 Background emissions

For some of the experiments, the start concentration was higher than through the experiment duration, although the test room was well ventilated between all experiments. The particle concentration in the room that is related to an increase of particle concentration C_{bkg} caused by the execution experiments during the test day is subtracted. The results showed that the average background concentration during Test-0 for the last experiments was 1.4 -2.0 times higher than the first one conducted
Other experiment procedure parameters that may have affected the records have been investigated. For instance, the order in which the experiments are performed. The time between the experiments had a minor impact, indicating the ventilating procedure and ventilation between the experiments was good enough. The recording of Test-0 started 10-20 min before the experiments. All instruments were turned on, and the conditions for the upcoming test were already set.

For some of the experiments, the particle concentration decreases during the experiment, demonstrating a core challenge in conducting performance assessment and calculations of the capture efficiency. An average concentration (B-2- ΔC-Avg.) used for the calculation of CE and depicts ΔC (C_{ook}-C_{bkg})-concentrations during cooking-background emissions,
In the calculations of CE, repeated experiments of the same test combination showing a significant deviation or abnormal trend are excluded
The subtraction has created some challenges in calculations where the concentration has shown a decreasing tendency. However, the test room is well ventilated, and the conditions are set in motion well before the cooking process is initiated**.** A better method to conceder background emissions is needed.
It was observed that the variability in particle concentration across replicated experiments dominated the uncertainty and constituted a mean RSD

Based on conducted data, the CE was ranged from 72%-97% for a different tested combination of airflow rates and two mounting heights of the hood. The mean RSD was 26% (8.5%-66%) when calculation during the experiments, of which the RSD of particle concentration across replicated experiments constituted an RSD of 24 % (2.7%-65.1). The calculation of CE post-experiment had a mean RSD of 29% (9.4%-64%), of which 28% (8.9% to 63%) related to particle variability
In the majority, increasing the airflow rate improved the CE with no significant impact on RSD (0.8%-1.4%). The influence of increasing the flow rate from 321 m^3/h to 395 m^3/h had no considerable effect when on CE when the range hood was mounted in a high of 70 cm and a slight of a negative impact on 54 cm. Implying there might be is a maximum flowrate beyond which the CE may begin to decrease for some reasons (still need to be investigated)

An average CE across the experiment combinations of airflow rate (144 m^3/h to 321 m^3/h) and hood mounting hights was estimated from 91% with hood mounted 54 cm above the cooktop and 88% when 70 cm—indicating an improvement of a lower mounting height of 3%.
The results showed an improvement of 15 % when increasing the airflow rate from the minimum requirement of 144 m^3/h (CE 81%) to 219 m^3/h (CE 95.6%) for the test setup with the hood mounted at the height of 54 cm. The improvement is insignificant when increasing the flow rate to 321 m^3/h.
Considering the pollutions exposure, the outcome from another point of view is that 19% is released in the room space with airflow of 144 m^3/h and 4.4 % when 219 m^3/h. From this context, the pollution in a kitchen-living room will be 4.3 times as high with an airflow of 144 m^3/h compared to 219 m^3/h.
CE comparison with other studies.

There are no standards for characterizing or specifying acceptable values of CE. Several studies have investigated the performance of the extracting range hood. For the most, the meal was cooked on a gas stove or tracer gas used. The hood is turned off after the end of the experiment or switched off all ventilation. The CE calculated in this study is meant to investigate both exposure and the effectiveness of the hood and refers to the kitchen hood's ability to remove emissions both during and after the cooking process. This means that the user keeps the hood on after the cooking process is completed.
Lunden rapporterte CE of 38% 183-244 m^3/h and 54–72% for high 392 to 496 m^3/h. In this studies the air exchange was constant. Ventkook was more similar to our experiments, where the ACH was not kept constant. They reported CE of 93,1-99,6 %.

5.4 The design of the exhaust flow rate

5.4.1 Measurements of air Air temperature and velocity in a thermal jet

The measurements of the central air velocity and the temperature were taken at the height of 0.1 to 0.4 above the heated oil. The results show an increment for the air velocity and a decrease for the temperature as the distance from the heated oil increase. This is explained by the motion and energy equation. A heat source causes air movement as the emitted heat heats the air near the source that will flow vertically. Replacement air is then drawn in towards the heat source, and heat-driven flow occurs. The convective heat output from the heat source is conserved in the convection load-increment in velocity and increase in temperature

In five of eight tests, the measured center velocity Um was increasing from the measuring point 0.3 m to 0.4 m above the oil, implicating there is a boundary layer.

5.4.2 Range hood mounting height and jet velocity

Calculated temperature and velocity

The calculated jet central temperature in different heights was decreasing in all applied formulas and a significant deviation compared to the measured once in the same mounting height. The variation was largest when comparing with the formula from Leif S., and lowest with Eimund S., A similar deviation was calculated when it comes to the air velocity, which was decreasing, in contrast to our measurements. This, despite all the methods, emphasizes that air velocity is large close to the source while it counteracts the air from the surroundings and grows in its further course. That might interact with the applied distance from the source in the formulas.

Therefore, this section discusses the calculation method used for the formulas applied for air velocity:

- Eimund Skårets: the distance is calculated as a product of two heights. Firstly, the distance above the heat source and a distance from the source to the convection pole imaginary point source ($y+y_p$). In this case, y_p is calculated to 0,59 m, meaning
- Danvak: the distance is calculated as a sum of the distance above the heat source and the diameter of the heat source ($y+d$). For instance, in this case, and a given point plus 0,28 m
- Leif I. Stensaas: the air velocity calculated with this method was very high as the formula only accounts for the distance (x)-from the bottom-cooktop- to a given point in the jet

None of the calculating methods accounts for Vena contraction. Vena Contraction is the point in a stream where the kinetic energy is at the maximum and pressure energy at the minimum, as the diameter of a stream is at the least. For this case, y_p concerning vena contraction is 0,47 m. That might explain the increasing measured air velocity when measured in point 0.4 m, meaning close to or in the outlet of the vena contraction section, thus a lower velocity. While in the case with Eimund skårets formulas, y_p is set higher 0,59 m

For instance, a note pointing out that the formulas for air velocity and temperature apply to distances above the heat source greater than twice the heat source diameter is later found in DANVAK, which means that the formulas are applicable for a minimum height of 0,58 m above the heated oil, a hood-mounted 60 cm above the cooktop in our case. That may explain the deviation between the measured and calculated values.

It may appear that the current of a convention load in an upward direction without interference from the vena contraction mentioned above has been considered in both eimund and DANVAK while

Leif I. Stensaas The mathematical method is specified to be applicable for designing the exhaust flowrate needed. Unlike the other methods, the heat source area is not considered, which might imply a linear heat source rather than for point source calculations as stated in the book. That explains abnormal velocity values and flow rate. Noting that the formulas are from a book published in 1986, the equations are a fundamental basis and dos, not consider several of the parameters that are taken into account in the others. Therefore, the results are not further compared in these sections

5.4.3 The design of exhaust airflow

The calculated exhaust flowrate needed for removal of emissions related to the same power input and equipment surface is linked to calculated particle-based CE.
For the hood installed at the height of 54 cm (0,52 m above a heat source), the flow rate was calculated by Eimund Skåret to 182 m^3/h. Particle-based CE for one of the tested configurations with the hood operating on 185 m^3/h was 95.6 %. Based on this, that may be considered as an acceptable correlation
The calculations using the formula from VDI results in airflow of 255 m^3/h for obtaining a pollutant removal 90% spillage coefficient. In connection with the particle-based CE, obtaining 90% removal requires a much higher exhaust flow rate with VDI compared to particle-based CE, where 95.6% was already achieved with 185 m^3/h.
As mentioned earlier, the calculation from Danvak is pointed out as not applicable for this height.
For a hood-mounted in the height of 70 cm (0,68 m above the heat source), 192 m^3/h was calculated by Eimund S, 130 m^3/h by Danvak, and 333 m^3/h by VDI. The highest obtained particle-based CE in this mounting height was 93.6%, with the hood operating on 285 m^3/h. Next is 92 % for configuration with 185 m^3/h, which again correlates more with Eimund S. considering that 333 m^3/h by VDI is actually for 90 % catchment
Not that the calculated CE is for our specific case with the given configurations. This comparison is not 100 % to be applicable.

.

6. Conclusions

A suitable upset and facility of a test laboratory to investigate exposure and capture efficiency related to real cooking in an open kitchen and living room have been one of the main tasks in this study. The result of this work is based on preliminary data and newly developed test method aimed for the Urban ventilation project and further advanced exposure studies

The developed test facility and conditions applied were considered suasible for the study. The highst RSDs were related to particle measurements, with a mean RSD of 30% across all nine conducted experiment combinations. For better readability, more tests are recommended.

A general trend from the preliminary data is that increasing the flow rate improves CE. An average CE across the experiment combinations of airflow rate (144 m^3/h to 321 m^3/h) and hood mounting hights was estimated from 91%, with an RSD of 24.5% when the hood was mounted 54 cm above the cooktop and 90% with an RSD of 37% when 70 cm. This results in an improvement of a lower mounting height of 2%.

For the hood mounted at the height of 54 cm, the results showed an improvement of 15 % when increasing the airflow rate from the minimum requirements of 144 m^3/h to 219 m^3/h. However, the improvement is unsignificant when increasing the airflow rate above 219 m^3/h.

Different approaches are used in the calculation of the velocity in the plum generated by cooking. The calculated values decreased with a higher distance from the heated source, in contrast to our measurement.

That implies the formulas are more applicable for designing needed exhaust airflow for a hood mounted above a certain minimum height. However, the observed deviations between measured central velocity and the calculated once predict they are not comparable. Therefore, further investigations for a more suitable analytical model are recommended for the upcoming “advanced exposure studies.”.

The needed exhaust airflows for the hood calculated by Eimunds formulas are the most once correlating with the tested flowrates and their CE. The calculated exhaust flow rate was 182 m^3/h for a mounting height of 54 cm (0,52 m above a heat source) and 192 m^3/h when 70 cm.

References

[1] *NEK IEC 61591:2019* I. Standard, 2019.

[2] *Byggteknisk forskrift (TEK17) med veiledning*, 2017.

[3] *Ventilation and Acceptable Indoor Air Quality in Residental Buildings*, A. S. 62.2, 2016.

[4] *421.503 Luftmengder i ventilasjonsanlegg. Krav og anbefalinger*, S. Byggforsk, 2017. [Online]. Available: https://www-byggforsk-no.ezproxy.oslomet.no/dokument/2753/luftmengder_i_ventilasjonsanlegg_krav_og_anbefalinger/

[5] M. Oberhomburg, "Resirculating cooker hoods-possiblities and challenges," in *Kitchen Ventilation*, International Webinar, K. Thunshelle, Ed., 2020: The Air Infiltration and Ventilation Centre (AIVC), Oslo Metropolitan University (OsloMet) and SINTEF [Online]. Available: https://www.aivc.org/event/6-may-2020-webinar-kitchen-ventilation. [Online]. Available: https://www.aivc.org/event/6-may-2020-webinar-kitchen-ventilation

[6] H. Augensen, "Extract cooker hoods-possibilities and challenges," in *Kitchen Ventilation*, International webinar, K. Thunshelle, Ed., 2020: The Air Infiltration and Ventilation Centre (AIVC), Oslo Metropolitan University (OsloMet) and SINTEF. [Online]. Available: https://www.aivc.org/event/6-may-2020-webinar-kitchen-ventilation. [Online]. Available: https://www.aivc.org/event/6-may-2020-webinar-kitchen-ventilation

[7] S. Ruud, "Documentation of cooker hood perfprmance, a laboratory perspective," in *Kitchen ventilation*, International webinar, K. Thunshelle, Ed., 2020: AIVC-The Air Infiltration, Ventilation Centre, OsloMet and SINTEF. [Online]. Available: https://www.aivc.org/event/6-may-2020-webinar-kitchen-ventilation. [Online]. Available: https://www.aivc.org/event/6-may-2020-webinar-kitchen-ventilation

[8] I. Walker, G. Rojas, and B. Singer, "Comparing extracting and recirculating residential kitchen range hoods for the use in high energy efficient housing," 2018.

[9] *NS-EN 13141-3:2017. Ventilasjon i bygninger- ytelsesprøving av komponenter/produkter for boligventilasjon*, N. Standard, 2017.

[10] *Standard Test Methode for Measuring Capture efficiency of Domestic Range Hoods*, ASTM, USA, 2018.

[11] *NEK IEC 61591:2019*, I. Standard, 2019.

[12] *552.305. Balansert ventilasjon av leiligheter* S. Byggforsk, 2017.

[13] K. Denizou, "Urban ventilation project, Arbeidspakke 1." [Online]. Available: https://www.sintef.no/prosjekter/2020/urban-ventilation/

[14] *552.301. Ventilasjon av boliger. Prinsipper*, S. Byggforsk, 2017.

[15] G. Buonanno, L. Morawska, and L. Stabile, "Particle emission factors during cooking activities," *Atmospheric Environment,* vol. 43, no. 20, pp. 3235-3242, 2009/06/01/ 2009, doi: https://doi.org/10.1016/j.atmosenv.2009.03.044.

[16] J. Gao, C.S., Wang, L., Song, TH., Zhou, X., Yang, J. And Zhang, X., *Determination of size-dependent source emission rate of cooking-generated aerosol particles at oil-heating stage in an experimental kitchen* (Aerosol Air Qual Res). 2013.

[17] Y. Zhao *et al.*, "Review of Effluents and Health Effects of Cooking and the Performance of Kitchen Ventilation," *Aerosol and Air Quality Research,* vol. 19, no. 8, pp. 1937-1959, 2019-01-01 2019, doi: 10.4209/aaqr.2019.04.0198.

[18] M. A. Torkmahalleh *et al.*, "PM2.5 and ultrafine particles emitted during heating of commercial cooking oils," *Indoor Air,* https://doi.org/10.1111/j.1600-0668.2012.00783.x vol. 22, no. 6, pp. 483-491, 2012/12/01 2012, doi: https://doi.org/10.1111/j.1600-0668.2012.00783.x.

[19] H. R. Katragadda, A. Fullana, S. Sidhu, and Á. A. Carbonell-Barrachina, "Emissions of volatile aldehydes from heated cooking oils," *Food Chemistry,* vol. 120, no. 1, pp. 59-65, 2010/05/01/ 2010, doi: https://doi.org/10.1016/j.foodchem.2009.09.070.

[20] M. M. Lunden, W. W. Delp, and B. C. Singer, "Capture efficiency of cooking-related fine and ultrafine particles by residential exhaust hoods," *Indoor Air,* Article vol. 25, no. 1, pp. 45-58, 2015, doi: 10.1111/ina.12118.

[21] W. W. Delp and B. C. Singer, "Performance assessment of U.S. residential cooking exhaust hoods," (in eng), *Environ Sci Technol,* vol. 46, no. 11, pp. 6167-73, Jun 5 2012, doi: 10.1021/es3001079.

[22] B. C. Singer, W. W. Delp, P. N. Price, and M. G. Apte, "Performance of installed cooking exhaust devices," *Indoor Air,* Article vol. 22, no. 3, pp. 224-234, 2012, doi: 10.1111/j.1600-0668.2011.00756.x.

[23] P. Jacobs, "Openbaar eindrapport VentKook Ventilatiesysteem met goede kookafzuiging," TNO, Delft, the Netherlands, TNO-report TNO 2018 R11055, 20 September 2018.

[24] Y.-S. Kim, I. S. Walker, and W. W. Delp, "Development of a standard capture efficiency test method for residential kitchen ventilation," *Science and Technology for the Built Environment,* vol. 24, no. 2, pp. 176-187, 2018/02/07 2018, doi: 10.1080/23744731.2017.1416171.

[25] O. Han, A. Li, and R. Kosonen, "Hood performance and capture efficiency of kitchens: A review," *Building and Environment,* vol. 161, p. 106221, 2019/08/15/ 2019, doi: https://doi.org/10.1016/j.buildenv.2019.106221.

[26] S. Meleika, T. Hicks, M. Pate, and J. Sweeney, "The design, construction and evaluation of a test chamber for measuring rangehood capture efficiency," *Science and Technology for the Built Environment,* vol. 26, no. 6, pp. 856-872, 2020/07/02 2020, doi: 10.1080/23744731.2020.1755194.

[27] W. Borsboom, W. D. Gids, I. Walker, and P. Jacobs, "Assessment of Range Hoods based on Exposure," 2018.

[28] Y. Li, A. Delsante, and J. Symons, "Residential Kitchen Range Hoods – Buoyancy-Capture Principle and Capture Efficiency Revisited," *Indoor Air,* vol. 7, no. 3, pp. 151-157, 1997, doi: https://doi.org/10.1111/j.1600-0668.1997.00001.x.

[29] H. Augensen, "Extract cooker hoods-possibilities and challenges," in *Kitchen Ventilation* International webinar, K. Thunshelle, Ed., 2020: The Air Infiltration and Ventilation Centre (AIVC), Oslo Metropolitan University (OsloMet) and SINTEF. [Online]. Available: https://www.aivc.org/event/6-may-2020-webinar-kitchen-ventilation. [Online]. Available: https://www.aivc.org/event/6-may-2020-webinar-kitchen-ventilation

[30] E. Skåret, *Ventilasjonsteknikk håndbok 48*. Universitet i Trondheim: Norges teknisk Høyskole, 2000, p. 219.

[31] H. E. H. P. K.-J. O. B.Stampe, *Danvak-GRUNBOG- Varme og klimateknikk*. DANVAK Aps, p. 451.

[32] L. I. Stensaas, *Ventilasjonsteknikk 1.Grunnlaget og systemer*, 3. utgave ed. (1.Grunnlaget og systemer). Universitetsforlaget, 1986, p. 483.

[33] *VDI 2052-06*, V. D. I, 2006.

[34] R. Kosonen, "The effect of supply air systems on the efficiency of a ventilated ceiling," *Building and Environment,* vol. 42, no. 4, pp. 1613-1623, 2007/04/01/ 2007, doi: https://doi.org/10.1016/j.buildenv.2005.09.030.

Further work

This master thesis is preliminary work aimed for further advanced exposure studies for the Research project “Healthy Energy-efficient Urban Home Ventilation.”
This section is dedicated to further work. Therefore, we suggest:

- Newer factory calibration of the measurements.
- Performance of tests with the same range hood operating in recirculation mode, for a comparison
- Switching off the rang hood after the end of cooking for the calculation of capture efficiency
- Better regulation of particle concentration concerning background emissions.
- Increase the emission surface/cooking appliance appearing to a real cooking event as more than one pan would have been used.
- Develop a procedure for zero-tests of all instruments before starting every test, ensure similar conditions, including cleaning the fat filter installed in the hood.
- Consider operating conditions with the same air exchange.
- If heated oil is tested further, another position of the cook.
- Conduct more experiments for the least variability.

Appendices

Appendix A: Range hood product fiches

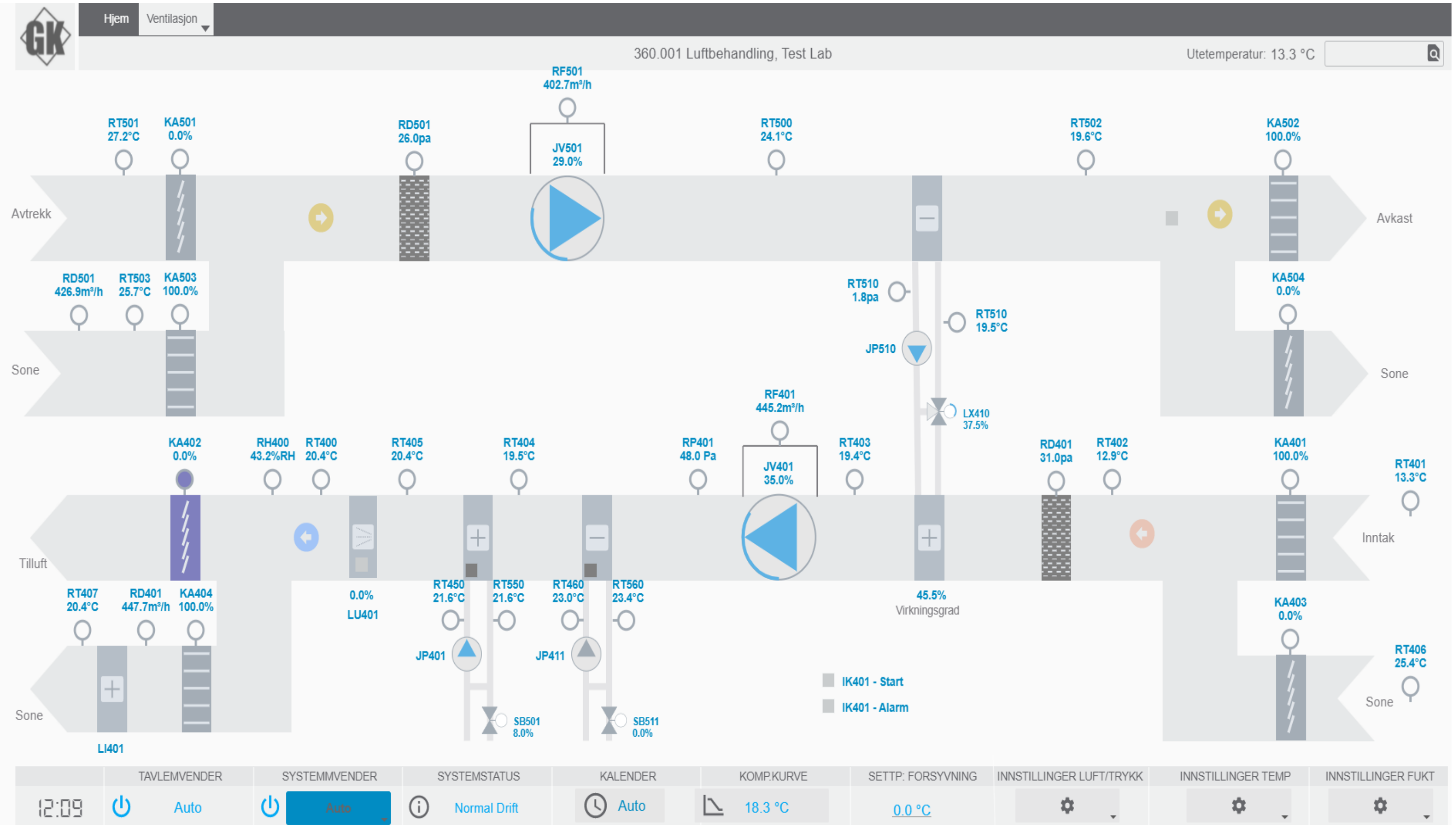
Some of the related to airflow concerning the “COMMISSION DELEGATED REGULATION (EU) No 65/2014” given by manufacture are shown in Table below

Fluid Dynamic Efficiency/Class	28.6/A
Grease Filtering Efficiency/Class	88.3 %/B
Exhaust air	
Air flow at minimum / maximum speed in normal use	257.7 m^3/h / 416.5 m^3/h
Air flow at intensive or boost setting	674.4 m^3/h
Measured airflow at best set-point	303.2 m^3/h
Recirculation	
Air flow at maximum in normal use	282 m^3/h330 m^3/h
Maximum airflow/Intensive setting	409 m^3/h

Appendix B: Overview of the instruments and their operating conditions

Instrument	Parameters	Size range	Accuracy	Operating Conditions	Measurement principle
Aerotrak: HANDHELP AIRBORNE PARTICLE COUNTER	Measuring in particles/m^3 in 3 different bins.	Particle size 0.3-25 µm; Channels: 3 (0.3, 2.5, 5.0 µm)	Counting efficiency: 50% at 0.3 µm;100% for particles >0.45 µm	5-35 C. 20-95% non-condensing RH	Not publicly available
Grimm: PORTABLE DUST MONITOR 1.108	PM1, PM2.5, PM10 measuring in particles/liter in 15 different bins.	Particle size 0.3-20 µm ; Channels: 15 (0.3, 0.4, 0.5, 0.65, 0.8, 1, 1.6, 2, 3, 4, 5, 7.5, 10, 15, 20 µm)	Reproducability: ± 3 %	Temperature Operation 4 to 45°C. 10 to 90 % RH non-condensing. Maximum Particle Concentration 2000 counts per cm3 or 0.1mg per cm3.	Measures particles by quantifying the angular dispersion or scattering caused by the passage of particles of various sizes through a light beam produced by a laser diode. The light that is scattered is collected at a 90° angle, through the aperture of a photodiode. The signals are then sent to a pulse height analyzer, where the presize size distribution of particles is derived. By summing up the total number of overall sizes, the total number concentration can be derived.
P-TRAK: ULTRAFINE PARTICLE COUNTER MODEL 8525	UFP. Concentration Range: 0 to 5 x 10^5 particles/cm^3	Particle size 0.02 to 1 µm.	Not publicly available	Temperature Operation 0 to 38°C. Flow Rate sample and total: Approx 100 cm^3/min. 700 cm^3/min	Mixes the particles with alcohol, causing them to grown into a larger droplet. The droplets are then passed through a focused laser beam, producing light flashes. The particle concentration is determined by counting the light flashes with a photodetector.
Rotronic CP11	RH, dew point, wet bulb	0.1%-99.95%	±3.0%(10-95% at 25C), ±5%(other)	(-20-60) °C. 10-90% RH, non condensing	Uses non dispersive infrared (NDIR) with automatic baseline correction (ABC) to measure the different parameters.
	CO2	0-9999ppm	±(30ppm+5% og reading) at 0-5000 ppm		
	Temperature	-20-60 °C	±0.3°C at5-40°C		
Fluke Infrared thermometer 64 max	Temperature celsius	-30 °C to 600 °C	±1.0 °C or ±1.0% of reading, whichever is greater / (-10 to 0 °C):± 2.0 / (-30 to - 10 °C) ± 3.0	0 °C to 50 °C Non- condensing @ ≤ 10 °C ≤ 90 % RH @ 10 °C to 30 °C ≤ 75 % RH @ 30 °C to 40 °C ≤ 45 % RH @ 40 °C to 50 °C	Measures surface temperature by measuring the amount of infrared energy radiated by the target's surface.
Thermocouples type K and T	Temperature celsius	Type K: –270 to 1260°C Type T:-270 to 370°C	Type K: Standard: +/- 2.2C or +/- .75% Type T: Standard: +/- 1.0C or +/- .75% (whichever is greater)	Operating temperature same as size range	Uses two wires legs that are welded together at one end, creating a junction. This junction is where the temperature is measured. When the junction experiences a change in temperature, a voltage is created. The voltage can then be interpreted using thermocouple reference tables to calculate the temperature.
AIR HANDLING CONTROLLER DPT-CTRL-2500-D	Air flow rate (m^3/h)	0 to 2500 Pa	Pressure <125Pa= 1 % + ±2 Pa Pressure >125Pa= 1 % + ±1 Pa	Operating temperature: -20-50 °C; Storage temperature: -40-70 °C Humidity: 0 to 95 % rH, non condensing	Multifunctional PID controller with differential pressure or air flow transmitter for building automation systems
DIFFERENTIAL PRESSURE TRANSMITTERS DPT250-R8-D	Pressure(Pa)	0 to 250 Pa	Pressure <125Pa= 1 % + ±2 Pa Pressure >125Pa= 1 % + ±1 Pa	Operating temperature: -10-50 °C; Storage temperature: -20-70 °C Humidity: 0 to 95 % rH, non	Measuring static and differential pressure, with field selectable units, range and output, all in a single device.

Appendix C: A schematic of the ventilation system in Gk-cloud



360.001 Luftbehandling, Test Lab

Utetemperatur: 13.3 °C

12:09

TAVLEMVENDER Auto

SYSTEMMVENDER Auto

SYSTEMSTATUS Normal Drift

KALENDER Auto

KOMP.KURVE 18.3 °C

SETTP. FORSYVNING 0.0 °C

INNSTILLINGER LUFT/TRYKK

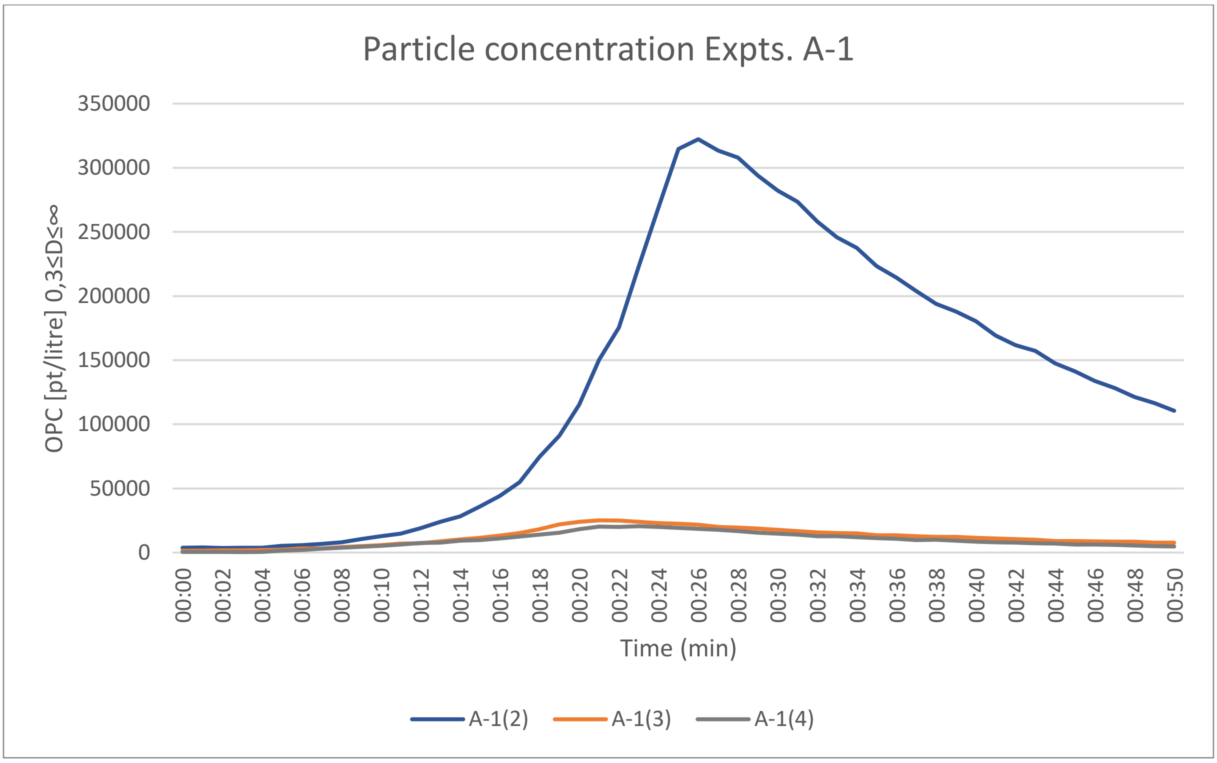
INNSTILLINGER TEMP

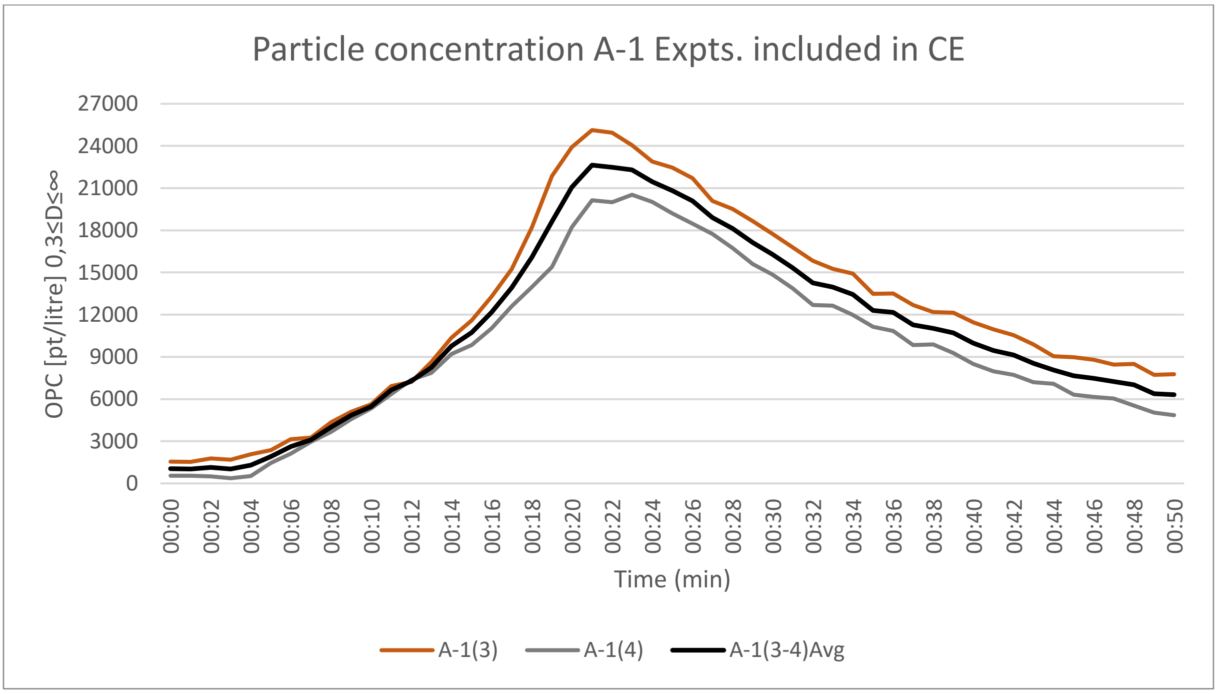
INNSTILLINGER FUKT

Appendix D: Particle concentration for the different tested combinations

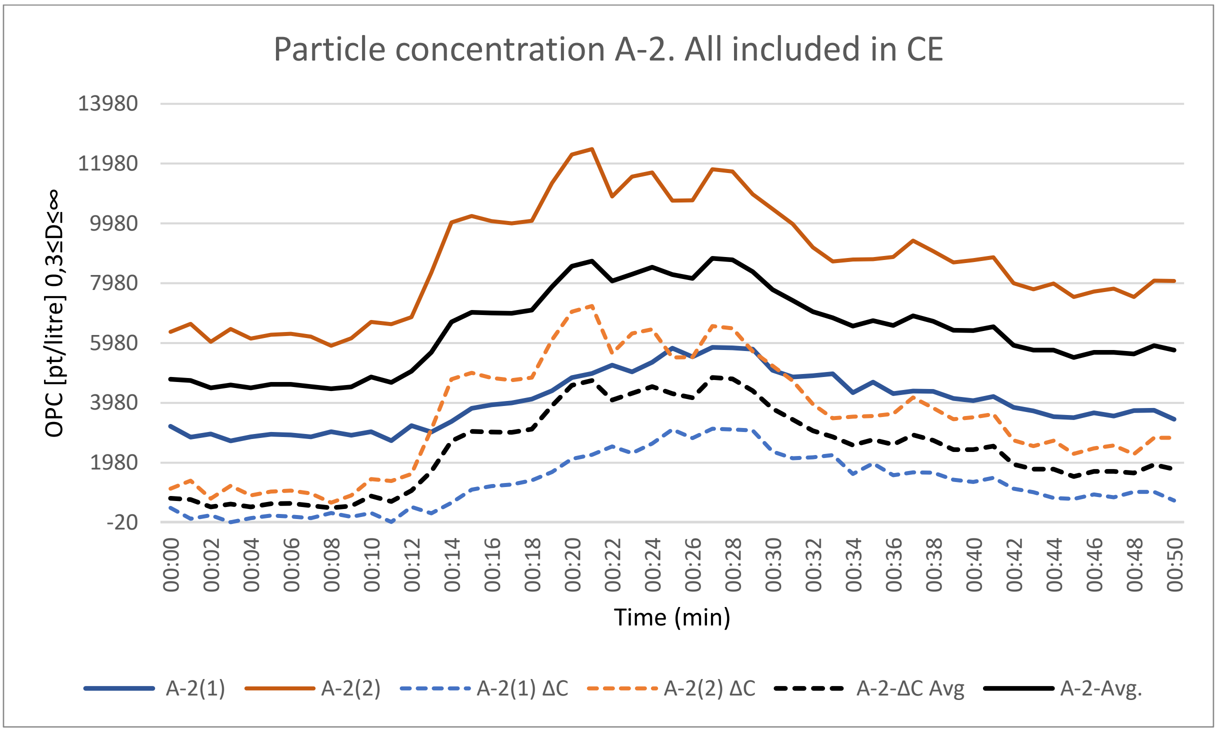
ΔC (Ccook-Cbkg)

Replicated experiments of the combination A-1: hood off, primary ventilation 72 m3/h

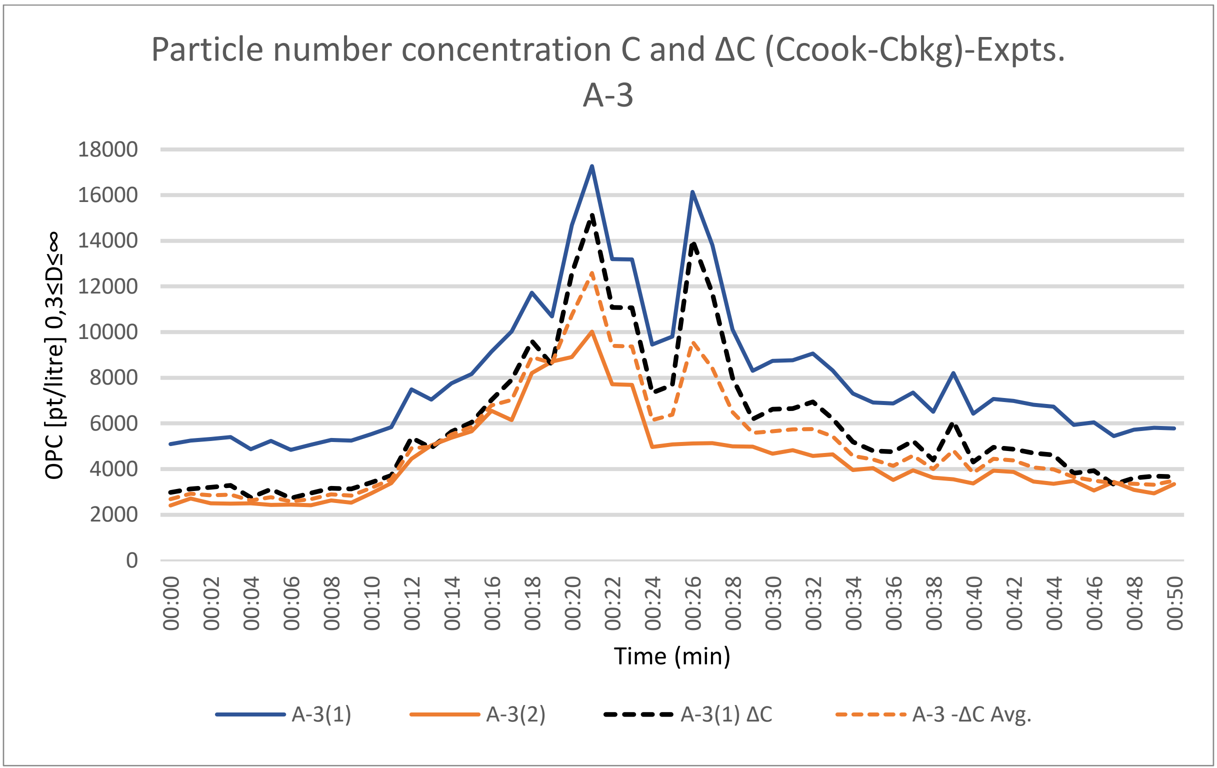




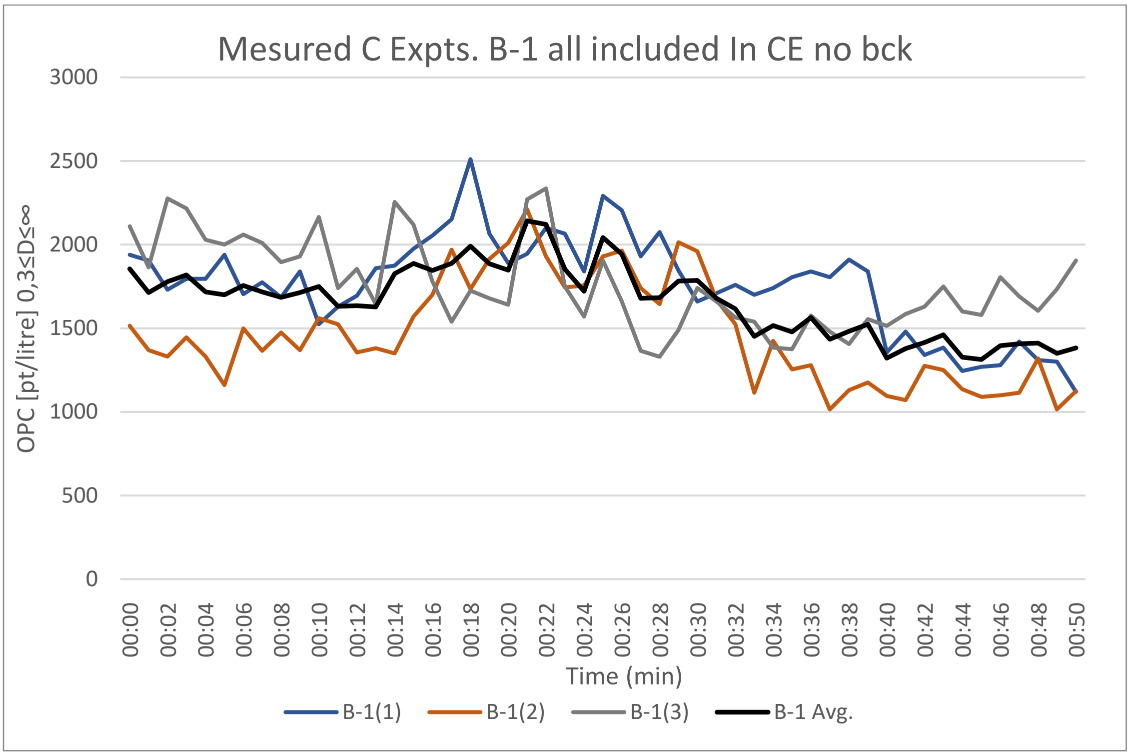
Replicated experiments of the combination A-2:flow rate 144 m3/h. 54 cm above the cooktop



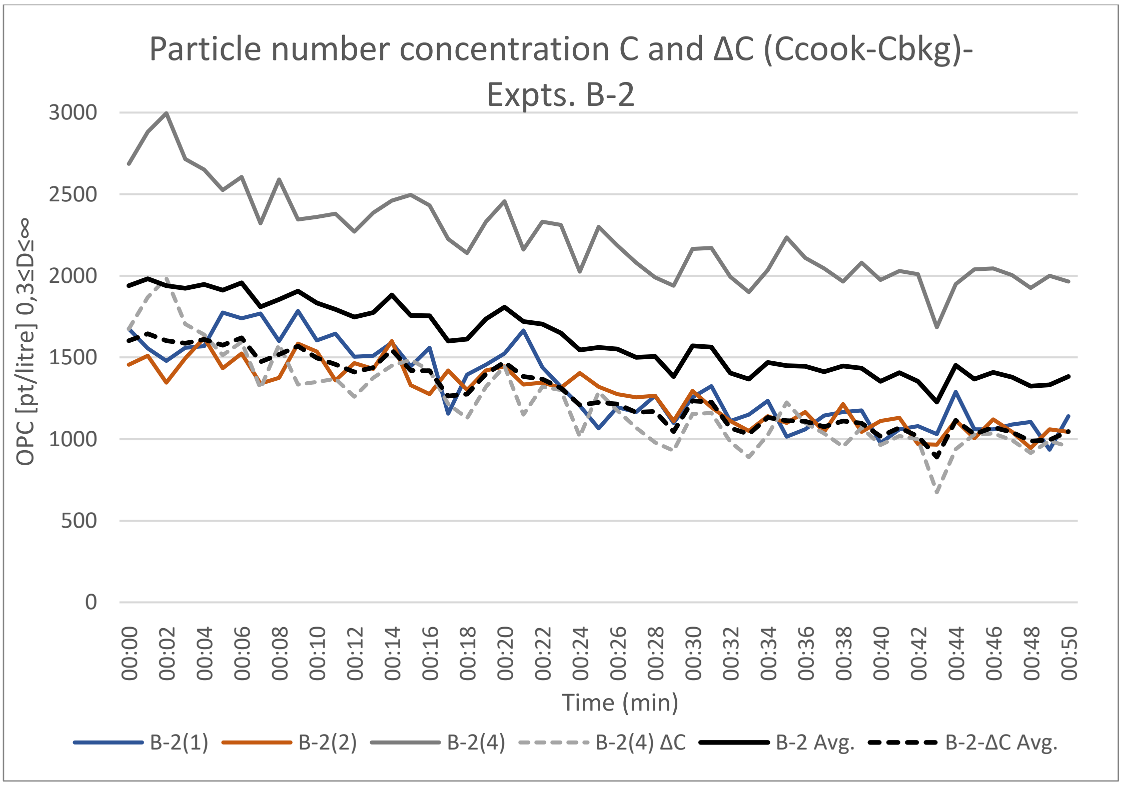
Replicated experiments of the combination A-3: flow rate 144 m3/h. 70 cm above the cooktop



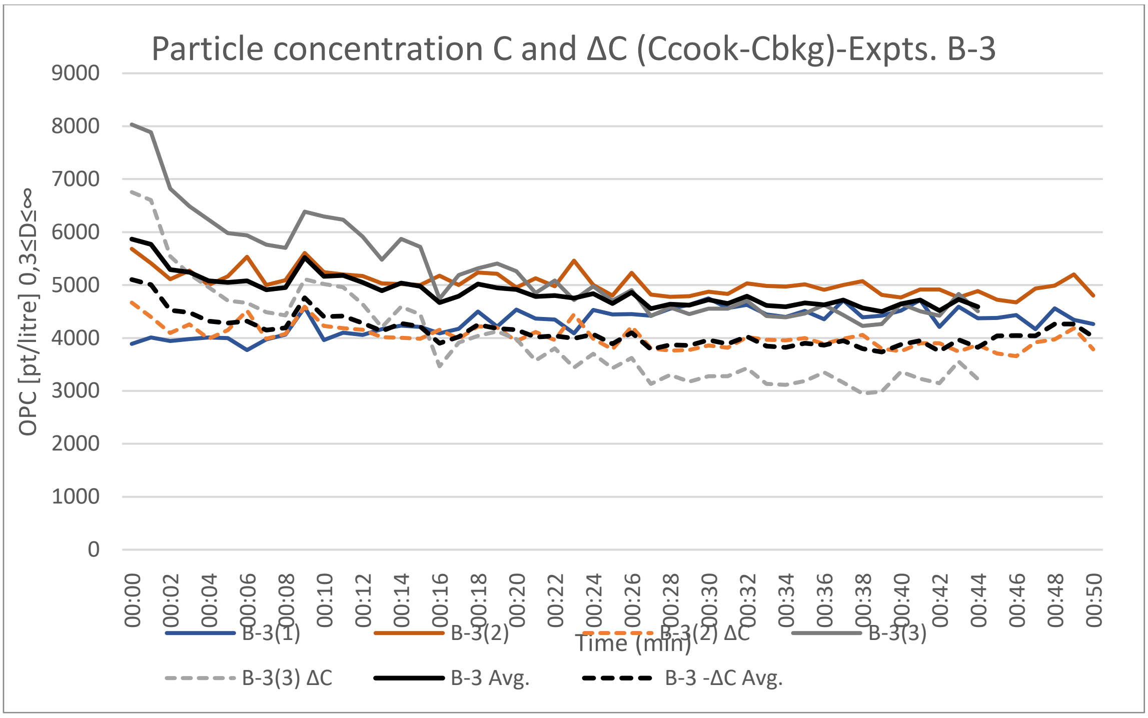
Replicated experiments of the combination B-1: flow rate 219 m3/h. 54 cm above the cooktop



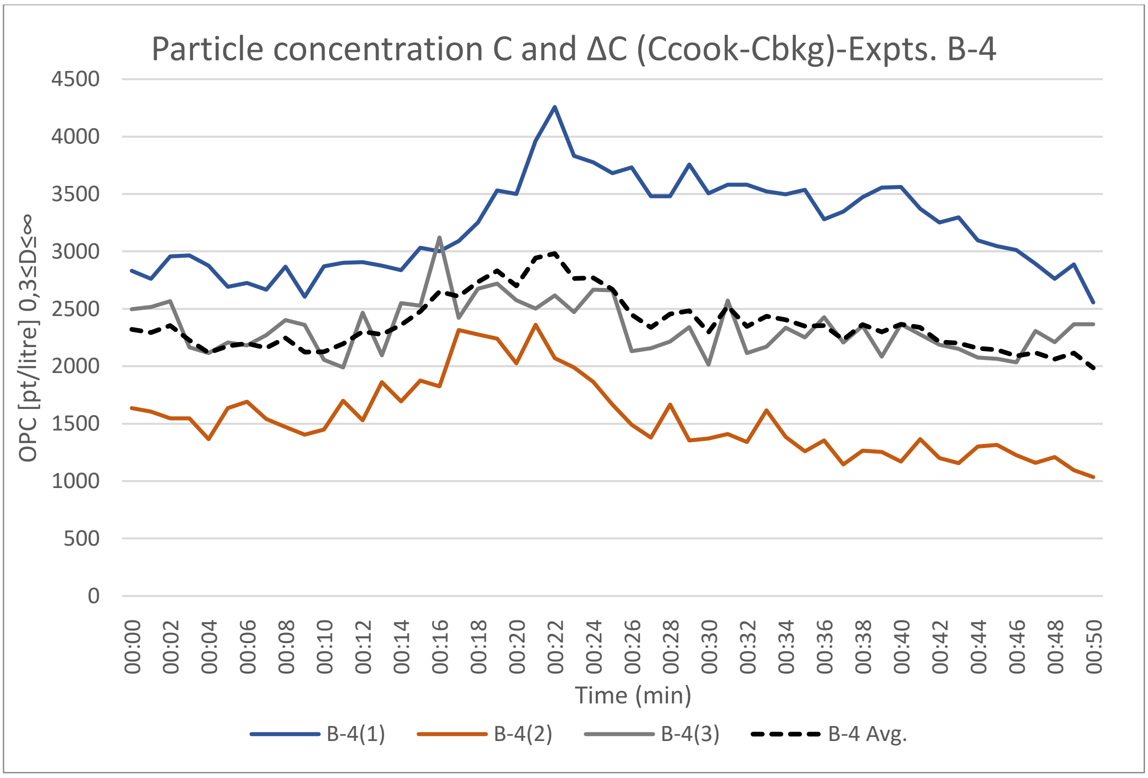
Replicated experiments of the combination B-2: flow rate 322 m3/h. 54 cm above the cooktop



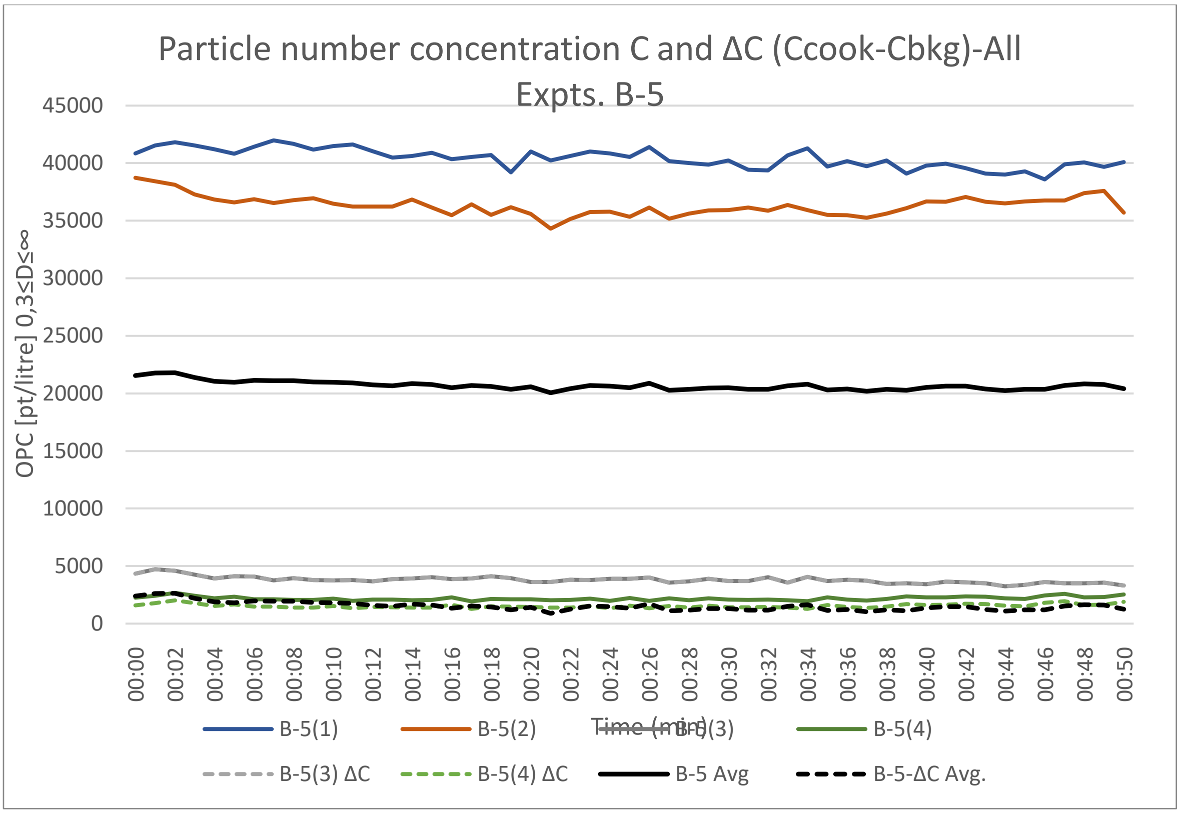
Replicated experiments of the combination B-3: flow rate 395 m3/h. 54 cm above the cooktop

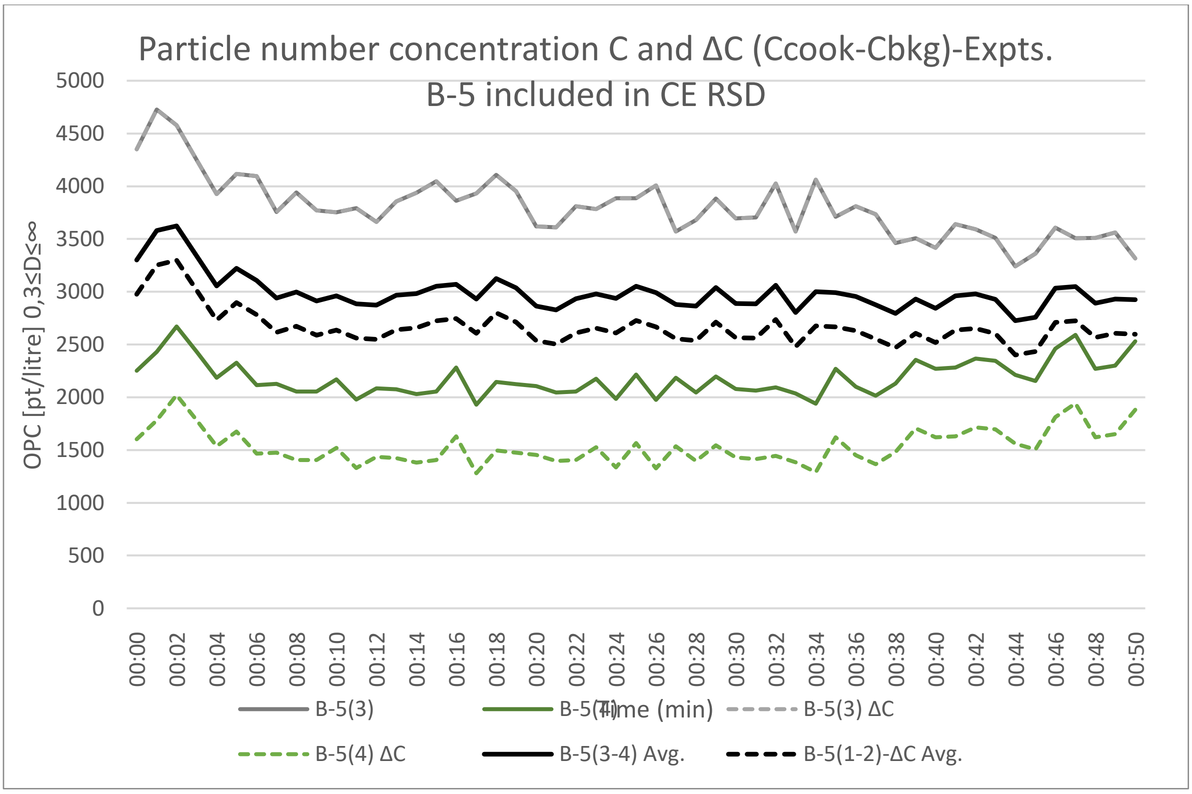


Replicated experiments of the combination B-4: flow rate 219 m3/h. 70 cm above the cooktop

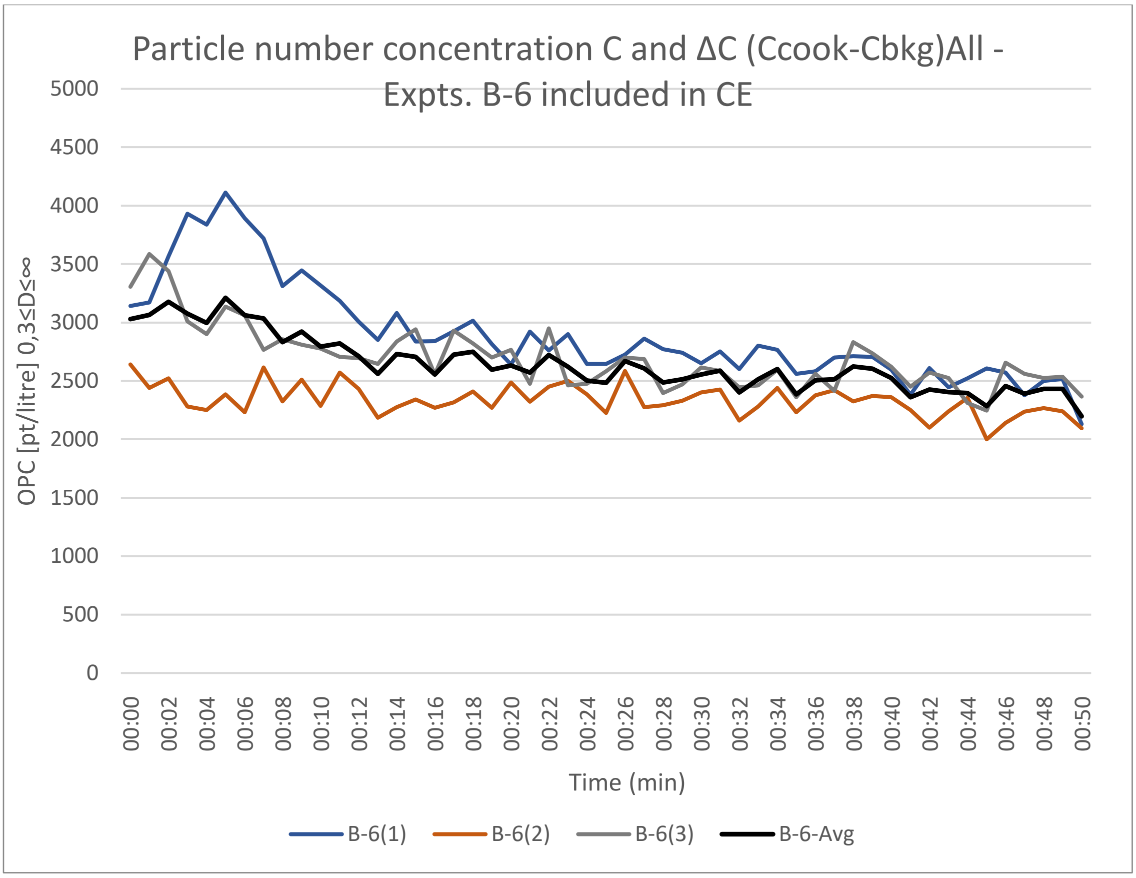


Replicated experiments of the combination B-5: Flow rate 322 m3/h. 70 cm above the cooktop





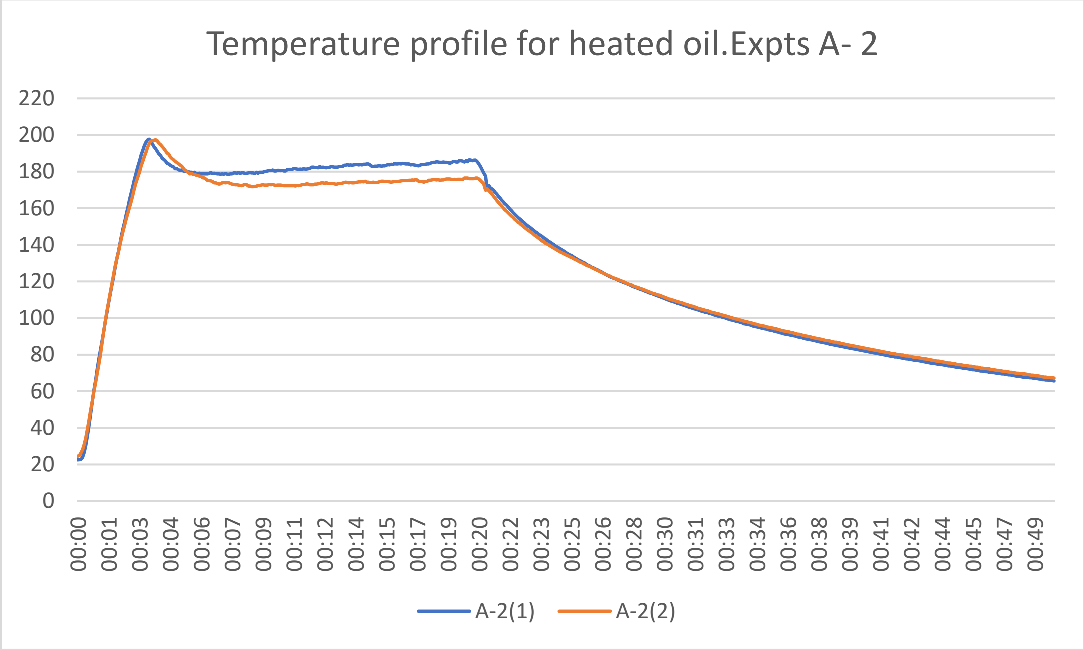
Replicated experiments of the combination B-6: flow rate 395 m3/h. 70 cm above the cooktop

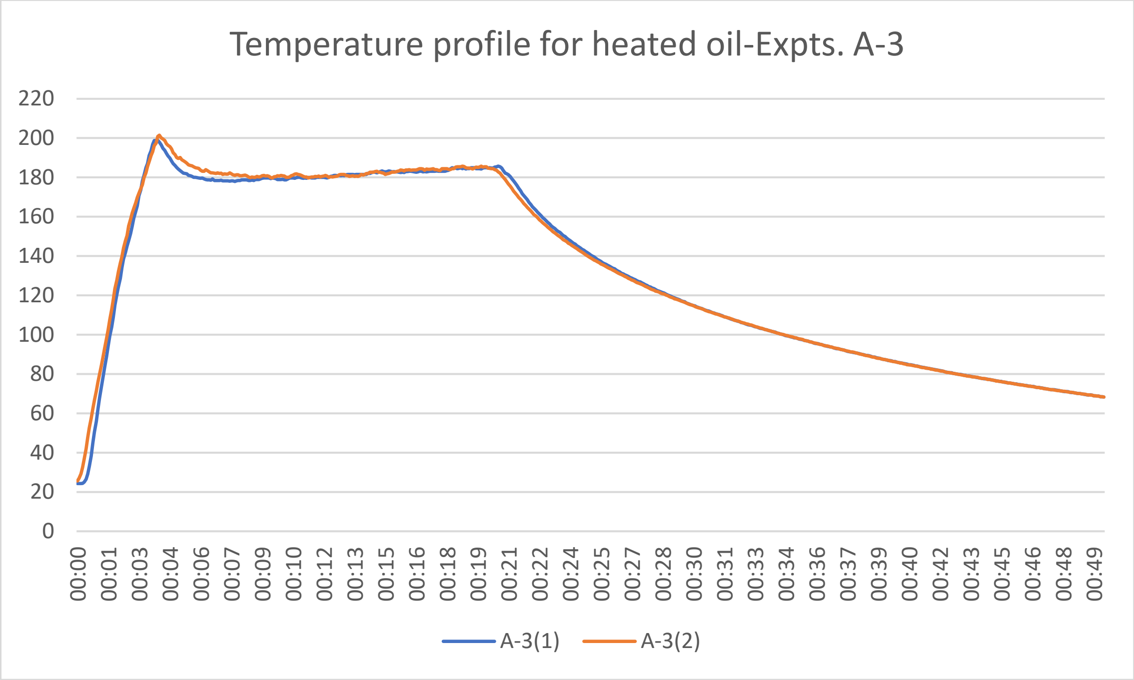


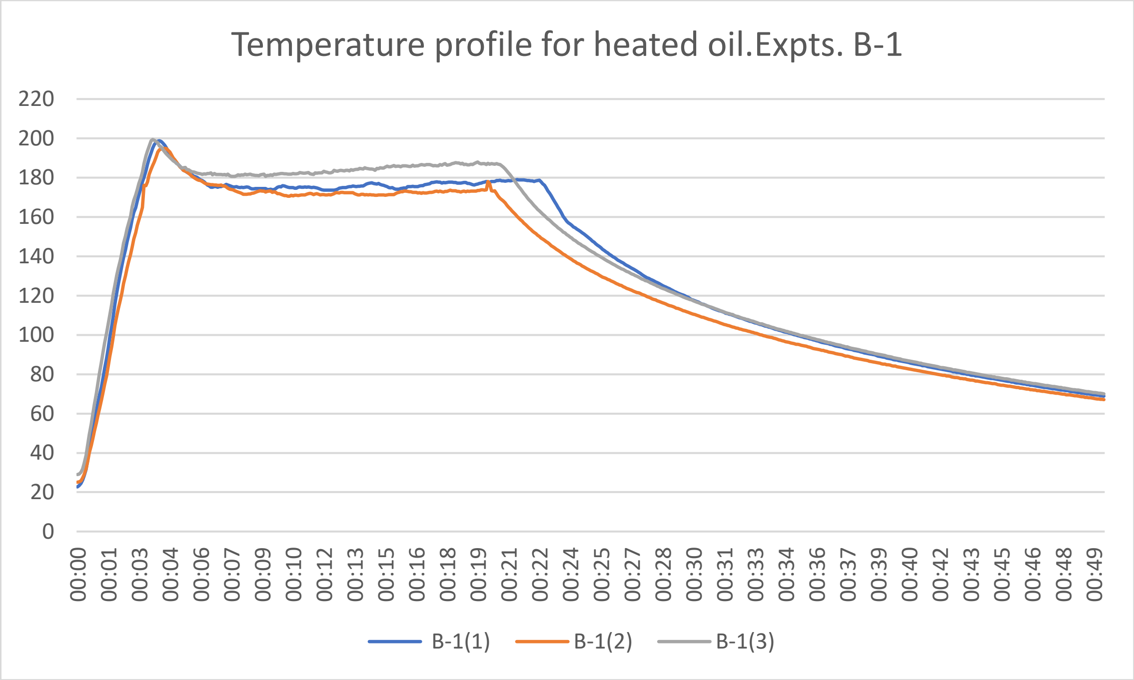
Appendix E: Temperature profile for heated oil for different tested combinations

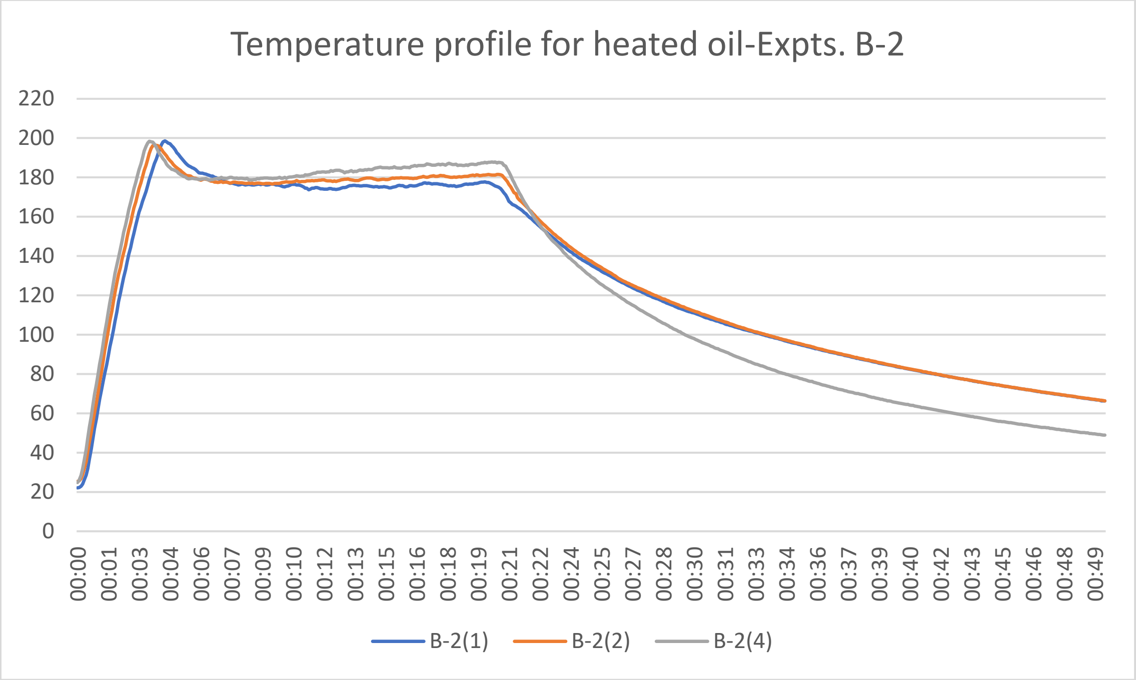
The last figure in the appendix is for all experiments

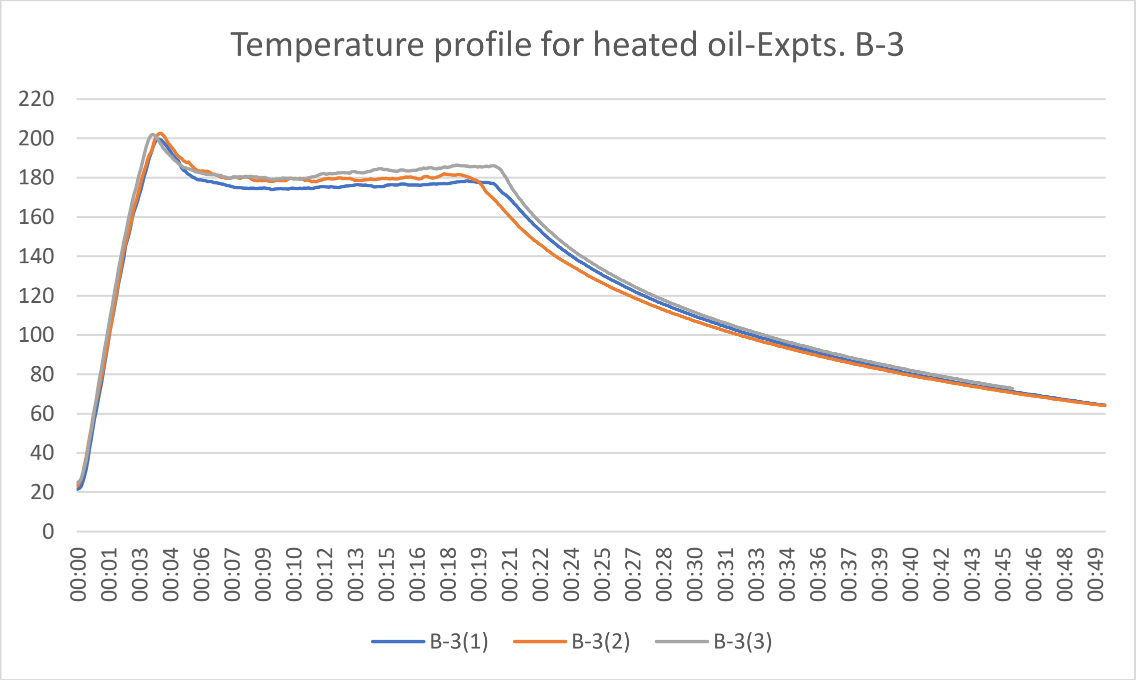
The flow rate and mounting height for each combination as descripted in Appendix D

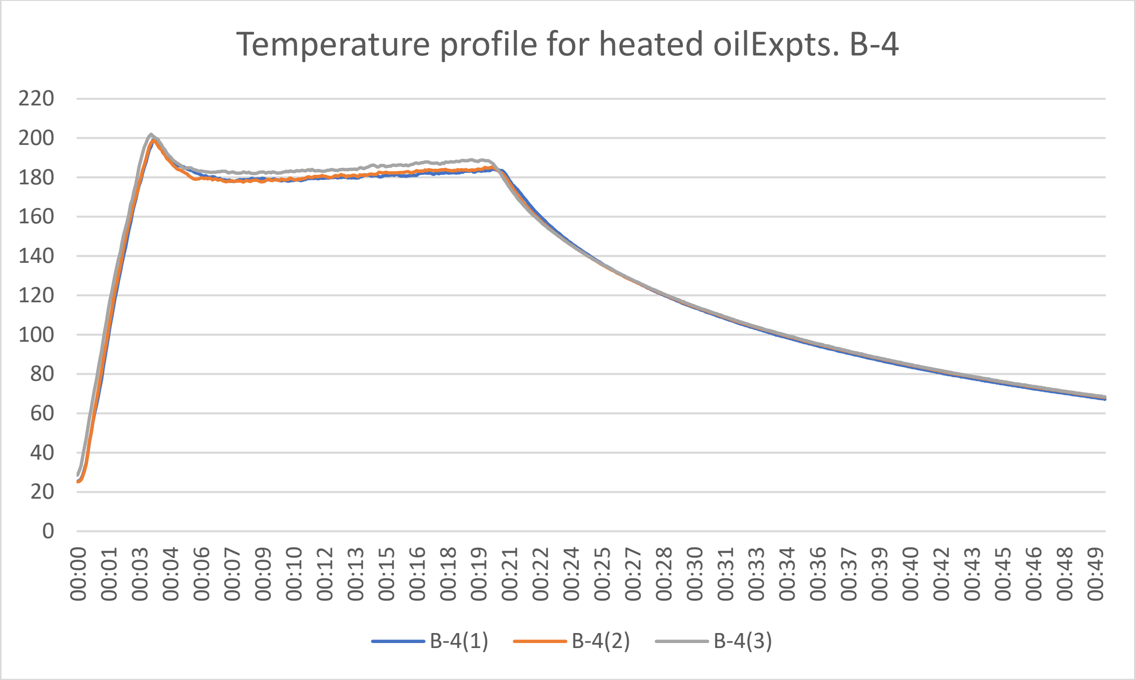


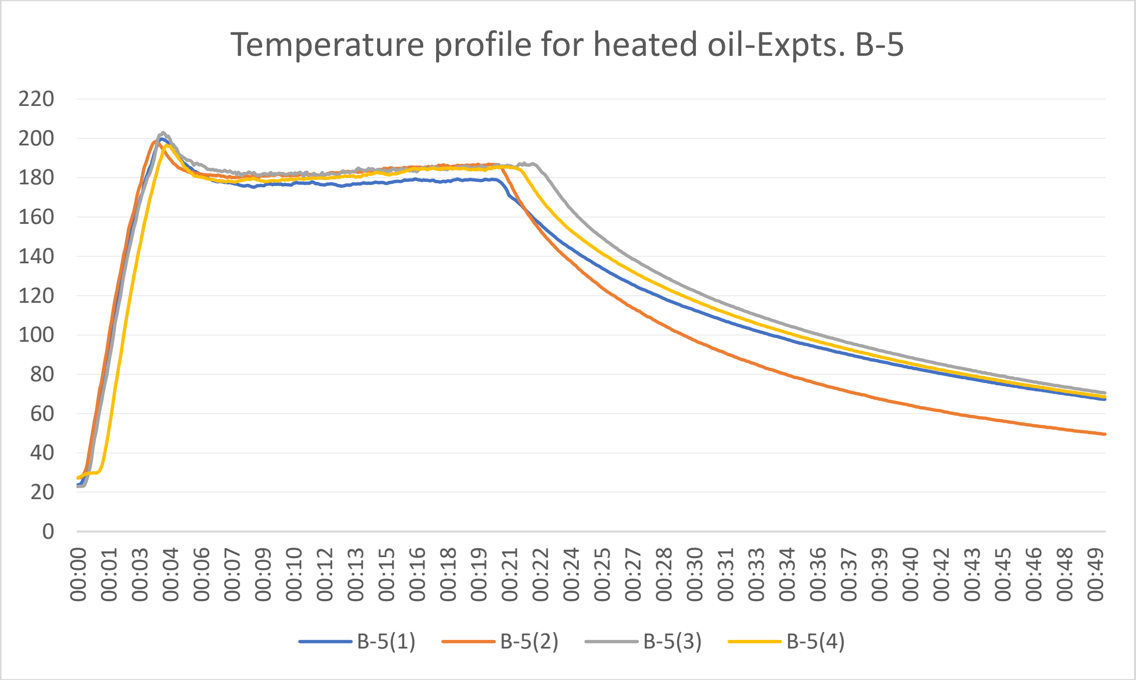

Temperature profile for heated oil-Expts. A-3
220
200
180
160
140
120
100
80
60
40
20
0
00:00
00:01
00:03
00:04
00:06
00:07
00:09
00:10
00:12
00:13
00:15
00:16
00:18
00:19
00:21
00:22
00:24
00:25
00:27
00:28
00:30
00:31
00:33
00:34
00:36
00:37
00:39
00:40
00:42
00:43
00:45
00:46
00:48
00:49
A-3(1)
A-3(2)

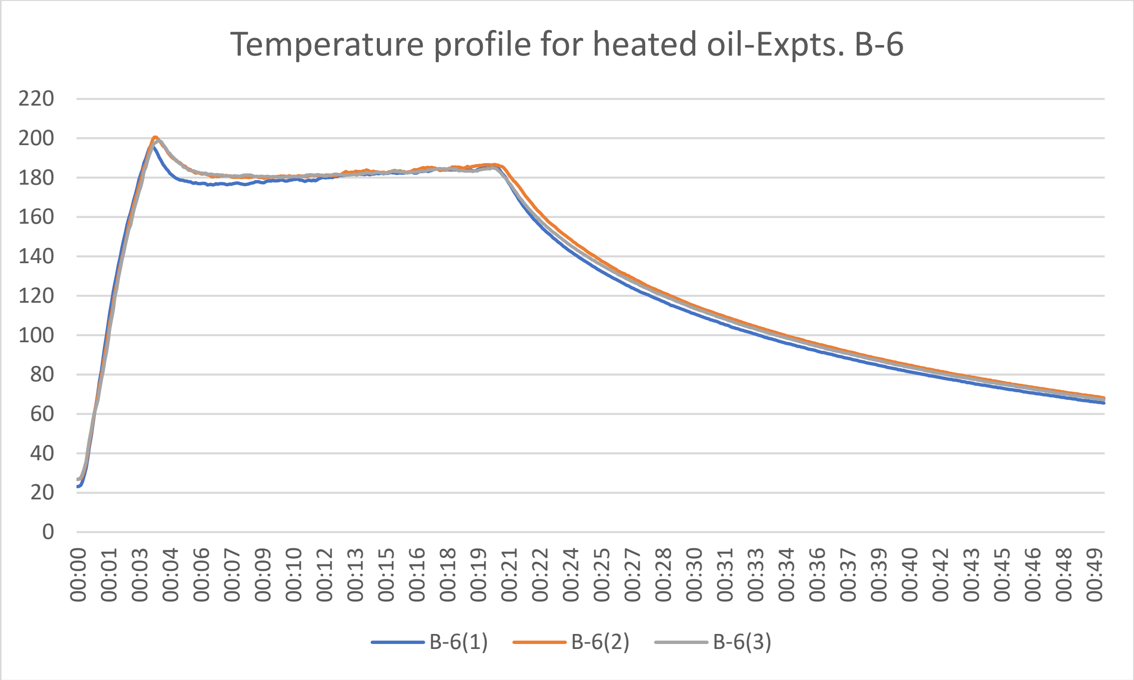

Temperature profile for heated oil.Expts. B-1
220
200
180
160
140
120
100
80
60
40
20
0
00:00
00:01
00:03
00:04
00:06
00:07
00:09
00:10
00:12
00:13
00:15
00:16
00:18
00:19
00:21
00:22
00:24
00:25
00:27
00:28
00:30
00:31
00:33
00:34
00:36
00:37
00:39
00:40
00:42
00:43
00:45
00:46
00:48
00:49
B-1(1)
B-1(2)
B-1(3)

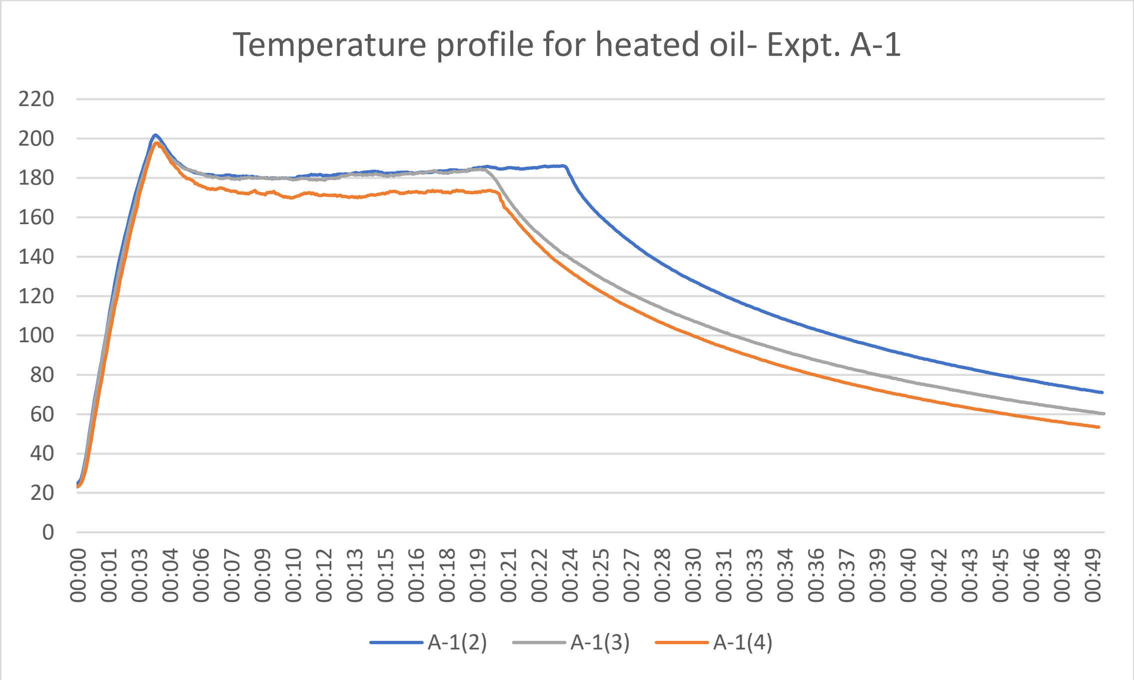

Temperature profile for heated oil-Expts. B-2
220
200
180
160
140
120
100
80
60
40
20
0
00:00
00:01
00:03
00:04
00:06
00:07
00:09
00:10
00:12
00:13
00:15
00:16
00:18
00:19
00:21
00:22
00:24
00:25
00:27
00:28
00:30
00:31
00:33
00:34
00:36
00:37
00:39
00:40
00:42
00:43
00:45
00:46
00:48
00:49
B-2(1)
B-2(2)
B-2(4)

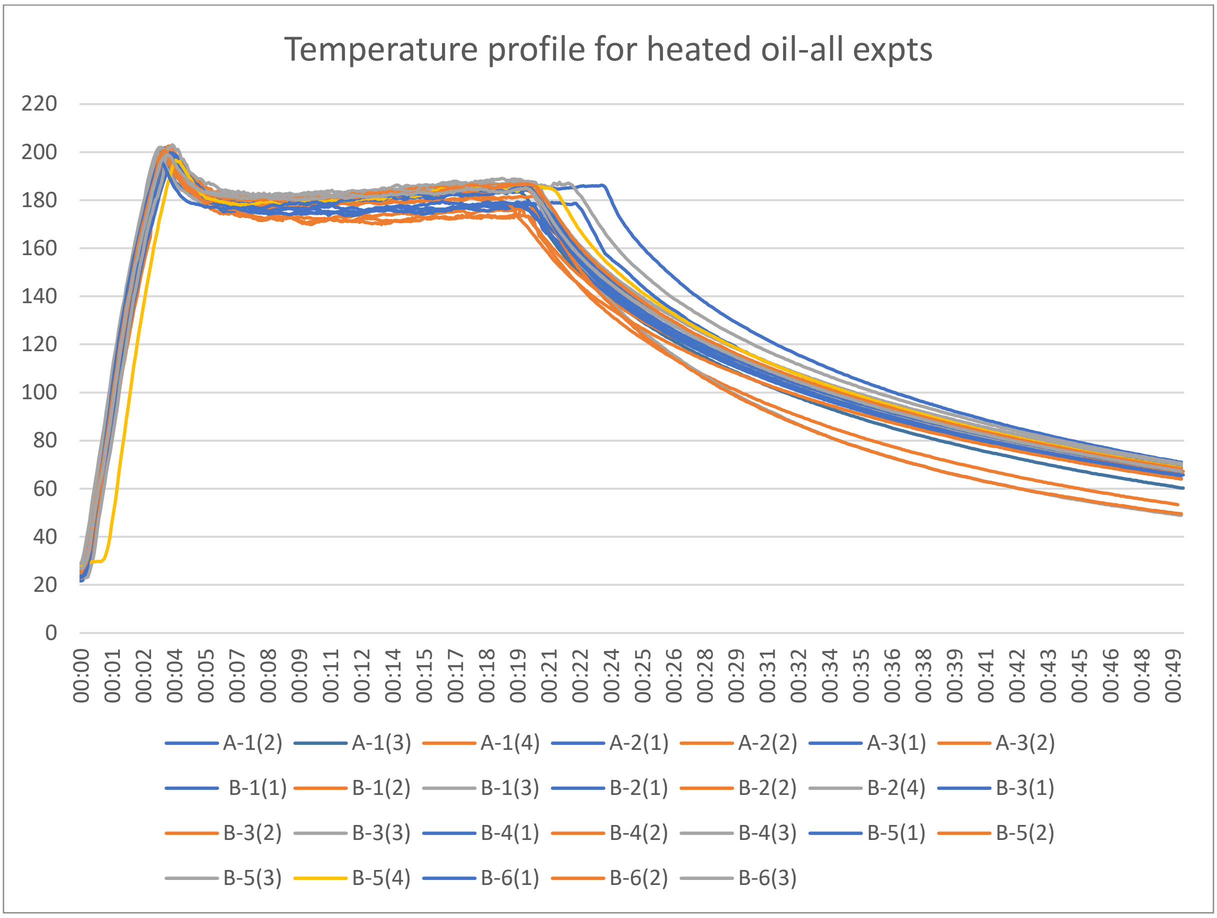

Temperature profile for heated oil-Expts. B-3
220
200
180
160
140
120
100
80
60
40
20
0
00:00
00:01
00:03
00:04
00:06
00:07
00:09
00:10
00:12
00:13
00:15
00:16
00:18
00:19
00:21
00:22
00:24
00:25
00:27
00:28
00:30
00:31
00:33
00:34
00:36
00:37
00:39
00:40
00:42
00:43
00:45
00:46
00:48
00:49
B-3(1)
B-3(2)
B-3(3)


Temperature profile for heated oilExpts. B-4
220
200
180
160
140
120
100
80
60
40
20
0
00:00
00:01
00:03
00:04
00:06
00:07
00:09
00:10
00:12
00:13
00:15
00:16
00:18
00:19
00:21
00:22
00:24
00:25
00:27
00:28
00:30
00:31
00:33
00:34
00:36
00:37
00:39
00:40
00:42
00:43
00:45
00:46
00:48
00:49
B-4(1)
B-4(2)
B-4(3)


Temperature profile for heated oil-Expts. B-5
220
200
180
160
140
120
100
80
60
40
20
0
00:00
00:01
00:03
00:04
00:06
00:07
00:09
00:10
00:12
00:13
00:15
00:16
00:18
00:19
00:21
00:22
00:24
00:25
00:27
00:28
00:30
00:31
00:33
00:34
00:36
00:37
00:39
00:40
00:42
00:43
00:45
00:46
00:48
00:49
B-5(1)
B-5(2)
B-5(3)
B-5(4)


Temperature profile for heated oil-Expts. B-6
220
200
180
160
140
120
100
80
60
40
20
0
00:00
00:01
00:03
00:04
00:06
00:07
00:09
00:10
00:12
00:13
00:15
00:16
00:18
00:19
00:21
00:22
00:24
00:25
00:27
00:28
00:30
00:31
00:33
00:34
00:36
00:37
00:39
00:40
00:42
00:43
00:45
00:46
00:48
00:49
B-6(1)
B-6(2)
B-6(3)

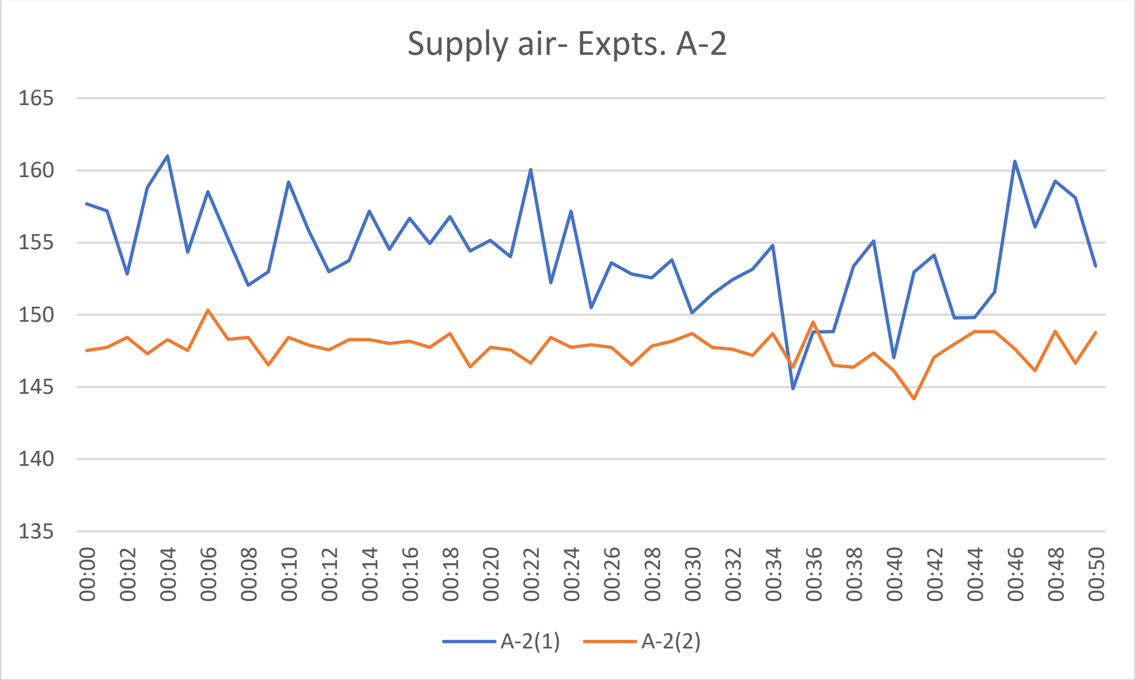

Temperature profile for heated oil- Expt. A-1
220
200
180
160
140
120
100
80
60
40
20
0
00:00
00:01
00:03
00:04
00:06
00:07
00:09
00:10
00:12
00:13
00:15
00:16
00:18
00:19
00:21
00:22
00:24
00:25
00:27
00:28
00:30
00:31
00:33
00:34
00:36
00:37
00:39
00:40
00:42
00:43
00:45
00:46
00:48
00:49
A-1(2)
A-1(3)
A-1(4)

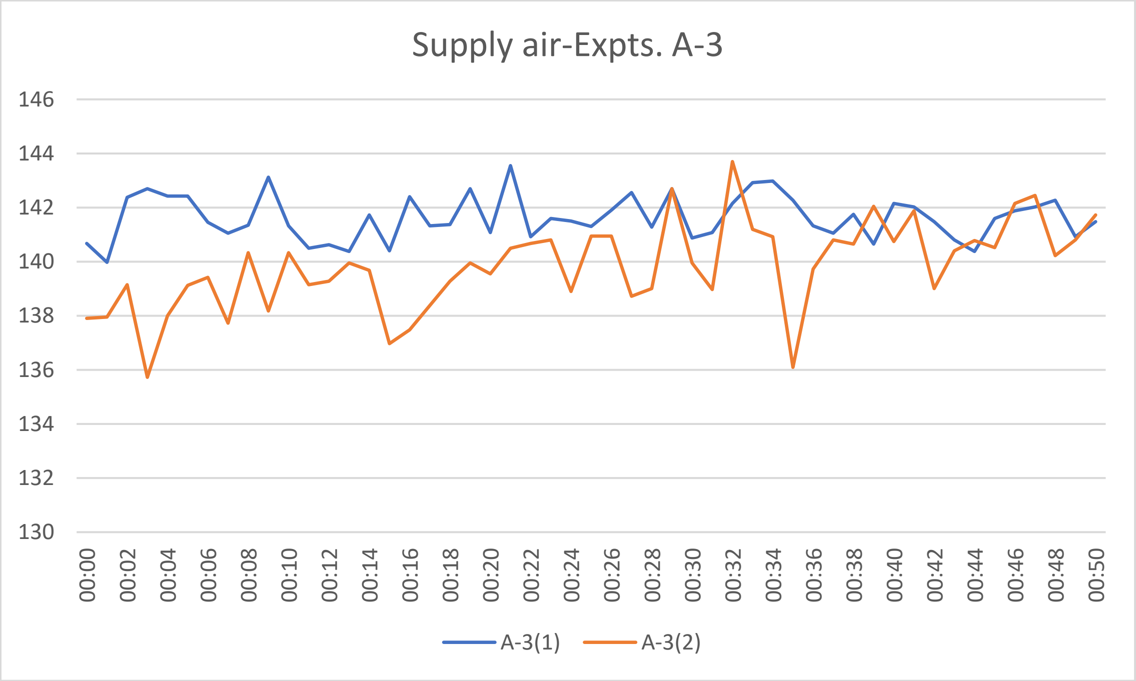

Temperature profile for heated oil-all expts
220
200
180
160
140
120
100
80
60
40
20
0
00:00
00:01
00:02
00:04
00:05
00:07
00:08
00:09
00:11
00:12
00:14
00:15
00:17
00:18
00:19
00:21
00:22
00:24
00:25
00:26
00:28
00:29
00:31
00:32
00:34
00:35
00:36
00:38
00:39
00:41
00:42
00:43
00:45
00:46
00:48
00:49
A-1(2)
A-1(3)
A-1(4)
A-2(1)
A-2(2)
A-3(1)
A-3(2)
B-1(1)
B-1(2)
B-1(3)
B-2(1)
B-2(2)
B-2(4)
B-3(1)
B-3(2)
B-3(3)
B-4(1)
B-4(2)
B-4(3)
B-5(1)
B-5(2)
B-5(3)
B-5(4)
B-6(1)
B-6(2)
B-6(3)

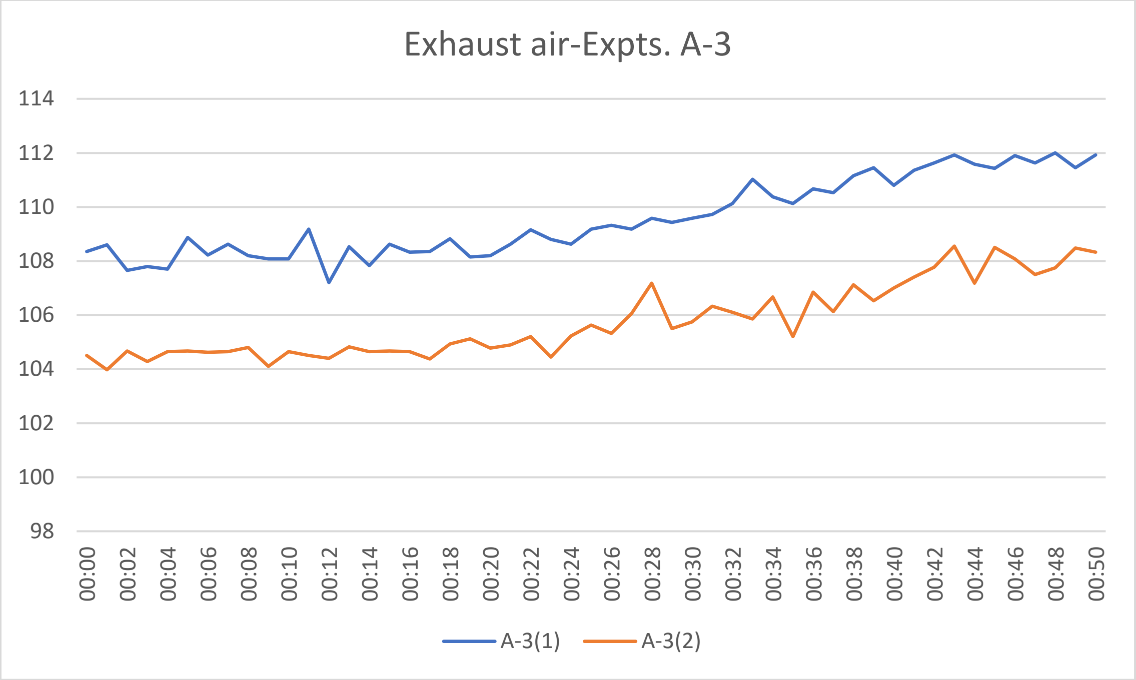
Appendix F: Profile of supply or exhaust air for different tested combinations

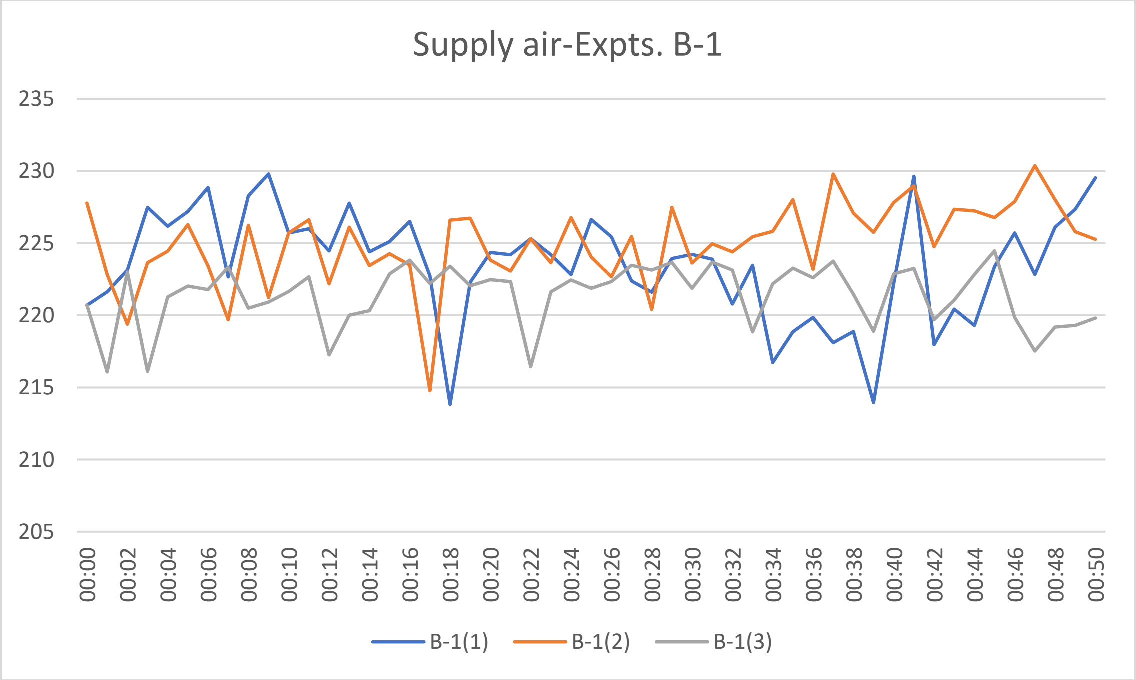
The last figure in the appendix is for all experiments

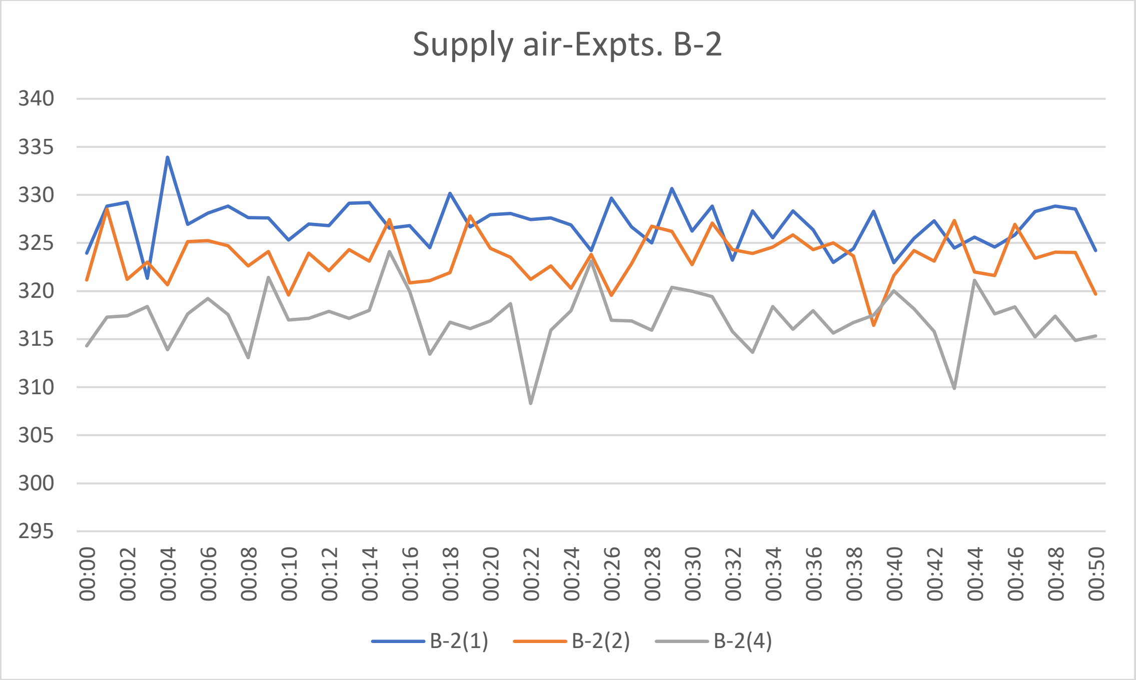
Air flow for each experiment is mentioned in Appendix D

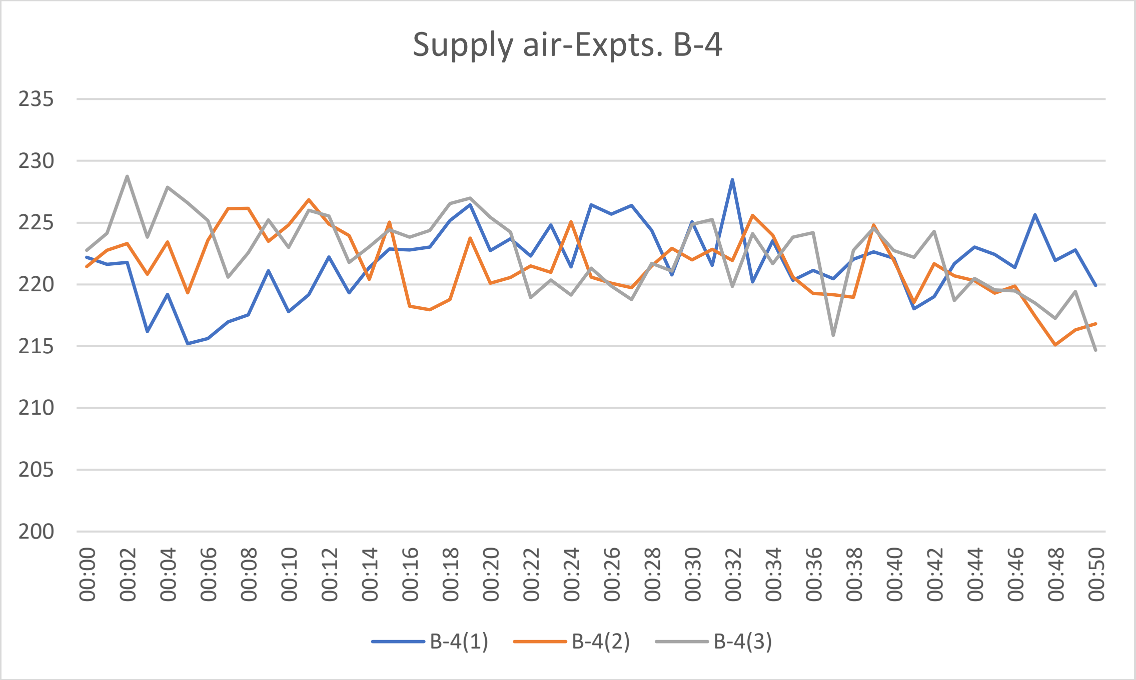


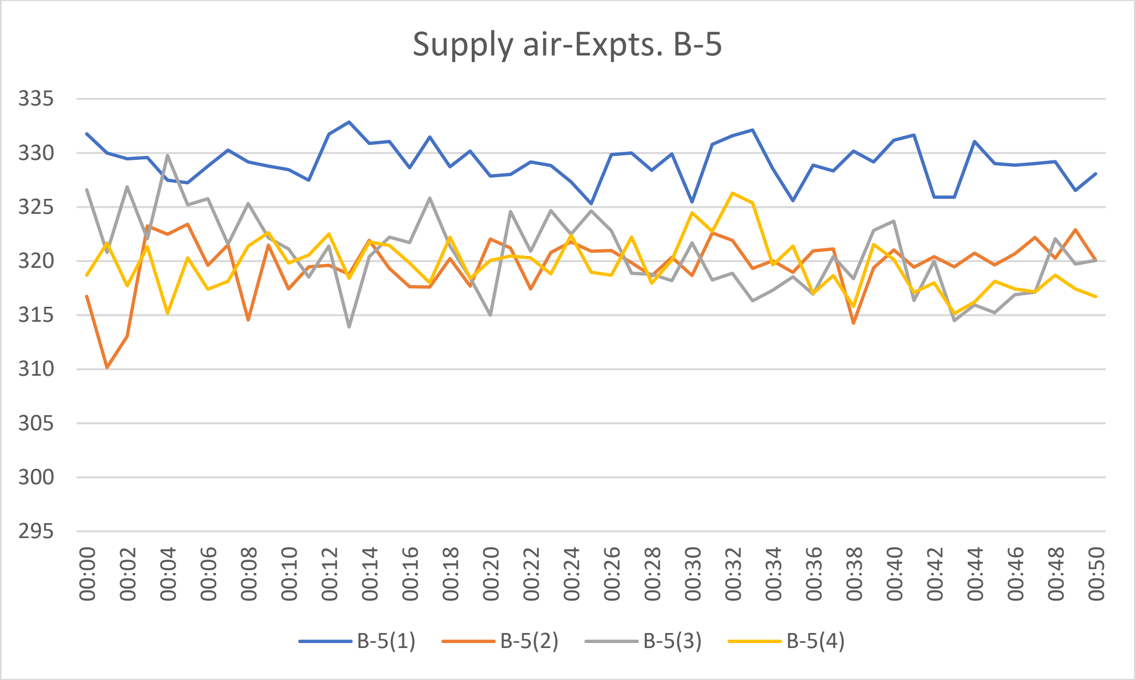


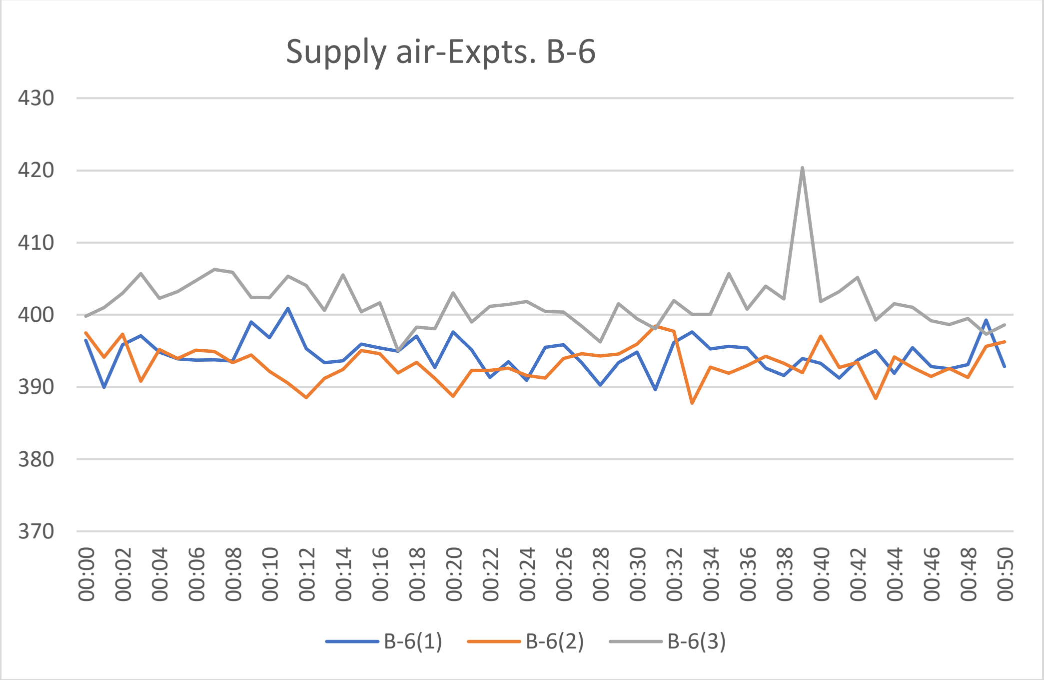

Exhaust air-Expts. A-3
114
112
110
108
106
104
102
100
98
00:00
00:02
00:04
00:06
00:08
00:10
00:12
00:14
00:16
00:18
00:20
00:22
00:24
00:26
00:28
00:30
00:32
00:34
00:36
00:38
00:40
00:42
00:44
00:46
00:48
00:50
A-3(1)
A-3(2)

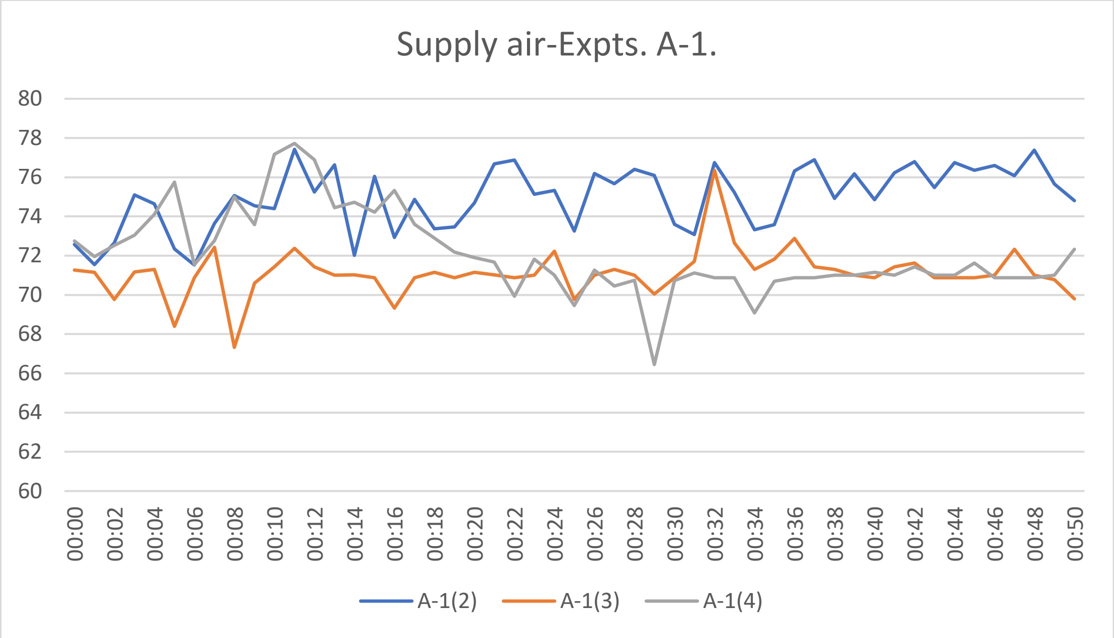

Supply air-Expts. B-1
235
230
225
220
215
210
205
00:00
00:02
00:04
00:06
00:08
00:10
00:12
00:14
00:16
00:18
00:20
00:22
00:24
00:26
00:28
00:30
00:32
00:34
00:36
00:38
00:40
00:42
00:44
00:46
00:48
00:50
B-1(1)
B-1(2)
B-1(3)

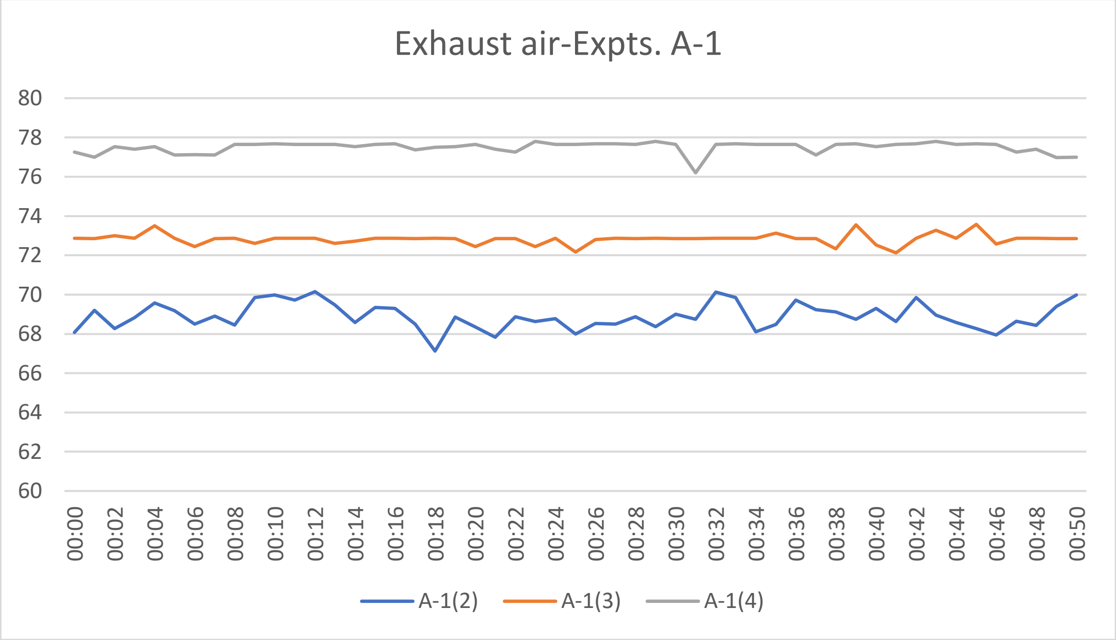

Supply air-Expts. B-2
340
335
330
325
320
315
310
305
300
295
00:00
00:02
00:04
00:06
00:08
00:10
00:12
00:14
00:16
00:18
00:20
00:22
00:24
00:26
00:28
00:30
00:32
00:34
00:36
00:38
00:40
00:42
00:44
00:46
00:48
00:50
B-2(1)
B-2(2)
B-2(4)

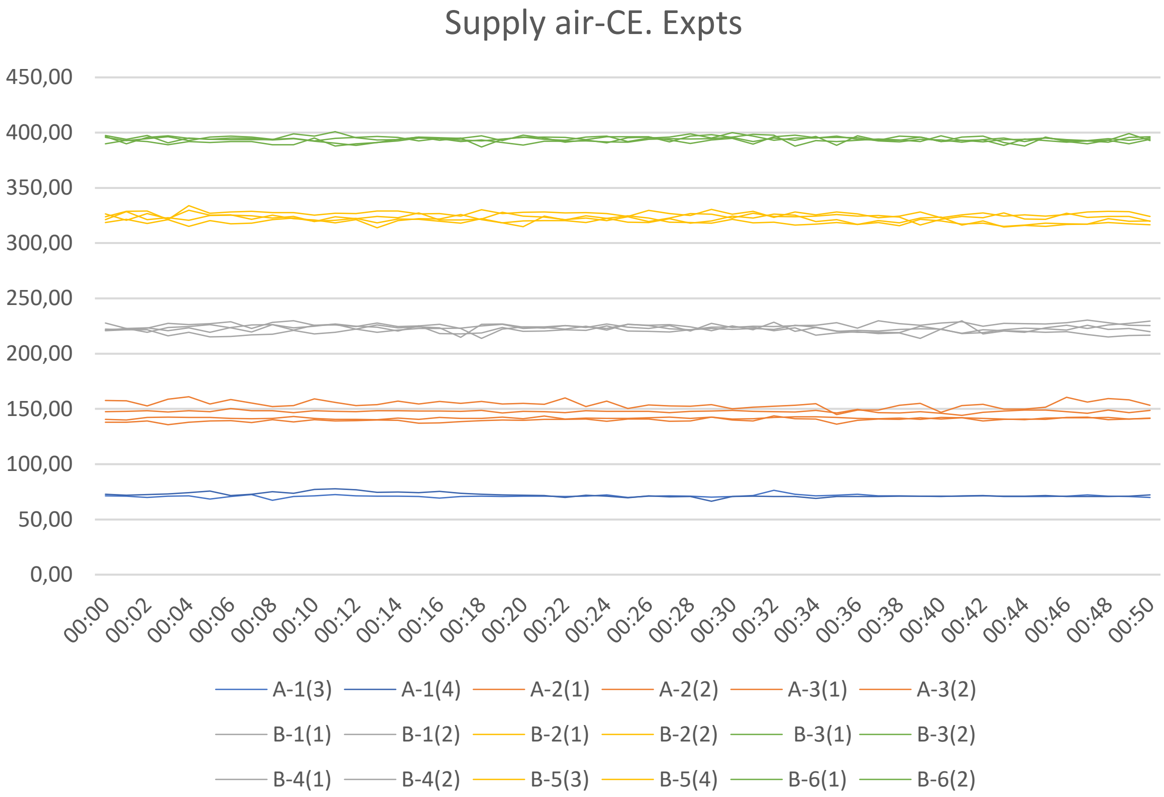

Supply air-Expts. B-4
235
230
225
220
215
210
205
200
00:00
00:02
00:04
00:06
00:08
00:10
00:12
00:14
00:16
00:18
00:20
00:22
00:24
00:26
00:28
00:30
00:32
00:34
00:36
00:38
00:40
00:42
00:44
00:46
00:48
00:50
B-4(1)
B-4(2)
B-4(3)


Supply air-Expts. B-5
335
330
325
320
315
310
305
300
295
00:00
00:02
00:04
00:06
00:08
00:10
00:12
00:14
00:16
00:18
00:20
00:22
00:24
00:26
00:28
00:30
00:32
00:34
00:36
00:38
00:40
00:42
00:44
00:46
00:48
00:50
B-5(1)
B-5(2)
B-5(3)
B-5(4)


Supply air-Expts. B-6
430
420
410
400
390
380
370
00:00
00:02
00:04
00:06
00:08
00:10
00:12
00:14
00:16
00:18
00:20
00:22
00:24
00:26
00:28
00:30
00:32
00:34
00:36
00:38
00:40
00:42
00:44
00:46
00:48
00:50
B-6(1)
B-6(2)
B-6(3)


Supply air-Expts. A-1.
80
78
76
74
72
70
68
66
64
62
60
00:00
00:02
00:04
00:06
00:08
00:10
00:12
00:14
00:16
00:18
00:20
00:22
00:24
00:26
00:28
00:30
00:32
00:34
00:36
00:38
00:40
00:42
00:44
00:46
00:48
00:50
A-1(2)
A-1(3)
A-1(4)


Exhaust air-Expts. A-1
80
78
76
74
72
70
68
66
64
62
60
00:00
00:02
00:04
00:06
00:08
00:10
00:12
00:14
00:16
00:18
00:20
00:22
00:24
00:26
00:28
00:30
00:32
00:34
00:36
00:38
00:40
00:42
00:44
00:46
00:48
00:50
A-1(2)
A-1(3)
A-1(4)


Supply air-CE. Expts
450,00
400,00
350,00
300,00
250,00
200,00
150,00
100,00
50,00
0,00
00:00
00:02
00:04
00:06
00:08
00:10
00:12
00:14
00:16
00:18
00:20
00:22
00:24
00:26
00:28
00:30
00:32
00:34
00:36
00:38
00:40
00:42
00:44
00:46
00:48
00:50
A-1(3)
A-1(4)
A-2(1)
A-2(2)
A-3(1)
A-3(2)
B-1(1)
B-1(2)
B-2(1)
B-2(2)
B-3(1)
B-3(2)
B-4(1)
B-4(2)
B-5(3)
B-5(4)
B-6(1)
B-6(2)

Appendix G: Average conditions, SD and RSD of test all test combinations

Expts.	Avg air temperature [°C]					Airflow [m3/h]		ΔPressure [Pa]	CE inclusion
	Test-room	Test-hall	Primary exhaust	Hood exhaust	Supply air	Tot. supply air	Exhaust air	Test room/hall	
A-1(1)	23,6	22,3	23,7	22,8	23,8	73,2	70	0,05	no
A-1(2)	23,7	22,3	23,7	23,0	24,0	75,0	69	0,02	No
A-1(3)	23,2	21,9	23,4	22,9	23,4	71,0	73	-0,96	Yes
A-1(4)	23,9	23,7	24,1	23,0	24,6	72,0	77	-1,87	Yes
A-2(1)	22,1	20,4	22,5	21,7	27,7	154,2		0,02	Yes
A-2(2)	22,3	20,9	23,0	21,8	28,5	147,7	110,0	0,02	Yes
A3-(1)	23,2	22,7	23,9	22,4	27,3	141,0	109,6	0,02	Yes
A3-(2)	23,1	21,9	23,8	22,3	28,0	139,0	105,8	-0,52	Yes
B-1(1)	22,8	22,7	23,2	22,1	24,6	223,5		0,02	Yes
B-1(2)	22,9	21,9	23,2	22,1	24,5	225,0		0,02	Yes
B-1(3)	23,1	22,3	23,7	22,5	24,9	221,4		-0,97	Yes
B-2(1)	22,1	20,9	22,3	21,8	23,5	326,6		0,02	Yes
B-2(2)	22,3	21,0	22,5	21,8	23,6	323,5		0,02	Yes
B-2(4)	23,0	22,0	23,4	21,9	24,3	317,1		-0,84	Yes
B-3(1)	21,7	20,6	21,9	21,6	23,0	394,5		0,02	Yes
B-3(2)	21,9	20,8	22,2	21,7	23,1	393,4		0,02	Yes
B-3(3)	21,9	21,0	22,4	21,6	23,3	392,1		0,02	No
B-4(1)	22,7	18,8	23,4	22,1	24,6	221,8		-0,50	Yes
B-4(2)	22,8	21,7	23,5	22,2	24,6	221,5		-0,85	Yes
B-4(3)	22,7	21,6	23,2	22,3	24,6	222,5		-0,85	Yes
B-5(1)	23,6	23,3	24,2	22,3	25,0	329,1		0,02	No
B-5(2)	23,6	23,3	24,2	22,2	25,2	319,7		0,02	No
B-5(3)	22,7	19,1	23,2	22,0	24,2	320,6		-0,74	Yes
B-5(4)	22,9	22,2	23,4	22,0	24,4	319,6		-0,93	Yes
B-6(1)	22,9	19,8	23,6	22,0	24,3	394,4		-0,66	Yes
B-6(2)	22,8	21,5	23,5	22,0	24,4	393,3		-0,70	Yes
B-6(3)	22,4	24,0	23,0	21,9	24,0	401,7		-0,82	Yes
Avg	22,8	21,6	23,2	22,1	24,8			-0,40	
SD	0,2	1,0	0,3	0,1	0,3	2,8	2,3	0,35	
RSD [%]	1,0	4,5	1,4	0,5	1,4	1,4	2,1		
SD CE expts	0,1	0,9	0,2	0,1	0,3	1,5	2,3	0,15	
RSD CE expts [%]	0,6	4,1	0,9	0,3	1,1	0,8	2,1		

Experiment conditions and total SD

Expts.	Avg air temperature [°C]					Airflow [m3/h]		ΔPressure [Pa]
	Test-room	Test-hall	Primary exhaust	Hood exhaust	Supply air	Tot. supply air	Exhaust air	Test room/hall
	SD	SD	SD	SD	SD	SD	SD	SD
All A-1	0,35	0,95	0,35	0,06	0,60	2,08	4,0	0,95
A-1 CE	0,49	1,27	0,49	0,07	0,85	0,71	2,8	0,64
A2 CE	0,11	0,37	0,34	0,06	0,60	4,57	0,0	0,00
A3 CE	0,06	0,54	0,09	0,08	0,49	1,41	2,7	0,38
B-1	0,15	0,39	0,26	0,22	0,17	1,82		0,57
B1 CE	0,15	0,39	0,26	0,22	0,17	1,82		0,00
B-2	0,44	0,65	0,57	0,11	0,46	4,84		0,50
B2 CE	0,09	0,08	0,14	0,00	0,13	2,23		0,00
B-3	0,14	0,21	0,21	0,04	0,13	1,17		0,00
B3 CE	0,14	0,18	0,17	0,05	0,10	0,80		0,00
B-4	0,05	1,63	0,16	0,10	0,03	0,54		0,20
B4 CE	0,05	1,63	0,16	0,10	0,03	0,54		0,20
B-5	0,48	1,99	0,54	0,17	0,45	4,59		0,50
B5 CE	0,12	2,17	0,14	0,03	0,13	0,70		0,13
B-6	0,23	2,09	0,31	0,08	0,22	4,58		0,08
B-6 CE	0,06	1,17	0,04	0,02	0,06	0,81		0,03
Avg alle expts	0,22	0,98	0,31	0,10	0,35	2,84	2,3	0,35
Avg CE expts	0,14	0,87	0,20	0,07	0,28	1,51	2,3	0,15

Overall RSDs for all test combinations

Expts.	Avg air temperature [°C]					Airflow [m3/h]			Oil temp.			Particle RSD			OPC-Grimm	Overall RSD		
	Test-room	Test-hall	Primary exhaust	Hood exhaust	Supply air	Tot. supply air	Tot. supply air	Exhaust Air	Tot expts. duration [%]	CE during expts[%]	CE post expts [%]	Tot expts. duration [%]	CE during expts[%]	CE post expts [%]	3% repaitability	Tot expts. duration [%]	CE during expts[%]	CE post expts [%]
	RSD	RSD	RSD	RSD	RSD	SD	RSD	RSD							0,3			
															0,3			
All A-1	1,49	4,18	1,48	0,25	2,50	2,08	2,9	5,5	5						0,3			
A-1 CE	2,07	5,58	2,08	0,31	3,54	0,71	1,0	3,8		3,8	3,7	22,2	10,8	12,6	0,3	24,20	14,10	15,50
									1,8						0,3			
A2 CE	0,51	1,79	1,48	0,27	2,13	4,57	3,0	0,0		3,6	0,9	52,4	49,9	42,1	0,3	52,62	50,22	42,34
															0,3			
A3 CE	0,28	2,44	0,39	0,35	1,76	1,41	1,0	2,5	1		0,8	41,8	7,5	32,9	0,3	42,01	8,54	33,16
															0,3			
B-1	0,66	1,73	1,13	0,99	0,69	1,82	0,8		3,7						0,3			
B1 CE	0,66	1,73	1,13	0,99	0,69	1,82	0,8			3,7	5,32	17	15,7	12,5	0,3	17,60	16,34	13,84
															0,3			
B-2	1,96	3,05	2,50	0,53	1,92	4,84	1,5		7,4						0,3			
B2 CE	0,41	0,37	0,63	0,00	0,54	2,23	0,7			2,5	3,7	34,2	30,1	32,3	0,3	35,01	30,23	32,54
															0,3			
B-3	0,62	1,00	0,96	0,17	0,57	1,17	0,3		2,1						0,3			
B3 CE	0,65	0,88	0,78	0,24	0,41	0,80	0,2			1,4	2,6	11	2,7	8,9	0,3	11,29	3,38	9,39
															0,3			
B-4	0,21	7,85	0,67	0,46	0,14	0,54	0,2		1,3						0,3			
B4 CE	0,21	7,85	0,67	0,46	0,14	0,54	0,2			1,4	0,5	36,4	24,9	38,2	0,3	37,27	26,16	39,01
															0,3			
															0,3			
B-5	2,08	9,07	2,29	0,77	1,82	4,59	1,4		8,5						0,3			
B5 CE	0,53	10,54	0,61	0,13	0,52	0,70	0,2			0,6	3,3	38,1	65,1	63	0,3	40,45	65,96	63,97
															0,3			
B-6	1,03	9,60	1,32	0,36	0,89	4,58	1,2		1,7						0,3			
B-6 CE	0,25	5,68	0,18	0,08	0,24	0,81	0,2			0,4	1,9	11,3	12,7	8,3	0,3	12,77	13,93	10,25
Avg alle expts	0,98	4,52	1,36	0,46	1,38	2,84	1,4	2,1	3,61			29,4				30		
Avg CE expts	0,62	4,10	0,88	0,31	1,11	1,51	0,8	2,1		2,2	2,5		24	28			25	29

Appendix H: Measured jet velocity and temperature at 4 points above the heated oil

Measurements this the hood operating in 4 different levels and mounted 54 cm alcove the cooktop

T room	22,50		Hood mounting height 70 cm	
Test C-5 108 m3/h-				
Height	Temp	ΔT	Velocity	Temp oil
[m]	[°C]		[m/s]	[°C]
0,1	41	18,50	0,18	185
0,2	33,4	10,90	0,37	186
0,3	29,9	7,40	0,42	184
0,4	41,9	19,40	0,45	183
Test C-6 182 m3/h				
Height	Temp		Velocity	Temp oil
[m]	[°C]		[m/s]	[°C]
0,1	48,5	26,00	0,18	185
0,2	47,5	25,00	0,35	183
0,3	45,5	23,00	0,38	183
0,4	43,1	20,60	0,32	184
Test C-7 285 m3/h				
Height	Temp		Velocity	Temp oil
[m]	[°C]		[m/s]	
0,1	45,5	23,00	0,17	183
0,2	41,7	19,20	0,31	184
0,3	41,6	19,10	0,37	183
0,4	42,1	19,60	0,41	183
Test C-8 359 m3/h				
Height	Temp		Velocity	Temp oil
[m]	[°C]		[m/s]	[°C]
0,1	43	20,50	0,03	185
0,2	37,2	14,70	0,37	185
0,3	35,6	13,10	0,43	186
0,4	35,7	13,20	0,39	187

Measurements this the hood operating in 4 different levels and mounted 54 cm alcove the cooktop

T rom 22,10 hood mounting height 54cm

Test C-1 108 m3/h-				
Height	Temp	ΔT	Velocity	Temp olje
[m]	[°C]	[°C]	[m/s]	[°C]
0,1	41,4	19,30	0	184
0,2	36,2	14,10	0,01	183
0,3	34,5	12,40	0,37	183
0,4	33,4	11,30	0,33	183

Test C-2 185 m3/h-				
Height	Temp	ΔT	Velocity	Temp olje
[m]	[°C]	[°C]	[m/s]	[°C]
0,1	45,7	23,60	0,10	184
0,2	39,7	17,60	0,35	183
0,3	37,5	15,40	0,37	184
0,4	38	15,90	0,34	186

Test C-3 322 m3/h-				
Height	Temp	ΔT	Velocity	Temp olje
[m]	[°C]	[°C]	[m/s]	[°C]
0,1	40,1	18,00	0,11	183
0,2	35	12,90	0,4	186
0,3	32,3	10,20	0,37	183
0,4	31,3	9,20	0,38	184

Test C-4 395 m3/h-				
Height	Temp	ΔT	Velocity	Temp olje
[m]	[°C]	[°C]	[m/s]	[°C]
0,1	43	20,90	0,05	184
0,2	35,8	13,70	0,33	185
0,3	42,7	20,60	0,4	184
0,4	41,4	19,30	0,27	186

Appendix I: Backgroud emissions

Test day	Record time Test-0	Time from previous expts.	Expt.	GRIMM [pt/litre]-Test-0-min	Background cons. substracted	Included in CE
				Min.		
05.mai	12:38		A2-1	2721	0	Yes
07.mai	11:24		B3-1	3776	0	Yes
	14:42	02:07	B3-2	4792	1016	Yes
	16:55	01:33	B3-3	5053	1277	No*
	18:51		A2-2	5248	1472	Yes
09.mai	17:09		B2-1	1400	0	Yes
	18:59	00:40	B2-2	1225	0	Yes
12.mai	09:48		B1-1	1575	0	Yes
	12:00	01:08	B1-2	1290	0	Yes
	16:37	03:26	A1-1	3076	no	NO*
	18:59	01:54	A1-2	3641	no	No*
14.mai	15:31		B5-1	38639		No*
	17:13	00:34	B5-2	37359		No*
18.mai	10:02		B6-1	2661	0	Yes
	11:37	00:27	B6-2	2271	0	Yes
	14:03	01:16	B4-1	2541	0	Yes
	15:43	00:29	B4-2	1410	0	Yes
	18:28	01:38	A3-1	4778	2117	Yes
21.mai	10:11		B5-3	4042	0	Yes
	12:05	00:43	B6-3	3021	0	yes
	13:41	00:36	B4-3	2421	0	yes
	15:29	00:49	A3-2	2461	0	Yes
	17:49	01:13	B2-3	did not measure		No
	19:14	00:22	B1-3	2121	0	yes
24.mai	13:29		A1-3	1440	0	Yes
	15:46	01:15	B2-4	2451	1011	Yes
	17:09	01:03	B5-4	2090	650	Yes
15.jun	16:56		A1-4	415	0	Yes

*Abnormal values during the actual test compared to the other identical expts.