MASTER'S THESIS

Humidity emission profiles and particle pollution in Danish households

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Humidity emission profiles and particle pollution in Danish households

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Investigation of indoor particle pollution and humidity emission profiles from household activities in Danish apartments/houses (based on measurements and literature).

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Abstract:

This report is a result of a master's thesis project, completed by a group of Building Energy Design students from Aalborg University.
The report consists of three parts analyzing different aspects of the indoor environment. The first part of the report is investigating moisture production profiles from indoor activities. It is a research based on literature and advanced building simulation models. In the second part of the report particle concentration in three Danish apartments has been investigated. To achieve this goal equipment had to be designed and assembled. Thus, group teamed up with a couple of Computer Science students who designed a data acquisition system for particle samplers. Measurement campaign lasted for three weeks and enabled the group to comprehensively describe how occupant behavior affects indoor PM 2.5 and PM 10 concentrations and estimate occupant exposure to particulate matter.
The third part of the report investigates the possibility of microplastic particle and fiber presence in the indoor air. Breathing thermal manikin has been used to determine if occupants are exposed to these particles by simulating human respiration. To analyze and process gathered data group received help from University staff who performed FPA-μFTIR-Imaging spectroscopy.
Findings and analysis of these three aspects IAQ is described in the following pages of the report.

Acknowledgments

We would like to express our gratitude to project supervisors Rasmus Lund Jensen and Li Liu for their patience, professional guidance, supervision and continuous motivation, without which this project would be impossible. We sincerely thank Joakim Levi Haslund and Casper Skov Mathisen who spent many hours developing data acquisition system for particle sensors, used in this project. Furthermore, we are in debt to Alvise Vianello for helping us tackle enormous issues of airborne microplastic research and for spending countless hours performing FPA-µFTIR-Imaging spectroscopy.

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1. Introduction

1.1 Research Background

The indoor environmental quality in Danish dwellings is the main focus area of for this master's thesis. Knowing how vast of a topic/an area this is, from its multitude of factors that can influence it, a few were chosen to be investigated: humidity increase caused by occupant activities, particle concentration and airborne microplastic have been selected.

The thesis is comprised out of three parts:

1- *Humidity profiles* based on different indoor activities
2- A study on *particle concentration* including a possible correlation between particles and different indoor air quality parameters that could help to control it (focusing on PM 2.5 and PM 10) and a
3- Pilot study of *airborne micro-plastic* investigating possible human exposure to this pollutant type.

A good indoor climate has a huge influence on people's health, and since Danes spend most of their time indoors, approximately 80% of the time according to DTI (Danish Technological Institute) (dti.dk, 2017), this is a critical matter.

Humidity

Humidity is defined/represented as the amount of water vapor present in the air. For a more precise quantification of humidity level, relative humidity is used, as it represents ratio (%) of the water vapor in the air to the maximum amount of water vapor that the air can retain at a certain/specific temperature.
Humidity, with its high or low amount of water vapor affects both the inhabitants (by perturbing their thermal comfort and indoor air quality) and the building itself; e.g., while high RH together with cold weather conditions will make people feel colder and high RH together with warm weather conditions will make people feel hot. Low humidity can cause a large number of adverse health effects on the inhabitants. Leading to dry skin, itchy eyes, discomfort in the throat and sinuses. AT the same time high humidity facilitates the growth of fungi and bacteria, also causing respiratory problems and/or allergic reactions.

There can be many reasons for high humidity levels; household activities such as cooking, washing, drying clothes, together with people breathing account for the primary sources of moisture that cause humidity increase indoors; e.g., one-person exhales approximately 200 ml. of water vapor per hour while awake and approx. 20 ml. during sleep (www.level.org.nz, n.d.). However, a fraction of moisture emitted by household activities is much more difficult to predict.
In order to reduce the likelihood of conditions that can lead to microbial growth, it is recommended that RH in occupied spaces is maintained lower than 65 % (ASHRAE standard 62.1, 2016).

A humidity level of no less than 30 % is recommended in order to avoid the previously mentioned effects of low humidity, even though no standard mentions the lowest suggested value.

Particles

In the atmospheric environment, particles are considered as a major class of pollutants, besides those occurring in gaseous or vapor form. Airborne particles and those present on indoor surfaces (settled dust) are the most significant ones when analyzing the indoor environment as the occupants can easily inhale them; settled dust can be inhaled as well if it becomes re-suspended. Being exposed to this type of particles can lead to serious health issues such as cardiovascular diseases, lung cancer, asthma attacks and other (Morawska and Salthammer, 2006).

Monitoring and controlling the airborne particles and the settled dust can be achieved by firstly understanding/determining their source (natural/anthropogenic outdoor sources and indoor sources). Their characteristics (by looking at their physical, chemical or biological properties), behaviour (a complex behaviour, due to the ability of airborne particles to interact and react in the presence of other particles with different characteristics). While monitoring and controlling particles imply a multitude of complex processes, this task represents an essential part in the direction of understanding the effect of particles on human health and their environment (Morawska and Salthammer, 2006).

1.2 Aims and Objectives

This research is aiming to develop user profiles for moisture emissions from household activities, as well as a study on particle concentrations in dwellings and possible traces of micro-plastic in the indoor air. These profiles and their determination methodology could later be used, together with different IAQ simulation software, predicting moisture emissions based on the most common indoor activities carried out on a daily basis. Particle study will investigate influences of household activities on indoor particle concentration, and other factors controlling particle distribution. The microplastic study is focusing on proving or disproving the existence of airborne microplastic particles in the indoor environment in regular Danish dwellings.

1.2.1 Humidity

The first objective would be to validate the humidity measurements recorded in three different apartments, by using BSim software, supplemented by a detailed journal with all indoor activities performed during measurement period well documented. This will constitute the basis of absorption/desorption models which, together with documented emissions from different activities, both from literature and planned experiments, can be quantified into daily emission profiles.

Additionally, 3 different types of houses with diverse family members, were previously investigated and RH%, temperature, and CO2 concentrations measured. Likewise, models of these houses will

be created in BSim, where the coefficient of absorption/desorption will be determined and deduction of the emissions from activities will be made.
From here, the main aim would be to develop a moisture generation profile for Danish dwellings.

1.2.2 Particles ($PM_{2.5}$ and PM_{10})

Particle concentration study will be focusing on a particle range from PM_{10} down to $PM_{2.5}$. Sensors will be installed in three different apartments located in Aarhus, where a detailed record/journal of the activities and exact time will be kept while recording the data.

The aim is to use the recorded data and couple it with daily logs in order to identify and document human exposure to particles released from typical household activities.

1.2.3 Micro-plastic

The aim of this study is to successfully measure different key spots in Danish dwellings by using a real size mannequin with an artificial lung. The process will include a filter where particles will be collected based on the air inhaled by the mannequin. The filters will be sent to a laboratory where researchers will analyze the data thus indicating (proving or disproving) if micro-plastic has found its way into indoor air posing as a treat to inhabitants.

1.3 Research questions

1.3.1 Moisture generation profiles

1. Is it possible to derive indoor moisture production from measurements, using advanced building simulation software?
   a) What is the accuracy of this procedure?
   b) What are the variations in the moisture production?
   -Depending on inhabitants.
   -Depending on activities and patterns.
2. What is typical moisture generation profile in kitchens and bathrooms in contemporary households?

1.3.2 Particle generation in indoor environment

1. What is the main source of particles in the indoor environment?
   a) What is the level of particles pollution in typical apartment buildings, in Denmark?
   b) How are particles transported inside the apartment?

2. What is the general risk of human exposure to the particulate matter pollution in typical apartment buildings, in Denmark?
   a) Which activities performed indoor are the most problematic regarding the particle emissions?

3. How can indoor particulate pollutants be better controlled?
   a) Is there a correlation between particle concentration and IAQ parameters?
   b) Should ventilation systems be controlled based on indoor particle concentration?

1.3.3 Airborne microplastics

4. Are airborne microplastic particles present in the indoor environment, in typical apartment buildings in Denmark?
   a) Can airborne microplastic particles be inhaled?
   b) In what quantities can it be inhaled during a 24h continuous exposure?

1.4 Structure of the thesis

It is important to understand the structure of this study. Therefore, paragraphs with detailed explanations of each chapter are described. In short, reort is comprised out of 5 chapters (including introduction).

Chapter one comprises the general introduction of the thesis which is further supplemented by the research background in this field. Moreover, detailed aims and objectives regarding all the subjects investigated are described (Humidity, $PM_{2.5}$ PM_{10}, and Micro-Plastic) and research questions formulated for them. The last information that is part of this chapter is the structure of the thesis.

The second chapter will briefly describe the type of measurements performed, equipment used and location where measurement campaign has been carried out.

The third chapter is describing the humidity research by introducing background information and defining the boundary conditions under which this investigation is made. Subsequently, a method of investigation is integrated into this phase, to give a clear concept of the way this subject was approached and analyzed. Furthermore, the data collected will be presented in forms of description, graphs along with a sub-conclusion of the chapter.

The fourth chapter incorporates study on the particulate matter found in typical dwellings due to emissions from indoor activities. The structure itself is similar to the one from the previous chapter, it stars with general information together with the limits that define the study, along with how the investigation was conducted. Moreover, all analyses are presented based on the recorded data during the measurement campaign that will end with a sub-conclusion derived from them.

The fifth chapter is the last investigation that this thesis incorporates. The focus is on Micro-Plastic and its traces in the indoor air, in typical Danish dwellings. There will be general facts as well as the delimitation of the study in addition to the description on how the subject was approached. The readings and the laboratory analysis will be presented together with a conclusion that will prove/disprove its existence.

2. Measurement Campaign

2.1 Background information

As for the measurement campaign to happen, it was required to decide on a place/area for all the planned activities to unfold. The action took place in Århus, one of the major cities of Denmark, more precisely in three different locations within the area of the city (private homes/apartments of the persons (students) who performed the measurement campaign). The timeframe for the measurements was approximately one month; from the 9th of November until the 5th of December 2017.

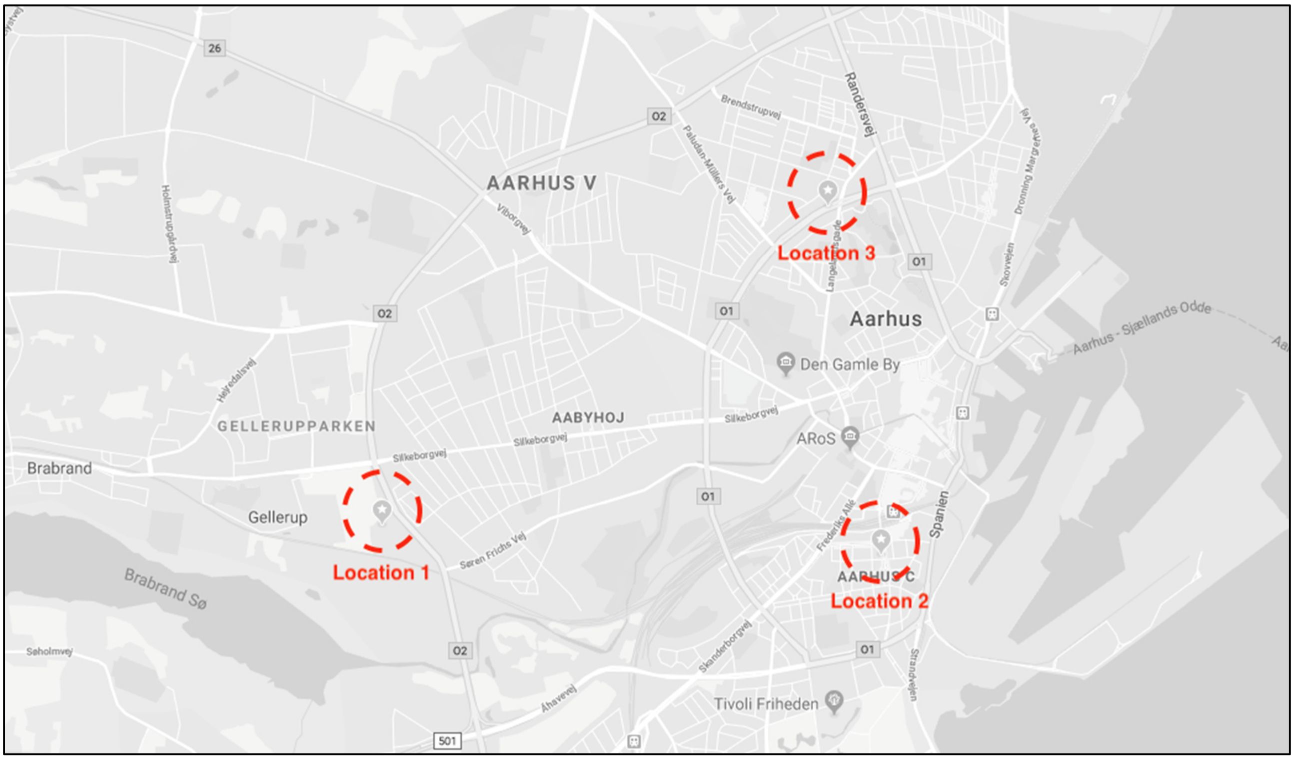


Figure 1 City map of Århus & locations of measurement campaigns

All the apartments are two-room apartments, each of them consisting of a bedroom, living room, kitchen and a bathroom. The age and type of the buildings to which the apartments belong are different though; Apartment 1 (location 1) is part of lightweight building construction, while apartment 2 and 3 (location 2 and 3) are part of a typical Danish brick building construction. Measured parameters are air temperature, relative humidity, CO2 concentration in each apartment. These parameters will be used later for dynamic building software simulations in which the three apartments will be modelled.
Particle concentration measurements have also been carried out at the same time. This data is analysed and described in chapter 4.
Measurements/investigation of microplastics was done simultaneously for three consecutive days in each apartment.

The outdoor operative temperature and relative humidity have been measured as well at location 1, with the purpose of using the data for a weather file, which later on will be as well used for the dynamic building simulations.

2.1.1 Location 1 – Åbyhøjgård 40

The apartment building is situated on Åbyhøjgård 40, 8230 in Århus. It was built in 2009, so it is a relatively new building, compared to the other two apartment buildings. It consists of lightweight building components, built on a steel structural frame that acts as the load bearing part.

The investigated apartment has a total area of 50 m^2, and it is situated on the ground floor of the building.

Normally the apartment is occupied by two persons, but during the measurement campaign, three people were occupying the apartment;

Figure 2 Åbyhøjgård 40, 8230 Aarhus (Google maps)

The apartment has a simple layout, consisting of a small bedroom, living room, bathroom and kitchen (together with hallway). See the plan of the apartment beneath.

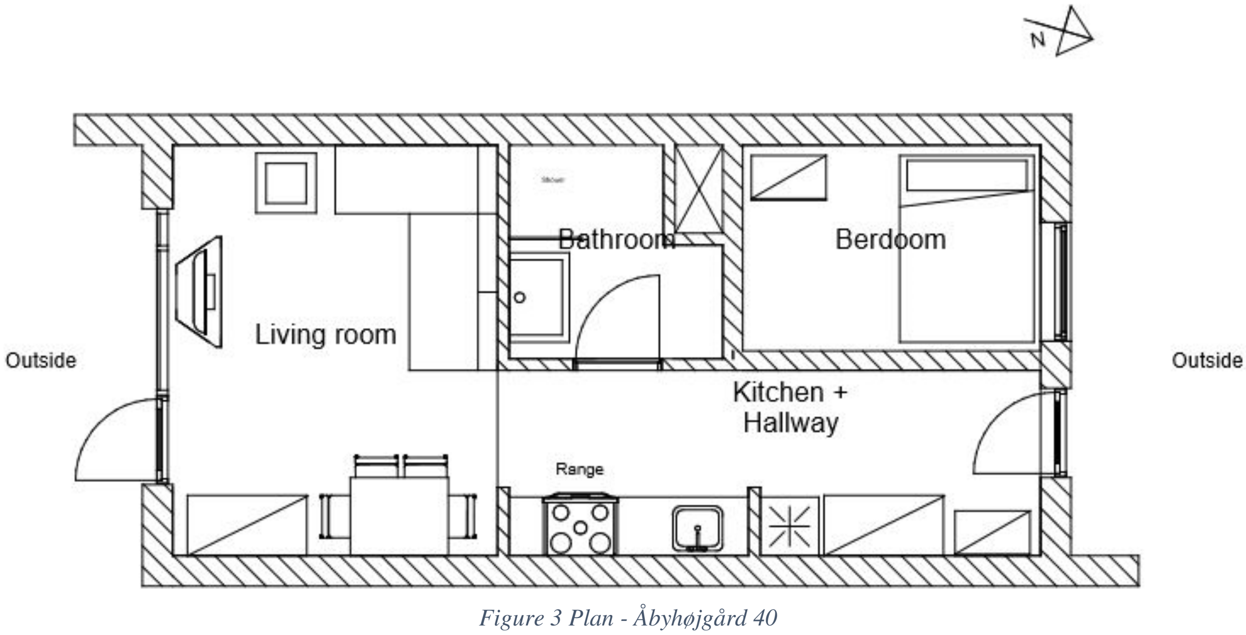


Figure 3 Plan - Åbyhøjgård 40

The apartment is naturally ventilated, with mechanical extraction in the bathroom and kitchen. The extraction hood in the bathroom has a continuous extraction flow, the extraction hood in the kitchen being activated only when needed. See the values for the extraction flows in the bathroom and kitchen in the following table:

Extraction Bathroom (m3/s)	Extraction Kitchen (m^3/s)
0,0067	0,035

Table 1 Bathroom and Kitchen Extraction Value

Overheating is an issue in the living room during the warm season due to the large windows facing South; while in the bedroom, because it is facing North, the temperatures are lower than in the living room. and no overheating problems occur.
As for the heating system, as a source of heat, district heating is used to warm up the apartment through radiators. In the bathroom. no radiators are placed, but floor heating is used.
If the heating is not on during a cold night, quite low temperatures can be experienced in the morning after, due to the low thermal mass of the building.
As natural ventilation is used, air enters the apartment through window vents from the living room and bedroom, traveling towards the kitchen and then being extracted from the bathroom. In this way the "bad" air being pushed out by the fresh one. Doors and windows are being often opened though.
Having an open space between the kitchen and living room, similar measured air temperature, relative humidity and CO2 is expected, especially during the night when there are no activities.
Overall, the apartment offers a good indoor climate, despite its reduced size.

2.1.2 Location 2 – Brammersgade 12

Figure 4 Brammersgade 12, 8000 Aarhus C (Google maps)

The apartment (location 2) is located on the ground floor of an apartment building situated on Brammersgade, 8000 Århus C. Building has been completed in 1897 and renovated a couple of times since then. The building contains four storeys and a basement. Same apartment layout is maintained throughout the building.
Typically to the time period building has been erected using solid brick construction for walls: external walls 450 mm, internal walls 120/250 mm. Floor partition is constructed using timber joists, with insulation in between, wooden floorboards and plaster have been used as finishes. In 2005 building undergone a renovation process during which internal layout has been altered and bathrooms designed for every apartment. In bathrooms new concrete storey partition has been constructed. Windows have also been replaced around this time into wooden windows with double glazing and lowE coating. However, based on observations it can be stated that since then windows have lost a significant amount of their airtightness (traces of condensation are sometimes present near the rubber gaskets).
In the basement storage, technical areas and laundry rooms are located. These spaces are only partially heated in order to maintain at least 5 °C temperature. Staircases, however, are unheated.
During the renovation process, no insulation to the walls or floor partition has been added.

The investigated apartment size is 53m^2. It is occupied by two persons (male and female). The apartment is composed of a bedroom, living-room, bathroom, kitchen and a small entrance space. Plan of the apartment can be seen below.

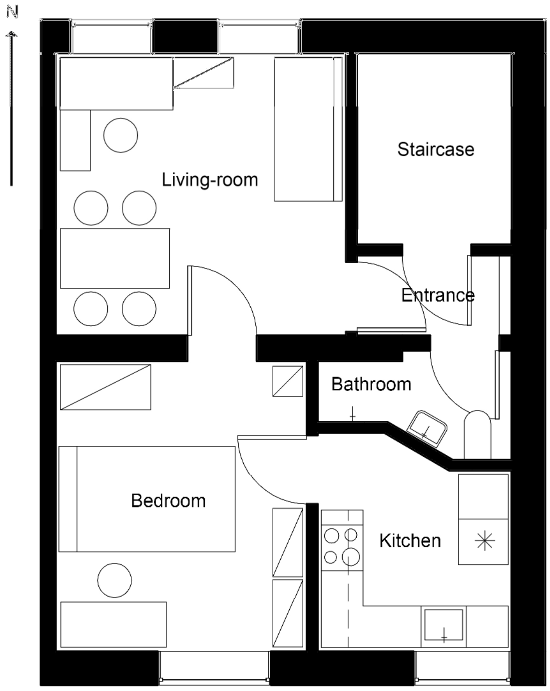


Figure 5 Plan - Brammersgade, 12 st

The apartment is naturally ventilated, with mechanical extraction installed in the bathroom and kitchen (exhaust hood). In the bathroom, extraction is connected to the light switch activating it when the light is on. Air flow is maintained for approximately 8 min after the light is switched off. Volume air flow of bathroom extraction is provided below.

Extraction Bathroom [m³/s]
0,004

Table 2 Bathroom Extraction Value

Exhaust hood in the kitchen is built into a kitchen cabinet and located 51 cm above the stove. It has a 21 cm movable glass front edge. 3 speed settings are available. Air flow measurement results are:

Setting 1 [m³/s]	Setting 2 [m³/s]	Setting 3 [m³/s]
0,027	0,034	0,037

Table 3 Kitchen Hood Extraction Values

Heating to the apartment is provided by a radiator system with conventional thermostatic valves. The system is designed as a standard two pipe system with vertical façade division. District heating with indirect connection and weather compensation mechanism has been designed as a heating medium source. Based on occupant observations, weather compensation mechanism sometimes act a bit too aggressively. When the apartment is aired, and the temperature drops down to 17 or 18 °C, it can take most of the day for the heating system to increase temperature to 20 °C (lower comfort limit for winter period, clothing level 1 clo (DS 474)). While on cold days when the outdoor temperature is below 5 °C, this time period is decreased to a couple of hours.
The apartment is occupied by 2 persons. During the measurement period, such occupancy remained largely unchanged.

2.1.3 Location 3 – Vestre Ringgade 230

The apartment building is situated on Vestre Ringgade, 8000 in Århus C. It was built in 1947 after the construction layout principle that started in the middle of the 1800's, was erected in 5 storeys, with only one staircase placed at every entrance. The apartments are often designed with 2 or 3 rooms and a hallway in direct connection with the staircase. Depending on the available construction materials such as timber, the buildings had a range of widths, in this case being 11,71m. The construction technique is based on common practice used in the middle of the 1900's with full brick walls and timber joists as the floor partitions.

Figure 6 Vestre Ringgade 230, 8000 Aarhus C (Google maps)

The external brick walls in the basement and ground floor were made with a thickness of 48cm on the façade line and gables with 36cm, while the upper floors, the external walls were made with a thickness of 36 cm. The internal loadbearing and dividing brick walls have a thickness of 16 cm. The partition brick walls are 12cm while the partition board panel walls were made of 70cm of wooden/timber board with a gap of 45 mm cavity. The roof construction is made out of wooden rafters with dormer construction. The insulation is placed in the ceiling of the mansard apartment and the external walls around it.

The investigated apartment size is 55m^2 and is situated at the mansard level 5tv, staircase 230 on Vestre Ringgade. It is occupied by two persons (male and female). The apartment is composed of a bedroom, living-room, bathroom, kitchen and an l-shaped hallway. See the following beneath.

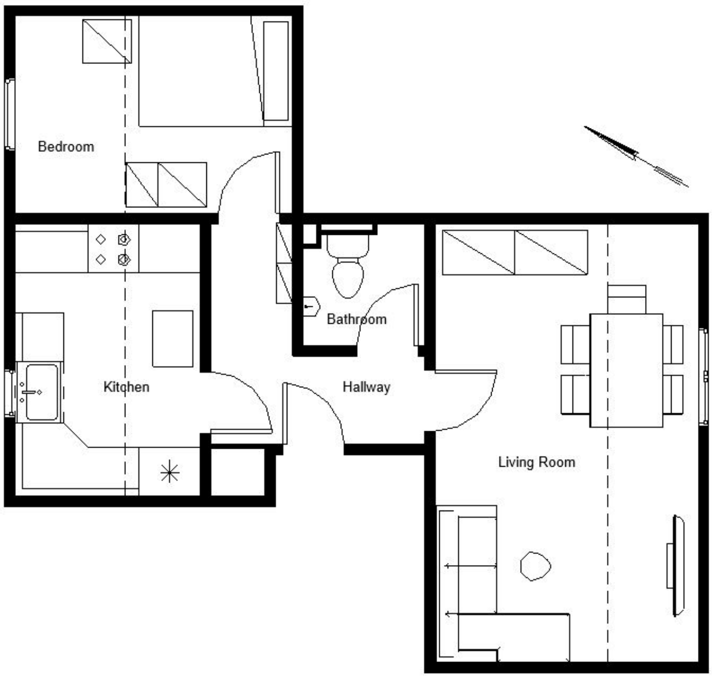


Figure 7 Plan - Vestre Ringgade 230, 5tv

The apartment is naturally ventilated. However, there is a mechanical extraction placed in the bathroom and a kitchen hood. The bathroom extraction is connected to the light switch with the possibility of turning it on when the light is on or controlled by the relative humidity level with the condition that the light switch is on. The extraction is a continuous flow see value in the next table.

Extraction Bathroom [m^3/s]
0,0176

Table 4 Bathroom Extraction Value

The kitchen hood was newly mounted (approx. 4 weeks before measurements) at the height of 53cm above the cooking stove and with a movable front glass edge of 6cm. The hood has 3 speed steps, and the measurement results are:

Setting 1 [m^3/s]	Setting 2 [m^3/s]	Setting 3 [m^3/s]
0,0176	0,0360	0,0515

Table 5 Kitchen Hood Extraction Values

The heating source is based on the district heating system. The internal layout is a common two pipe system with vertical façade copper pipes. The system has installed weather compensation mechanism. However, the heating system was updated to cover a heating demand much lower on the grounds that a renovation is due to start, and it was synchronized with lower energy demand that will be achieved upon renovation completion. Thus, current heating demand cannot be met. In addition, the kitchen has no radiator installed, therefore, the indoor temperature in this specific room is quite low.

The apartment is occupied by 2 persons; however, the occupancy is shifting due to visits and can be seen in the table beneath.

Date	Occupancy	Notes
12/11/2017-24/11/2017	2	1Male, 1Female
24/11/2017-02/12/2017	3	1Male, 2Females
02/12/2017-05/12/2017	4	2Males, 2Females

Table 6 Occupancy Schedule - Vestre Ringgade

2.2 Equipment

2.2.1 Moisture

As for the relative humidity measurements, two different sensors were used depending on their placement:

<table>
<tr><th>Indoor</th><th>Outdoor</th><th>Outdoor</th></tr>
<tr>
<td>

Figure 8 IC-meter</td>
<td>

Figure 9 Eltek Squirrel</td>
<td>

Figure 10 Eltek transmitter</td>
</tr>
<tr>
<td>IC-meter
Used to measures:
Air temperature °C
Relative humidity %
CO_2 concentration ppm</td>
<td>Eltek Squirrel 1000 series
Used as radio telemetry data logger, (receive a signal from the transmitter and send it to the computer where the information was stored).</td>
<td>Eltek GenII transmitter
Use to send the signal to the Squirrel and measure outdoor relative humidity % and operative temperature °C.</td>
</tr>
</table>

Table 7 Equipment used to measure IAQ Parameters

2.2.2 Particles

For the purpose of particle measurements, a custom-made particle sampler has been designed consisting of:
1 - particle sensor (SDS 011), 2 - microcomputer (Raspberry Pi 3 Model B), 3 - USB/UART converter, 4 - sensor housing and 5 – small hose.

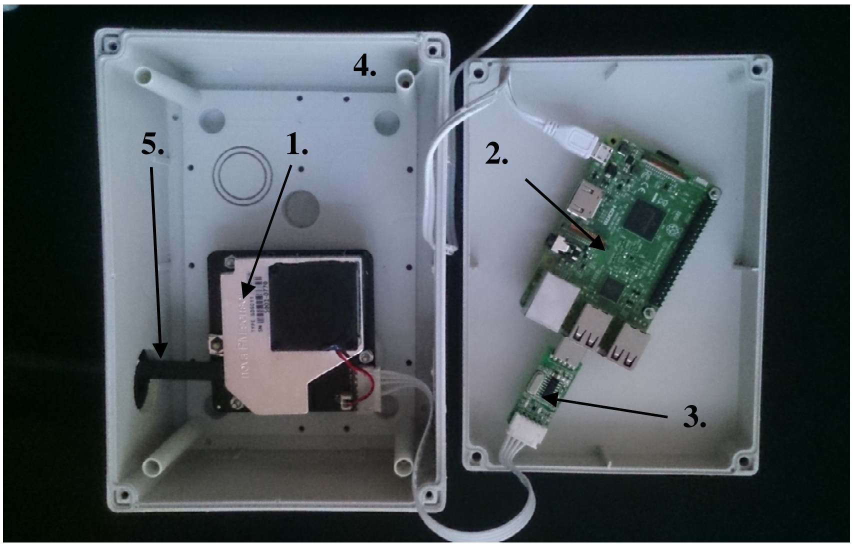


Figure 11 Sampler (Open)

Particle sensor SDS 011 has been chosen for its characteristics, which are ideally suited for indoor particle measurements. The sensor works on light scattering principle and can provide a large amount of real-time data. SDS 011 is already equipped with a fan, which acts as a pump directing air with airborne particles into the pathway of a laser detector. Additionally, a hose up to 1 m in length can be attached to the sensor, if the sensor itself cannot be placed in pollution zone. However, to maintain accuracy it is recommended to keep the hose as short as possible. Therefore, a hose of only 6 cm long has been attached, to make sure that air inlet for sampling is located outside of the sensor housing.

Nova Fitness SDS 011 particle sensor		
	Measured parameters	PM 2.5; PM 10
	Range	0 – 999,9 µg/m³
	Working Temperature	-10 - +50 °C
	Working Humidity	Max. 70 %
	Minimum particle resolution	0,3 µm
https://nettigo.eu	Relative error	Max ± 15% and ±10 µg/m³ At 25 °C and 50 % RH

Table 8 SDS 011 sensor characteristics

As a power supply for the setup, a standard CEE 7/16 plug has been chosen. It is directly connected to a microcomputer which in turn powers the sensor through USB/UART converter. This way it is relatively easy to ensure a stable supply of power for the setup. On the other hand, it limits where and how equipment can be used.

Power supply choice combined with the working environment of the sensor and microcomputer indicates that this set up cannot be used outdoors for prolonged periods of time.

Laser detector of the particle sensor has a limited service lifespan of up to 8000 hours. Therefore, sampling procedure has been designed as follows:

1. Sampling took place for 30 seconds and gathered data is averaged.
2. WiFi connection is established and data sent to the server.
3. The sensor remains idle for 20 seconds.
4. The process starts again.
5. The fan is running constantly, to reduce noise issues.

In this way, the usable service life of the particle sensor is doubled, while providing PM 2.5 and PM 10 values every minute for accurate real-time concentration monitoring. More information about data acquisition method can be found in appendix A.

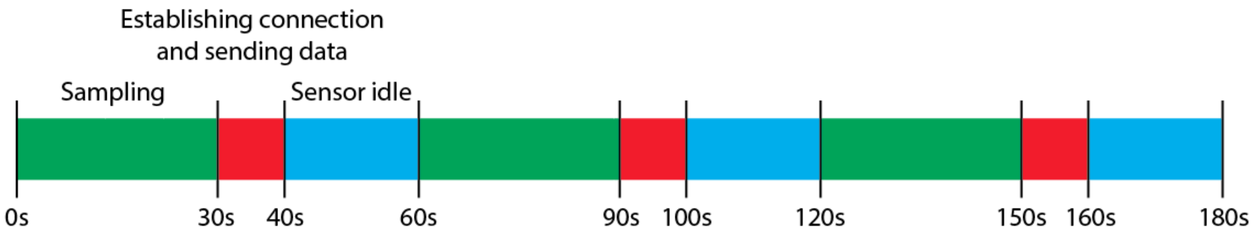


Figure 12 Sampling cycle of the sensor

Figure 13 Custom made particle sampler

Calibration of particle sensors

A calibration of the particle sensors was needed in order to "validate" the performed measurements and at the same time, to investigate the accuracy of newly built sensors.
For this purpose, a more accurate particle sensor had to be used; the TSI Aerodynamic Particle Sizer 3321 was used as the reference measuring instrument.
Two sets of data were logged with the purpose of creating calibration curves for the particles measurements, and only the overlapping data was selected.
Since SDS Nova fitness particle sensor has a measuring unit in µg/m3, units had to be converted to mg/m3 and afterwards compared with the APS instrument. Calibration curves were created for both PM 2,5 and PM 10 for each data set.

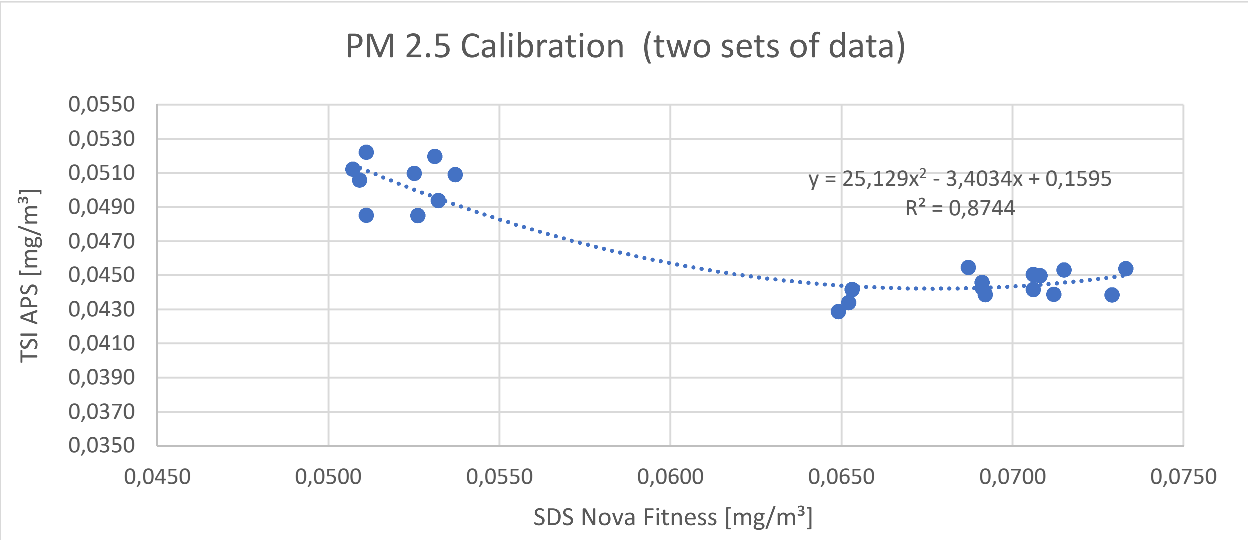


Figure 14 PM 2.5 Calibration (two sets of data)

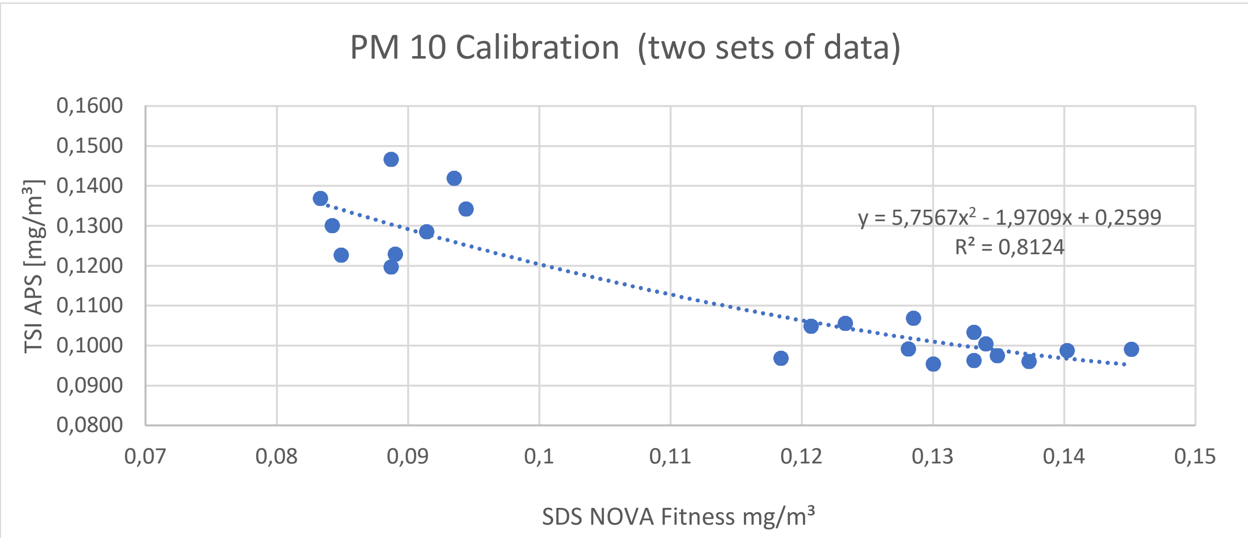


Figure 15 PM 10 Calibration (two sets of data)

A calibration curve based on the two sets of data has been generated; the data is clearly scattered into two separate groups leaving a gap in between, which limits calibration accuracy.
Due to equipment constraints, only one sampler has been calibrated. Therefore, this calibration serves as a representative case. Additionally, due to lack of time, a calibration curve has not been applied to the measurements.

3. Moisture Production Profiles

3.1 Background Information

All buildings are exposed to outdoor condition and as a result, direct contact with water in vapor and liquid phase is inevitable. At the same time, indoor activities are leading to an increment of moisture emission which, further affects the building envelope/construction due to moisture accumulation and migration. Indoor moisture issues are associated with different conditions such as; indoor activities, temperature, indoor humidity, outdoor conditions as well as the design and construction technique of the building and building envelope (Lu, 2003).
Hygroscopic materials have an important role in stabilizing indoor RH%. All surfaces including the furniture can absorb moisture when the relative humidity is high, thus releasing it when the air is dry. This phenomenon is known as moisture buffering effect and could allow passive control over the indoor RH% which could further have a good influence over the energy consumption, surface condensation hence the growth of mold (Yang et al., 2007).

There are studies made that document moisture emissions from different indoor activities. Most of the data is quite old, over the years the way people live, building technique/materials and systems drastically changed, thus changing the indoor environment and parameters that influence it.
The focus of this thesis will go towards the indoor moisture production due to different activities the inhabitants might have, from where moisture profiles in typical Danish houses will be made. This will allow to document and further use the data in software simulations to predict future indoor moisture content.

3.2 Method of Investigation

3.2.1 Proof of concept test

Part of the user profile development process consists of moisture load determination from measurements. For this project, indoor air quality data has been acquired from eight dwellings. Data consists of pure measurements; no daily logs or schedules of occupant behavior were available. In order to determine how much of the measured indoor humidity level is a by-product of occupant activities, a decision was made to use computer simulations. However, before developing moisture absorption/desorption computer models, the validity of this approach had to be evaluated. For this reason, a proof of concept test has been developed.

Proof of concept test consists of the simple two-day measurement period (from 2017-09-27 16:00, until 2017-09-30 10:00) performed indoors (kitchen space) and outdoors. A detailed occupant activity log, have been kept for that period as well. Based on the log a moisture load is estimated using literature and implemented in the computer model. Results obtained from moisture

absorption/desorption model are then compared with the measurements in order to evaluate if moisture load in computer simulations could reproduce measured results.
Indoor measurements of air temperature, relative humidity, absolute humidity and carbon dioxide have been performed with Trotec DL200L datalogger (for details see table 9).

Trotec DL200L	**Parameter**	**Accuracy**	**Range**
 www.trotec24.dk	Air temperature	+/- 0,3 °C	-20 °C – 50 °C
	Relative humidity	+/- 2%	0 – 100 %
	CO_2	+/- 50 ppm	0 – 5000 ppm

Table 9 Specifications for Trotec DL200L datalogger

Air temperature is used to estimate heat contributions from equipment and people. CO_2 levels help to determine infiltration and ventilation rates by using dilution equation. In order to simplify the equation and reduce the number of variables, periods outside of the occupied time is used to determine infiltration rate. Thus, a dilution equation without pollution source can be used:

$$c = (c_o - c_i)e^{-n\tau} + c_i$$

$c = pollutant\ concentration\ [m^3/m^3]$
$c_o = initial\ concntration\ [m^3/m^3]$
$c_i = concentration\ in\ the\ supply\ air\ [m^3/m^3]$
$n = air\ changes\ [h^{-1}]$
$\tau = time\ [h]$

Outdoor data have been gathered for only two essential parameters of air temperature and relative humidity with BL30 datalogger (see table 10).

Trotec BL30	**Parameter**	**Accuracy**	**Range**
 www.trotec24.dk	Air temperature	+/- 1,0 °C	-40 °C – 70 °C
	Relative humidity	+/- 3%	0 – 100 %

Table 10 Specifications Trotec BL30 datalogger

However, for reliable simulation results, wheatear data is essential. Therefore, as a basis for the weather file a Danish Design Reference Year 2013 has been used, with relative humidity and air temperature data replaced by outdoor measurements.

Moisture load estimation

In order to estimate moisture load, a detailed activity log has been kept, documenting time and duration of specific activities, their description and occupant presence. Then based on literature moisture emission from each specific activity has been estimated. However, in literature, there is a lot of contradictory values from different time periods and researchers, or values are stated per day, which is unsuitable for the purpose of this project. Therefore, a decision was made to estimate moisture load by performing measurements for as many activities as possible. Measurements have been performed based on weight, assuming, that difference in weight before and after the activity is mainly moisture emitted to the environment.
Results of moisture load estimation have been presented in the below.

Date	Time	Activities	Moisture Load [g]	Reference
	Always	Evaporation from plants	5,88	(Yik, Sat and Niu, 2004)
2017-09-27	19:00	Water kettle	21,00	Measured
2017-09-28	06:00	Water kettle	21,00	Measured
	07:00	Water kettle	21,00	Measured
		Washing Dishes	58,00	(Lstiburek and Carmody, 1993)
		Toaster	4,00	Measured
	08:00 - 11:00	Evaporation from dishes	6,00	(Yik, Sat and Niu, 2004)
	12:00	Water kettle	21,00	Measured
		Toaster	4,00	Measured
		Frying	41,50	(Koch, Koch and Byggeteknik, 1986)
	13:00	Washing Dishes	50,00	(Lstiburek and Carmody, 1993)
	14:00 - 15:00	Evaporation from dishes	6,00	(Yik, Sat and Niu, 2004)
	19:00	Warming up dinner	42	(Koch, Koch and Byggeteknik, 1986)
2017-09-29	07:00	Water kettle	21,00	Measured
		Toaster	4,00	Measured
		Boiling Eggs	100	Measured
	08:00	Water kettle	21,00	Measured

	14:00	Washing Dishes	28	(Lstiburek and Carmody, 1993)
		Evaporation from dishes	6,00	(Yik, Sat and Niu, 2004)
	15:00	Water kettle	21,00	Measured
		Washing hands	14,00	(Koch, Koch and Byggeteknik, 1986)
	17:00	Cooking on a stove (simmer)	37,5	(Lstiburek and Carmody, 1993)
	19:00	Coffee Cup	3	(Koch, Koch and Byggeteknik, 1986)
2017-09-30	07:00	Water kettle	21,00	Measured
		Toaster	4,00	Measured
		Boiling Eggs	39,75	Measured
	10:00	Water kettle	21,00	Measured
		Boiling Eggs	39,75	Measured

Table 11 Moisture load estimation for proof of concept test

Simulation/Results

Simulation has been performed using BSim software. The model contains a geometry of the apartment where measurements took place. However, thorough simulation only have been performed for the kitchen. This decision has been made because data for neighboring rooms were not available. Thermal and moisture conditions in adjoining rooms have been evaluated based on observations and quick, one-time, measurements, then defined in the software as a sinusoidal curve variation. With geometry and constructions defined a following procedure for the model validation have been followed:

1. Infiltration and ventilation rates estimated with dilution equation.
2. People load has been defined based on occupancy log, and small adjustments made to metabolic rate in order to validate fluctuations in CO_2 level.
3. Equipment load is estimated based on activity log and observations.
4. Fluctuations in temperature have been validated by adjusting equipment load.
5. Moisture load, estimated by literature and measurements, is defined in the software.
6. Results in moisture levels between simulation and measurements compared.

Results of the proof of concept test have been presented in the following graphs.

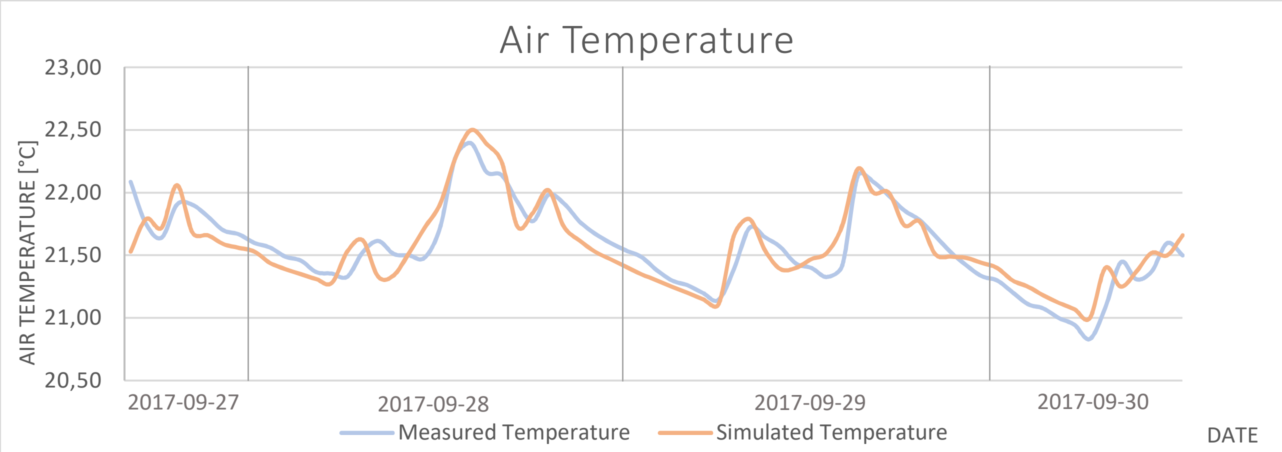


Figure 16 Proof of concept test (Air Temperature)

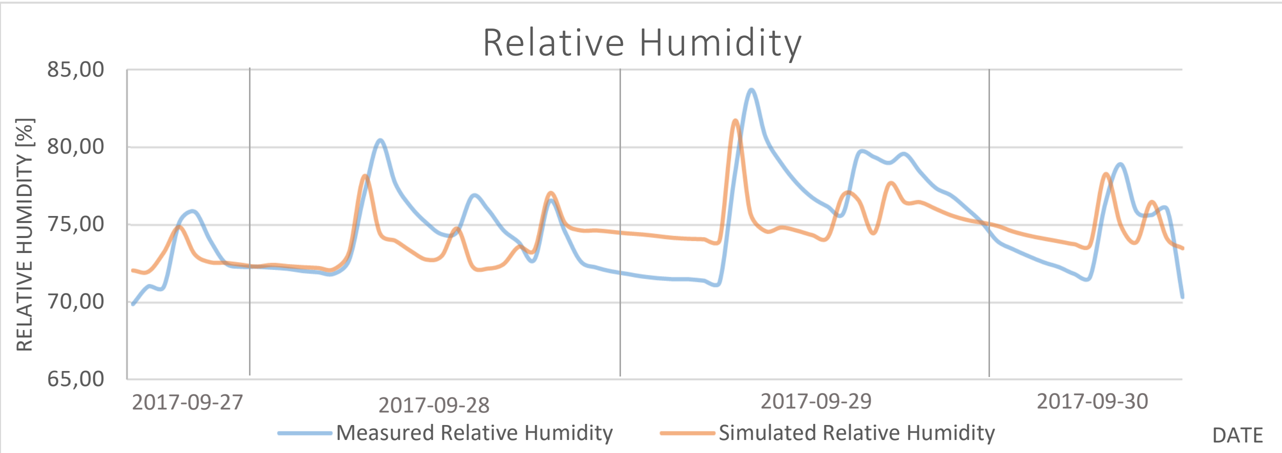


Figure 17 Proof of concept test (Relative humidity)

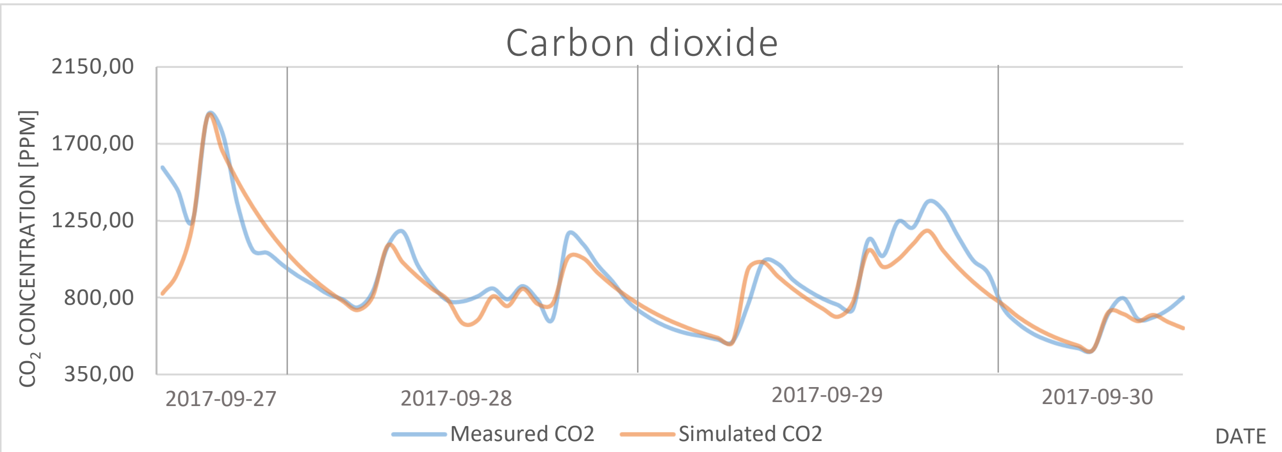


Figure 18 Proof of concept test (CO2 levels)

On the first attempt, relative humidity values have been compared. However, relative humidity is strongly influenced by air temperature, and even though simulated air temperature corresponds well with the measurements, differences between the two can still be observed. Therefore, a decision was made to compare absolute humidity values. In this way, air temperature no longer exerts influence on humidity values and allows much more accurate comparison.

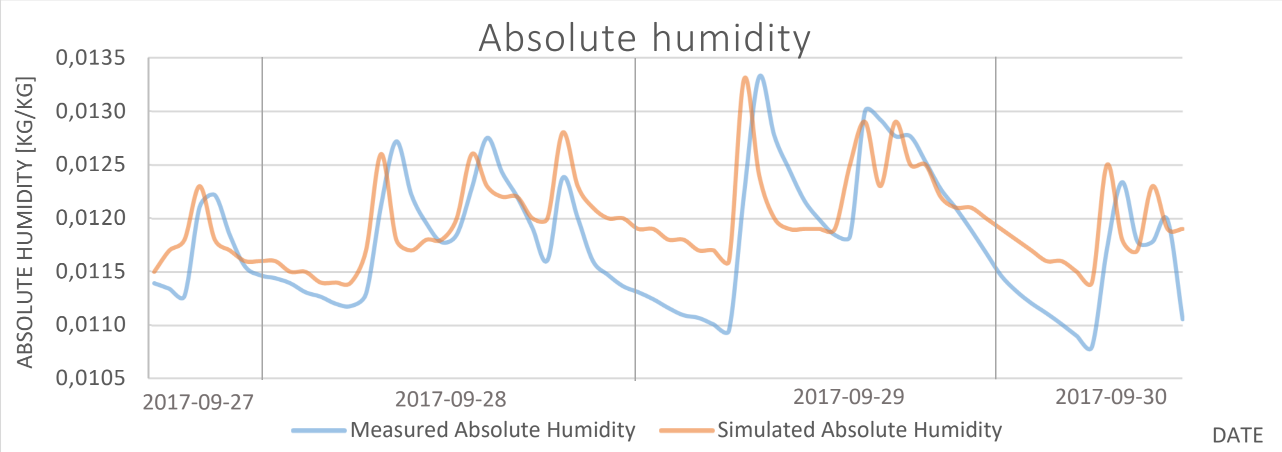


Figure 19 Proof of concept test (Absolute humidity)

Absolute humidity values enable a much clearer picture for comparison. Based on these results it can be observed that there is a good correlation between measured and simulated moisture loads. Most of the peak values are corresponding quite well. Greater difficulties occur when trying to match absorption/desorption rates. These parameters are strongly dependent on materials and moisture balance of the environment. First of all, software cannot estimate, what influence furniture, have on moisture absorption/desorption rates. Secondly, rates can very well be influenced by moisture levels in adjacent rooms. In order to reduce these influences, simulation has been performed for a longer period of time, so that materials achieve a certain moisture balance before comparison takes place. Unfortunately, without any available measurements for adjacent rooms, it is impossible to ensure, that moisture exchange with those areas through materials or mixing is correct.

Nevertheless, this concept test proves the validity of this method (using measurements and simulation software in order to determine moisture load profile).

3.3 Moisture production from activities

In order to create a moisture production profile that could be used together with an advanced building simulation software, moisture emissions from typical activities must be determined. However, in literature, emissions can be widely varying, depending on the source. Additionally, most of the research into moisture generation rates took place in the earlier decades. Thus effects of some technological advances on moisture emission rates are not known. Therefore, a decision was made to measure and investigate moisture generation rates from different activities and compare the results obtained by different researchers.

In this project moisture generation from different activities has been determined based on the mass difference. Assuming, that difference in mass before and after the activity is a result of moisture transport, absorption, and desorption. For this purpose, a precision scales Sartorius Entris 22021-1S has been used (specifications can be found in the table below).

Parameter	Value
Weighing capacity	2200 g
Readability	0,01 g
Linearity	0,03 g
Repeatability (standard deviation)	<±0,01 g

Table 12 Parameters of Sartorius Entris 22021-1S scales (Sartoris-Entris-Manual)

3.3.1 Moisture emissions from drying of clothes

A common source of moisture in the household is drying of clothes. In order to determine this moisture quantity released into the indoor environment, it is essential to find out the amount of water remaining in the clothes after washing. This quantity is mainly influenced by the mechanical drying cycle of the washing machine.
In this project, three different mechanical drying cycles have been investigated: 800 rpm, 1200 rpm, and 1600 rpm.
To represent the most common washing conditions, an average mix of different clothes made from different fabrics has been gathered and washed using standard 40 °C washing programme.
In addition to moisture amount remaining in the clothes after washing, two items of the same type of clothing have been taken after each washing cycle, and moisture release from them has been measured in the apartment for 3 hours. In this case, an average moisture release rate can be determined, which is an important simulation parameter.

Washing clothes with 800 RPM drying cycle				
Test. No.	**Before washing [g]**	**Directly after washing [g]**	**Difference [g]**	**Difference [%]**
1	1586,11	2823,23	1237,12	178 %

Table 13 Results of Washing clothes with 800 RPM drying cycle

Washing clothes with 1200 RPM drying cycle				
Test. No.	**Before washing [g]**	**Directly after washing [g]**	**Difference [g]**	**Difference [%]**
1	1827,52	2601,4	773,88	142 %
2	2610,27	3759,33	1149,06	144 %
3	4514,29	6356,13	1841,84	141 %
Average				142,3 %

Table 14 Results of Washing clothes with 1200 RPM drying cycle

Washing clothes with 1600 RPM drying cycle				
Test. No.	**Before washing [g]**	**Directly after washing [g]**	**Difference [g]**	**Difference [%]**
1	1883,09	2529,89	646,8	134 %
2	1502,12	1968,12	466	131 %
Average				132,5 %

Table 15 Washing clothes with 1600 RPM drying cycle

Analysis of the results clearly shows, that 1600 RPM drying cycle is the most advantageous, with an additional average water content of 32,5% of initial weight. On the other hand, greatest improvement is achieved when switching from 800 RPM (78% of additional moisture content) to 1200 RPM mode (42,3% of additional average moisture content).

However, these type of measurements only gives a partial picture. In order to use this information together with advanced building simulation software moisture release rate also has to be determined.
To form an idea of the possible moisture release rate, two items of the same type (T-shirts and underwear) have been measured from each clothes batch and weighed for three hours at an interval of no more than 30 minutes.

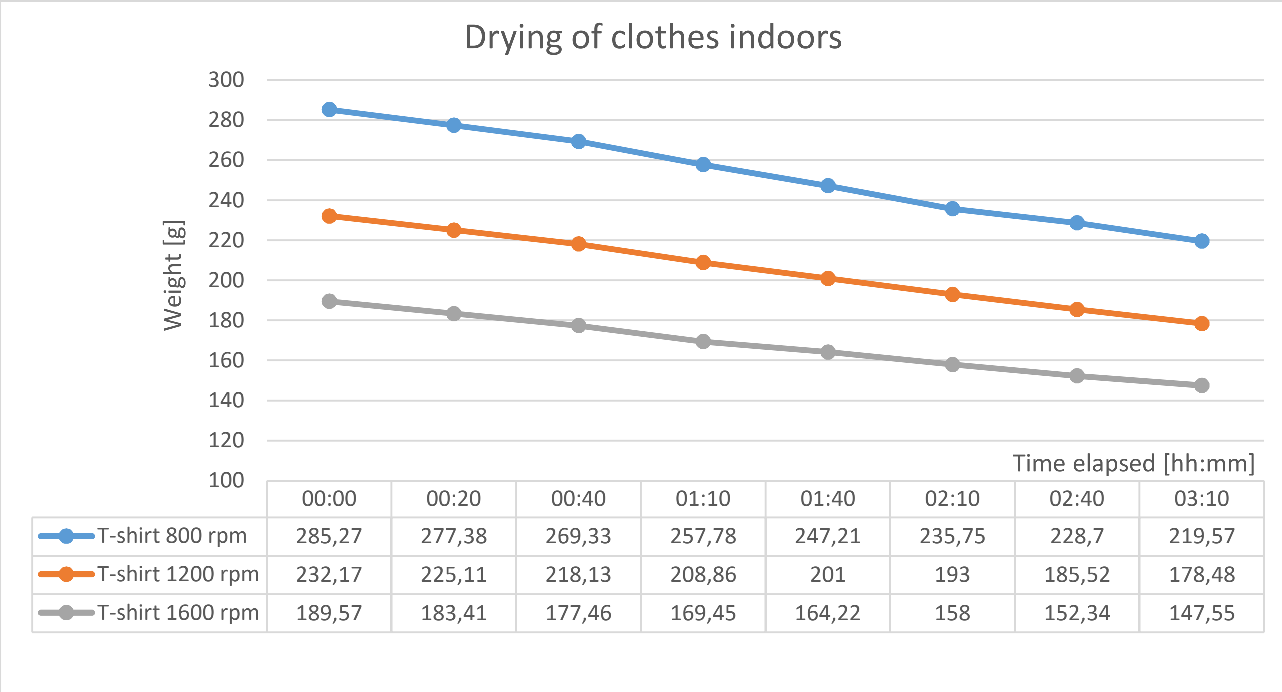


Figure 20 Evaporation of moisture from washed clothes

3.3.2 Moisture emissions from cleaning and dishwashing

When it comes to dishwashing, two main actions that can affect indoor moisture concentration: evaporation from wet dishes and remaining water in the sink. Normally, dishes are either left to dry or they are wiped with a cloth. In either case, water eventually ends up in the indoor air. In order to determine these moisture quantities, two tests have been performed: one - using absorbent paper towels (to find out moisture content remaining on the dishes after washing), two – with a cloth (to determine water deposited in the cloth after drying the dishes). Water is remaining in the sink after washing has also been measured by gathering water with a paper towel and then weighing it.

MOISTURE EMISSIONS FROM DISHWASHING		
	Moisture from dishes [g]	**Moisture deposited in the sink [g]**
Test 1 (Paper towel)	22,89	29,08
Test 2 (Cloth)	27,87	16,6
Average	25,38	22,84

Table 16 Moisture emissions from dishwashing

The number of dishes washed is from regular dinner for two persons (data from individual items can be found in the appendix B).

In the regular household, the surface can often be cleaned with a wet cloth, especially kitchen countertops; this has also been measured by weighing wet cloth before and after cleaning the surfaces.

MOISTURE EMISSIONS FROM CLEANING SURFACES			
	Moisture deposited on surfaces [g]	**Cleaned area [m²]**	**Moisture deposition [g/m²]**
Test 1	4,86	1,125	4,32
Test 2	2,51	1,449	1,73
Test 3	3,92	1,152	3,4
Test 4	6,56	1,4214	4,62
Average	4,4625		3,52

Table 17 Moisture emissions from cleaning surfaces

3.3.3 Moisture emissions from personal hygiene

While most of the moisture emissions from activities related to personal hygiene can be well estimated by using literature, some additional measurements have been carried out to find moisture deposited in the towel after washing hands, taking a shower and water deposited in the sink after washing hands.

MOISTURE DEPOSITED IN THE TOWEL (AFTER TAKING A SHOWER)			
	Before [g]	**After [g]**	**Moisture deposited [g]**
Test 1	591,48	642,56	51,08
Test 2	630,56	650,15	19,59
Test 3	585,7	621,11	35,41
Test 4	582,64	644,45	61,81
Average			41,97

Table 18 Moisture deposited in the towel after taking a shower

MOISTURE EMISSIONS FROM WASHING HANDS		
	Deposited in the towel [g]	**Deposited in the sink [g]**
Test 1	2,97	2,33
Test 2	2,34	2,22
Average	2,655	2,275

Table 19 Moisture emissions from washing hands

3.3.4 Moisture emissions from cooking

One of the largest sources of moisture generation in the contemporary household is cooking. A number of tests have been performed to determine moisture emitted from common cooking activities.

MOISTURE EMISSIONS FROM COOKING	
Activity	**Moisture emission [g]**
Using an electric kettle to boil water	22,43
Boiling eggs (hard boiled)	152,71
Cooking spaghetti (250 g)	386,99
Cooking rice (for 2 persons)	16,96
Chicken soup (duration hh:mm 01: 35)	1445,77
Boiling pasta (duration 00:24)	217,79
Bolognese pasta sauce (00:36)	230,02
Frying 4 eggs (00:10)	20,73

Table 20 Moisture emissions from cooking activities

3.4 BSim modeling (Komfort Huse)

3.4.1 Stenagervænget 12

Building description

Figure 21 Stenagervænget 12, Google Maps

The building is situated on Stenagervænget 12, Skibet,7100 Vejle and was built and placed into an exhibition in the period of 1/Mar/2007 to 18/Dec/2008 (Build_Up, 2009). The architectural concept is based on a style that resembles with around 70% of the single-family houses that are currently in use, which can allow it to fit in most of the residential neighborhoods. It is considered the first passive house project, built in Denmark, with walls entirely from brick construction with a layer of insulation of 380mm. The roof is traditionally made with wooden rafters and an insulation layer of 505mm plus an additional layer of 95 mm in the ceiling construction. Windows are made of aluminum/wooden frames with 3 layers of glass filled with argon gas. The house's layout is made with rooms arranged around the living/kitchen area that forms the center of the house. (Isover, 2017)
In the year 2010 there were 2 families using the house, one family consisting of 2 adults and one child living until April 2010, while another family moved in June 2010, formed as well from 2 adults and 1 child.

Model description

Aalborg University has investigated/measured the house from January 2009 to September 2011. In the fig22 can be observed the sensor placement in different rooms marked with orange. One bedroom and bathroom have operative temperature and relative humidity recorded while the living room and second bedroom have the same IAQ parameters and also CO_2. The indoor climate measurements were performed with Eltek equipment.

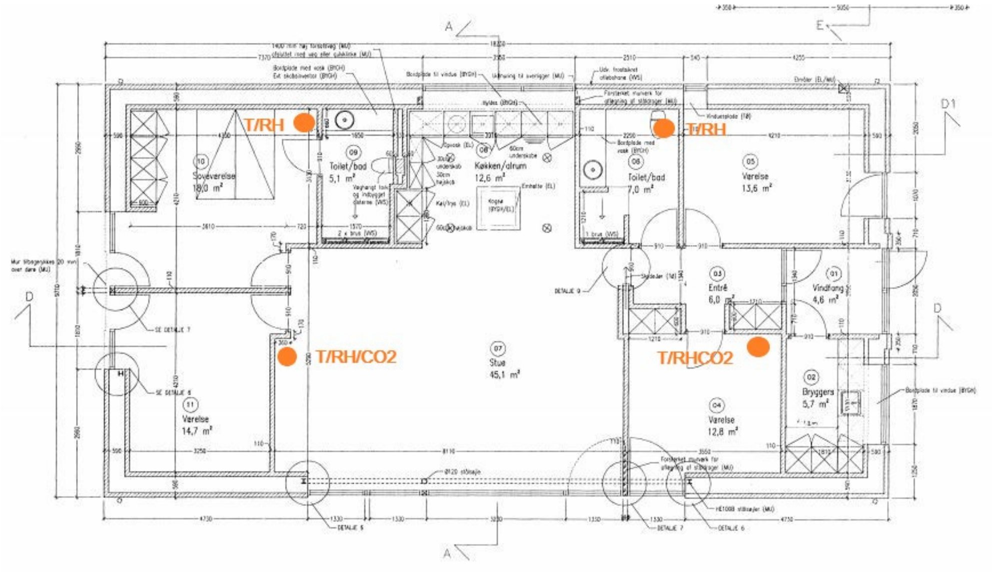


Figure 22 Floor Plan of Stenagervænget 12 - Sensor Position

The Heating system is connected to a heat pump that can provide the necessary heating output in the cold season and cooling in the warm season. Most of the areas are having underfloor heating installed, around 80m^2, which increase the level of comfort, while only the bedrooms are using radiators.
The ventilation system is placed in the attic with maximized pipe size (Ø180mm) for distribution to diminish the noise and an average flow of 123 m^3/h.

Simulations

BSim was used to recreate the house and its conditions in order to simulate the indoor environment. The measured data were used for model validation by comparing them with the outcome of the simulations. Each measured room was replicated as a single thermal zone due to different criteria like room function, orientation, occupancy, activities, etc. except the kitchen together with the living room which is open and considered to be in the same room.

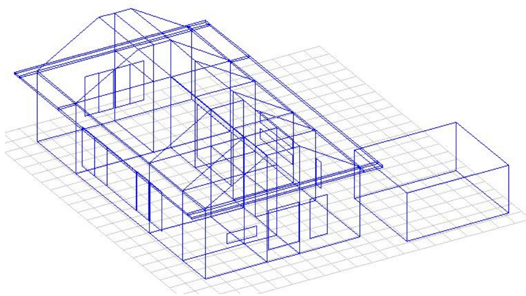


Figure 23 BSim model of Stenagervænget 12

The systems were recreated in the digital model where ventilation and heating values were taken from the description of the house done by Aalborg University. The occupancy was determined based on the CO2 measured in the specific rooms.

For simulations, a weather data with recorded outdoor parameters was created for the year 2010 which was used for model validation.

Simplifications:

1) Geometry was changed very little. First, the two-bedroom walls were aligned, and the bathroom extended into the bedroom to create square shapes. The second change occurred in the opened area between the kitchen and the living room. A wall with an opening was inserted in between.

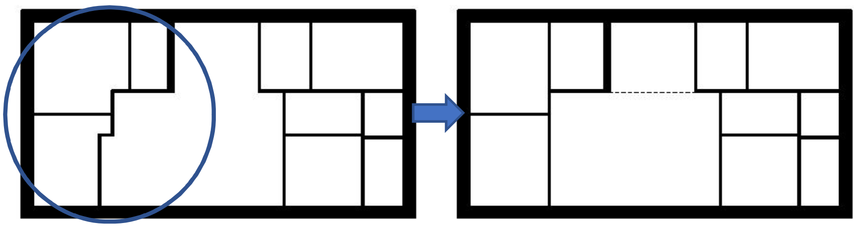


Figure 24 Geometry simplification of the BSim model

2) The heating system is a combination between underfloor heating and radiators. However, in the simulations, only a radiator system was used to cover the heating demand.
3) Based on the ventilation layout and extraction values, mixing was made. The airflow pattern splits in between the extraction from the bathrooms, kitchen and laundry room.

Further, the validation of the kitchen together with the living room is presented over the full year of 2010.

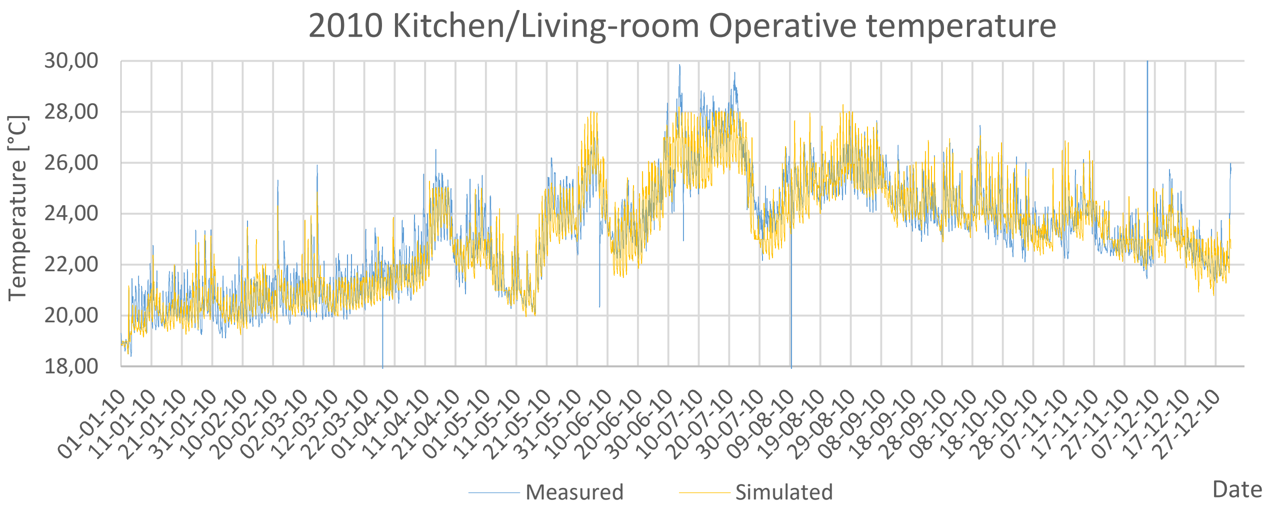


Figure 25 Yearly Validation - Operative Temperature – Living/Kitchen

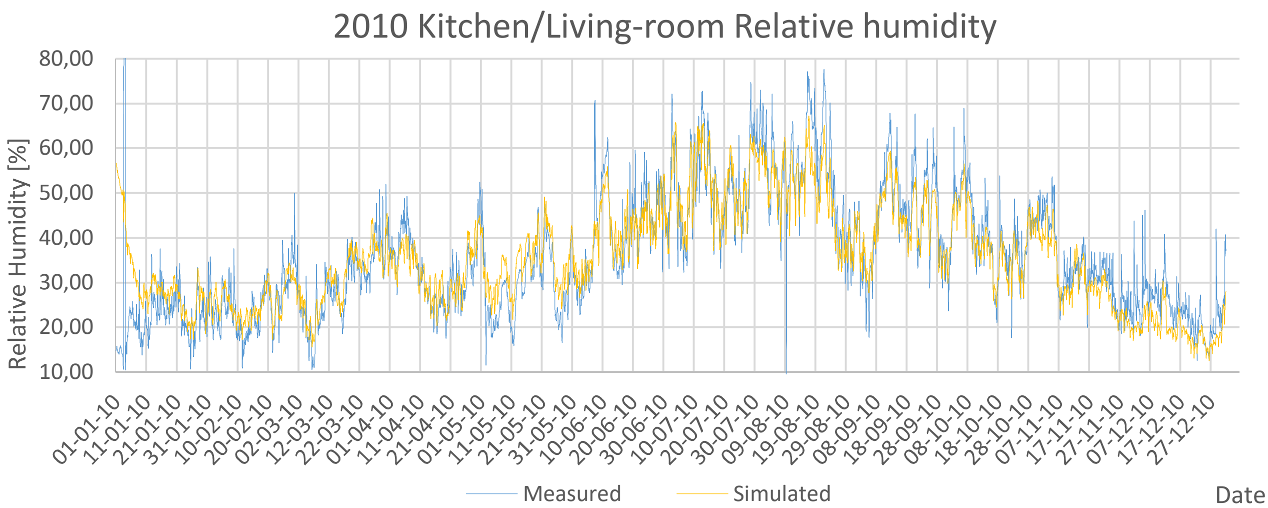


Figure 26 Yearly Validation - Relative Humidity - Living/Kitchen

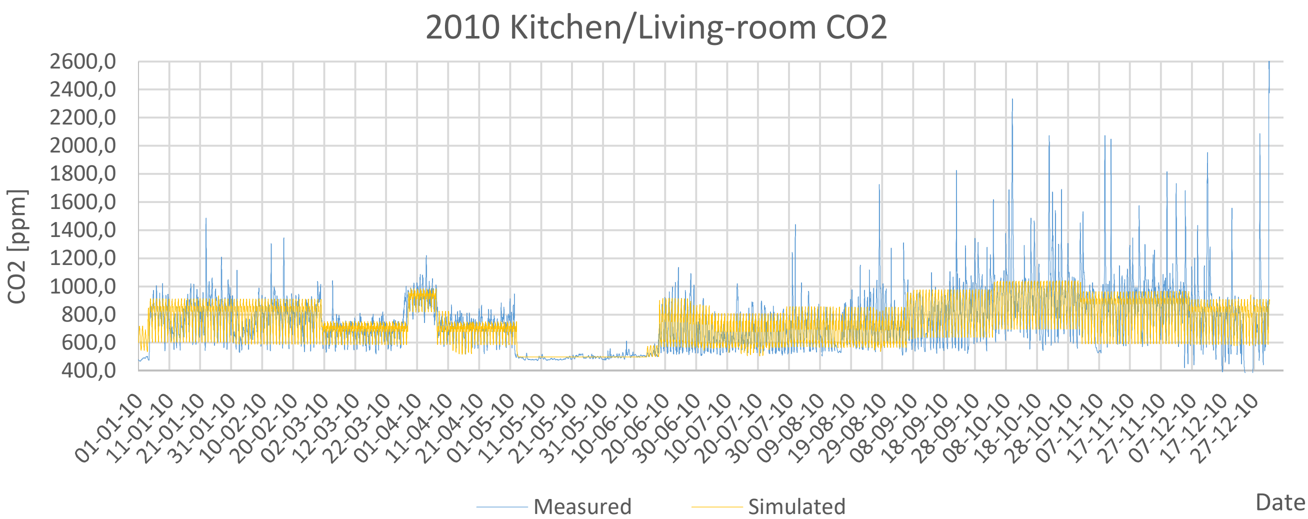


Figure 27 Yearly Validation - CO2 - Living/Kitchen

Analysis and Procedure

Determination of moisture load is based on the measured parameters from where absolute humidity is extracted as Kg of water vapor / Kg of air [kg/kg]. Validated simulations with no moisture load serve as a baseline, from where moisture generation difference between the measured values and simulations indicate the indoor activities and their moisture emissions.

To be able to take into account the absorption/desorption of moisture into the construction as well as creating a relation between the moisture load [g/h] inserted in BSim with the absolute humidity [kg/kg], a number of simulations were made. Gradually the moisture content was increased from 50 [g/h] up to 1000 [g/h], and the response of each simulation followed. See the following graphs for the conversion formula.

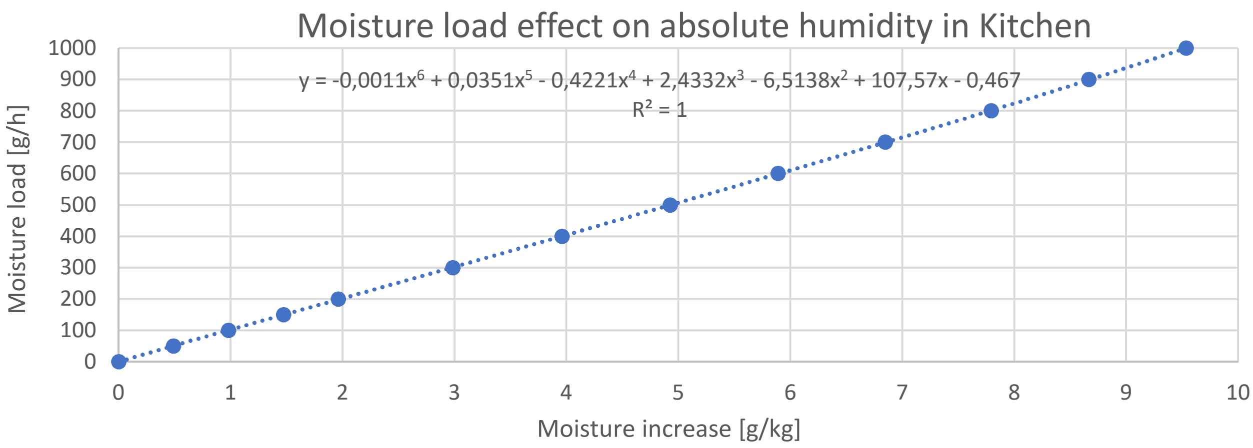


Figure 28 BSim model response to moisture load in Kitchen

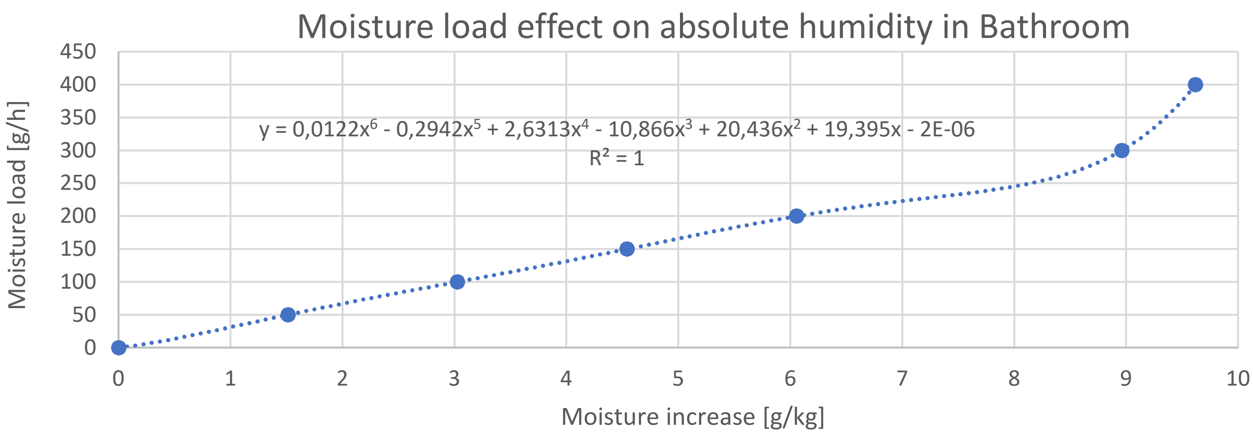


Figure 29 BSim model response to moisture load in Bathroom

Further, based on visual examination of the absolute humidity, measured and simulated values, an investigation is performed to differentiate the time when the baseline simulation does not exceed the measured values. In this case, in the first months (Jan-May) cannot be used in simulations as a result of the measured values that lower than the simulations. This could be due to a number of influences, from absorption/desorption of moisture by the construction, airflows, occupancy, infiltrations; The issue is found in the kitchen/living area where simulations results are quite high. Therefore, tests with the extracted profiles are made for the second half of the year 2010.

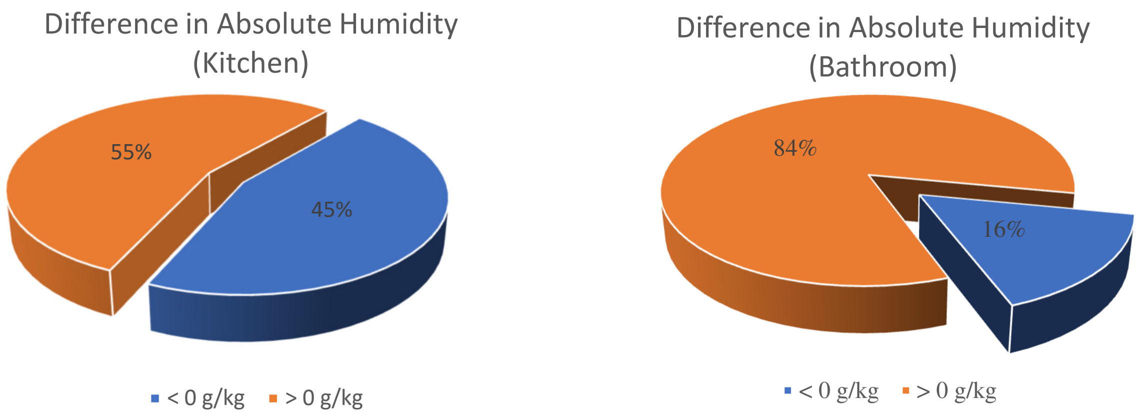


Figure 30 Percentage of time when baseline simulation (no moisture load) exceeds measured/calculated absolute humidity

In both investigated rooms, there is an amount of time when the baseline is higher than the measurement. Therefore, these values will be disregarded and treated as no moisture.

In regards to the above methodology, there will be tested a number of profile extracted.

1- Continuous moisture load
2- Continuous moisture load for weekdays and weekends
3- Continuous monthly moisture load
4- Standard day profile

Continuous moisture load

The approach for this type of profile is based on the hourly difference between the measured absolute humidity and the baseline simulation. Taking into account the response of the tested model it was possible to determine an hourly moisture load in kg/h. Mean values constitute the continuous moisture load profile.

	Mean difference in absolute humidity [g/kg]	*Mean moisture load [g/h]*
Kitchen	0,83	75,17
Bathroom	1,44	50,41

Table 21 Continuous moisture load profile

Further, simulation tests with these profiles were made.

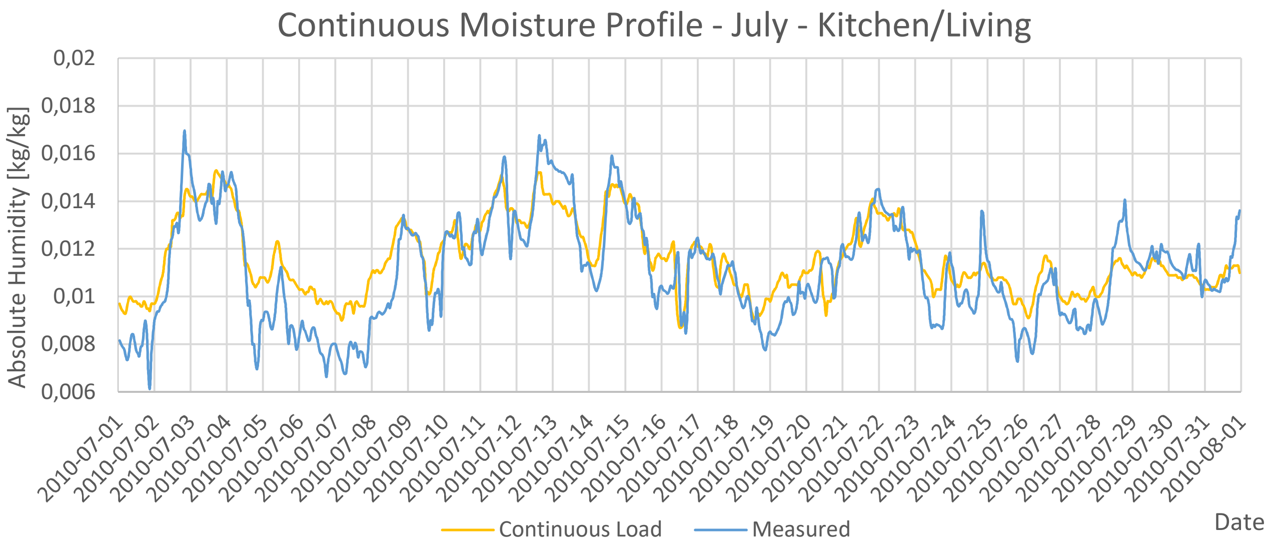


Figure 31 Continuous moisture profiles test - Kitchen/Living

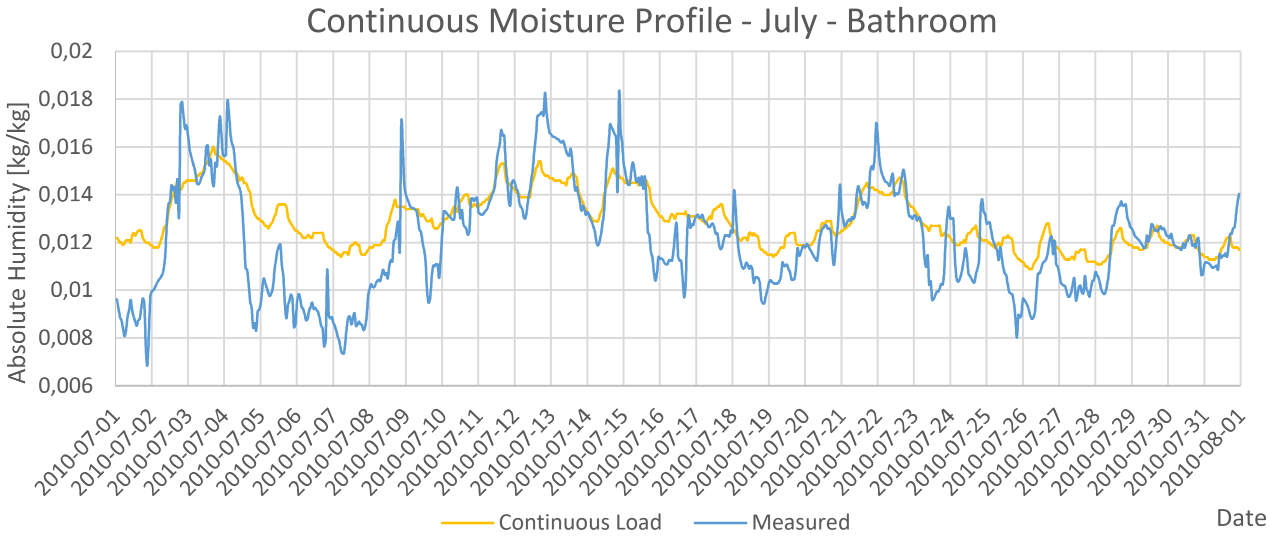


Figure 32 Continuous moisture profiles test - Bathroom

This type of profile indicates the correlation between the moisture activity that is emitted and the volume of space.
Since kitchen and living room are placed within the same space, a large area, the moisture emissions from activities throughout the day are dispersed in its volume, as a consequence of this matter, there aren't high peaks nor high moisture concentrations.
On the other hand, the bathroom area is quite the opposite. The volume is rather small while having high moisture load from activities like showering. The increment in load is substantial thus running in between the baseline of the measured values and its peaks.

Weekdays and weekends moisture load

Extraction technique of the second set of moisture profiles is similar to the continuous moisture load. The difference lays in the division of days between weekday and weekends. In theory, people have different daily schedules when compared these two types of days. The idea is to catalog the moisture production variation.

	Mean moisture load - Weekdays [g/h]	*Mean moisture load – Weekends [g/h]*
Kitchen	65,60	70,61
Bathroom	43,31	60,44

Table 22 Week/Weekends moisture profile

Schedules with these profiles were made in BSim and simulated. The results are presented in the graphs beneath.

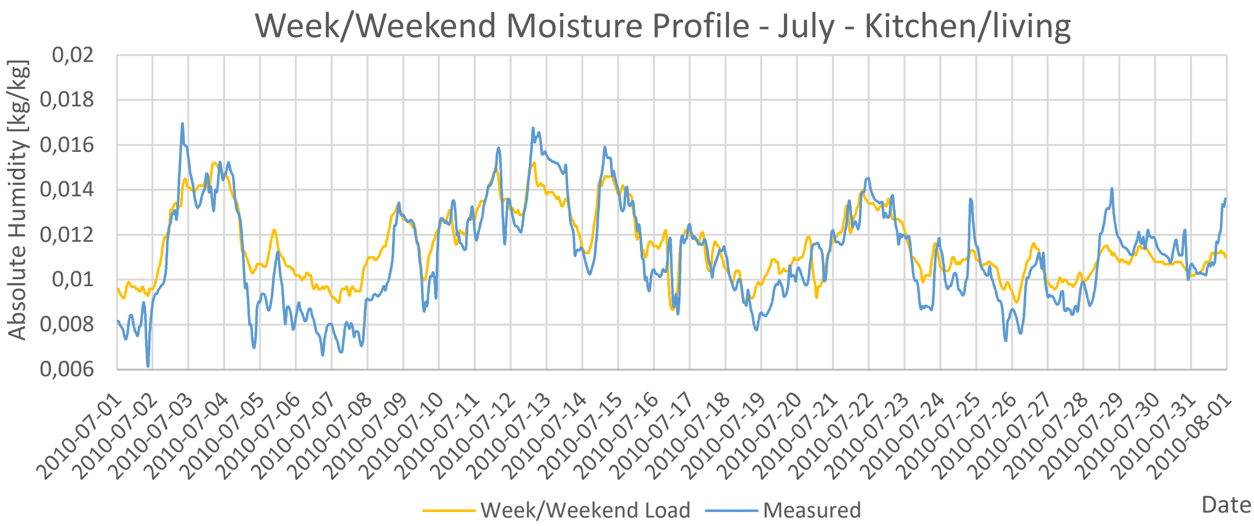


Figure 33 Week/Weekend profiles test - Kitchen/Living

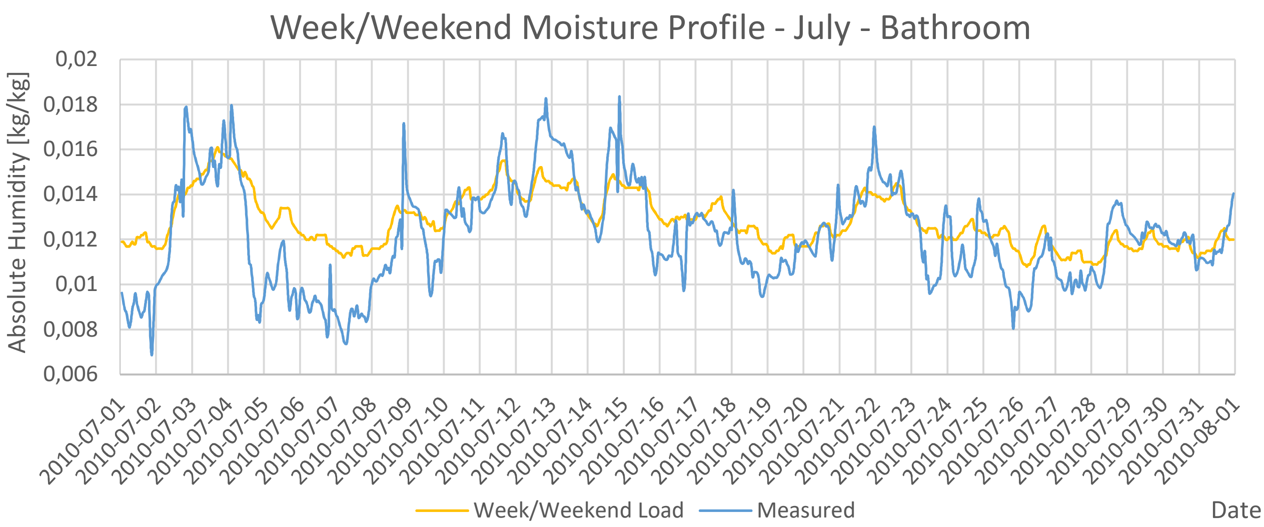


Figure 34 Week/Weekend profiles test - Bathroom

These profiles show little change from the constant moisture profiles. This is to be expected since the moisture load found was not varying much.

Continuous monthly moisture load

This type of moisture profile comprises mean monthly values. The following graph indicates the mean moisture load over the full year. It is noticed that during the warm period the values are higher which contradicts with literature. The measured absolute humidity was visually analyzed, and it appears that it is generally higher in the summer. This could, for instance, indicate the lack of ventilation that removes the extra moisture when compared with the cold season when ventilation is working.

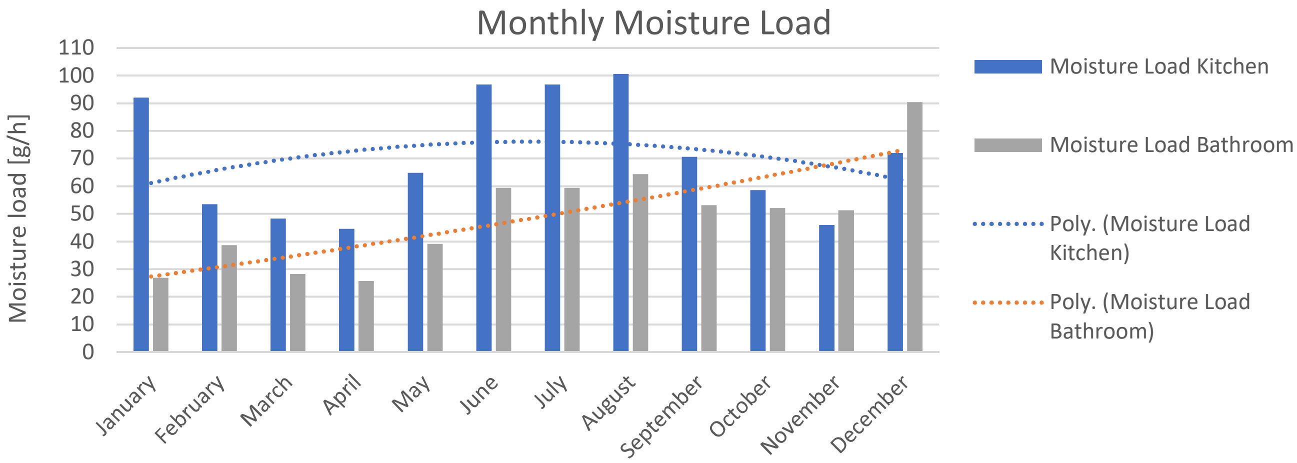


Figure 35 Monthly moisture load profile

From the analysis made, the profile is tested, changes are presented in the graphs beneath.

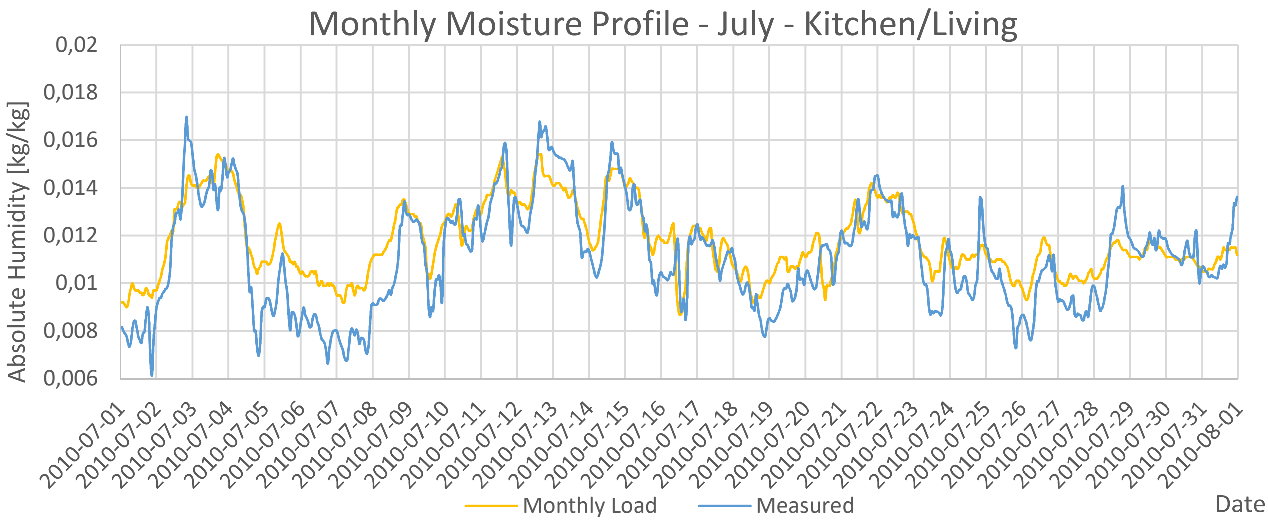


Figure 36 Monthly moisture profile test - Kitchen/Living

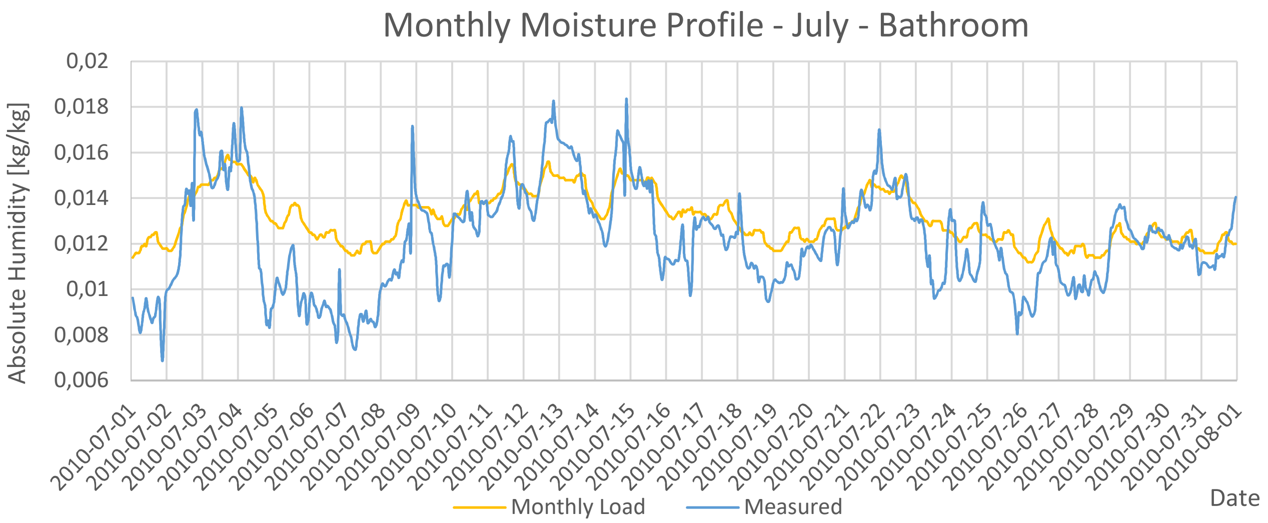


Figure 37 Monthly moisture profile test - Bathroom

It can be seen from the above analysis that it follows the outcome of the previously tested profiles. Generally, following the patterns while the biggest change occurs in smaller space, bathroom.

Standard day profile

By treating the data and extracting hourly mean values, it was possible to determine a moisture load for each hour, as in a standard day of indoor moisture emission from activities.

Hour	*Mean moisture load Kitchen [g/h]*	*Mean moisture load Bathroom [g/h]*
00	61,85	43,28
01	57,53	44,55
02	55,97	44,32
03	53,61	44,17
04	53,61	43,23
05	47,10	43,59
06	47,05	43,96
07	43,40	39,03
08	46,55	35,03
09	51,04	37,59
10	53,37	40,74
11	42,75	34,51
12	50,34	43,59
13	61,82	46,35
14	68,57	40,64
15	58,65	33,98
16	66,13	36,78
17	73,72	39,07
18	85,24	36,09
19	80,21	48,81
20	80,96	51,15
21	71,67	50,58
22	71,31	45,86
23	68,85	44,28

Table 23 Standard day moisture profile

The hourly values are inserted in the simulation software and the outcome compared with the measured values.

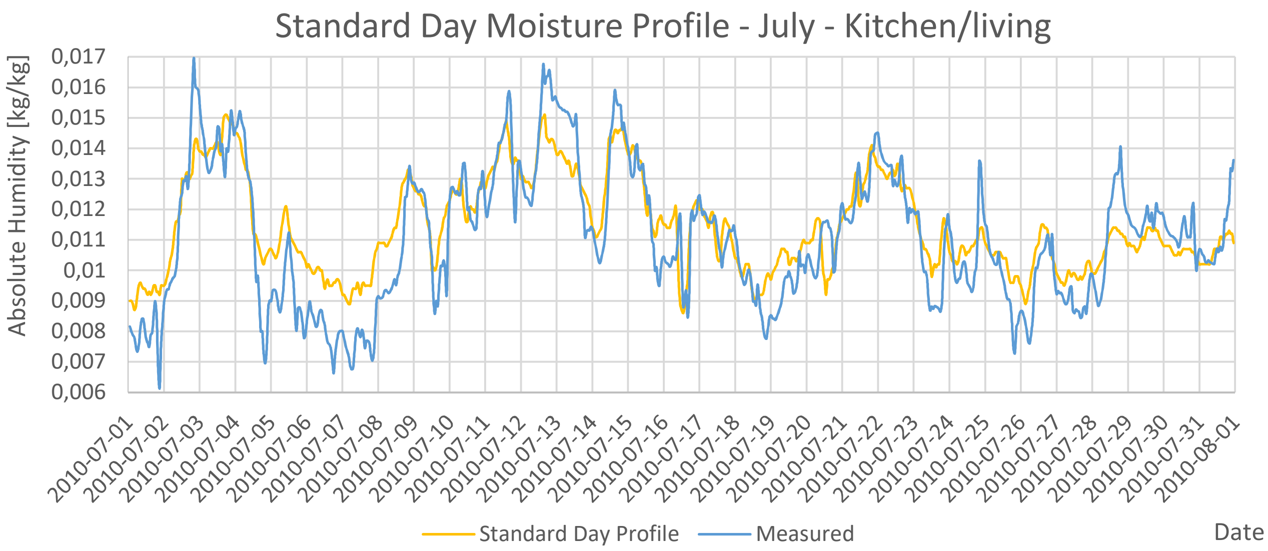


Figure 38 Standard day moisture profile test - Kitchen/Living

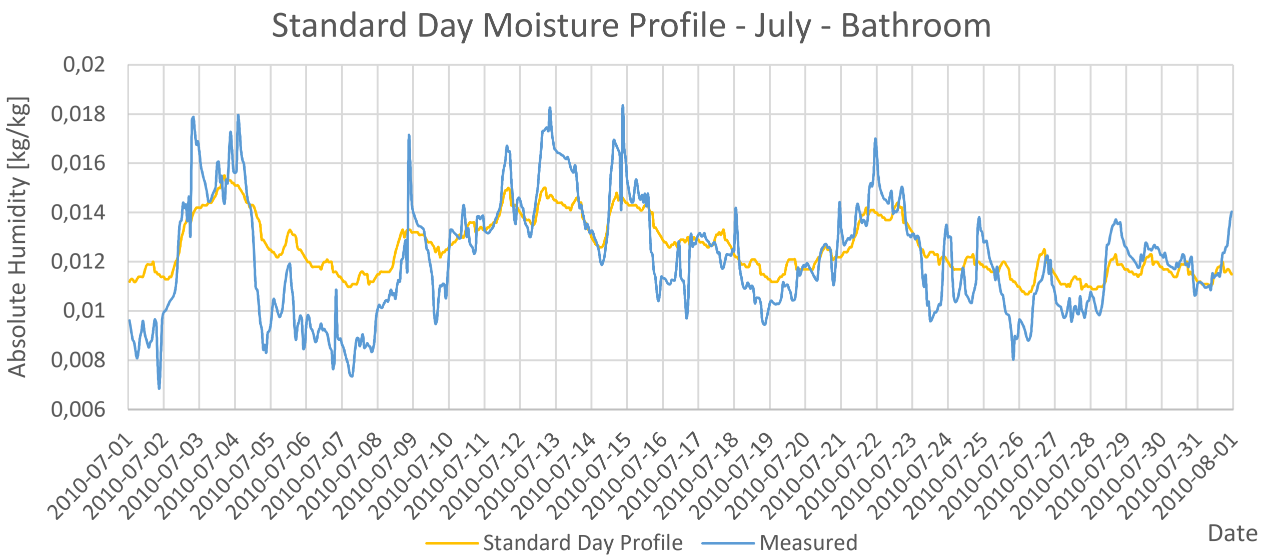


Figure 39 Standard day moisture profile test - Bathroom

The difference between the moisture profiles found is not substantial. The outcome of all the simulations is similar with small variations.

Overview

An overview of all the profiles extracted from this specific house are presented in a general table:

Profiles (Bathroom)	*Average [g/kg]*	*Standard deviation*	*Correlation factor*	*MAD*	*MSE*	*RMSE*	*MAPE*
Measurements	7,29	3,22					
No profile	6,21	2,70	0,92	1,28	2,73	1,65	18,2%
Continuous moisture load	9,49	2,64	0,91	1,16	2,27	1,50	18,2%
Continuous moisture load for weekdays and weekends	9,41	2,65	0,91	1,13	2,19	1,48	17,6%
Continuous monthly moisture load	9,81	2,48	0,91	1,36	2,99	1,72	23,3%
Standard day profile	9,23	2,63	0,92	1,06	1,95	1,39	16,1%

Table 24 Overview of humidity profiles – Bathroom

Profiles (Kitchen)	*Average [g/kg]*	*Standard deviation*	*Correlation factor*	*MAD*	*MSE*	*RMSE*	*MAPE*
Measurements	6,53	3,59					
No profile	6,76	2,51	0,75	0,83	5,64	2,37	17,6%
Continuous moisture load	8,32	2,79	0,67	0,78	9,43	3,07	10,5%
Continuous moisture load for weekdays and weekends	8,25	2,80	0,67	0,74	9,39	3,06	9,97%
Continuous monthly moisture load	8,31	2,90	0,67	0,75	9,41	3,06	9,97%
Standard day profile	8,18	2,79	0,67	0,72	9,36	3,05	9,5%

Table 25 Overview of humidity profiles – Kitchen/Living

MAD – mean absolute deviationMSE – mean square error
RMSE – root mean square error MAPE – mean absolute percentage error

Humidity profiles extracted are similar in between them as well as compared with the measured values. The continuous moisture load is a good aim when trying to simulate spaces where activities do not peak that much. Furthermore, when looking at rooms with high temporary moisture load, like bathrooms, cannot be visually represented by the continuous moisture load profile due to the high and repetitive peaks that take place at different hours, however, when the moisture emissions are averaged, they do not fall far from the continuous moisture profile.

3.4.2 Stenagervænget 49

Building description

The building situated on Stenagervænget 49, Skibet, 7100 Vejle consists of lightweight construction components, and it is a part of the Komfort Husene project; a project with the aim of showing a way for buildings with passive heating in Denmark.

The house is built on two storeys, the ground floor consisting of an entrance space, kitchen, living room, bathroom and one utility room; the first floor consists of three rooms and a bathroom. The access from the ground floor to the first floor is done by the stairs. On the first floor, the rooms are separated by a hallway (multirum).

Figure 40 House Stenagervaenget 49

The appearance of the building seems to be very simple with sharp and straight angles, the building being shaped in the form of a box. The rectangular windows with black frames create a beautiful contrast with the white exterior finish. Most of the windows being placed on the South and West façade offer the possibility of capturing and utilizing the solar radiation.

Ventilation and heating of the building are done with the help of the Nilan VP18 unit, which in combination with a heat pump, provides good indoor climate conditions.

The house is inhabited by a family consisting of two adults and two teenagers.

Model description

The indoor environment and energy consumption of the house has been measured and analyzed by Aalborg University for a period of approximately 2 and ½ years and the placement of the sensors that were used for this purpose can be seen in the plans shown below. (see the red dots).

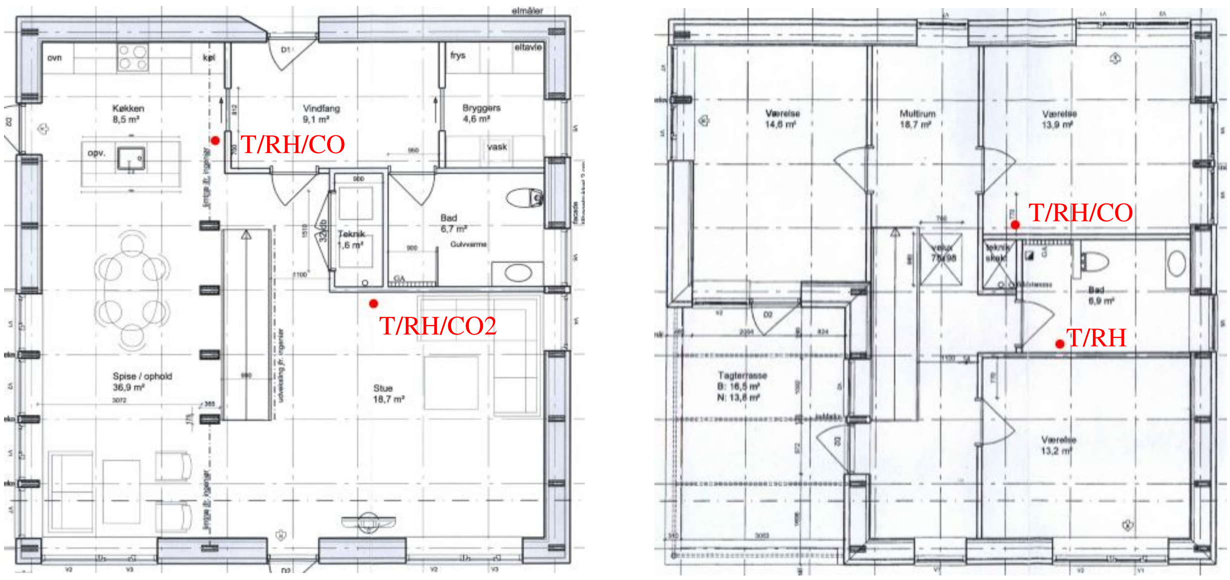


Figure 41 Ground floor (left) and 1st floor (right) plan of Stenagervænget 49

Simulations

To simulate the same indoor environmental conditions as the ones measured by the Aalborg University, Bsim was used, and a model was built.
The house is on two levels, see figure 41, with the kitchen situated on the ground floor and the bathroom on the first floor.
Apart from the kitchen and the bathroom, the rest of the rooms were added into separate thermal zones as well, so the accuracy of the simulations would be as high as possible.
Minor simplifications were done to the model; the areas and different dimensions were modeled as accurately as possible to the actual areas and dimensions. The simulations are done for the entire year of 2010, but because the house was not used until April, the validation is done form the first of April until the end of the year.

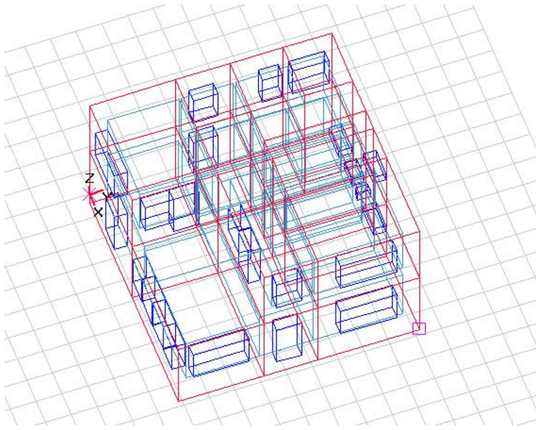


Figure 42 Bsim model of Stenagervænget 49

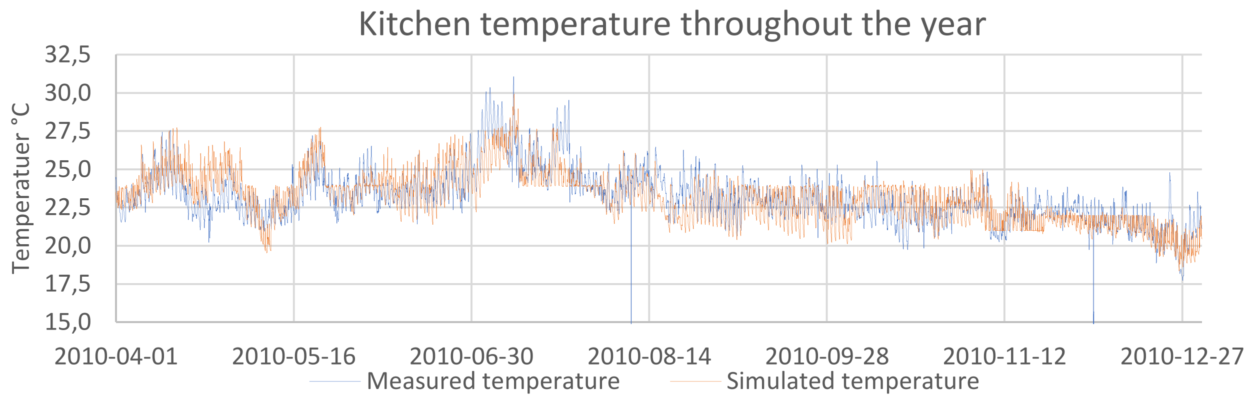


Figure 43 Kitchen temperature throughout the year - model validation

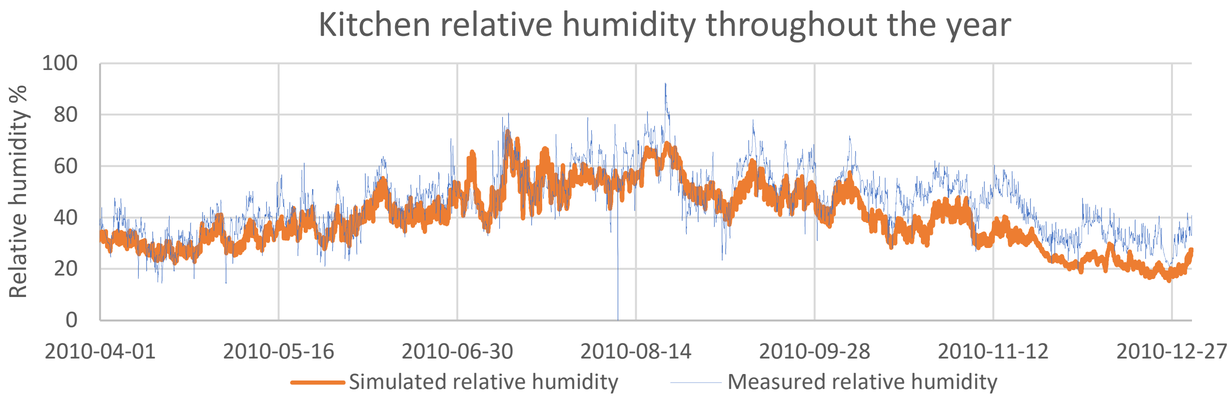


Figure 44 Relative humidity throughout the year - model validation

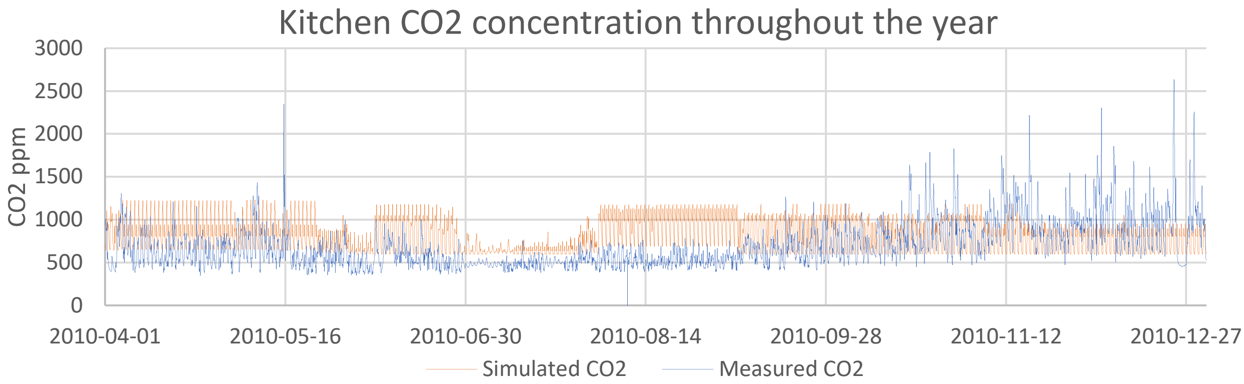


Figure 45 Kitchen CO2 concentration throughout the year - model validation

Analysis and Procedure

The starting point of the analysis and procedure is the validation of the model. At first, the baseline model was validated with no moisture load.
For this model, in particular, to get a conversion formula, the step increase of moisture content had to be changed to lower step increases. That is due to the fact that the sizes of the kitchen and bathroom are smaller than in the other two models; the saturation point is reached aftwer small number of iterations.

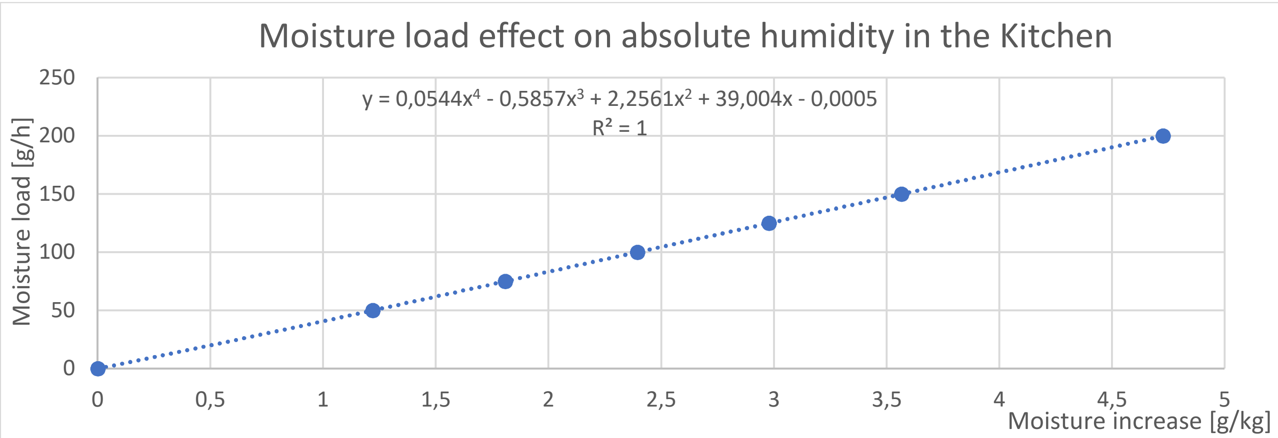


Figure 46 BSim model response to moisture load in the Kitchen Stenagervænget 49

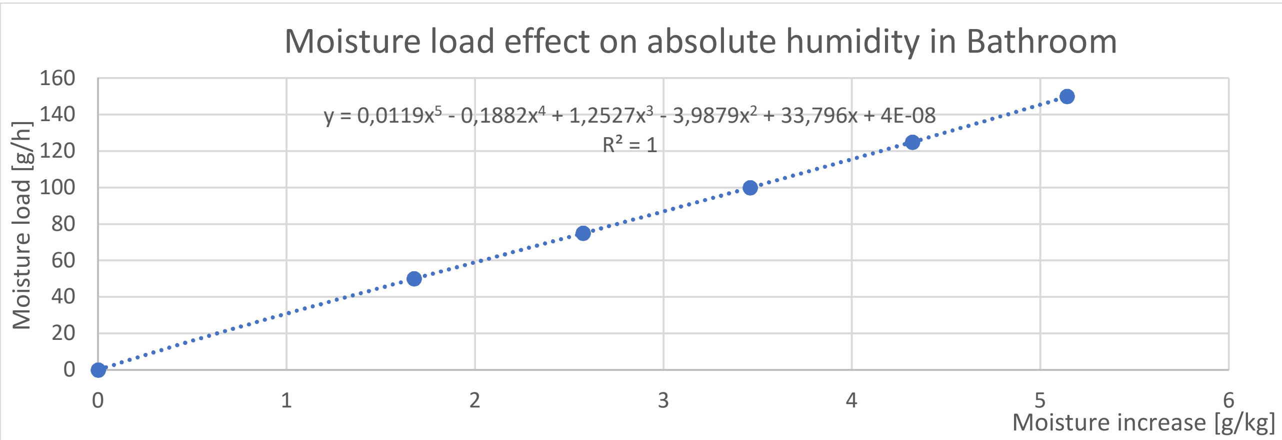


Figure 47 BSim model response to moisture load in Bathroom Stenagervænget 49

A simple calculation was done to find out and illustrate whether the percentage of time in which the difference between the measured and simulated (baseline) absolute humidity, is higher or lower than 0. In case of a difference smaller than 0, then no moisture content needs to be added. A difference higher than 0 would indicate that moisture content can be added.

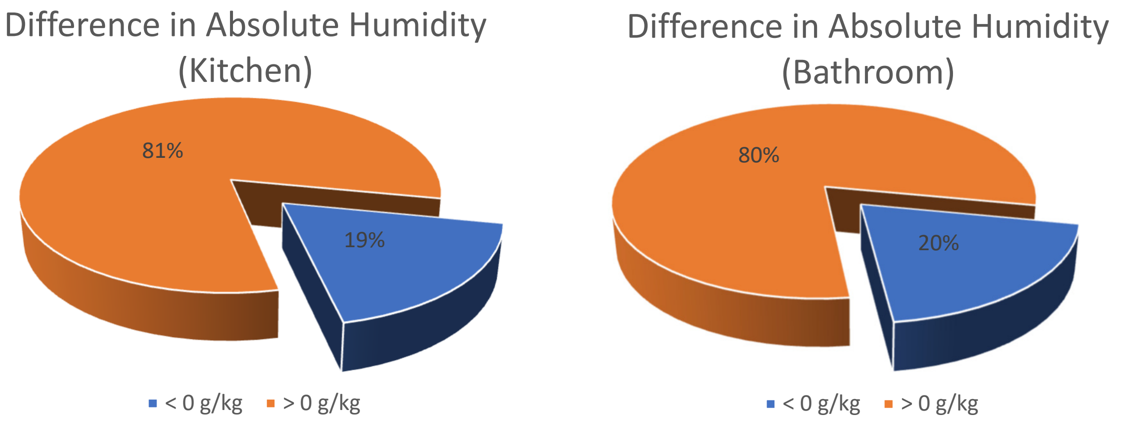


Figure 48 Percentage of time when baseline simulation (no moisture load) exceeds measured/calculated absolute humidity

Continuous moisture load

The continuous moisture load is the profile that was tested the first time; the simulation was performed after the following mean moisture load was added to the kitchen and bathroom. See table 26.

	Mean difference in absolute humidity [g/kg]	*Mean moisture load [g/h]*
Kitchen	-0,133	44,85
Bathroom	-0,130	39,77

Table 26 Continuous moisture load profile

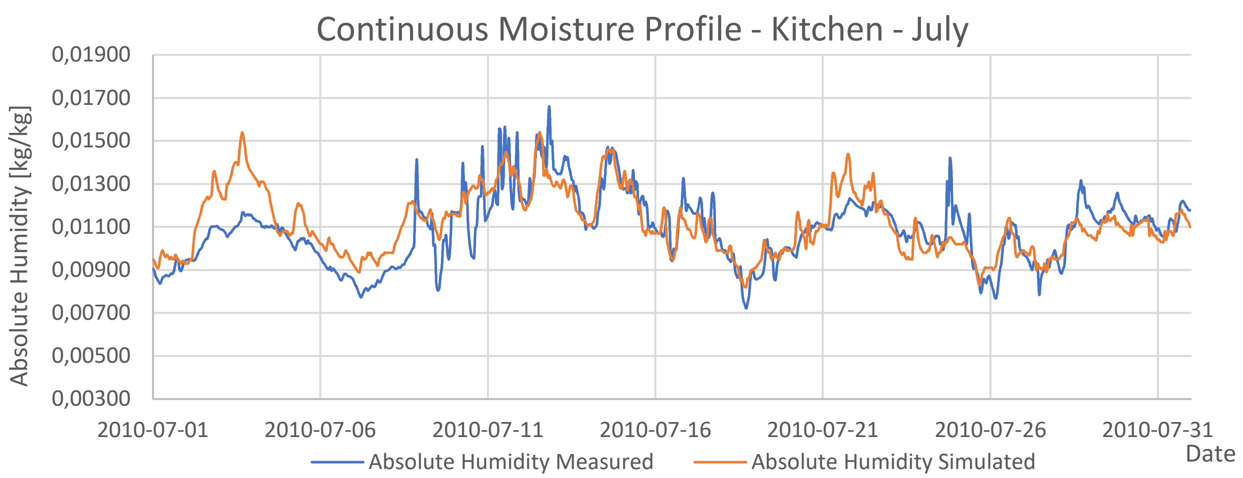


Figure 49 Continuous Moisture Profile Kitchen July

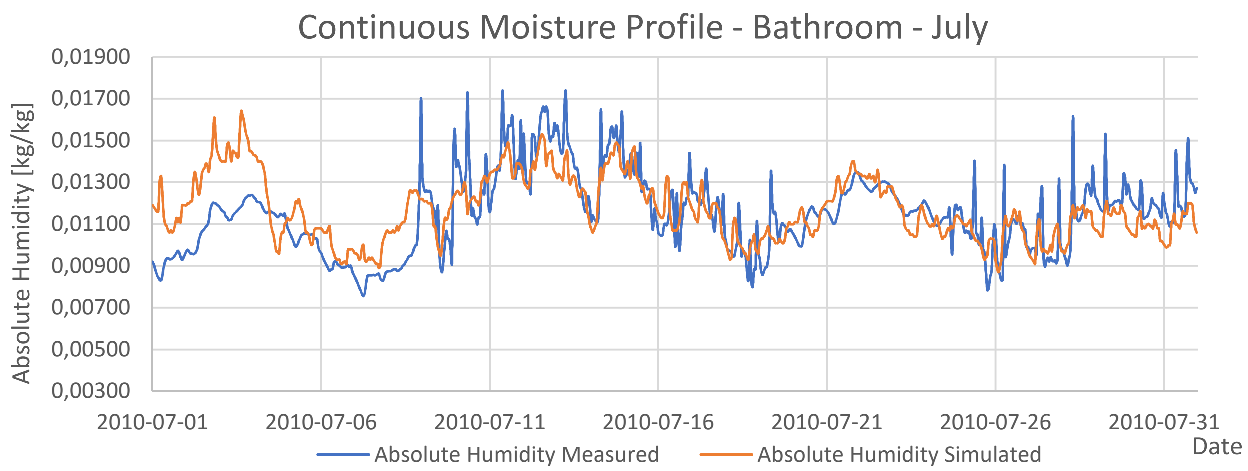


Figure 50 Continuous Moisture Profile Bathroom July

The negative mean difference in absolute humidity indicates that with a constant moisture load, the mean simulated absolute humidity is slightly higher than the measured absolute humidity (that being easily noticeable on the graphs).
It can be assumed that the small size of the rooms could cause the simulated absolute humidity to be slightly higher than measured.
As it is a constant moisture load, not many peaks can be observed, but the simulated absolute humidity seems to be very close to the measured one.

Weekdays and weekends moisture load

	Mean moisture load - Weekdays [g/h]	*Mean moisture load – Weekends [g/h]*
Kitchen	44,34	46,13
Bathroom	39,54	40,35

Table 27 Week/Weekends moisture profile

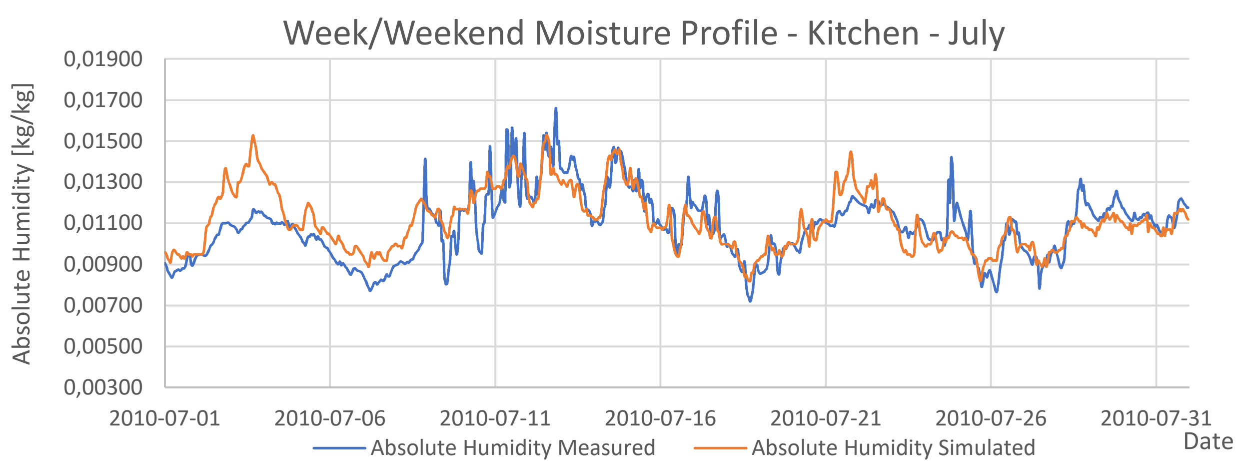


Figure 51 Week/Weekend Moisture Profile - Kitchen - July

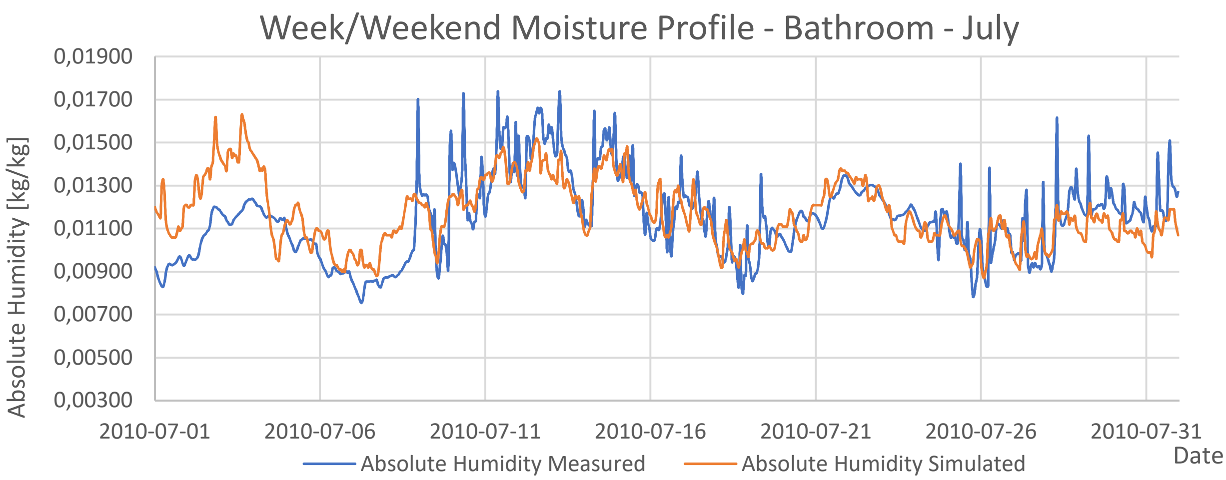


Figure 52 Week/Weekend Moisture Profile - Bathroom – July

No difference can be observed between the constant moisture load and the weekly/weekend moisture load. Apart from that, the mean difference in absolute humidity increased from -0,13 to -0,11 g/kg for both rooms.

Continuous monthly moisture load

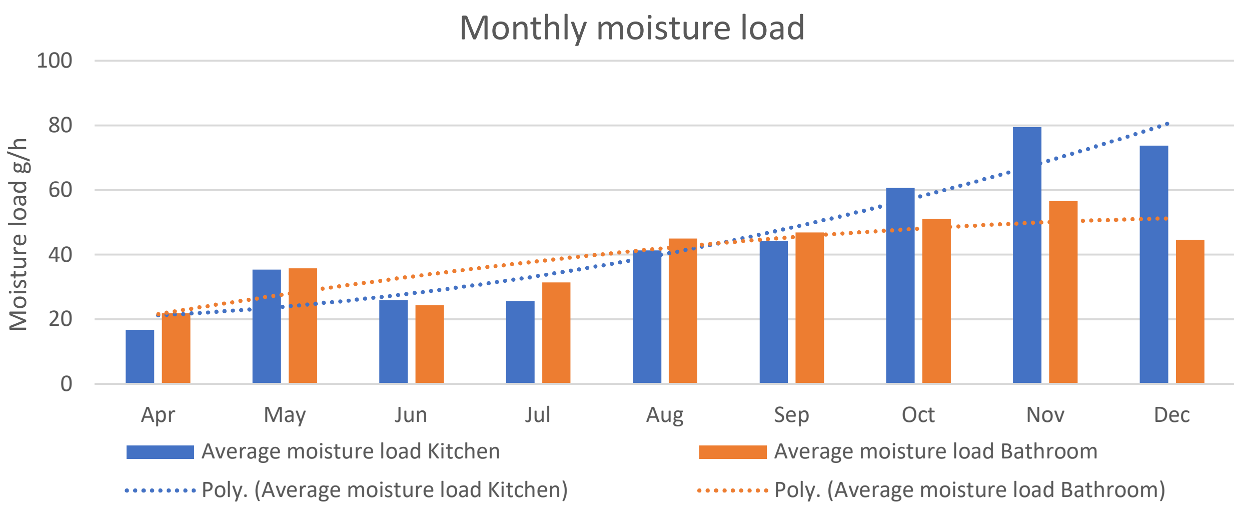


Figure 53Monthly moisture load Stenagervænget 49

A normal trend can be observed when looking at both bathroom and kitchen (monthly moisture load); normally during the warm season, the air becomes drier, therefore with less moisture content. In April, lower values can be observed; that is due to the fact that the family only moved into the house at the end of March - beginning of April.

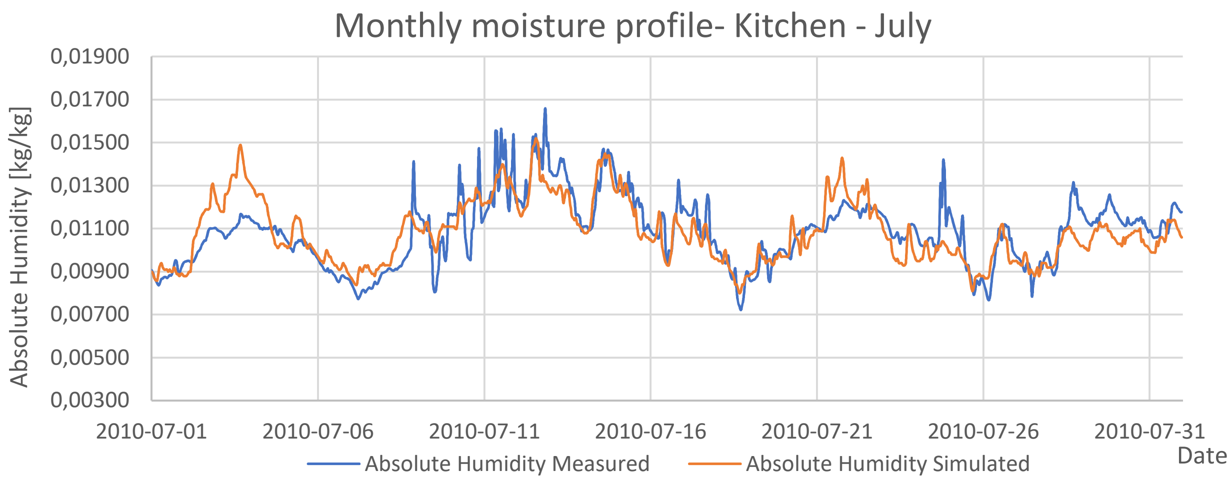


Figure 54 Monthly moisture profile- Kitchen - July

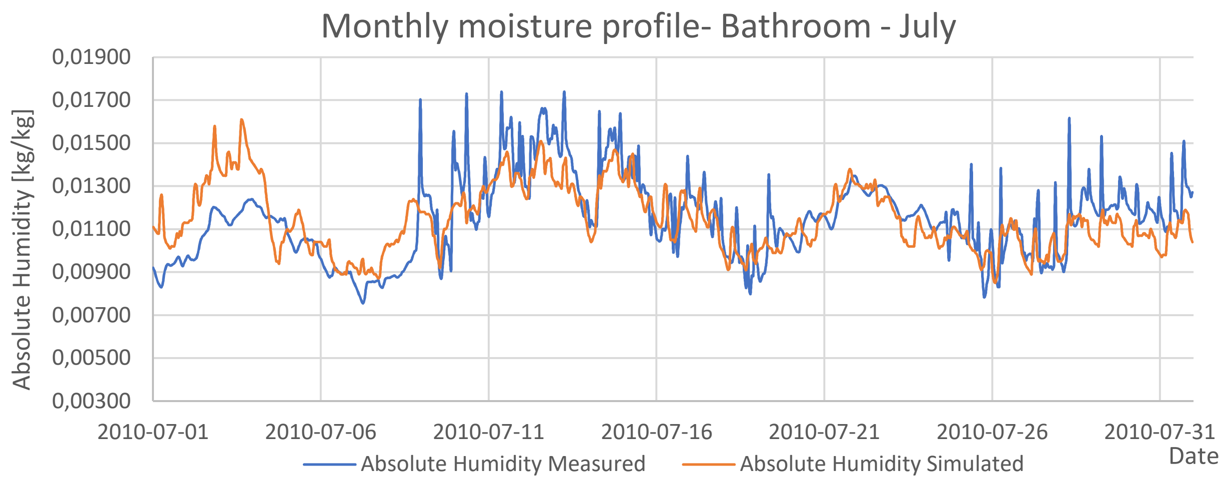


Figure 55Monthly moisture profile- Bathroom - July

There are almost no changes in absolute humidity after the simulation of the model with the monthly moisture profile. The absolute humidity is a bit lower, but the change is almost not visible.

Standard day profile

Hour	Mean moisture load Kitchen [g/h]	Mean moisture load Bathroom [g/h]
00	57.86	51.09
01	55.76	45.70
02	54.01	42.02
03	52.43	39.59
04	50.62	38.25
05	41.83	30.39
06	37.68	41.40
07	36.70	30.80
08	37.74	60.17
09	36.31	54.99
10	32.44	40.39
11	31.81	37.81
12	32.30	36.21
13	32.24	34.78
14	33.21	34.56
15	35.29	35.07
16	37.96	35.54
17	42.31	24.79
18	45.97	25.96
19	54.69	24.39
20	58.03	23.76
21	59.33	49.63
22	60.08	59.77
23	59.84	57.53

Table 28 Standard day moisture profile

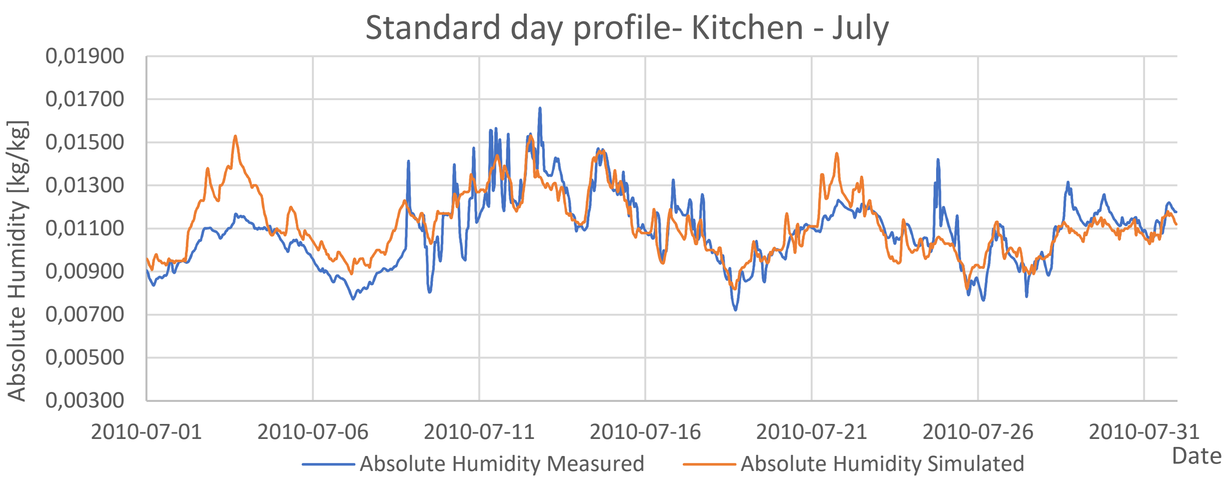


Figure 56 Standard day profile- Kitchen - July

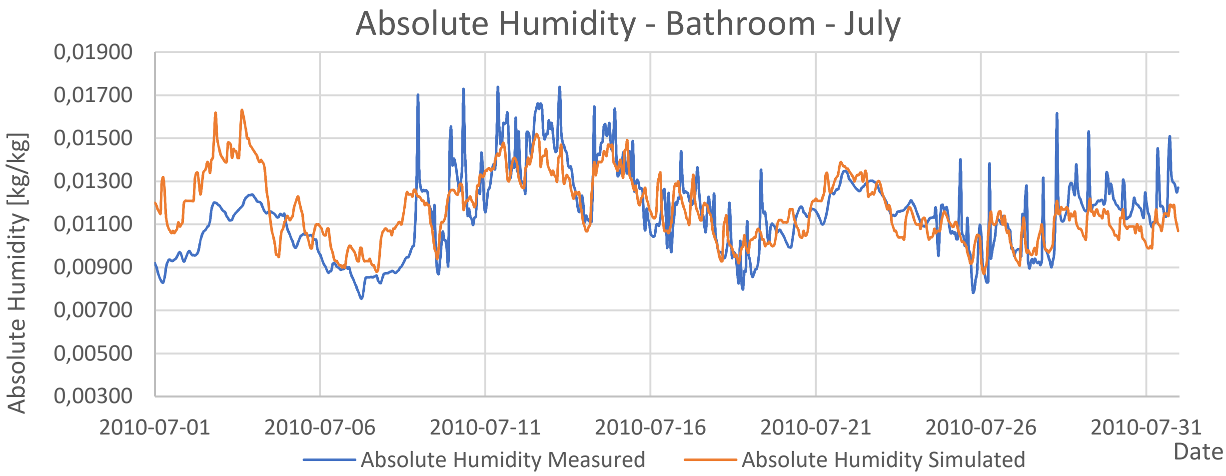


Figure 57 Absolute Humidity - Bathroom - July

The moisture profiles that were analyzed appear to work, but to some extent. The results of all the profiles are barely comparable with each other; since there are no significant changes, therefore the one conclusion could be that the (constant load profile

An overview of all the profiles extracted from this specific house are presented in a general table:

Overview

Profiles (Bathroom)	*Average [g/kg]*	*Standard deviation*	*Correlation factor*	*MAD*	*MSE*	*RMSE*	*MAPE*
Measurements	8,97	2,54					
No profile	7,80	2,15	0,80	1,49	3,62	1,9	16,5%
Continuous moisture load	9,11	2,02	0,80	1,16	2,3	1,51	14,5%
Continuous moisture load for weekdays and weekends	9,09	2,02	0,81	1,14	2,23	1,49	14,3%
Continuous monthly moisture load	9,07	1,97	0,82	1,1	2,1	1,45	13,9%
Standard day profile	9,10	2,02	0,80	1,15	2,25	1,50	14,4%

Table 29 Overview of humidity profiles - Bathroom

Profiles (Kitchen)	*Average [g/kg]*	*Standard deviation*	*Correlation factor*	*MAD*	*MSE*	*RMSE*	*MAPE*
Measurements	8,08	2,39					
No profile	7,11	2,43	0,89	1,1	2,14	1,46	16,05%
Continuous moisture load	8,21	2,34	0,89	0,85	1,18	1,08	12%
Continuous moisture load for weekdays and weekends	8,19	2,34	0,90	0,84	1,12	1,06	11,7%
Continuous monthly moisture load	8,20	2,17	0,92	0,72	0,88	0,94	9,8%
Standard day profile	8,21	2,33	0,90	0,84	1,13	1,06	11,7%

Table 30 Overview of humidity profiles – Kitchen/Living

MAD – mean absolute deviationMSE – mean square error
RMSE – root mean square error MAPE – mean absolute percentage error

3.4.3 Stenagervænget 45

Building description

Figure 58 Stenagervænget 45, Google Maps

The building is situated on Stenagervænget 45, Skibet,7100 Vejle. It was designed and built as a part of a much larger project called Komfort Husene, comprised out of 10 passive houses. First inhabitants moved into the building in 2010.

Building primarily consists of two parts, defined by their functions. First, part is divided into two stories and contains bedrooms, bathrooms, study and utility areas. The second part of the building is a large volume space comprised out of kitchen and living room (here living-room is located on a first-floor platform). Centre of the building also contains an atrium which increases daylight levels and offers an opportunity for natural ventilation in the summer.
The building is constructed in a way, so it utilizes passive solar gains by using thermal mass. Therefore most of the building constructions are heavy. External walls are made out of 620 mm sandwich construction with 400 mm of insulation between concrete elements. The roof is constructed using 180 mm concrete hollow core elements and 400 mm of insulation. Ground deck – 100 mm reinforced concrete slab on 440 mm polystyrene insulation. Windows are highly energy efficient triple glazing units with average U-value of 0,67 W/m²K. (Isover, 2017)

Most of the heating for the house is supplied through ventilation, first increasing supply air temperature with heat exchanger and later, if necessary, with the heating coil. Additionally, more conventional hydronic floor heating is present in the wet rooms. (Isover, 2017)

Ventilation in the building is ensured by Nilan VP18 Compact ventilation unit. (Larsen, 2008) It is performing by variable air volume principle. However, measurements define only ~50% capacity of volume flow and no indications of how this flow is varying throughout the measurement period are available. Additionally, before entering the ventilation unit fresh air is passing through 5x40m ductwork laying in the ground, where fresh air is preheated during winter and precooled during summer. Ventilation system, more precisely exhaust air, is also used as a low-temperature heat source for domestic hot water production, by using air to water heat pump. (Isover, 2017)

In February 2010 a four-person family (2 adults and 2 teenagers) had moved into the building. Therefore, a continuous residence period from February $8^{th,}$ 2010 till December $31^{st,}$ 2010 has been selected for investigation.

Model description

Aalborg University has investigated and performed measurements in the house from April 2009 to September 2011. Overview of the sensor placement and measured parameters can be observed in the figure below. All IAQ measurements were performed using Eltek equipment. (Larsen, Jensen and Daniels, 2012)

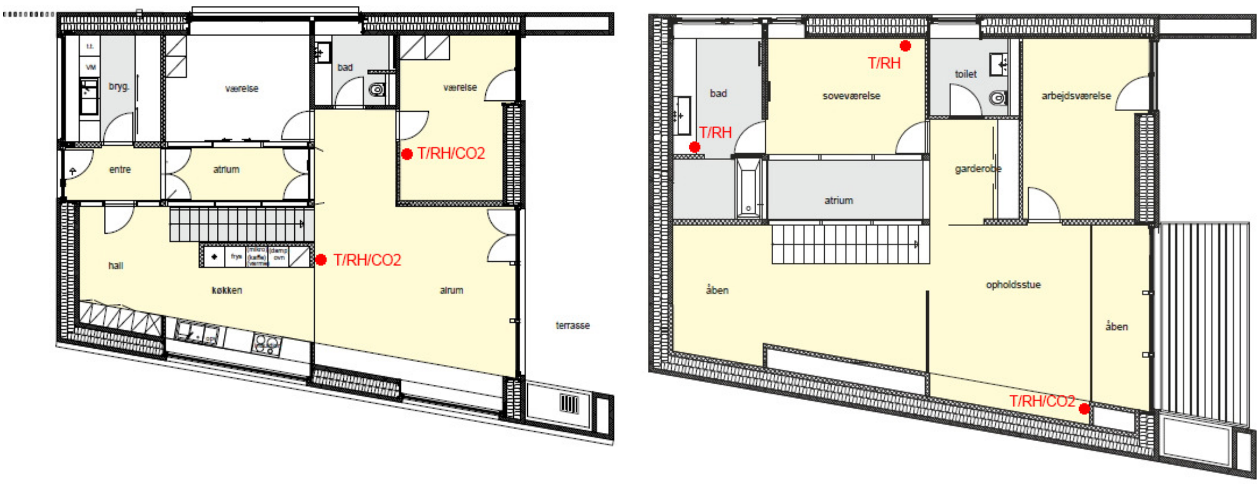


Figure 59 Ground floor and 1st floor of Stenagervænget 45 - Sensor Position (Isover, 2017)

In order to create an advanced building simulation model using BSim software, some simplifications and assumptions had to be made. First of all, small simplifications of the geometry and divisions of spaces into respectful thermal zones had to be performed (see figure below).

Figure 60 BSim model plan and division of thermal zones

Further on, complicated building's ventilation and heating systems had to be simplified:

1. Instead of difficult to simulate forced air heating system a simple radiator heating has been used.
2. Since only ~50% capacity of volume air flow is known, in order to simulate conditions closer resembling actual VAV system a decision was made to use minimum air flow during winter months, 50% air flow in spring/autumn and maximum flow during summer.
3. Precooling of fresh air during the summer is represented by a small cooling system activated only during summer.
4. No precise data about paint types and surface treatments of constructions, which can affect moisture absorption and desorption rates have been available. Therefore, an assumption has

been made, that most of the wall and ceiling surfaces have been treated in the most common way - acrylic paint with moisture resistance 3-4 × 10^9 (Universitet, 2012).

5. Fresh air is supplied to bedrooms/living-rooms and extraction is present in bathrooms and kitchen. Thus, in order to imitate air flows inside the building ventilation air volume has been divided to achieve a balanced ventilation system and represented in the model by mixing system (mixing system, - defines air flows between thermal zones).

Simulations

In order to verify the validity of advanced building simulation model, a few iterations have been carried out and each of them compared with the measurements.

The procedure for model validation:
1 - CO_2 measurements have been used to determine occupancy and air flows in the building.
2 - Heating and cooling system outputs and set points are adjusted until operative temperature reaches desired level.
3 - Equipment load is adjusted according to the temperature and occupancy.

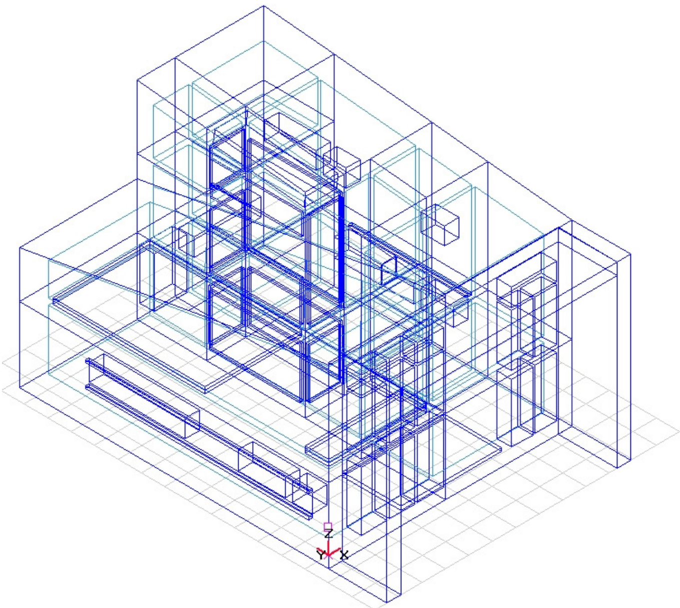


Figure 61 BSim model of Stenagervænget 45

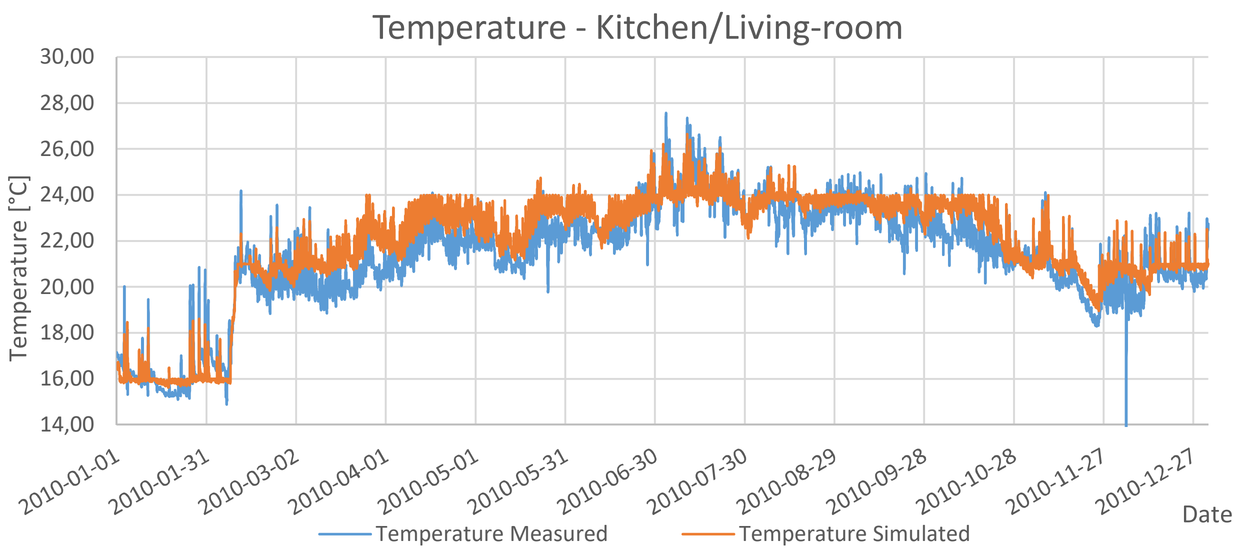


Figure 62 Temperature Validation - Kitchen/Living-room Stenagervænget 45

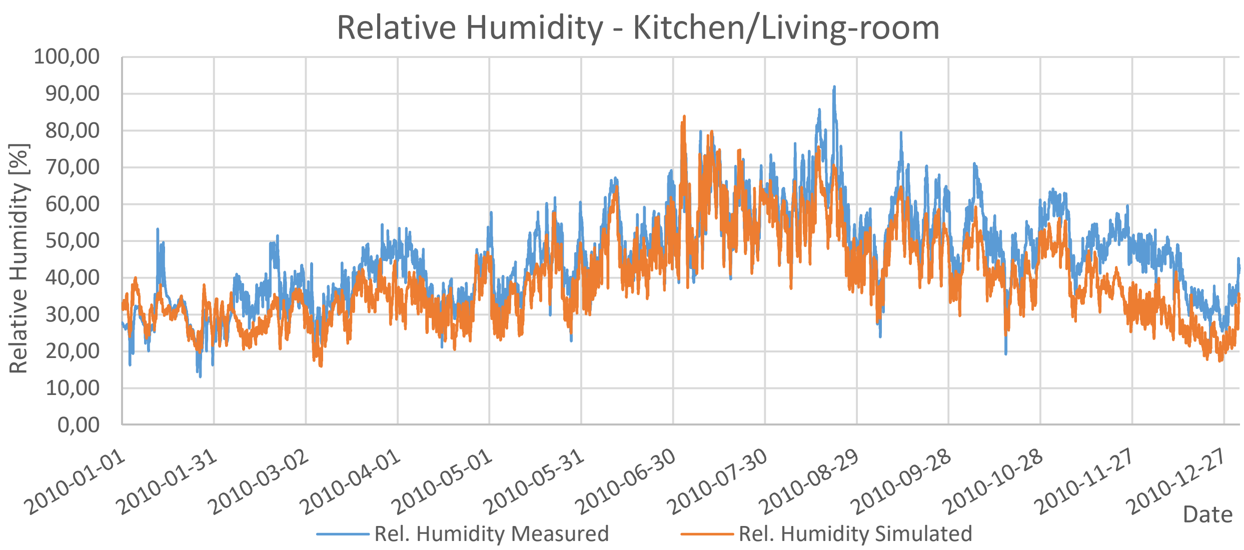


Figure 63 Relative Humidity Validation - Kitchen/Living-room Stenagervænget 45

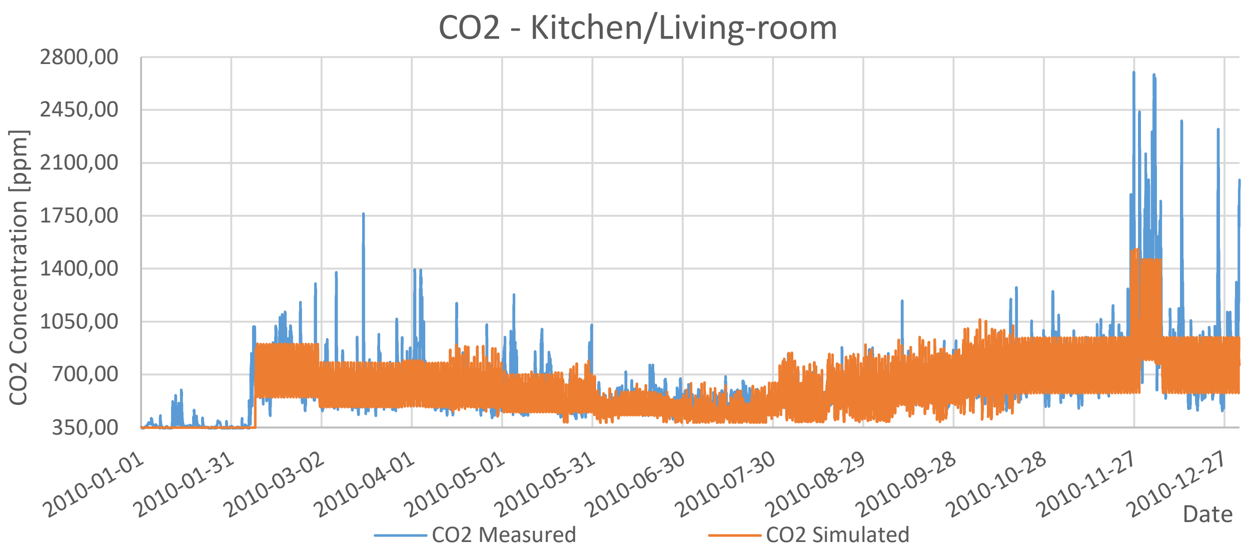


Figure 64 CO2 Validation - Kitchen/Living-room Stenagervænget 45

Validation for one of the rooms in Stenagervænget 45 can be seen in figures above.

Procedure

Analysis of the model has been carried out using moisture ratio kg $_{\text{of water vapor}}$/kg $_{\text{of air}}$ in order to reduce temperature influence on other moisture parameters such as relative humidity.

A large number of variables, like ventilation air flow, infiltration, natural ventilation, moisture absorption and desorption by construction materials, all control moisture concentration levels. Since these parameters can change from time step to time step, one would need to solve a complex system of differential equations in order to find out what exact influence moisture load would have on the overall moisture content in the air.

Such approach would be very time-consuming and cumbersome. Therefore, there was a need for more straightforward, simplified way of establishing how does computer model respond to added moisture load.

One way of solving this problem is establishing a relation between added moisture load, and absolute humidity is to run a number of simulations with increasing moisture load and register model response (black box modeling). From this data, it becomes possible to generate an equation which could predict moisture load necessary to achieve desired model behavior.

On the first attempt, a constant moisture load has been tested in bathroom and kitchen/living-space by running simulations with moisture load varying from 0 – 1600 g/h and the average increase in absolute humidity registered. Outcome and generated prediction equations can be seen in the following graphs.

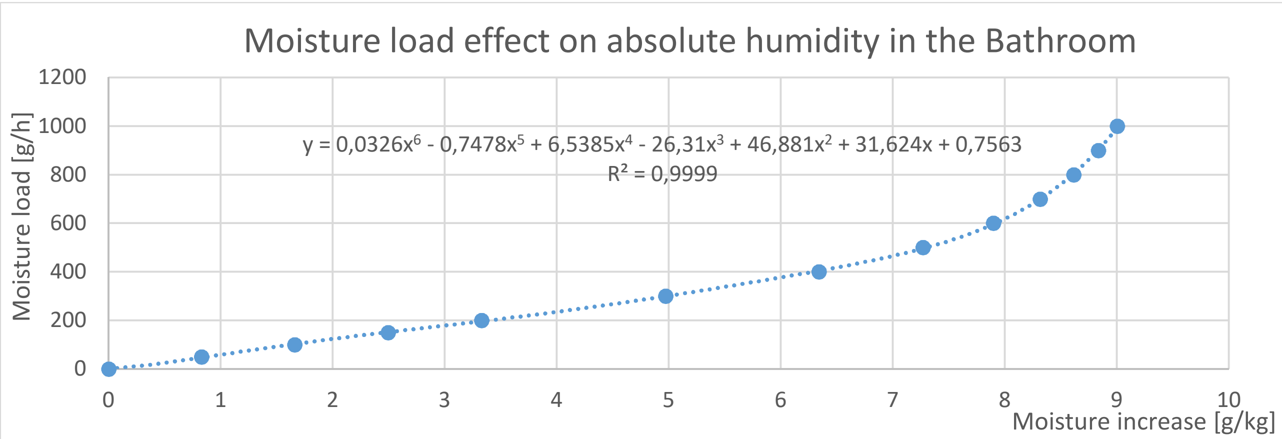


Figure 65 BSim model response to moisture load in the Bathroom

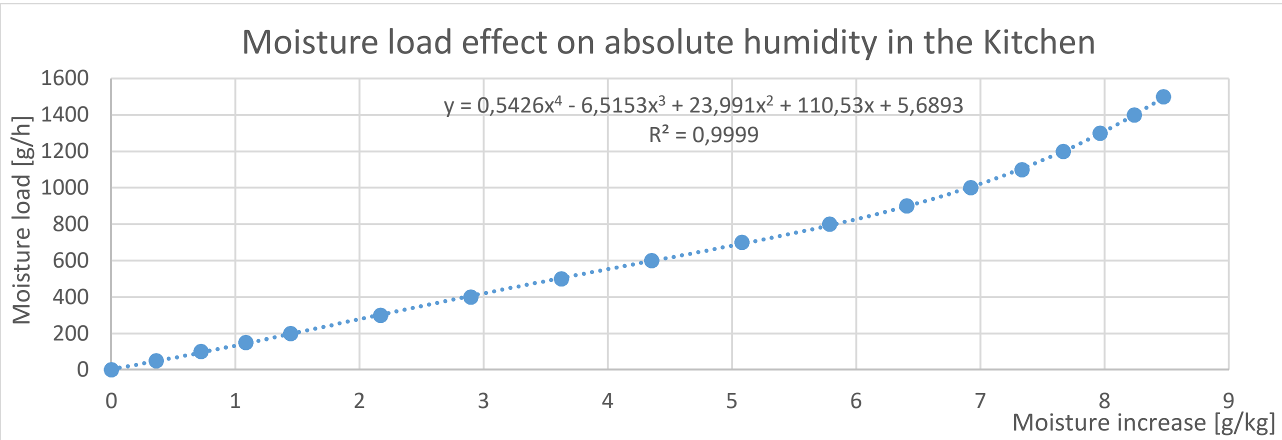


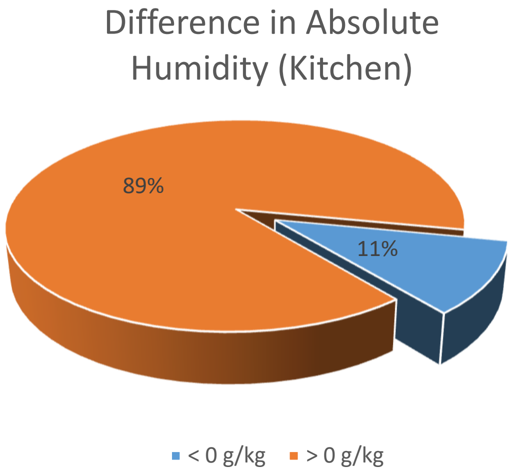
Figure 66 BSim model response to moisture load in the Kitchen

Analysis

The following profiles will be investigated based on Stenagervænget 45 case:

1 – Continuous moisture load (single value of hourly moisture load without any variations).
2 – Continuous moisture load for weekdays and weekends.
3 – Continuous monthly moisture load.
4 – Standard day profile.
5 – Advanced day profile.

With model response established it becomes possible to estimate and test different moisture profiles. However, before estimate moisture load value, it is necessary to analyze absolute humidity difference between baseline simulation and measurements.



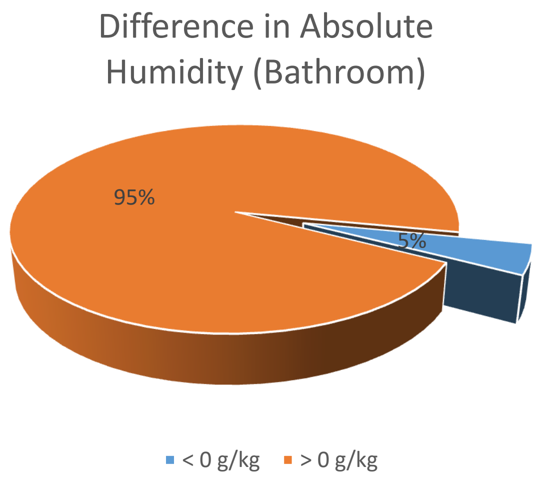


Figure 67 Percentage of time when baseline simulation (no moisture load) exceeds measured/calculated absolute humidity

The analysis shows that for specific periods of time baseline simulation already exceeds measured/calculated absolute humidity. It is most likely that higher values occur because of discrepancies between air flows and people load in reality and simulation. For further analysis, time periods, when simulated absolute humidity exceeds measurements, will be treated as periods when no moisture load is needed.

In order to evaluate similarities between measurements and simulations wide range of metrics will be used, such as average absolute humidity, standard deviation, correlation factor and others.

Constant moisture load

First generated and tested moisture profile is constant moisture load. In order to formulate continuous moisture load, the difference in absolute humidity between baseline simulation and measurements has been calculated for every hour (values where simulated humidity is higher than measurements replaced with a zero). Then by using previously generated response equation moisture load for every hour can be determined and mean value calculated. Results can be seen in the following table (rest of the graphs can be found in digital appendix 2E).

	Mean difference in absolute humidity [g/kg]	*Mean moisture load [g/h]*
Kitchen	1,05	145
Bathroom	1,87	113

Table 31 Constant moisture load data (Stenagervænget 45)

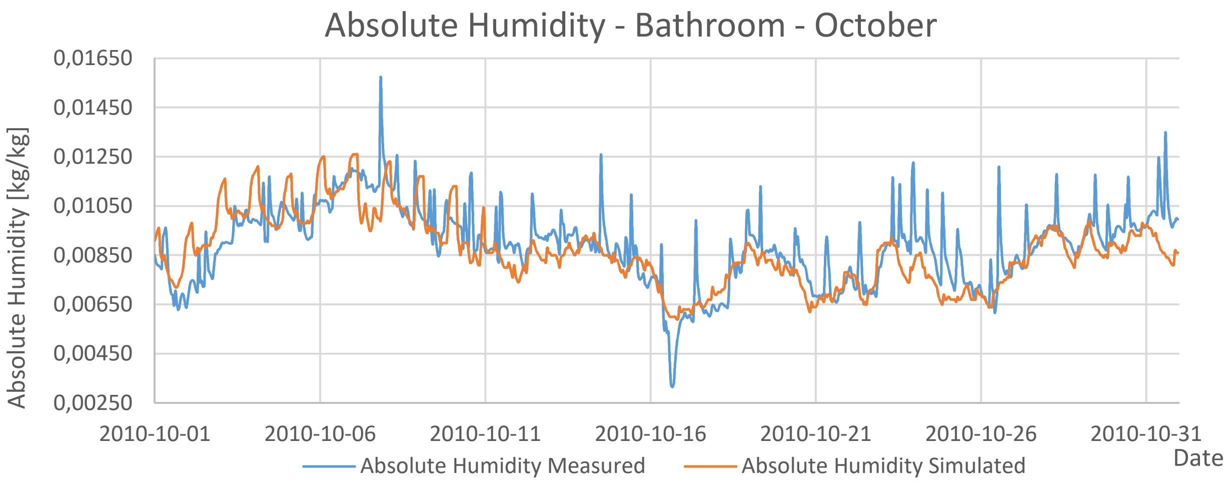


Figure 68 Constant moisture load simulation results - Bathroom (Stenagervænget 45)

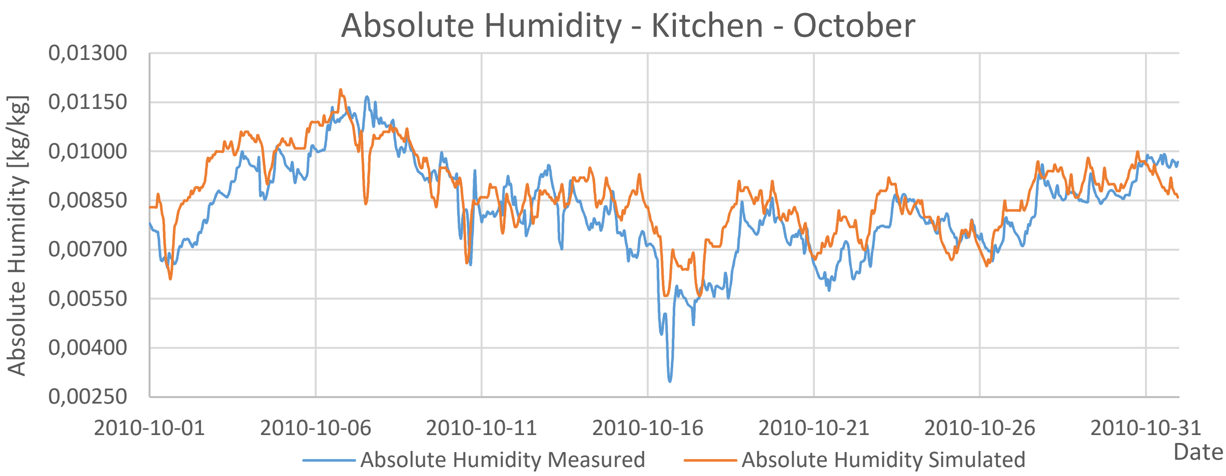


Figure 69 Constant moisture load simulation results - Kitchen (Stenagervænget 45)

Constant moisture load is a relatively fast and simple way of estimating moisture generation rate from human activities. Unfortunately, as it is evident in the case of the bathroom, where high moisture emitting activities are taking place, constant moisture load fails to replicate peak values. Therefore, a conclusion can be reached that constant moisture load profile can be used in simulations where extended degree of accuracy is not necessary.

Weekdays and weekends moisture load

The second type of moisture load, to be generated using the same principle is constant moisture load for weekdays and weekends.

	Mean moisture load - Weekdays [g/h]	*Mean moisture load – Weekends [g/h]*
Kitchen	142	151
Bathroom	111	119

Table 32 Weekday and weekend continuous moisture load profile data (Stenagervænget 45)

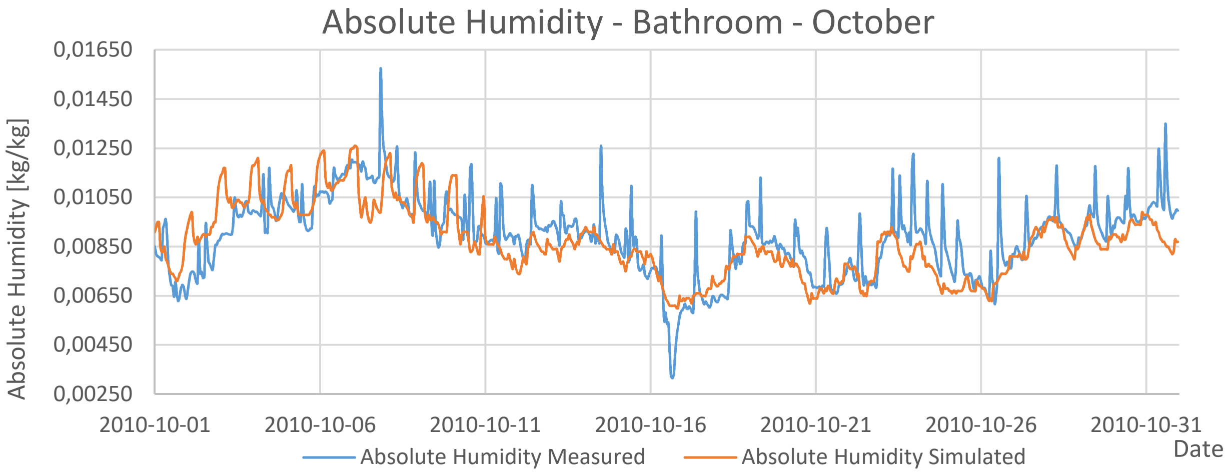


Figure 70 Weekday and weekend continuous moisture load profile simulation results - Bathroom (Stenagervænget 45)

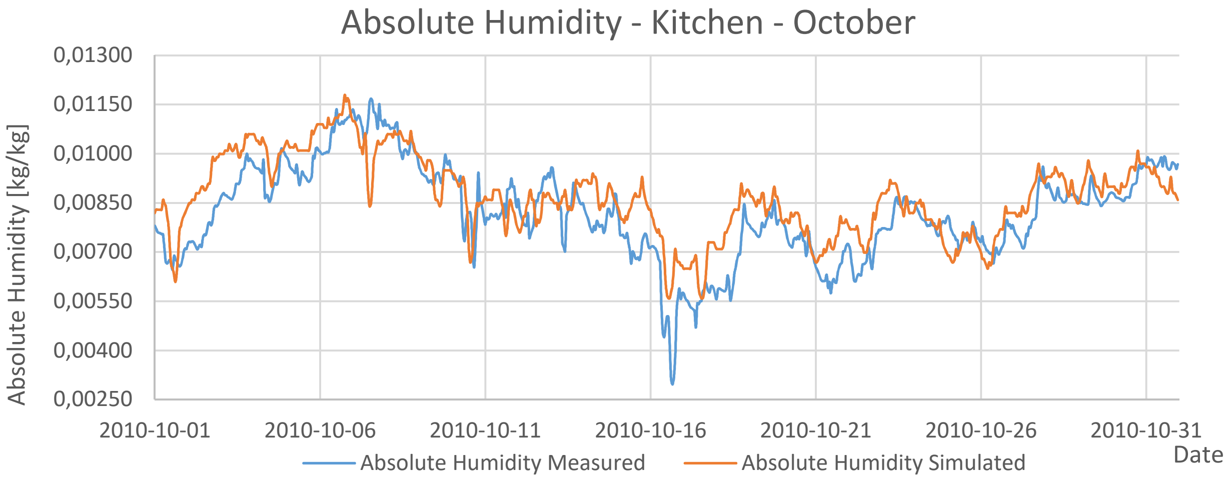


Figure 71 Weekday and weekend continuous moisture load profile simulation results - Kitchen (Stenagervænget 45)

The small difference between weekday and weekend moisture load data allows us to predict that simulation results will not be very different from constant load simulations, as proven by the results presented above.

Continuous monthly moisture load

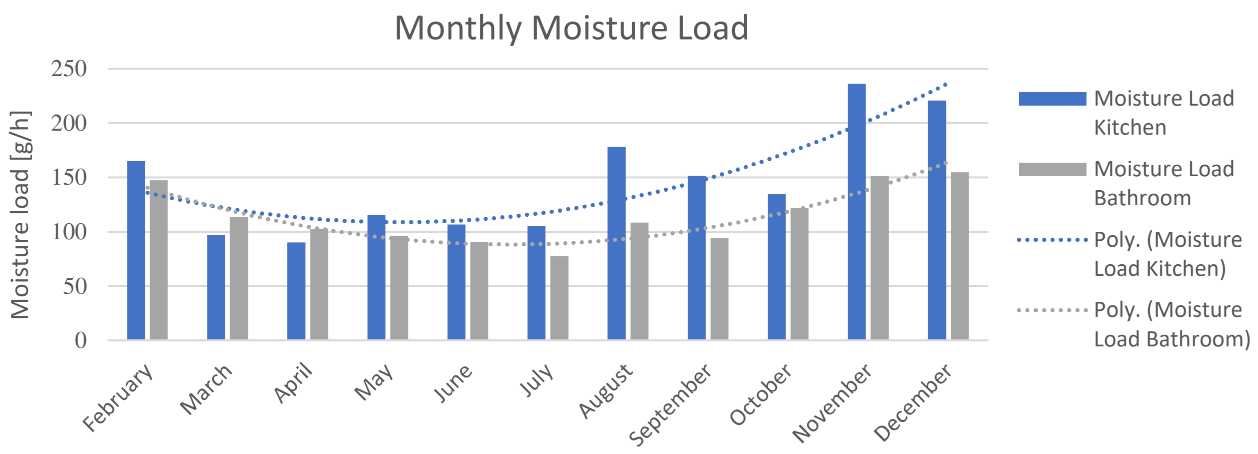


Figure 72 Monthly moisture load profile data (Stenagervænget 45)

Analysis of monthly moisture load data reveals that there is a significant variation in moisture load between the different time of year. During winter months moisture load seems to be relatively higher, then summer. These findings fit well with previously completed studies and literature (for example (Tenwolde and Ashrae, 1994).

Monthly moisture load profile results are presented in an overview table (page 74). Surprisingly simulation results show a lower correlation with measurements than constant load. Such findings could suggest that method used for determining moisture profile should be adjusted. For increased accuracy, moisture load calculation equation should be generated for every month rather than for an entire year.

Standard day profile

Using previously described principles analysis has been carried out to formulate a standard day moisture load profile. Mean moisture load for every hour has been calculated and later combined into a "standard day."

Hour	Mean moisture load Kitchen [g/h]	Mean moisture load Bathroom [g/h]
00	161	94
01	160	91
02	157	89
03	153	87
04	145	81
05	132	79
06	94	92
07	108	127
08	124	148
09	135	156
10	142	148
11	143	145
12	147	147
13	153	138
14	153	127
15	154	120
16	158	117
17	128	115
18	111	116
19	155	113
20	162	116
21	169	85
22	170	92
23	165	100

Table 33 Hourly moisture load profile data (Stenagervænget 45)

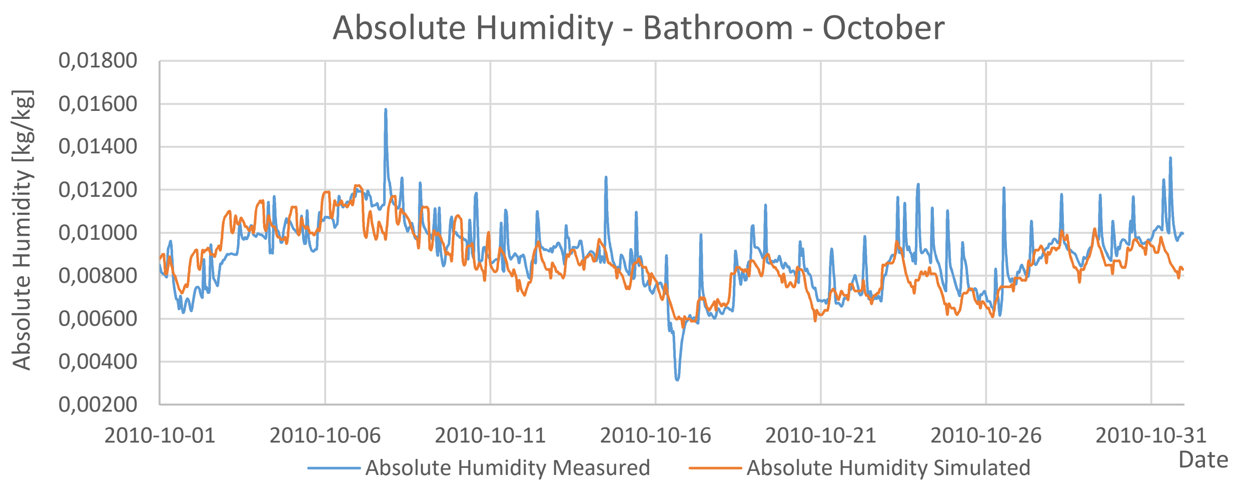


Figure 73 Standard day moisture load profile simulation results - Bathroom (Stenagervænget 45)

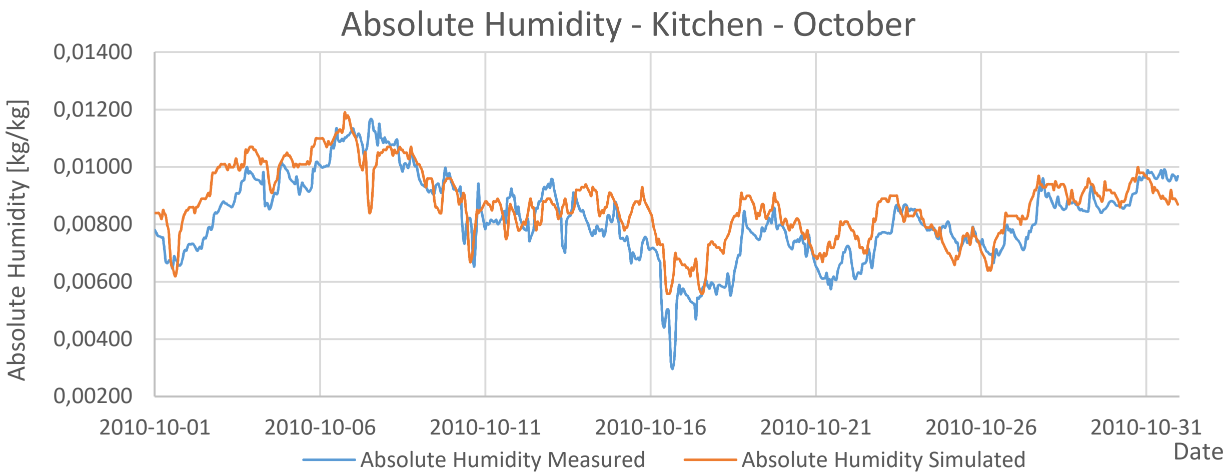


Figure 74 Standard day moisture load profile simulation results - Kitchen (Stenagervænget 45)

Once more, simulation results suggest that approach of establishing model response to moisture load has to be refined because peak value variation is not present in the model.

Advanced day profile

Another way of generating moisture production profile is to base it on measurements, literature, and observations.

In this analysis an assumption has been made that bathroom with its entrance from the master bedroom is only used by two people.

1. According to Koch, et al. average shower produces moisture load of 500 g. For two people taking a shower once a day it would produce a moisture load of 1000g. However, based on observations, a case can be made, that while approx. 500 g of moisture is produced per shower, not all of it is transferred to the air within one hour. Besides of evaporating instantly, a lot of moisture is deposited on the shower floor, sometimes even on the walls in the form of condensation. These moisture deposits often stay on surfaces for prolonged periods of time slowly increasing absolute humidity in the bathroom. Therefore, moisture emission from taking a shower could be spread over a period of a few hours to represent this cycle correctly.
2. Another common action of personal hygiene is washing hands. According to Koch et al. average person washes hands 10 times a day, and average moisture emission from washing hands is 5 g (measurements).
3. In the larger bathroom, it is also common to dry clothes. According to Koch et al. average four-person household produces 860 kg of laundry a year. Measurements carried out earlier show that moisture addition from washing clothes with 1200/1600 rpm drain cycle is equal to ~40% of the washed clothes weight. Average moisture emission from drying clothes inside per hour can be estimated as: $\frac{0,4 \cdot 860}{365 \cdot 24} = 0,039\ kg/h$.

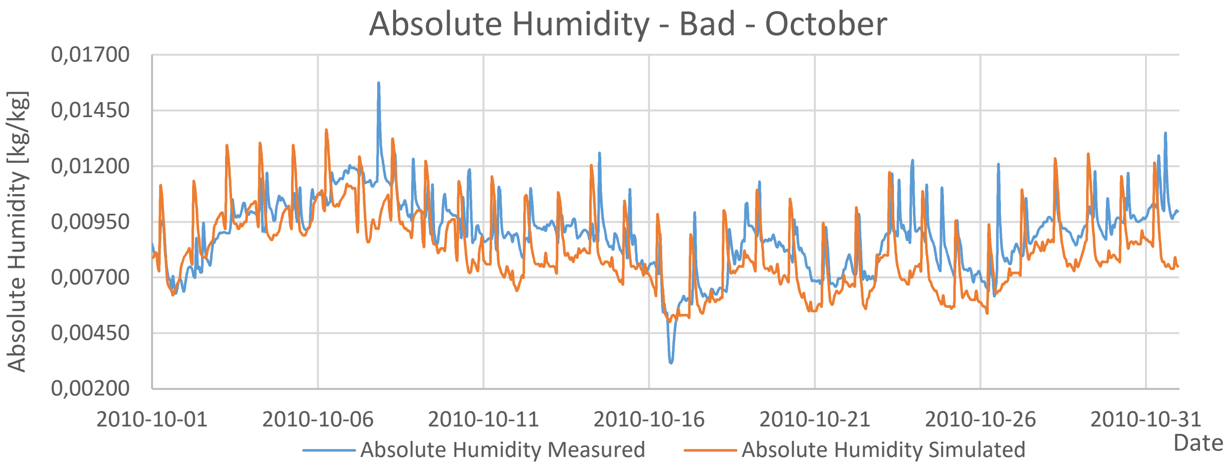


Figure 75 Advanced day moisture load profile simulation results - Bathroom (Stenagervænget 45)

Hour	Moisture load [g]	Activity	Source
00	40	Drying Clothes	Measurements
01	40	Drying Clothes	Measurements
02	40	Drying Clothes	Measurements
03	40	Drying Clothes	Measurements
04	40	Drying Clothes	Measurements
05	40	Drying Clothes	Measurements
06	40	Drying Clothes	Measurements
07	400	Drying Clothes, Shower	Measurements, (Koch, et al. 1986)
08	290	Drying Clothes, Shower evaporation	Measurements, (Koch, et al. 1986)
09	240	Drying Clothes, Shower evaporation	Measurements, (Koch, et al. 1986)
10	140	Drying Clothes, Shower evaporation	Measurements, (Koch, et al. 1986)
11	90	Drying Clothes, Shower evaporation	Measurements, (Koch, et al. 1986)
12	40	Drying Clothes	Measurements
13	40	Drying Clothes	Measurements
14	40	Drying Clothes	Measurements
15	40	Drying Clothes	Measurements
16	40	Drying Clothes	Measurements
17	57	Drying Clothes, Washing hands	Measurements, (Koch, et al. 1986)
18	57	Drying Clothes, Washing hands	Measurements, (Koch, et al. 1986)
19	57	Drying Clothes, Washing hands	Measurements, (Koch, et al. 1986)
20	57	Drying Clothes, Washing hands	Measurements, (Koch, et al. 1986)
21	57	Drying Clothes, Washing hands	Measurements, (Koch, et al. 1986)
22	57	Drying Clothes, Washing hands	Measurements, (Koch, et al. 1986)
23	40	Drying Clothes	Measurements
Total	**2022**		

Table 34 Advanced day (Literature based) moisture profile data

Overview

Profiles (Bathroom)	Average [g/kg]	Standard deviation	Correlation factor	MAD	MSE	RMSE	MAPE
Measurements	8,69	2,43					
No profile	6,84	2,36	0,85	1,89	5,12	2,26	22,0%
Continuous moisture load	8,69	2,09	0,84	1,02	1,75	1,32	12,9%
Continuous moisture load for weekdays and weekends	8,70	2,09	0,84	1,02	1,75	1,32	12,9%
Continuous monthly moisture load	8,85	1,93	0,80	1,13	2,15	1,46	14,8%
Standard day profile	8,72	2,11	0,85	0,99	1,67	1,29	12,6%
Advanced day profile	8,26	2,48	0,77	1,29	3,00	1,73	15,4%

Table 35 Overview of tested moisture profiles for Bathroom (Stenagervænget 45)

Profiles (Kitchen)	Average [g/kg]	Standard deviation	Correlation factor	MAD	MSE	RMSE	MAPE
Measurements	7,85	2,44					
No profile	6,85	2,44	0,94	1,1	1,74	1,3	14,8%
Continuous moisture load	7,88	2,24	0,94	0,64	0,67	0,82	8,8%
Continuous moisture load for weekdays and weekends	7,87	2,24	0,94	0,64	0,67	0,82	8,7%
Continuous monthly moisture load	7,97	2,20	0,93	0,69	0,77	0,88	9,7%
Standard day profile	7,88	2,24	0,94	0,64	0,65	0,81	8,7%

Table 36 Overview of tested moisture profiles for Bathroom (Stenagervænget 45)

MAD – mean absolute deviation
MSE – mean square error
RMSE – root mean square error
MAPE – mean absolute percentage error

Evaluation metrics like average, standard deviation and correlation factor reveal that without any moisture load present BSim model has overall lower humidity levels yet profile correlation is relatively similar, compared to the measurements. Therefore, if fast and simple way of representing moisture load in the advanced building simulation is needed, constant moisture load, can be a very good approximation. That is especially in the case of the kitchen area, where humidity peaks caused by occupant activity are smaller in magnitude and frequency.
In the bathroom constant moisture load is a relatively good approximation, bringing measurements and simulation quite close together. On the other hand, absolute humidity profile in the bathroom is dominated by sharp peaks, which cannot be reproduced by constant moisture profile, or any profile generated by using black box model response. Thus, if looking for a more accurate way of representing moisture load in the bathroom an altered investigative approach, such as literature based profile is necessary.

3.5 BSim modeling (Apartments)

3.5.1 Apartment Location 1

Building description

A full description of the construction and systems of the modeled apartment can be found in the Measurement Campaign Chapter 2.1.1.
The apartment consists of living-room facing South, bedroom facing North, bathroom, kitchen and a hallway leading directly in the kitchen. The measuring equipment was placed in all the rooms inside the apartment, see figure 76; direct solar radiation on any of the sensors was avoided.
The measurement campaign lasted approximately one month, starting on 09/11/2017 and ending on 05/12/2017; during that time, air temperature, relative humidity and CO_2 concentration has been measured. As for the occupancy of the apartment, during the period of the measurement campaign 3 persons occupied the place.

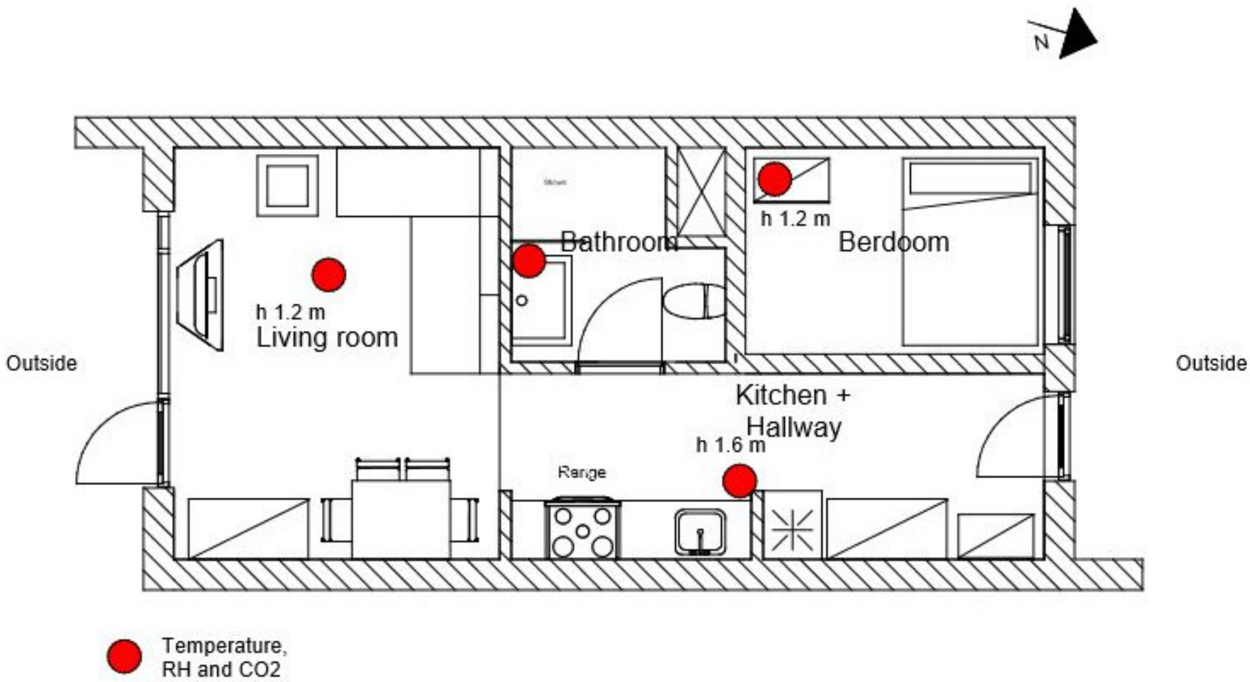


Figure 76 Placement of IC-Meters, Åbyhøjgård 40

Model description

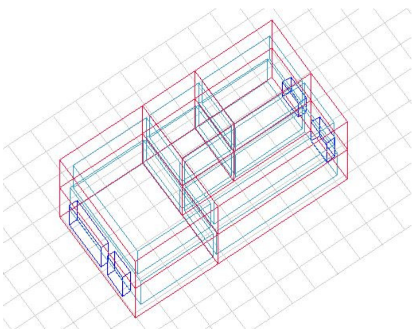


Figure 77 Åbyhøjgård 40

The model itself is very simple, and no simplifications were needed. A first floor was added to the model, and similar thermal properties were assigned to it. The walls separating the apartment from the neighboring apartments were assigned to be facing the same thermal conditions as inside the modeled apartment.
The building components such as external and internal walls, consist of lightweight materials. District heating is used for the

heating system in the apartment, radiators being used as heat distributors. Natural ventilation with forced extraction in the bathroom and kitchen is used.

Simulations

Building a weather file was the first step as the validation of the model wouldn't be possible without it. Therefore, during the period of the measurement campaign, outdoor air temperature and relative humidity were logged so they can later be used for the weather file; other weather parameters were used from the DRY 2013 file and an online weather data archive.
Finally, a baseline model was validated with no moisture load added.

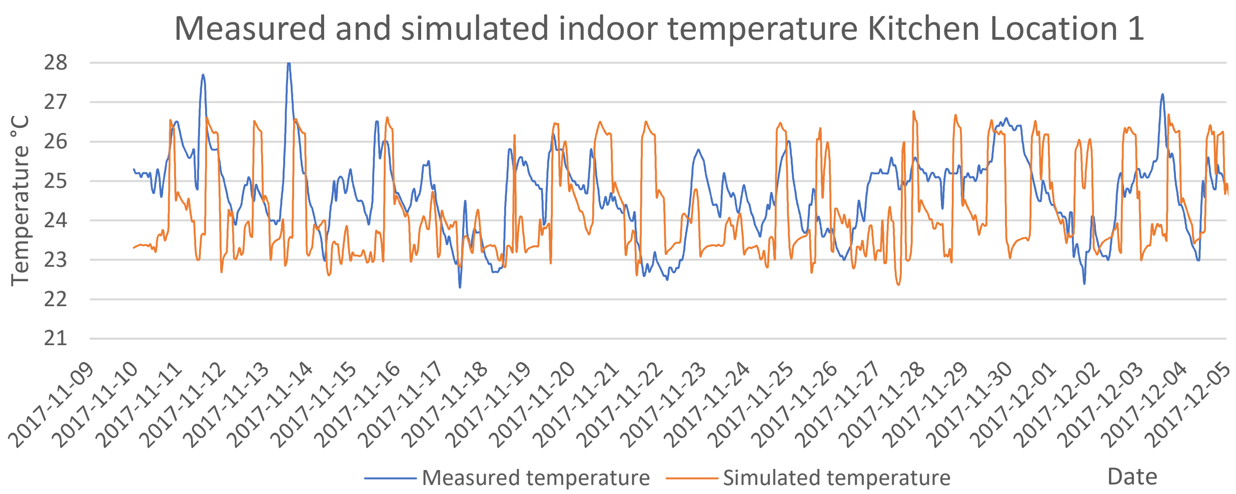


Figure 78 Validation - Air Temp. Kitchen

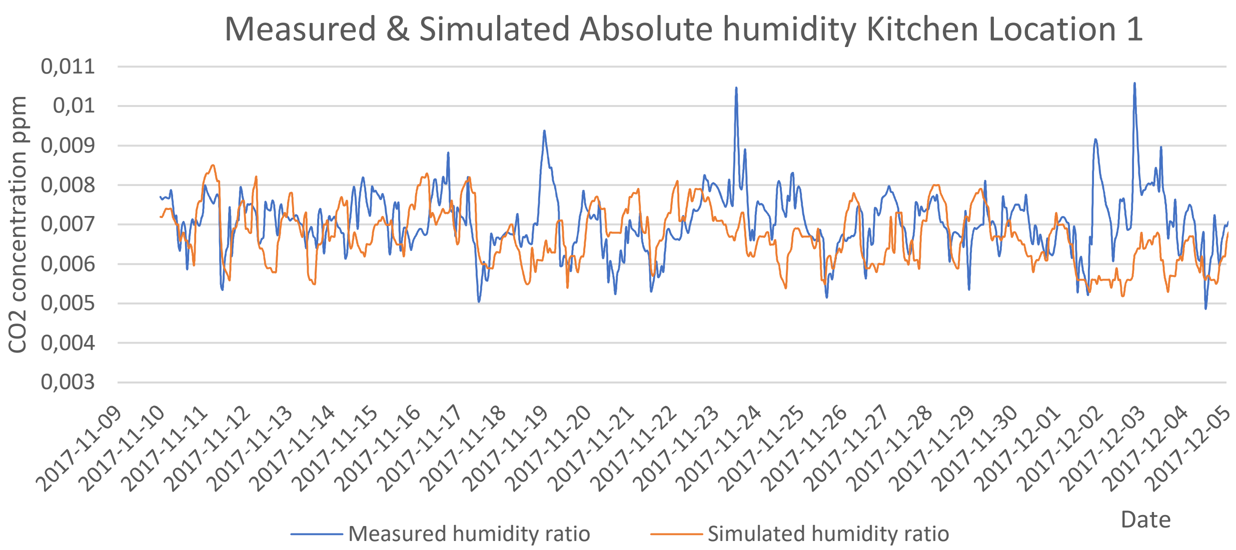


Figure 79 Validation - Absolute Humidity Kitchen

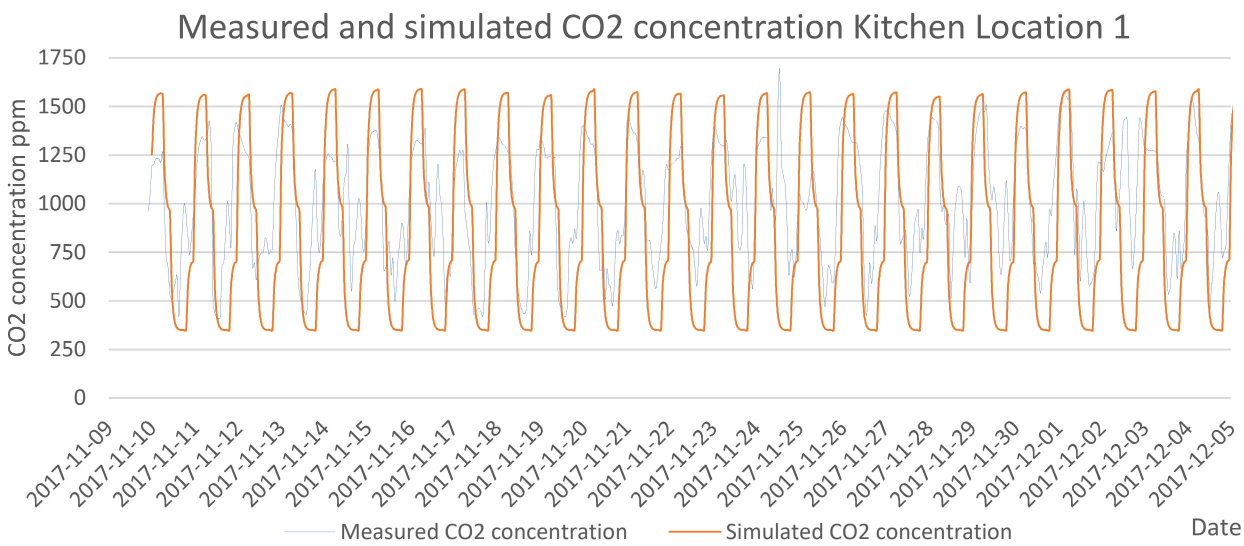


Figure 80 Validation - CO2 - Kitchen

Analysis and Procedure

All the days between the 9th of November and 5th of December have been selected and analyzed, in order to determine the moisture production in the apartment. To account for the moisture load in the apartment, an activity log was kept throughout the entire measurement campaign; moisture emissions were afterwards estimated using literature and previously performed measurements. Using the logged activities and their moisture emissions, different moisture profiles have been tested:

1) Continuous moisture load
2) Continuous moisture load for weekends and weekdays
3) Standard day profile

An example of one of the days that were analyzed can be seen below; the rest of the analyzed days can be seen in appendix C2.

Weekend 19/11/2017			Duration	Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity					
09:26	09:40	Breakfast	00:14	35.00	12.83		47.83
09:40	09:45	Dishwashing	00:05	50.00	4.58	6	60.58
16:15		Washing hands		5.00			5.00
16:15	16:40	cooking/stove	00:25	166.00	45.83		211.83
18:18		Washing hands		5.00			5.00
18:18	18:36	cooking/stove	00:18	166.00	16.50		182.50
19:13	19:17	dishwashing	00:04	50.00	7.33	6	63.33
19:17	19:53	cooking/stove	00:36	166.00	33.00		199.00
19:53	20:00	dishwashing	00:07	50.00	6.42	6	62.42
						Total [g/day]	**837.50**

Table 37 Daily moisture emissions from activities

An overview of all the analyzed days can be seen below:

Bathroom Day/Date		Total Moisture Generation [g/day]	Average Daily Emission [g]	Hourly Average Week/Weekend [g/h]	Standard Deviation	Standard Error	Total Average [g/day]	Total Hourly Average [g/h]
Weekday	11/10/2017	1502.65	**1628.2**	**67.84**	**733.19**	**177.82**	**1781.71**	**74.24**
	11/13/2017	2391.40						
	11/14/2017	2245.6						
	11/15/2017	913.80						
	11/16/2017	1910.6						
	11/17/2017	1105.5						
	11/20/2017	1528.1						
	11/21/2017	2517.25						
	11/22/2017	155.7						
	11/23/2017	2294.6						
	11/24/2017	1830.67						
	11/27/2017	2058.47						
	11/28/2017	321.25						
	11/29/2017	1303.3						
	11/30/2017	1394.25						
	12/1/2017	2735.55						
	12/4/2017	1471.45						
Weekend	11/11/2017	2646.33	**1935.1863**	**80.63276**	**560.82952**	**198.28318**		
	11/12/2017	1529.22						
	11/18/2017	1833.42						
	11/19/2017	1486.2						
	11/25/2017	2943.3						
	11/26/2017	1667.7						
	12/2/2017	1920.95						
	12/3/2017	1454.37						

Table 38 Bathroom-List of days investigated and total moisture emission

Kitchen Day/Date		Total Moisture Generation [g/day]	Average Daily Emission [g]	Hourly Average Week/Weekend [g/h]	Standard Deviation	Standard Error	Total Average [g/day]	Total Hourly Average [g/h]
Weekday	11/10/2017	312.42	**688.4**	**28.69**	**245.44**	**63.37**	**697.77**	**29.07**
	11/13/2017	857.75						
	11/14/2017	1136.2						
	11/15/2017	411.08						
	11/16/2017	933.1						
	11/17/2017	767.6						
	11/20/2017	379.8						
	11/21/2017	659.50						
	11/22/2017	917.3						
	11/23/2017	715.2						
	11/24/2017	937.17						
	11/27/2017	723.33						
	11/28/2017	675.92						
	11/29/2017	494.08						
	11/30/2017	406.25						
Weekend	11/11/2017	784.33	**707.095**	**29.46229167**	**175.412117**	**71.61169689**		
	11/12/2017	661						
	11/18/2017	693.58						
	11/19/2017	837.5						
	11/25/2017	390.58						
	11/26/2017	875.58						

Table 39 Kitchen-List of days investigated and total moisture emissions

Continuous Moisture Load

Based on the analysis of the investigated days, the following average moisture emissions per day, have been tested.

Overview	*Mean difference in absolute humidity [g/kg]*	*Mean moisture load [g/h]*
Kitchen	0,92	29,07
Bathroom	3,31	74,24

Table 40 Continuous Moisture Load Profile

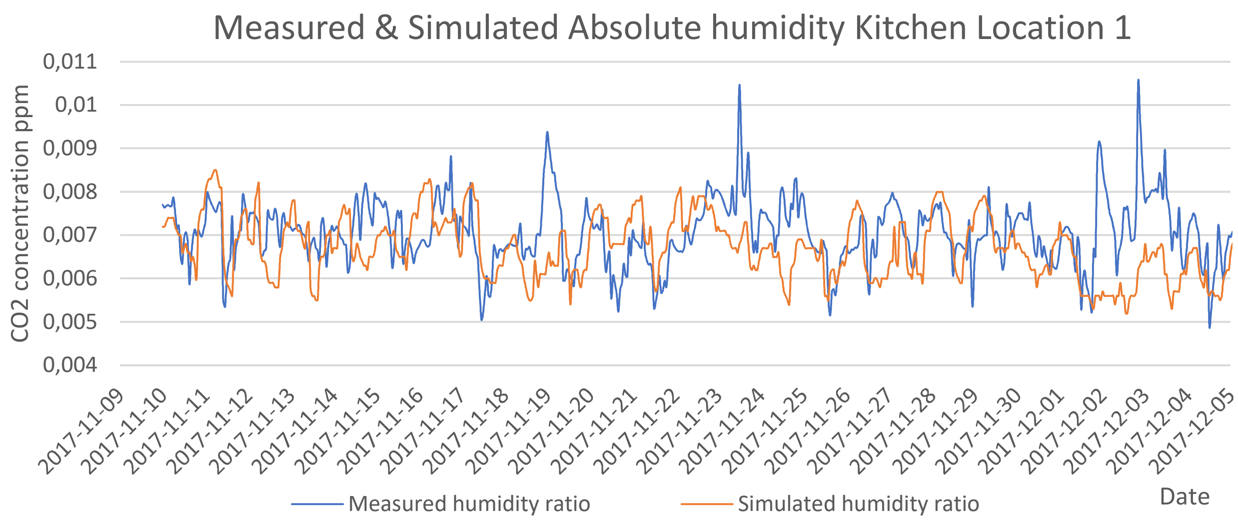


Figure 81 Kitchen Simulation - Continuous Moisture Load Profile

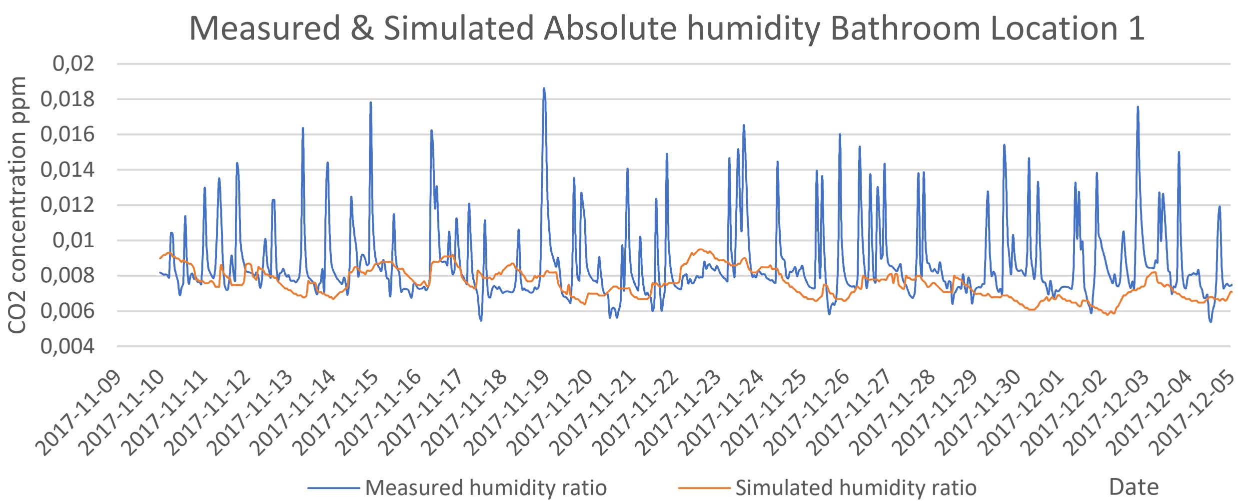


Figure 82 Bathroom Simulation - Continuous Moisture Load Profile

Adding constant moisture load to the kitchen did not change much the absolute humidity, a slight increase of the simulated absolute humidity but almost not visible. As for the bathroom, the simulated absolute humidity raised to the bottom level of the measured absolute humidity, but in order to get the peaks, a more complex moisture load profile is needed.

Continuous moisture load for weekends and weekdays

The analyzed days have been split into two groups: weekdays and weekends; Since the occupancy does not change very much during the weekend, it was not expected that the continuous moisture load for weekends and weekdays, would make a difference when compared to the constant moisture load tested previously. More than that, the mean moisture load during weekends is very close to the moisture load during weekdays; therefore, similar results to the previous test are expected.

	Mean moisture load - Weekdays [g/h]	*Mean moisture load – Weekends [g/h]*
Kitchen	28,69	29,46
Bathroom	67,84	80,63

Table 41 Continuous Moisture Load Profiles for Weekdays and Weekends

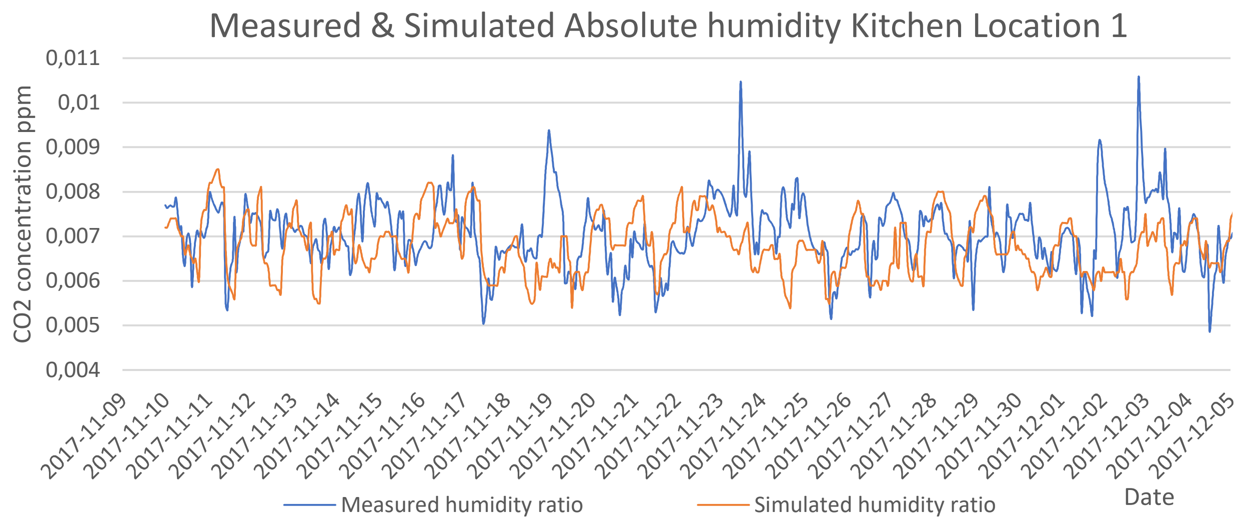


Figure 83 Simulation – Kitchen Simulation - Continuous Moisture Load Profile for Weekdays and Weekends

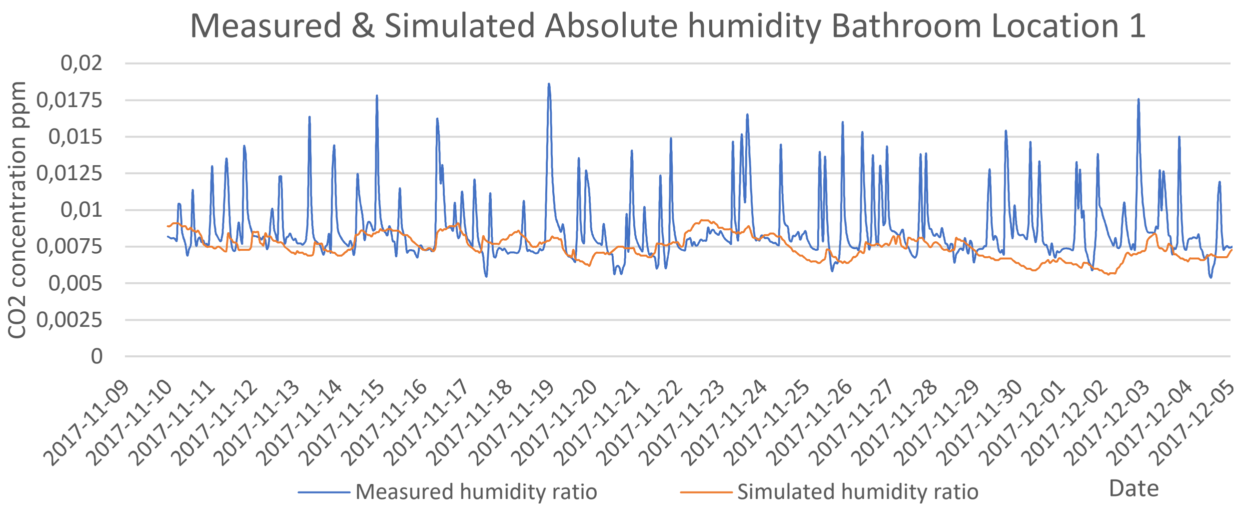


Figure 84 Bathroom Simulation - Continuous Moisture Load Profile for Weekdays and Weekends

As expected, differences are not visible when the continuous moisture load for weekends and weekdays is tested.

Standard day profile

To build a standard day profile, the frequency of each activity was investigated. Theoretically, looking for patterns is what this is all about. The time when different events occur at the highest frequency is the time that the profile is based on. The different events that have been used in building the standard day profile can be seen below.

Kitchen Activities	*Average Emission [g]*	*Standard deviation*	*Standard Error*
Coffee	12,06	2,41	1,21
Breakfast	66,9		
Cooking	166	-	-
Washing Hands	5	-	-
Washing Dishes	50,3	24,3	3,84

Table 42 List of Kitchen activities

Bathroom Activities	*Average Emission [g]*	*Standard deviation*	*Standard Error*
Morning routine	159,29	5,9	1,1
Shower	621	261,45	32,68
Evening Routine	155,14	3,08	0,61

Table 43 List of Bathroom activities

Hour	*Moisture load Kitchen [g/h]*	*Mean moisture load Bathroom [g/h]*
00	0	0
01	0	0
02	0	0
03	0	0
04	0	0
05	0	0
06	0	159
07	0	159
08	10	622
09	67	0
10	50,3	0
11	0	0
12	0	622
13	10	0
14	197	0
15	50,3	0
16	0	0
17	10	0
18	197	0
19	50,3	0
20	0	0
21	0	311
22	0	155
23	0	155

Table 44 Standard Moisture Load Profile for Kitchen and Bathroom

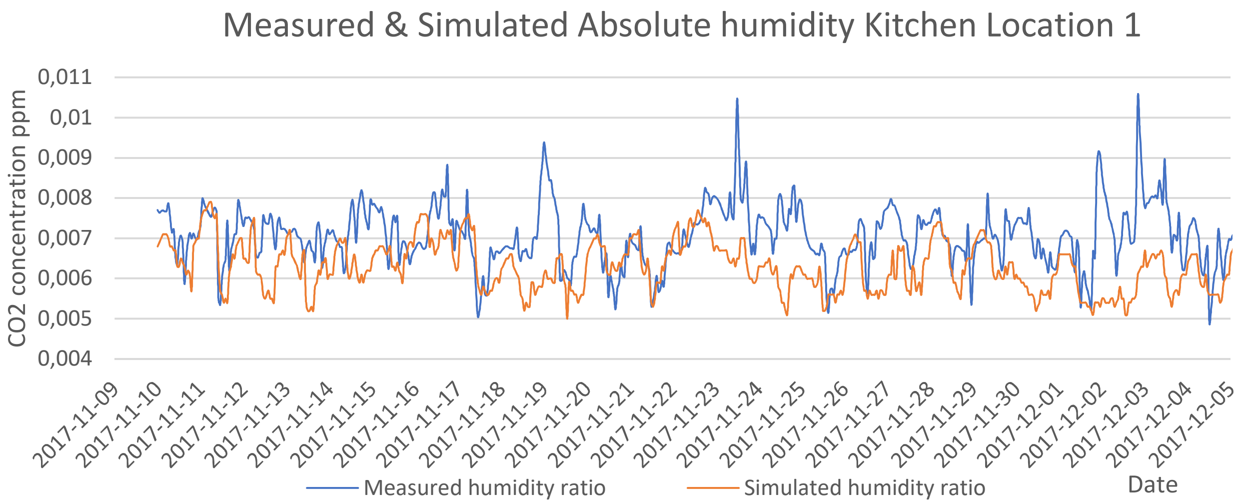


Figure 85 Kitchen Simulation - Standard Day Profile

Even with the standard day profile tested, there are no big changes in the kitchen. The simulated absolute humidity seems to follow the same pattern as the measured one, but in most of the time, it does not increase as much as it should.

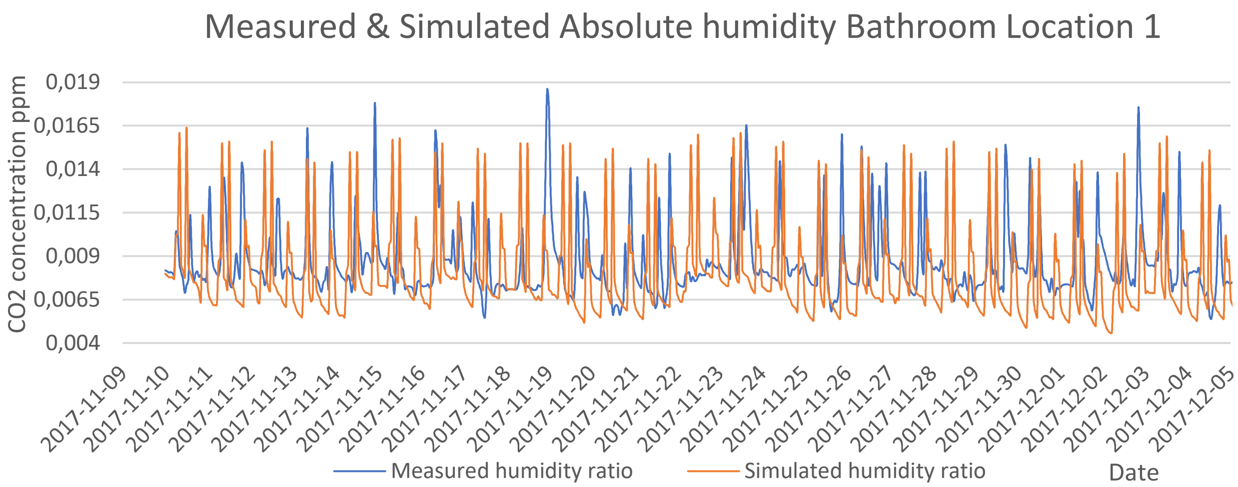


Figure 86 Bathroom Simulation - Standard Day Profile

The peaks seem to correspond to the measured ones, meaning that a quite accurate estimation of moisture emission from the showers has been done. It can be seen that after each peak, the absolute humidity drops lower than the measured; it indicates that perhaps an evaporation "activity" should have been added after each shower in order to reduce the drop of simulated absolute humidity.

Overview

Profiles (Kitchen)	*Average [g/kg]*	*Standard deviation*	*Correlation factor*	*MAD*	*MSE*	*RMSE*	*MAPE*
Measurements	7,06	0,73					
No profile	6,21	0,62	0,26	0,94	1,40	1,18	12,87%
Continuous moisture load	7,92	0,67	0,65	0,71	0,71	0,84	9,9%
Continuous moisture load for weekdays and weekends	6,80	0,64	0,20	0,71	0,83	0,91	9,94%
Standard day profile	6,80	0,64	0,20	2,71	0,83	0,91	9,94%

Table 45 Kitchen profile overview

Profiles (Bathroom)	*Average [g/kg]*	*Standard deviation*	*Correlation factor*	*MAD*	*MSE*	*RMSE*	*MAPE*
Measurements	8,65	2,06					
No profile	5,25	0,92	0,07	3,39	16,33	4,04	36,8%
Continuous moisture load	7,56	0,81	0,07	1,55	5,86	2,42	15,44%
Continuous moisture load for weekdays and weekends	7,48	0,80	0,05	1,57	6,09	2,46	15,59%
Standard day profile	7,90	2,57	0,14	2,24	9,94	3,15	24,9%

Table 46 Bathroom profile overview

MAD – mean absolute deviation
MSE – mean square error
RMSE – root mean square error
MAPE – mean absolute percentage error

Determining a moisture profile based on activities and literature seems to be giving good results. In this case, analyzing the outcome of each particular test, or moisture profile, it can be said that the result of the simulations will always be as good as the accuracy of the moisture profile, or, as good as the accuracy of the activity log on which the moisture profile is based.

3.5.2 Location 2

Building description

A full description of the construction and systems of the modeled apartment can be found in the Measurement Campaign chapter 2.1.2.

The apartment consists of living-room (facing north), bedroom (facing south), kitchen, bathroom and a small entrance space. Measurement equipment has been placed in four main areas of the apartment in such locations, so that disturbance by direct solar radiation would be minimized (see picture below). Recorded data is the air temperature, relative humidity, and CO_2 concentration. Measurement campaign started on 09/11/2017 and was completed on 05/12/2017. During the measurement period occupancy of the apartment remained mostly unchanged, for most of the time only the two tenants were present.

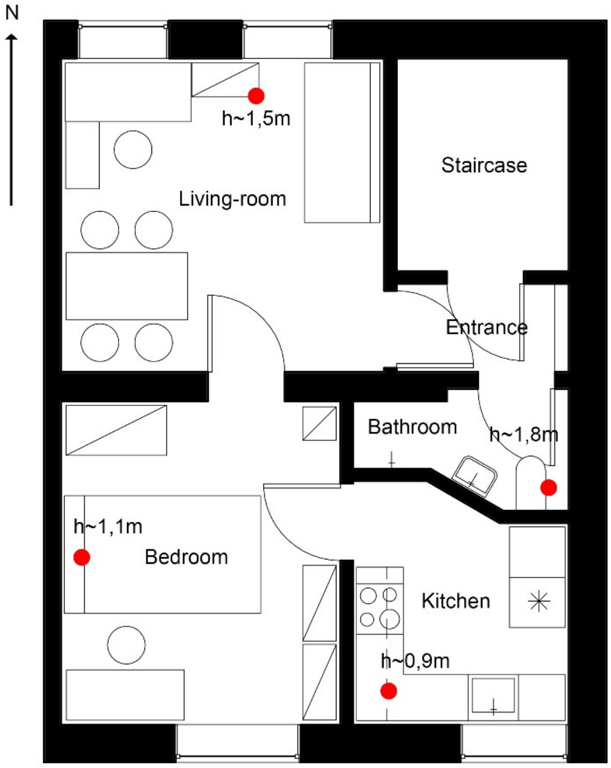


Figure 87 Placement of IC-Meters, Brammersgade 12

Model description

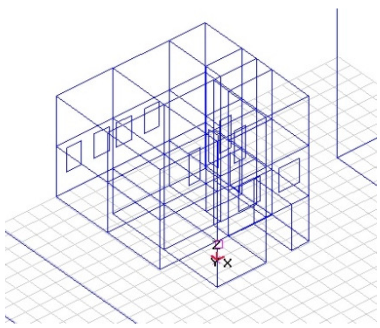


Figure 88 Vestre Ringgade 230

Only the necessary building part has been modeled in BSim – apartment itself and adjoining spaces. Basement has been modeled as a minimally heated space where the temperature does not drop below 10 °C. Neighboring apartments have been assigned same thermal and humidity properties as the modeled dwelling. Minimal simplifications have been applied to the geometry. Only a shared diagonal bathroom/kitchen wall has been changed into a straight line while dividing two rooms, so they maintain their original area and volume. Constructions have been defined based on both original and renovation drawings and specifications. All original walls (external and internal load bearing/stabilizing) have been built as a solid brick construction. Floor partitions are made as light constructions, using timber beams and insulation in between. Systems in the apartment are simple: radiator heating and natural ventilation with forced extraction in the bathroom and kitchen.

Simulations

During the measurement period, outdoor air temperature and relative humidity have been logged in two locations in Aarhus to be used for a weather file. Rest of necessary weather parameters for a comprehensive weather file have been downloaded from an online weather data archive (www.meteoblue.com). Missing data have been substituted with values from DRY 2013 data.

Next model has been validated using a number of techniques:

- Occupancy has been estimated by using activity logs.
- Forced extraction rates have been measured using ventilation cone and unidirectional anemometer.
- Infiltration/natural ventilation flow has been estimated using CO_2 measurements and dilution equation.
- Heating output has been estimated by trial and error.

No additional moisture load has been added for the validation as it should be determined later. Model validation for kitchen air temperature, CO_2 concentration, and absolute humidity can be seen below. (Validation graphs for bathroom can be found in appendix D1.)

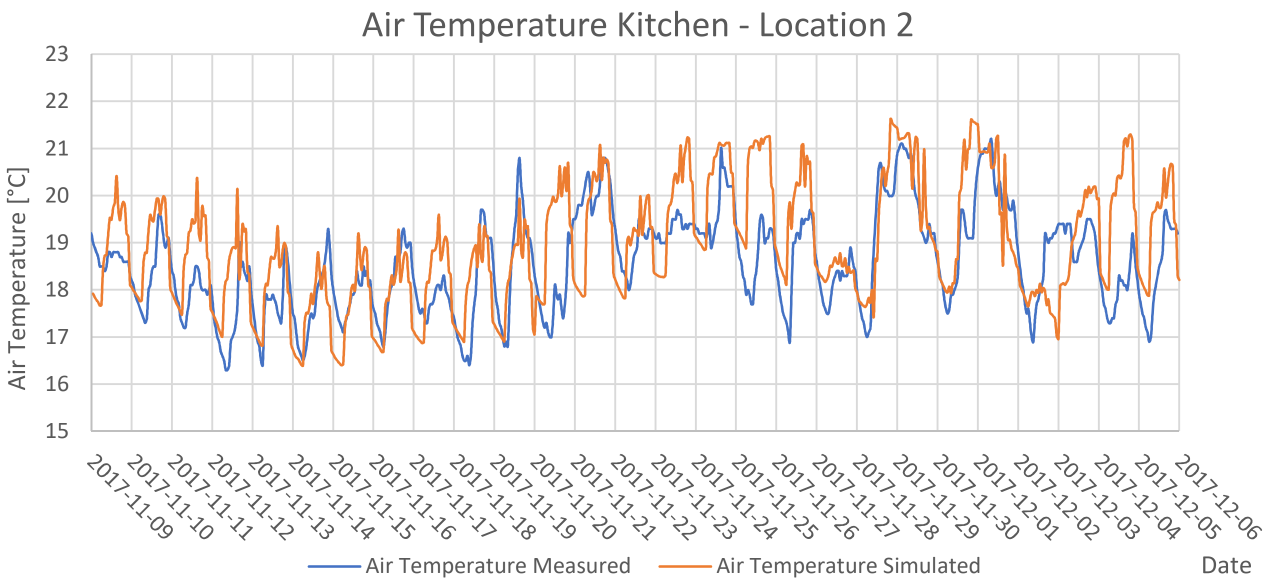


Figure 89 Validation - Air Temp. Kitchen

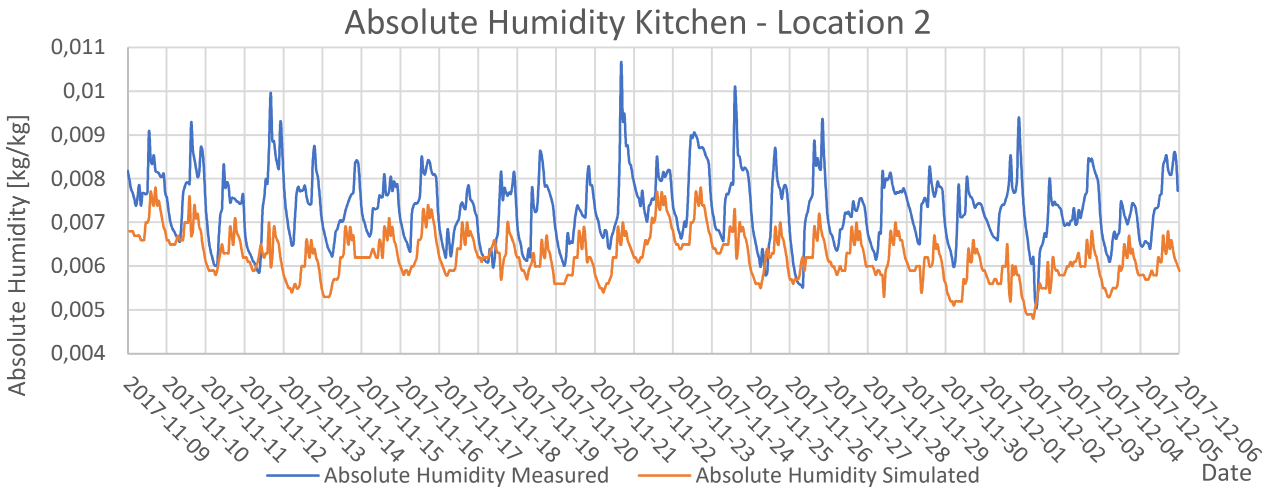


Figure 90 Validation - Absolute Humidity Kitchen

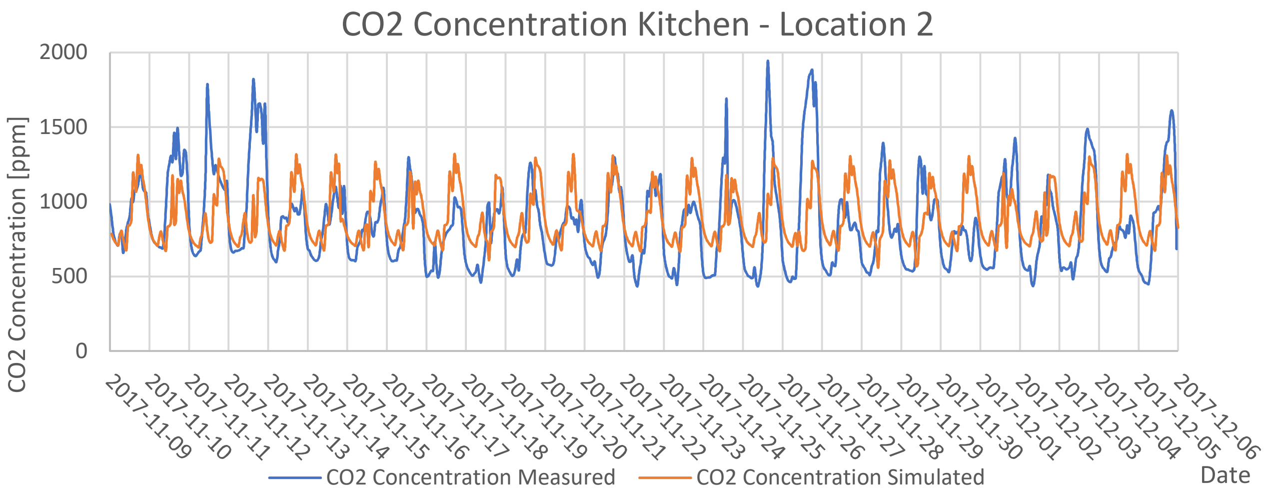


Figure 91 Validation - CO2 - Kitchen

Analysis and Procedure

The purpose of aforementioned advanced building simulation model validation is to establish correct thermal and ventilation properties of the apartment, no moisture load representing occupant activities has been included. In order to define moisture load, a detailed activity log, kept during the measurement period, has been used and individual moisture emissions estimated using literature and measurements completed previously. By combining data from different days, profiles have been generated and tested in advanced building simulation model. Iterations made if necessary. The following profiles will be investigated:

4) Continuous moisture load
5) Continuous moisture load for weekends and weekdays
6) Standard day profile

15 days have been selected and analyzed in order to determine moisture production. Example for one of the days can be seen below (analyzed data for kitchen and bathroom can be found in appendices D2 and D3 respectively).

Weekday 24/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
08:00	08:05	Breakfast	Water kettle, toasts	1	21
08:35	08:42	Breakfast	Water kettle	1	21
09:06	09:07	Washing dishes		1	16
12:13	12:19	Cooking	Brewing hot chocoloate	1	10
14:11	14:19	Washing dishes		2	47
13:57	15:25	Cooking	Frying onions, boiling pasta, cooking soup, frying meatballs, Hood on 2	2	1057
				Total [g/day]	**1172**

Table 47 Daily moisture emissions from activities

Overview of all analyzed days can be seen below.

Kitchen-Day/Date		**Total Moisture Generation [g/day]**	**Average Daily Emission [g/day]**	**Hourly Average Week/Weekend [g/h]**	**Standard Deviation**	**Standard Error**	**Total Average [g/day]**	**Total Hourly Average [g/h]**
Weekday	10/11/2017	306	**399,67**	**16,65**	**318,29**	**106,10**	**351,50**	**14,65**
	14/11/2017	256						
	16/11/2017	350						
	22/11/2017	204						
	23/11/2017	227						
	24/11/2017	1196						
	27/11/2017	155						
	29/11/2017	377						
	01/12/2017	526						
Weekend	11/11/2017	151	**303,3333**	**12,64**	**96,47**	**39,38**		
	12/11/2017	338						
	18/11/2017	382						
	19/11/2017	392						
	25/11/2017	337						
	02/12/2017	220						

Table 48 Kitchen-List of days investigated and total moisture emissions

<table>
<tr><th colspan="2">Bathroom-Day/Date</th><th>Total Moisture Generation [g/day]</th><th>Average Daily Emission [g/day]</th><th>Hourly Average Week/Weekend [g/h]</th><th>Standard Deviation</th><th>Standard Error</th><th>Total Average [g/day]</th><th>Total Hourly Average [g/h]</th></tr>
<tr><td rowspan="9">Weekday</td><td>10/11/2017</td><td>1050</td><td rowspan="9">1028,11</td><td rowspan="9">42,85</td><td rowspan="9">179,79</td><td rowspan="9">59,93</td><td rowspan="15">1050,42</td><td rowspan="15">43,77</td></tr>
<tr><td>14/11/2017</td><td>1070</td></tr>
<tr><td>16/11/2017</td><td>560</td></tr>
<tr><td>22/11/2017</td><td>1060</td></tr>
<tr><td>23/11/2017</td><td>1130</td></tr>
<tr><td>24/11/2017</td><td>1070</td></tr>
<tr><td>27/11/2017</td><td>1070</td></tr>
<tr><td>29/11/2017</td><td>1075</td></tr>
<tr><td>01/12/2017</td><td>1170</td></tr>
<tr><td rowspan="6">Weekend</td><td>11/11/2017</td><td>1085</td><td rowspan="6">1072,5</td><td rowspan="6">44,69</td><td rowspan="6">14,40</td><td rowspan="6">5,88</td></tr>
<tr><td>12/11/2017</td><td>1060</td></tr>
<tr><td>18/11/2017</td><td>1075</td></tr>
<tr><td>19/11/2017</td><td>1080</td></tr>
<tr><td>25/11/2017</td><td>1085</td></tr>
<tr><td>02/12/2017</td><td>1050</td></tr>
</table>

Table 49 Bathroom-List of days investigated and total moisture emission

Continuous Moisture Load

Based on the analysis of selected days, average moisture emissions per day can be determined and transformed into a constant moisture load in g/h.

Overview	*Mean difference in absolute humidity [g/kg]*	*Mean moisture load [g/h]*
Kitchen	1,12	14,65
Bathroom	2,54	43,77

Table 50 Continuous Moisture Load Profile

Constant moisture load values presented above have been tested in the BSim model. Since bathroom and kitchen share a wall, moisture from one room could affect the indoor air quality in the other, by being transported through the construction. Therefore, moisture profile for both rooms has been simulated simultaneously.

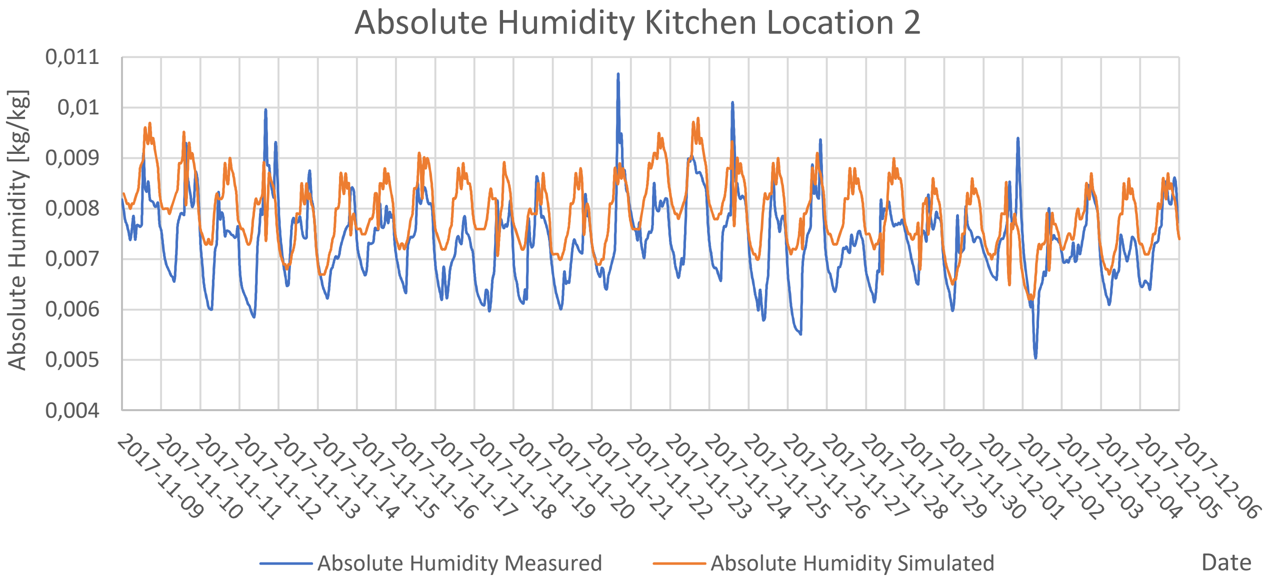


Figure 92 Kitchen Simulation - Continuous Moisture Load Profile

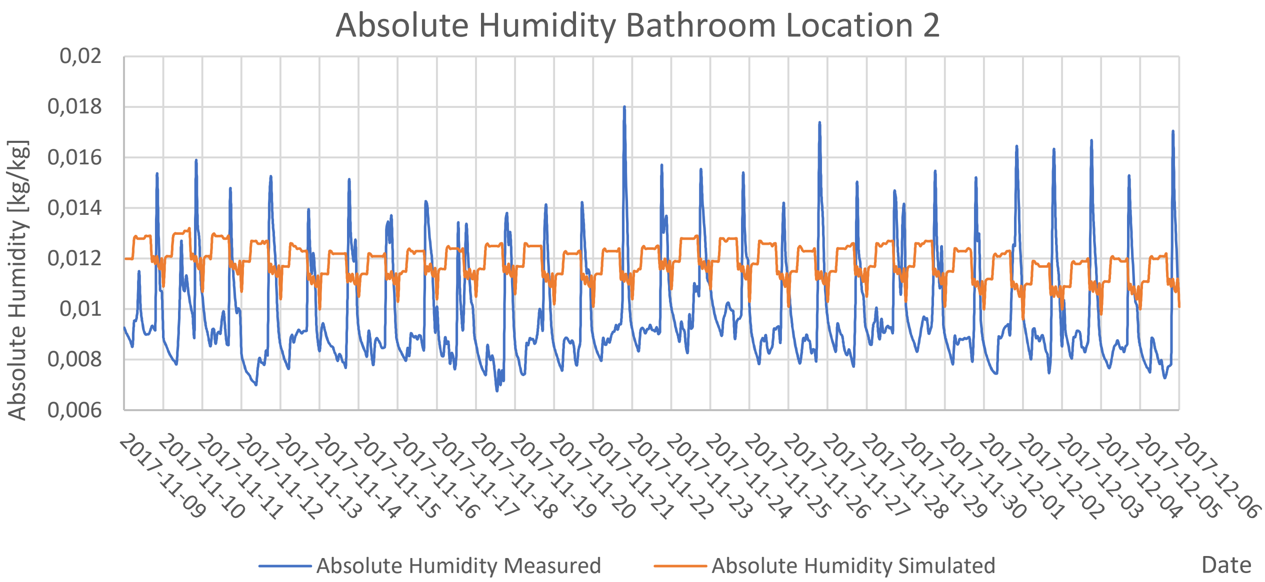


Figure 93 Bathroom Simulation - Continuous Moisture Load Profile

Constant moisture load, derived from moisture emissions based on activities, produce rather high absolute humidity values. In the kitchen were moisture load is smaller overall pattern seems to be fitting, yet average absolute humidity is somewhat higher. Bathroom, on the other hand, presents much stranger results. Average absolute humidity is way above baseline, and in most cases when peak moisture values occur (due to shower) humidity levels drop. That can be explained by active forced ventilation during the evenings.

Continuous moisture load for weekends and weekdays

All analyzed days can be split into two main groups: weekdays and weekends. Since occupancy during the weekends is higher, there is a good chance that moisture load due to activities will also be higher during the weekends. However, regarding moisture load very small difference is seen between the two. In the case of the kitchen, it is even opposite (weekend emissions are lower than weekday).

	Mean moisture load - Weekdays [g/h]	*Mean moisture load – Weekends [g/h]*
Kitchen	16,65	12,64
Bathroom	42,85	44,69

Table 51 Continuous Moisture Load Profiles for Weekdays and Weekends

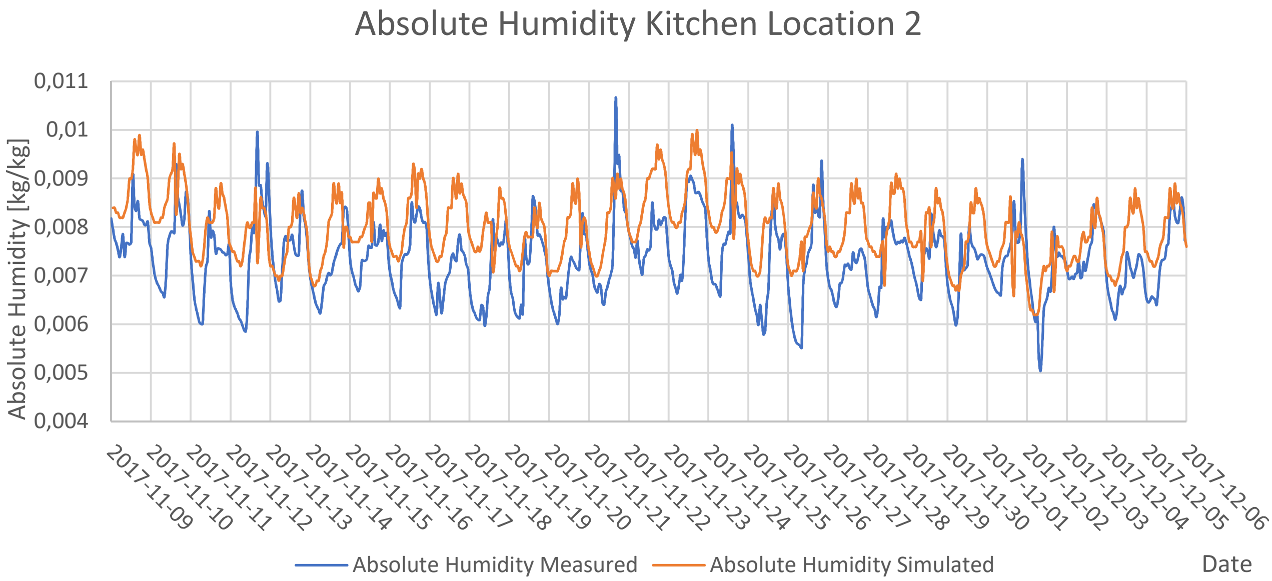


Figure 94 Simulation – Kitchen Simulation - Continuous Moisture Load Profile for Weekdays and Weekends

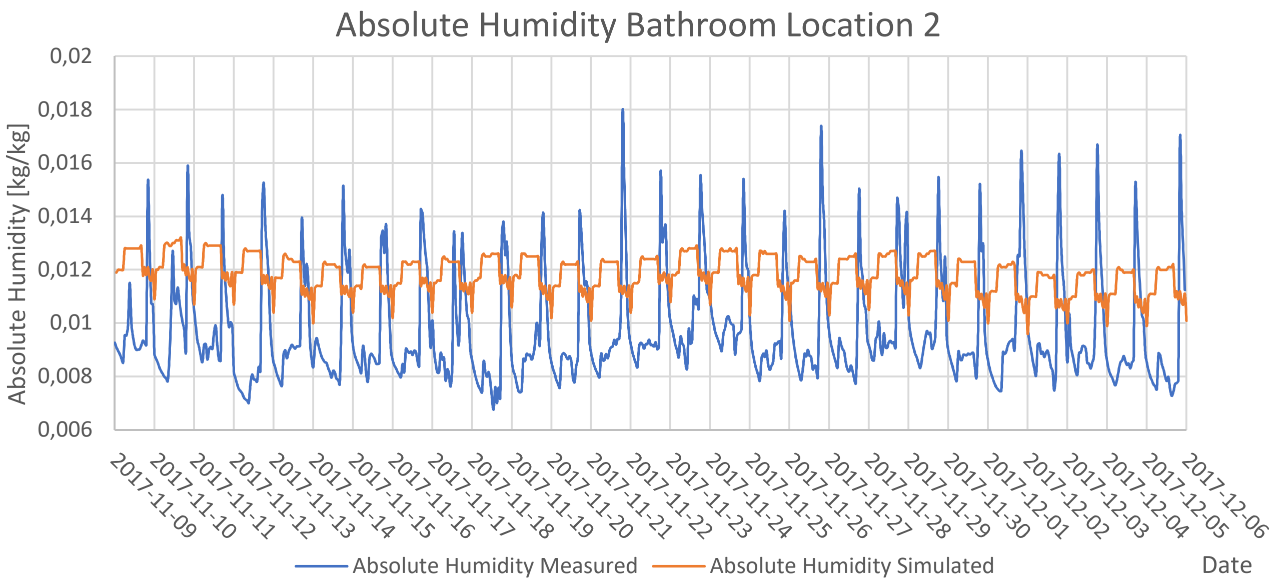


Figure 95 Bathroom Simulation - Continuous Moisture Load Profile for Weekdays and Weekends

Standard day profile

In order to form a standard day profile data from previously analyzed days has been taken and sorted into different activity categories. Then measurements are analyzed for patterns and most common times when different activities occur determined. Finally, average emissions from different activities can be spread out throughout the day to form a profile.

The activities used are presented in the following table.

Kitchen Activities	*Average Emission [g]*	*Standard deviation*	*Standard Error*
Water kettle (Breakfast)	37,8	8,69	2,24
Breakfast cooking	21,8	53,54	13,82
Washing hands	7,30	3,72	0,96
Washing dishes	70,27	30,10	7,77
Cooking	115,4	104,76	27,05
Cleaning	15,5	10,63	2,74
Water kettle	15,4	16,77	4,33
Plants (constant)	1,00		

Table 52 List of Kitchen activities

Bathroom Activities	*Average Emission [g]*	*Standard deviation*	*Standard Error*
Morning routine	21,53	3,81	0,98
Shower	911,67	169,26	43,70
Using bathroom	37,00	10,82	2,79
Cleaning	9,33	21,20	5,47
Clothes (evaporation)	34,00	37,38	9,65

Table 53 List of Bathroom activities

In order to produce more accurate daily profile additional simulations have been carried out:

- The correction factor for kitchen exhaust hood – 0,5.
- Water and condensation evaporation after a shower. (500g = 300g (1st hour) + 150g (2nd hour) + 50g (3rd hour).

Detailed results of these simulations can be found in appendices D4 and D5.

The additional correction has been made to the moisture load distribution as well. Moisture from dishwashing has been dispersed over 24 hour period to represent evaporation from wet dishes continuously present in the kitchen. Small moisture load (20g) from wet clothes washed and dried in the bathroom every evening has been added (it is based on measurements described in chapter 3.3).

Eventually, standard day profile has been developed. See the following table.

Hour	*Moisture load Kitchen [g/h]*	*Mean moisture load Bathroom [g/h]*
00	4	4
01	4	4
02	4	4
03	4	0
04	4	0
05	4	0
06	21	0
07	20	20
08	18,6	3
09	9	3
10	4	3
11	4	3
12	4	3
13	4	3
14	17	3
15	90	3
16	14	10
17	9	300
18	4	150
19	4	100
20	21	150
21	9	50
22	4	29
23	4	4

Table 54 Standard Moisture Load Profile for Kitchen and Bathroom

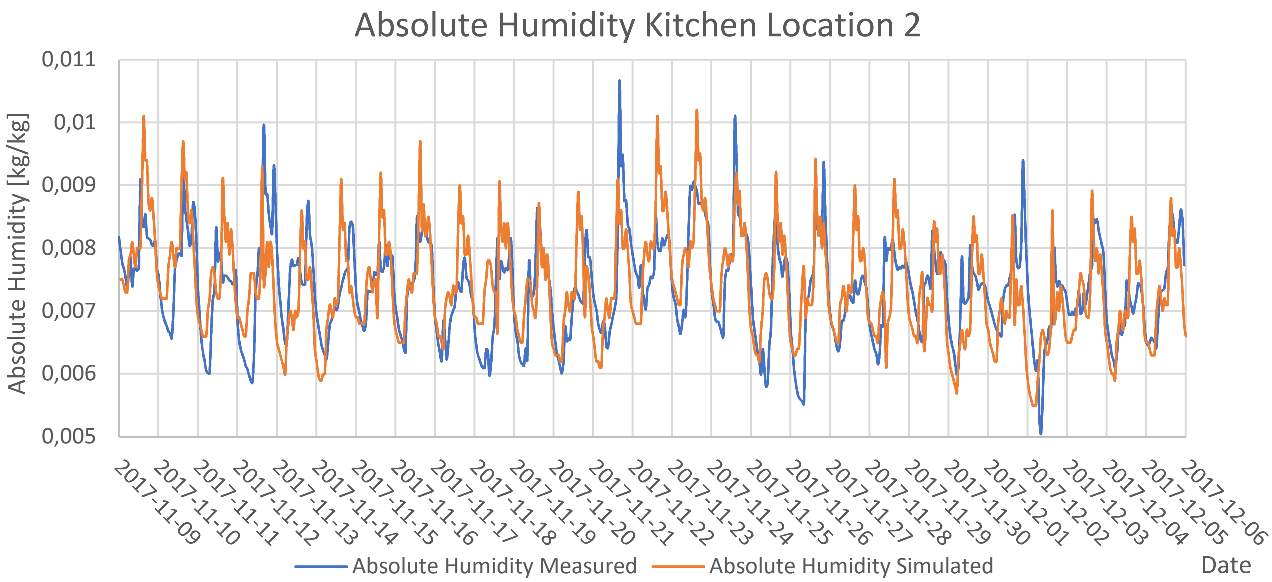


Figure 96 Kitchen Simulation - Standard Day Profile

Simulation results indicate that main peaks are approximately the same in magnitude as in the measurements. Although in the profile there is always one peak due to cooking, which is not always present in the measurements.

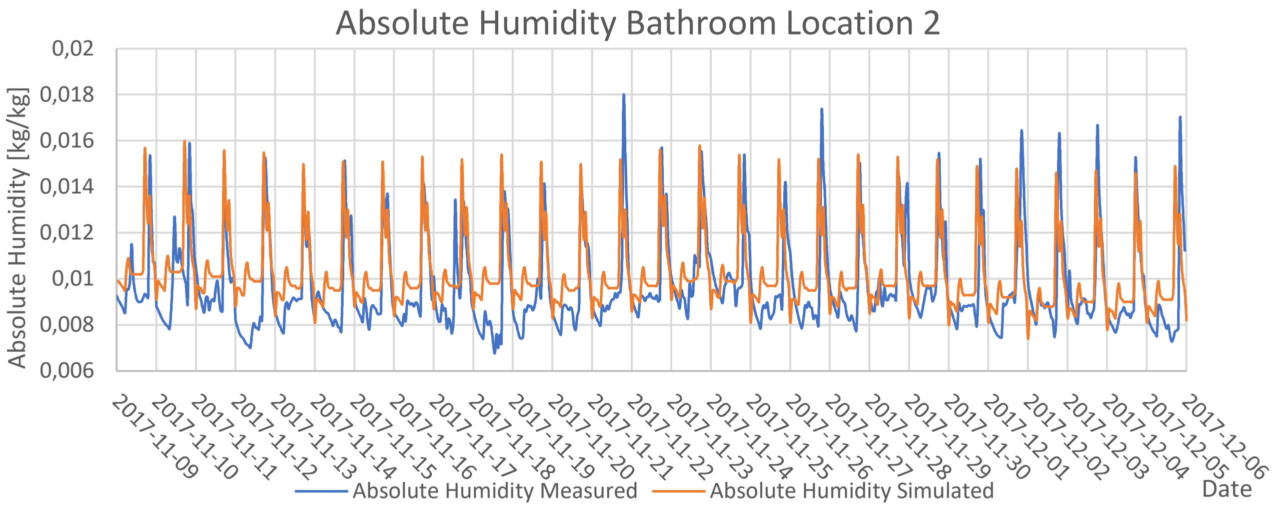


Figure 97 Bathroom Simulation - Standard Day Profile

In the bathroom, high peaks of taking a shower have been corresponding quite well. Although general humidity level is somewhat higher. Possibly because of discrepancies in airflow. During the night bathroom, doors are typically left open in order to air the space and reduce humidity level. Such explanation is supported by the data. In the graph, it is quite clear that lowest humidity values are registered in the early morning hours after the bathroom has been aired. However, in the simulated model lowest values are rarely matched, thus indicating that space is not ventilated sufficiently in the model.

Overview

Profiles (Kitchen)	*Average [g/kg]*	*Standard deviation*	*Correlation factor*	*MAD*	*MSE*	*RMSE*	*MAPE*
Measurements	7,35	2,43					
No profile	6,23	0,53	0,58	1,14	1,67	1,29	15,0%
Continuous moisture load	7,92	0,67	0,65	0,71	0,71	0,84	9,9%
Continuous moisture load for weekdays and weekends	8,00	0,70	0,65	0,77	0,82	0,90	10,9%
Standard day profile	7,39	0,81	0,62	0,54	0,48	0,70	7,3%

Table 55 Kitchen profile overview

Profiles (Bathroom)	*Average [g/kg]*	*Standard deviation*	*Correlation factor*	*MAD*	*MSE*	*RMSE*	*MAPE*
Measurements	9,66	1,95					
No profile	7,11	0,34	0,27	2,55	10,01	3,16	24,1%
Continuous moisture load	11,83	0,68	-0,31	2,87	9,79	3,13	31,9%
Continuous moisture load for weekdays and weekends	11,82	0,67	-0,31	2,87	9,76	3,12	38,9%
Standard day profile	10,22	1,57	0,60	1,21	2,89	1,70	12,9%

Table 56 Bathroom profile overview

MAD – mean absolute deviation MSE – mean square error
RMSE – root mean square error MAPE – mean absolute percentage error

In this particular case, when activities are used to determine moisture profile it is self-evident that constant moisture load is least accurate of all. It produces much higher values than necessary and in the case of the bathroom even a negative correlation. If constant moisture load is the goal, then approach used in chapters 3.4.3 of establishing model response would be more precise.
On the other hand, daily profile based on individual activity measurements and daily logs has been proven to be a much more accurate way of deriving a detail moisture profile, designed to replicate the peaks.

Weekly graphs illustrating different tested moisture loads can be found in digital appendix 2F.

3.5.3 Location 3

Building description

The full description of the building, the apartment investigated plus its systems can be found under Measurement Campaign chapter 2.1.3.
The apartment has windows situated on both sides of the block, Kitchen and Bedroom have a North-Vest orientation respectively South-East for the Living-Room. The measurement equipment installed was verified for solar disturbances and placed as indicated on the plan beneath. There is a sensor in each room except the hallway. The data recorded is the air temperature, relative humidity, and the Co2 concentrations. During the measurement campaign period from 11/11/2017 to 05/12/2017, the occupancy of the apartment was changing due to people visiting. In normal conditions, there are 2 persons living in this apartment. See table in measurement campaign chapter 2.1.3 for occupancy schedule.

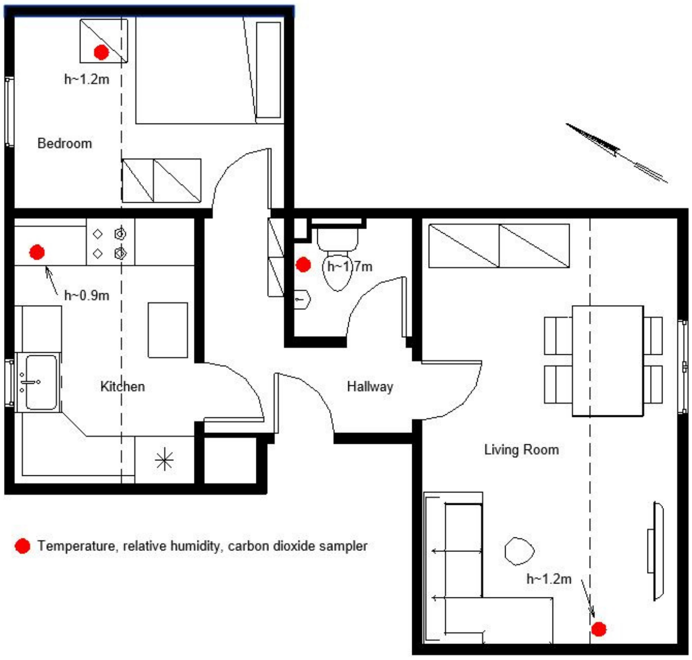


Figure 98 Placement of IC-Meters, Vestre Ringgade 230

Model description

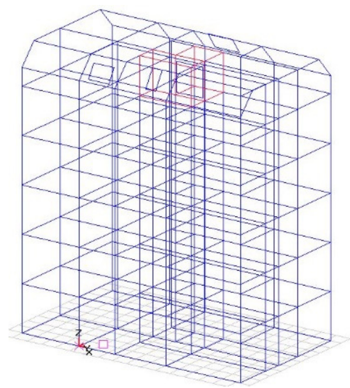


Figure 99 Vestre Ringgade 230

The block was recreated in BSim, but only to some extent, the length of the block was reduced to the apartment size plus rooms from the neighboring apartments to avoid having direct contact of walls with outdoor, thus improving the simulation outcome. The original building height is preserved, and the apartment is placed in the mansard. Hence the shape is similar to the original apartment. The layout of the apartment is kept, the only difference is in the hallway, an opening is inserted due to the L-shaped hallway. The constructions are made based on-site investigations performed, together with information from the original plans and descriptions. The external walls are full brick constructions with no cavity, while the roof/mansard is a light construction with a slight amount of insulation.

Simulations

Simulations are made using weather data with real outdoor conditions, which were recorded during the measurement campaign to improve the simulations. Each room is placed into a thermal zone based on different conditions during the day, activities, occupancy, etc.
The systems are recreated in each room; however, the heating output is not known and will be made as a trial and error while the infiltrations will be assumed by using the dilution equation, in a room based, bedroom in this case, on the Co2 level decrease curve when the room is empty.
Further, model validation graphs from one room, in this case, kitchen, is presented. Validation of the model is made without moisture load as it can be seen in the absolute humidity graph, the measured values are higher than simulations.

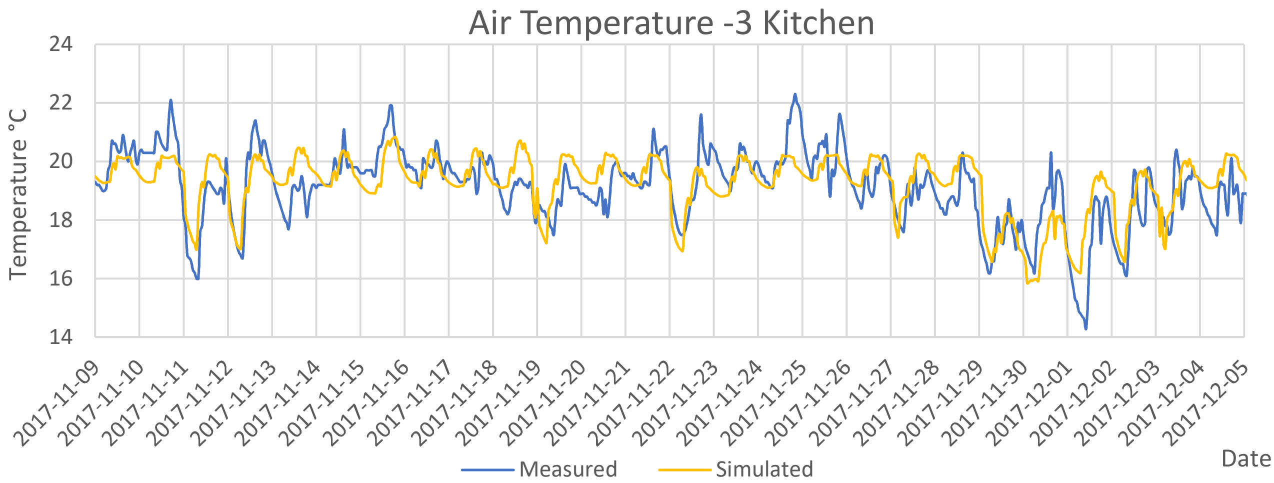


Figure 100 Validation - Air Temp. Kitchen

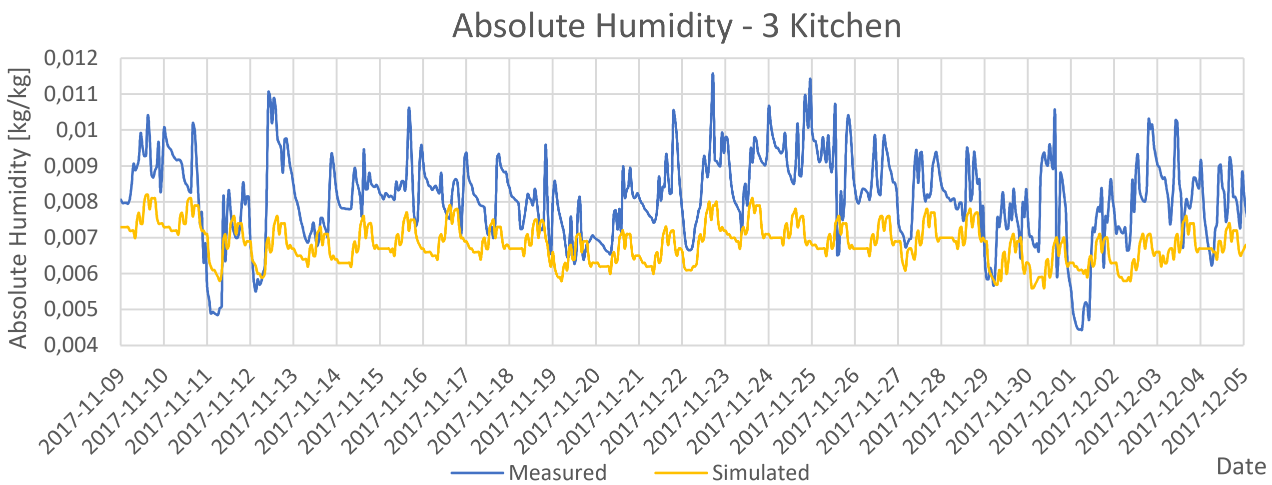


Figure 101 Measured vs. Baseline of simulation - Absolute Humidity Kitchen

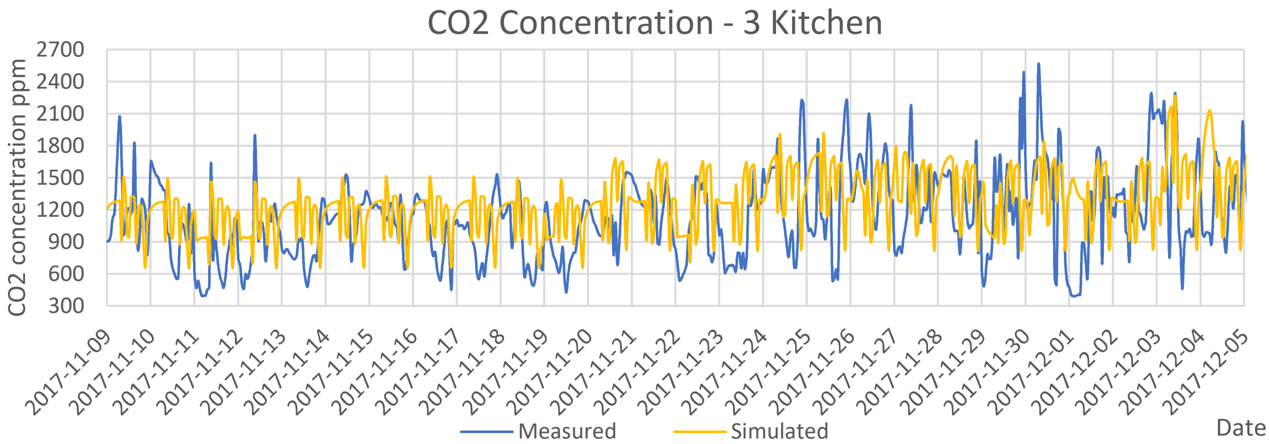


Figure 102 Validation - CO2 - Kitchen

Analysis and Procedure

The approach used for defining moisture load is based on detailed activity journal kept during the measurement campaign. The moisture emissions are estimated using results from experiments made, as well as activities documented by literature.

First, the apartment is reproduced in BSim and validated with no moisture load which will serve as a baseline. Further, the moisture profiles made will be tested through simulations and compared with the measured absolute humidity. There will be several profiles made, such as:

7) Continuous moisture load
8) Continuous moisture load for weekends and weekdays
9) Standard day profile

Further, a cataloged daily schedule with moisture emission is presented, the rest of the analyzed days can be found in appendix E2.

Weekday 14/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
09.28		Washing Hands		2	10,00			10,00
09.29	09.42	Breakfast		2	71,00	23,83		94,83
09.40	09.47	Washing Dishes		2	50,00	9,17	6,00	56,00
09.54	10.00	Coffee Filter		2	10,00			10,00
14.03		Washing Hands		1	5,00			5,00
14.04	15.01	Cooking	Stew + Boiling Potatoes	1	1026,00	52,25		1078,25
14.37	14.41	Washing Dishes		1	50,00		6,00	56,00
14.44		Washing Hands		2	10,00			10,00
14.45	15.25	Eating		2	158,00	73,33		231,33
15.25		Washing Hands		2	10,00			10,00
17.30	17.37	Washing Dishes		1	50,00	6,42	6,00	62,42
							Total [g/day]	**1623,83**

Table 57 Daily moisture emissions from activities

Continuous Moisture Load

In this case, representative days will be chosen based on observation and repetition in the activity journal. Each activity will have the moisture emission documented, and a total daily moisture emission will be made.

Further, an hourly average is extracted by averaging the daily cumulative moisture load in each investigated room from all accounted days.

Overview	*Mean difference in absolute humidity [g/kg]*	*Mean moisture load [g/h]*
Kitchen	1,49	61,54
Bathroom	3,94	55,10

Table 58 Continuous Moisture Load Profile

The values found for continuous moisture load was 61,54 g/h for the kitchen and 55,10 g/h for the bathroom. In BSim schedules with moisture, load was made for both rooms and simulated. Following graphs represent the moisture load after simulations.

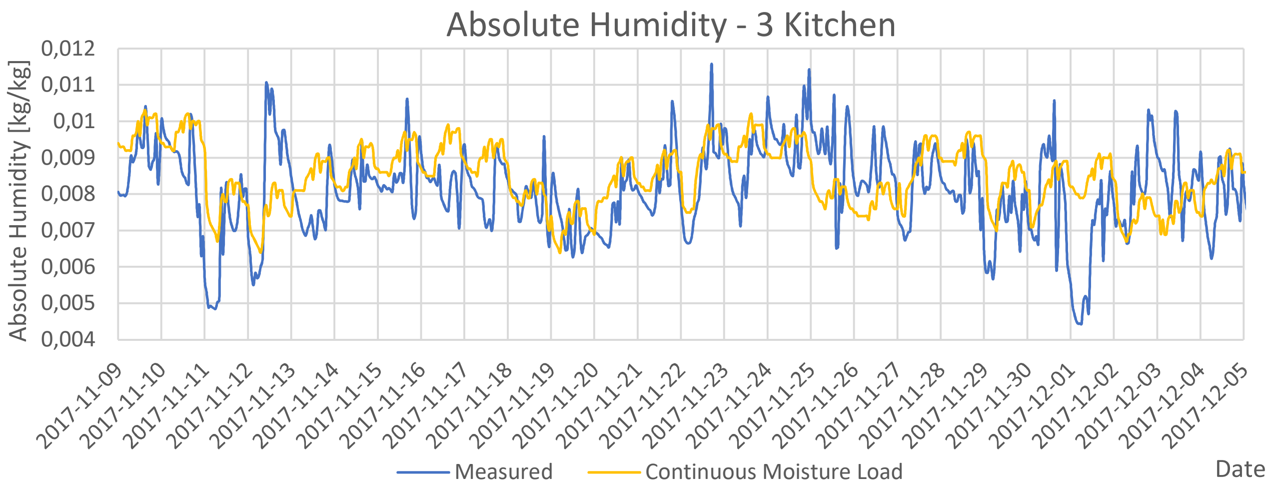


Figure 103 Kitchen Simulation - Continuous Moisture Load Profile

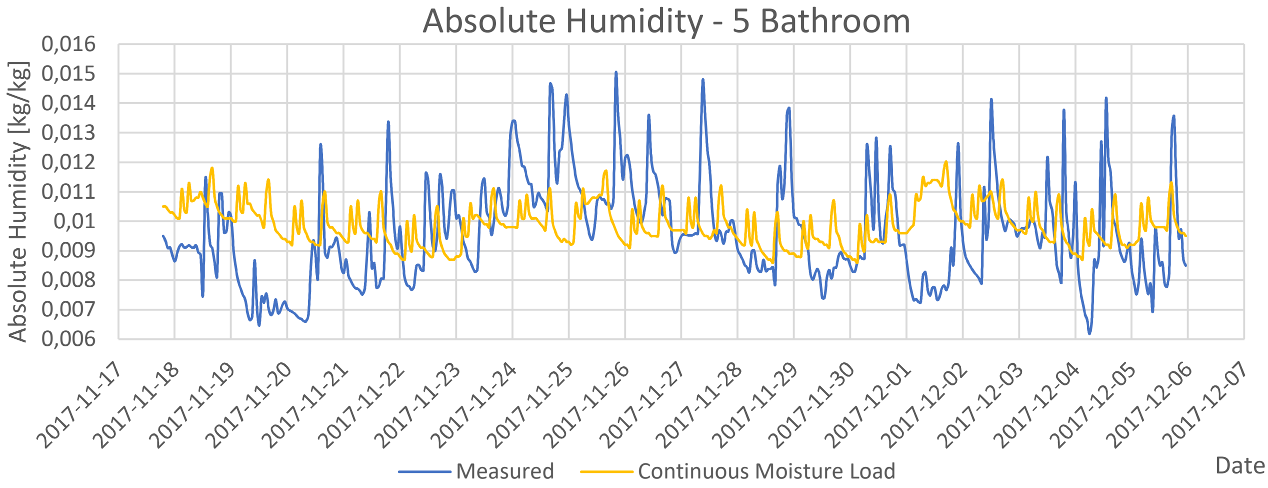


Figure 104 Bathroom Simulation - Continuous Moisture Load Profile

The same condition was maintained in the simulation, similar to/same as in the validation, the only difference being the new moisture load from the profile found. The overall simulated absolute humidity increased and tends to follow the pattern of the measured values. It appears to be somewhere in the middle of the measured absolute humidity.

Continuous moisture load for weekends and weekdays

Similar to continuous moisture load profile, but in this case, representative days during the week and weekends are chosen, and a total moisture emission is found. Schedules will be made in the simulation software where hourly averages of the two types of days will be inserted.
The following tables present the investigated days from the activity journal and the total moisture emissions during 24h.

<table>
<tr><th colspan="2">Kitchen-Day/Date</th><th>Total Moisture Generation [g/day]</th><th>Average Daily Emission [g]</th><th>Hourly Average Week/Weekend [g]</th><th>Standard Deviation</th><th>Standard Error</th><th>Total Average [g/day]</th><th>Total Hourly Average [g/day]</th></tr>
<tr><td rowspan="8">Weekday</td><td>13/11/2017</td><td>391,42</td><td rowspan="8">1320,69</td><td rowspan="8">55,03</td><td rowspan="8">821,32</td><td rowspan="8">290,38</td><td rowspan="12">1476,94</td><td rowspan="12">61,54</td></tr>
<tr><td>14/11/2017</td><td>1623,83</td></tr>
<tr><td>15/11/2017</td><td>1218,9</td></tr>
<tr><td>16/11/2017</td><td>2630,50</td></tr>
<tr><td>20/11/2017</td><td>697,6</td></tr>
<tr><td>23/11/2017</td><td>788,3</td></tr>
<tr><td>24/11/2017</td><td>2383,49</td></tr>
<tr><td>27/11/2017</td><td>831,42</td></tr>
<tr><td rowspan="4">Weekend</td><td>12/11/2017</td><td>1733,5</td><td rowspan="4">1633,19</td><td rowspan="4">68,05</td><td rowspan="4">1067,87</td><td rowspan="4">533,93</td></tr>
<tr><td>19/11/2017</td><td>672,98</td></tr>
<tr><td>25/11/2017</td><td>1033,8</td></tr>
<tr><td>02/12/2017</td><td>3092,5</td></tr>
</table>

Table 59 Kitchen-List of days investigated and total moisture emission

Bathroom - Day/Date		Total Moisture Generation [g/day]	Average Daily Emission [g]	Hourly Average Week/Weekend [g]	Standard Deviation	Standard Error	Total Average [g/day]	Total Hourly Average [g/day]
Weekday	09/11/2017	1069,33	**1559,1**	**64,96**	**585,63**	**239,08**	**1322,33**	**55,10**
	20/11/2017	1873,58						
	21/11/2017	1555,5						
	23/11/2017	776,28						
	27/11/2017	2427,8						
	30/11/2017	1652,4						
Weekend	18/11/2017	1413,3	**1085,5**	**45,23**	**631,56**	**257,83**		
	19/11/2017	479,57						
	25/11/2017	1048,2						
	26/11/2017	426,3						
	03/12/2017	2124,55						
	04/12/2017	1021,28						

Table 60 Bathroom-List of days investigated and total moisture emission

Based on these values a profile was deducted for days during the week time as well as weekends. The following table presents the result of the profiles for both rooms.
Overview of results:

	Mean moisture load - Weekdays [g/h]	*Mean moisture load – Weekends [g/h]*
Kitchen	55,03	68,05
Bathroom	64,96	45,23

Table 61 Continuous Moisture Load Profiles for Weekdays and Weekends

The same simulation principle was applied, schedules for both rooms was made, in this case for two types of days. The simulation outcome is not much different from the constant load profile for the whole period. As a comparison, all the loads tested range from 55,03 g/h as the smallest load and up to 68,05 g/h as the highest, since there is no significant variation, it is expected to have a similar outcome.

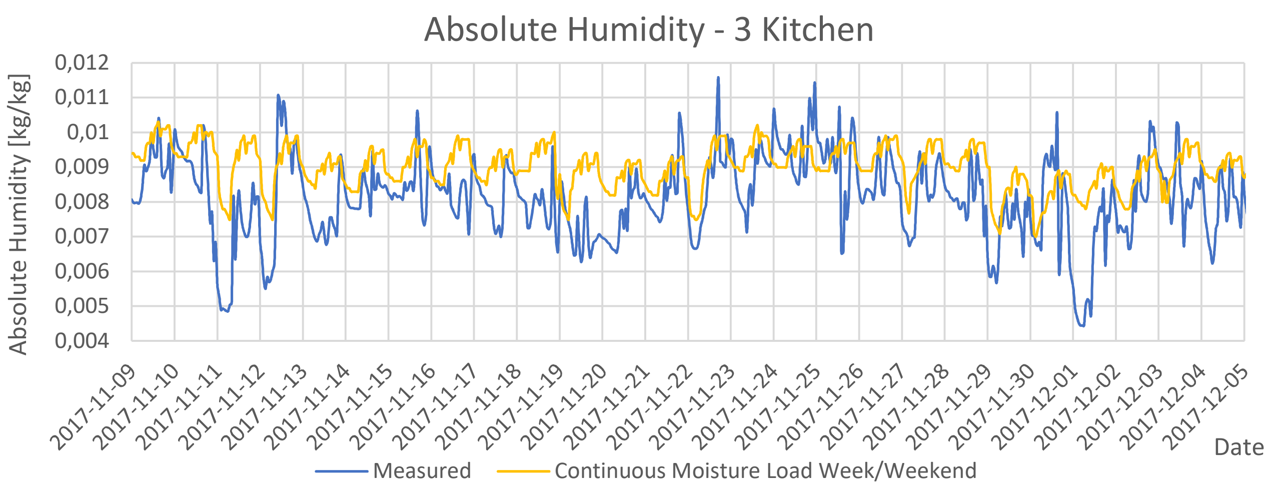


Figure 105 Simulation – Kitchen Simulation - Continuous Moisture Load Profile for Weekdays and Weekends

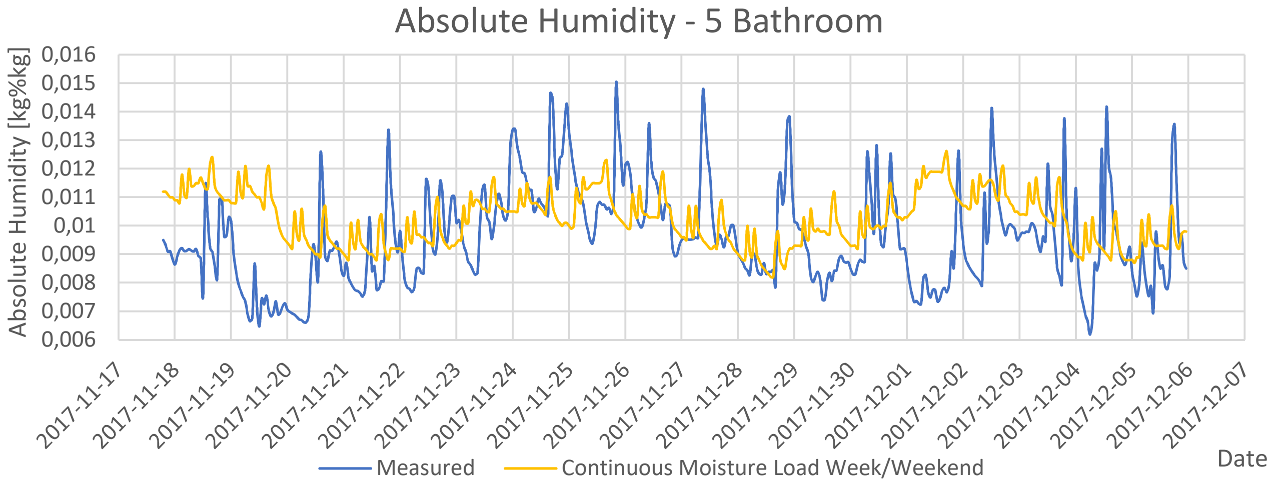


Figure 106 Bathroom Simulation - Continuous Moisture Load Profile for Weekdays and Weekends

Standard day profile

The concept of making this type of profile is based on average moisture emission from each specific activity type, from all the days investigated. The moisture load emissions are spread throughout the day as hourly averages, based on most common activity repetition at a certain hour, that could be noticed.
The activities used are presented in the following table.

Kitchen Activities	*Average Emission [g]*	*Standard deviation*	*Standard Error*
Coffee	12,06	2,41	1,21
Kettle	22,43	-	-
Breakfast	71	-	-
Cooking	377,97	472,21	79,82
Eating	122,04	66,54	23,53
Washing Hands	24,58	23,66	3,84
Washing Dishes	59,73	23,66	3,84
Warming up Food	44,77	17,49	7,82

Table 62 List of Kitchen activities

The morning and evening routine from the bathroom activities are in fact the daily hygiene moisture emission values that could be found in the literature. It refers to personal hygiene such as hand washing, toothbrushing. (Anne pia Koch, 1987)
Since it was not possible to keep such a detailed journal that could indicate when handwashing occurred, the daily moisture emission was scattered throughout the day.

Bathroom Activities	*Average Emission [g]*	*Standard deviation*	*Standard Error*
Morning routine	98,53	49,30	12,73
Shower	424,08	164,62	30,06
Evening Routine	114,46	31,56	8,43

Table 63 List of Bathroom activities

Based on the moisture emissions and the repetition of the different activities, a detailed hourly moisture profile was developed. See table underneath.

Hour	Moisture load Kitchen [g/h]	Mean moisture load Bathroom [g/h]
00	0	0
01	0	0
02	0	0
03	0	0
04	0	0
05	0	0
06	0	0
07	0	0
08	42,68	0
09	194,04	32,84
10	59,73	0
11	0	0
12	0	0
13	197,17	32,84
14	188,98	32,84
15	182,77	0
16	0	38,15
17	197,17	38,15
18	188,98	0
19	182,77	0
20	0	0
21	0	250
22	0	174,08
23	0	38,15

Table 64 Standard Moisture Load Profile for Kitchen and Bathroom

These specific profiles were inserted in the simulation software, and the results are:

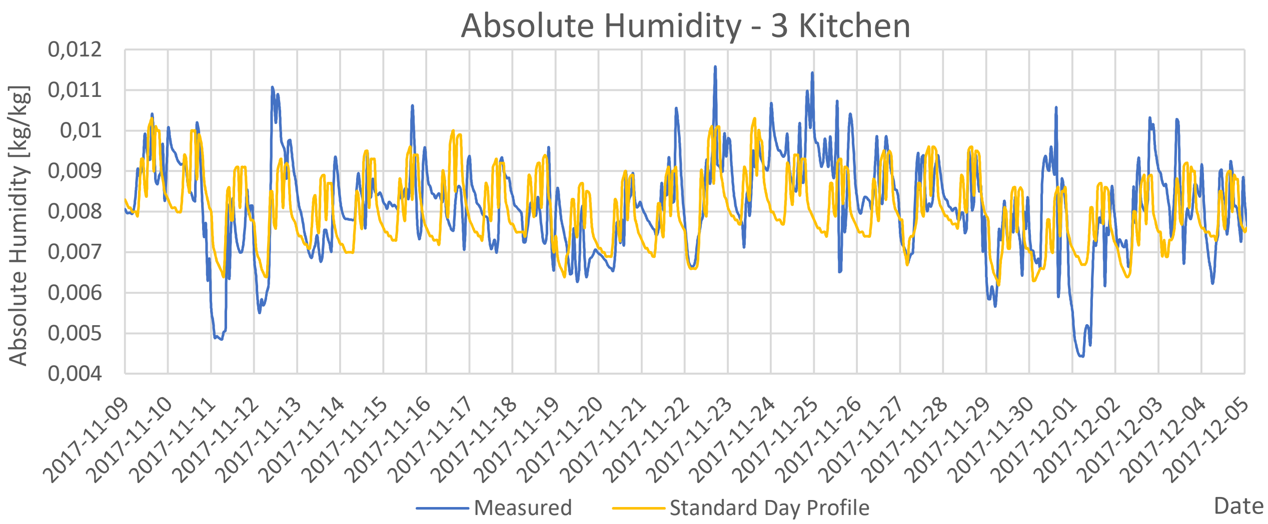


Figure 107 Kitchen Simulation - Standard Day Profile

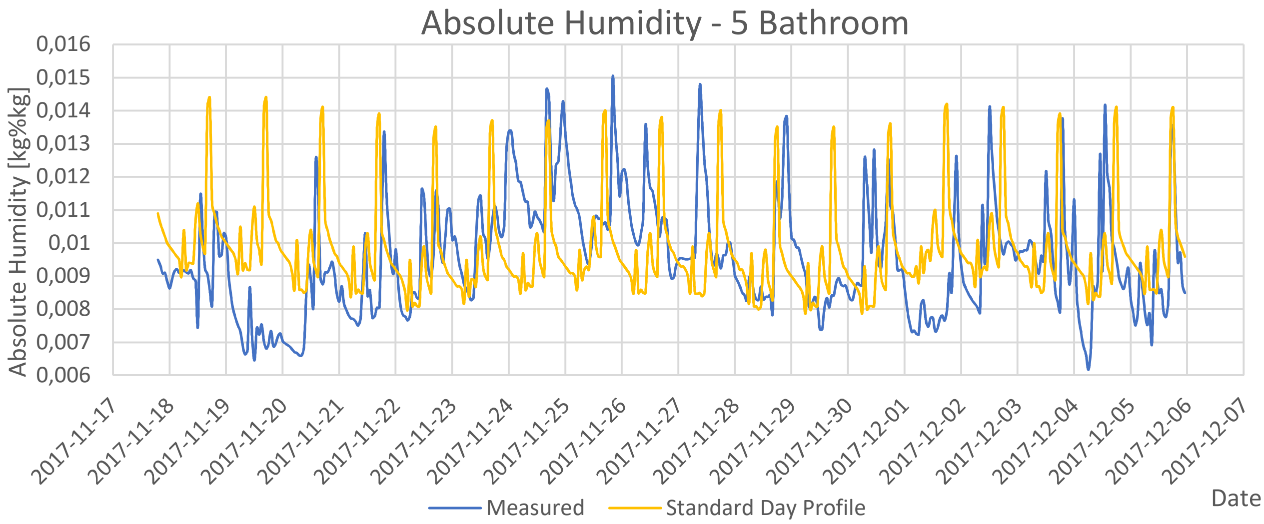


Figure 108 Bathroom Simulation - Standard Day Profile

As it can be seen in the kitchen simulations, a significant number of measured peaks correspond with the moisture profile inserted. In general, the patterns look similar which indicates a good correlation with the moisture production from different activities.

The bathroom standard daily profile has the same height in peaks. This proves the moisture load to be sufficient during the high-water usage. The daily bathroom schedule is very random, hence the peaks that take place at a different time almost every day.

Overview

Further, an overview of all the humidity profiles is presented.

Profiles (Kitchen)	*Average [g/kg]*	*Standard deviation*	*Correlation factor*	*MAD*	*MSE*	*RMSE*	*MAPE*
Measurements	8,10	1,18					
Continuous moisture load	8,52	0,84	0,37	0,99	1,54	1,24	13,1%
Continuous moisture load for weekdays and weekends	9,02	0,62	0,51	1,11	1,87	1,37	15,3%
Standard day profile	8,07	0,89	0,41	0,92	1,31	1,14	11,8%

Table 65 Overview of kitchen profile results (Location 3)

Profiles (Bathroom)	*Average [g/kg]*	*Standard deviation*	*Correlation factor*	*MAD*	*MSE*	*RMSE*	*MAPE*
Measurements	9,54	1,71					
Continuous moisture load	9,87	0,70	-0,09	1,53	3,76	1,94	16,7%
Continuous moisture load for weekdays and weekends	10,21	0,93	0,02	1,59	4,17	2,04	17,8%
Standard day profile	9,75	1,37	0,09	1,56	4,40	2,09	16,8%

Table 66 Overview of Bathroom profile results (Location 3)

MAD – mean absolute deviationMSE – mean square error
RMSE – root mean square error MAPE – mean absolute percentage error

Looking at the average values, the profiles are quite similar, based on the activity journals it was possible to disperse the moisture production and get standard day profiles that simulate quite well the real conditions. In this case, the standard day profile was closer to the measured values.

3.6 Conclusion

Indoor moisture production profiles have been determined using two different methods, by deriving them from measurements using advanced building simulation software or developed based on a detailed activity journal and literature based moisture emissions.

Komfort Hus

The profiles extracted using the advanced building simulation tool do not significantly vary from one profile to another within the same house. For example, in Stenagervænget 49 the difference between the continues load and weekday/weekend profile in the kitchen varies with by only 6%, Stenagervænget 12 has a difference of 13,7% while Stenagervænget 45 it is below 1%. This indicates that there is no substantial difference in moisture production between weekends and weekdays, (due to a different schedule and occupancy). Hence the continuous moisture load profile is a good estimation if peak accuracy can be disregarded.

When comparing developed humidity profiles, between different analyzed houses, a higher discrepancy has been discovered. The difference in moisture emission is up to 70%, when looking at constant hourly load, even though the number of occupants is similar (No. 45 vs. No. 49). This emphasizes that the moisture production can be rather different due to activities/patterns and less by the number of inhabitants. However, to have a better overview of this matter, constant moisture emission values have been normalized over the room area (see table below). A general occupancy profile is also listed. In this way, the results can be easily compared.

Continuous moisture load g/h/m^2

	Komfort Hus (mechanical ventilation)			Apartments (natural ventilation)		
Place	Nr.12	Nr.45	Nr.49	Location 1	Location 2	Location 3
Bathroom	7,1	3,8	15,3	15,2	15,5	22,0
Kitchen	1,4	0,8	12,9	2,6	2,2	9,5
Occupancy	(2adults - 1child)	(2adults - 2 teenagers)	(2adults - 2 teenagers)	(3 adults)	(2 adults)	(2 adults + visitors)

Table 67 Comparison of constant moisture load profiles

Apartments

The method of calculating continuous moisture load from daily moisture production values gives rather close results for bathroom usage (except in the case of location 2). The difference in between the apartments is moisture load variation is 31%.
Surprisingly, even though Location 1 has 3 occupants, Location 3 still has a larger moisture production. This again, proves that the occupant's habits are more likely to influence the results and not the variations in the occupancy. Moreover, simulating with such a profile is not very accurate if peak hours are needed.

Continuous moisture profile used in different apartments is quite similar, which could suggest that the 24-hourly mean moisture generation rate was defined quite well-using schedules and individual activity moisture emissions. On the other hand, the kitchen emissions fluctuate more, and this entirely depends on the cooking activities as well on the forced extraction usage.

The individual standard day schedule, constrained to each apartment, seems to satisfy the peak magnitude and repetition best, it correlates well with measurements in the bathroom as much as it does in the kitchen. This further concludes that this type of moisture profile is accurate enough to be used in simulations were peak loads are essential. However, further investigations are needed in order to transpose it into a more general profile.

Another important parameter to be considered is ventilation type. Investigated houses are mechanically ventilated, and the apartments have natural ventilation, with extraction in kitchen and bathroom. Data from previously reviewed table suggests that general tendency of lower humidity levels in mechanically ventilated spaces exist.

Based on analyzed material, a general profile that could fit both types of buildings is not therefore possible due to widely varying occupant habits. However, the findings can serve as a baseline from where a specific type of profiles could be derived, for different household types.

4. Particle Concentration

4.1 Background Information

Presence of particulate matter in the indoor air is diverse in composition, based on emissions from different activities, building materials and other indoor sources (e.g. pets, plants etc.), as well as infiltration of particles created by natural outdoor or anthropogenic outdoor sources. There is a wide range of particle sizes found inside a dwelling, from molecular clusters of a few nm to particles with diameters larger than 10 µm, this being a corresponding difference in diameter of 3000 x. (Nazaroff, 2004).

Particles in the atmospheric environment are considered a major pollutant source with a substantial potential for health hazards. In that case particles are not to be neglected.

As there is a wide range of particles, a classification was required; therefore: particles are classified by size (coarse, fine and ultra-fine particles), by their source and by their properties.

Particles inside our apartments can either be transported from the outdoor environment, through open windows, doors or any cracks, or, they can be generated indoor, by different activities; therefore, it is extremely important to understand the source and behavior of particles, to be able to "control" them. Understanding how different activities create a negative effect on people's health, as well as on the environment, constitutes another extremely important part of this topic.

4.2 Method of Investigation

Investigation procedure is based on the performed measurements, together with detailed activity journals from each measurement site, considering that they serve as a starting point. The data is transposed into detailed daily charts to illustrate particle variations and peaks. All activities that leave a mark over the particle concentration pattern are then analyzed and most problematic cases further investigated.

For each location, there will be a number of aspects investigated that are targeted from various activities. The idea is to find the main source and the most common, of particle emission in the indoor environment that correlates with human behavior/activities. This will give a good insight over the level pollution in typical apartments in Denmark. Moreover, the neighboring rooms will be checked in case that pollutant has spreading capabilities.

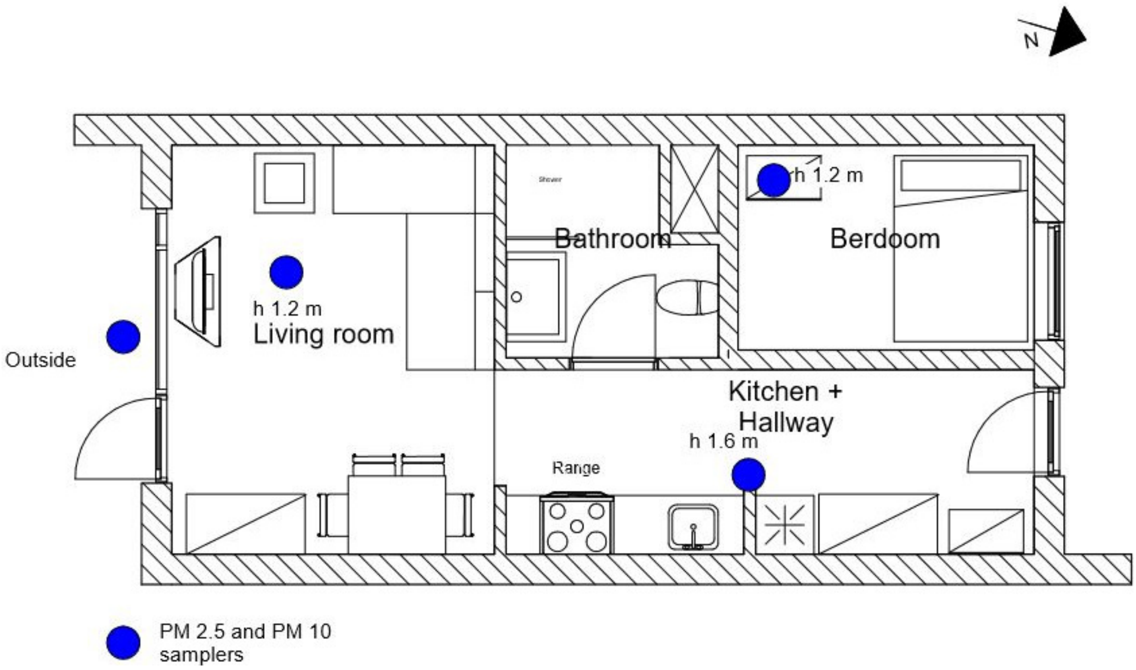
The selected activities will be discussed in detail and determine what is the human exposure risk and how could this be avoided or improved. Even more, determination of possible ways of further controlling the pollutants will be made.

Last but not least, having IAQ parameters recorded on the side of particle concentration gives the possibility to check for correlation. If such will be found, it could help determine ways of improving the overall indoor environment.

4.3 Measurement analysis

4.3.1 Location 1 - apartment description

This apartment has been previously described in detail and can be found under Measurement Campaign chapter 2.1.1.
It is situated on the ground floor of a two storeys high apartment bloc in Århus. The apartment is naturally ventilated with forced extraction in the bathroom and kitchen. As for the heating system, radiators are used to heat up the apartment.
The measurement campaign started on the 11th od November 2017 and ended on the 5th of December 2017. During this period of time, particle sensors were placed in the living room, kitchen and bedroom. No sensors were placed in the bathroom, due to the risk of high level of humidity. See the following plan



	**Hallway & Kitchen** Surfaces: Floor - Wooden Parquet Walls – Wall Paper + White Paint Ceiling – Plaster + White Paint
	**Bedroom** Surfaces: Floor - Wooden Parquet + Small Carpet Walls - Wall Paper + White Paint Ceiling - Plaster + White Paint
	**Living-Room** Surfaces: Floor - Wooden Parquet + Small and Big Carpet Walls - Wall Paper + White Paint Ceiling - Plaster + White Paint
	**Bathroom** Surfaces: Floor – Tiles Walls - Plaster + White Paint Moisture Resistant Ceiling - Plaster + White Paint Moisture Resistance

Air quality guidelines for PM 2.5 and PM 10, from the World Health Organization, were used to display the level of particle pollution in typical apartment buildings in Denmark.

Particulate matter guidelines	
PM 2.5:	10 µg/m3 annual mean
	25 µg/m3 24-hour mean
PM 10:	20 µg/m3 annual mean
	50 µg/m3 24-hour mean

Table 68 World health organization guidelines for particle concentration (World Health Organization, 2005)

Due to the relatively short size of the measurement campaign, the 24-hour mean guidelines were used.

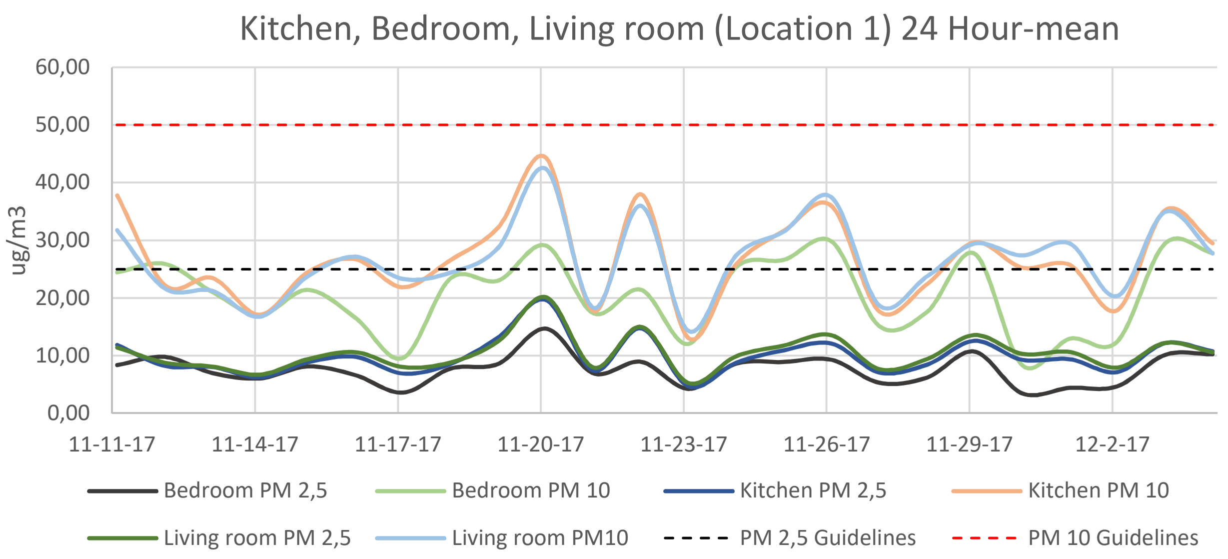


Figure 109 24-Hour mean of measurements done at Location 1

The levels of PM 2.5 and PM 10 seem to be well below the recommended values for the 24-hour mean, giving a clear synopsis of the level of particle concentration in typical apartment buildings in Denmark. As expected, a slight difference in particle concentration between different rooms can be observed; the bedroom, in some parts, has a lower level of both PM 2.5 and PM 10. That is directly related to the outline of the apartment and to the activities that take place in each of the rooms.

Many activities or events, taking place inside any apartment, are seen as sources of particles. In order to keep track of different activities that took place during the measurement campaign, a daily activity log was created.
The activity log is containing each and every activity that took place inside the apartment, including the precise time of the beginning and end of each event, was afterwards used for the data treatment.

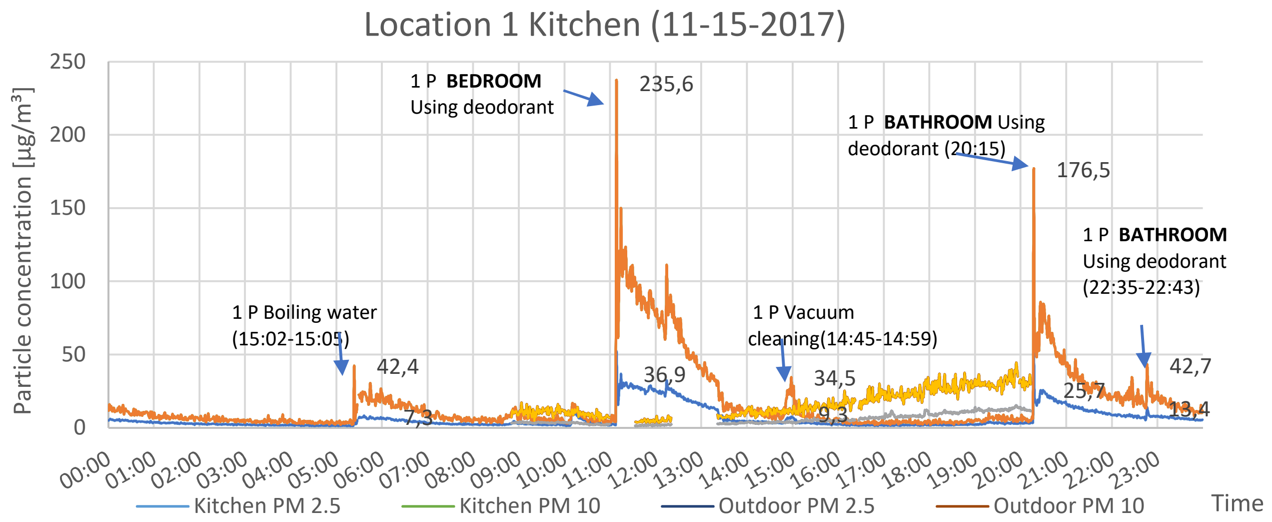


Figure 110 Daily chart for particle data treatment

Daily charts similar to the one above, were created so that different activities/events could be recognized based on the activity log. If no activity was written in the log, but a "peak" (increase in particle concentration) was noticed, that activity was marked as unidentified.
The detailed information about each identified peak was afterwards concentrated into a table, where the different types of activities were sorted.

Following this procedure, the sources of particle concentration increase were easily noticed.
For location 1, the predominant activity that has the highest release of particles is the use of deodorant in the bedroom and bathroom; the spread of particles to the other rooms in the apartment can be noticed almost every time the deodorant is used. The magnitude of these high peaks of deodorant use increased the difficulty of identifying other activities with the lower release of particles.

It was discovered that the main sources of particles in location 1 are:

1. The use of deodorant in the bedroom (highest particle release)
2. The use of deodorant in the bathroom (second highest particle release)
3. Cooking & making breakfast (third highest particle release)

1. The use of deodorant in the bedroom

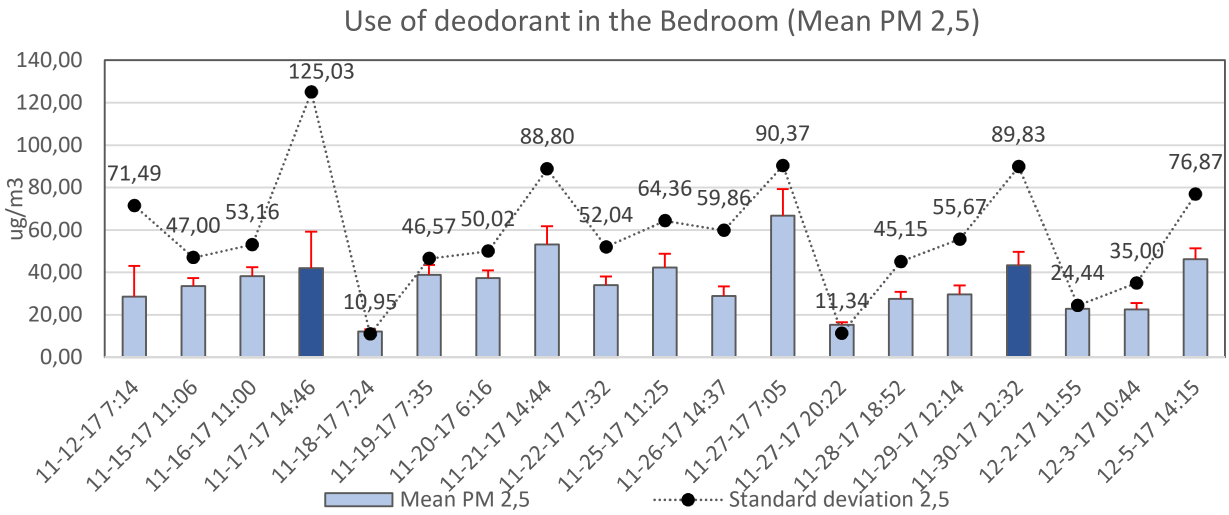


Figure 111 Use of deodorant in the bedroom (activities)

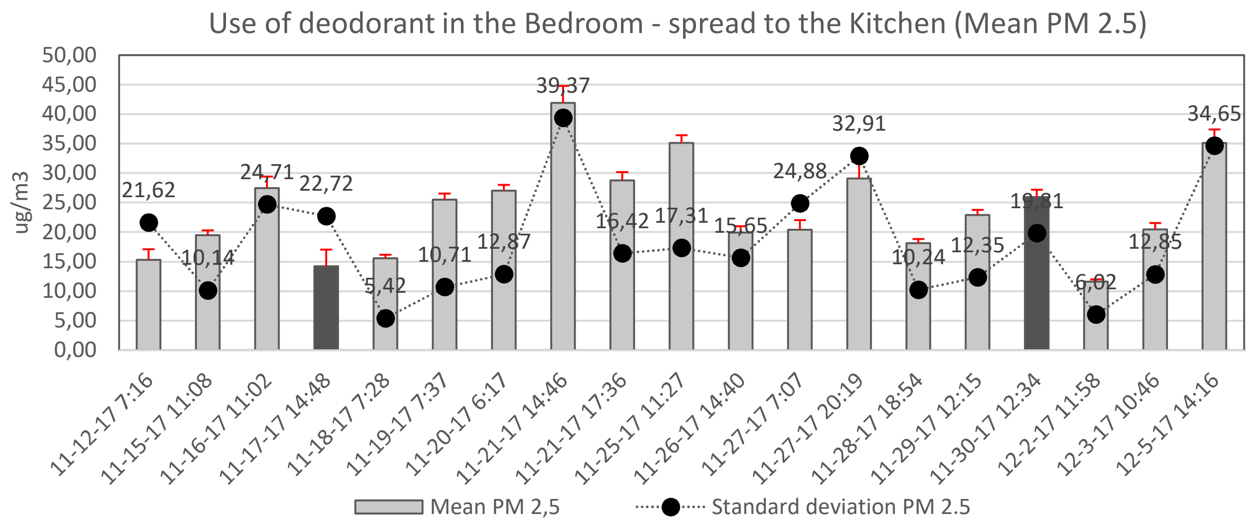


Figure 112 Use of deodorant in the Bedroom - spread to the Kitchen (Mean PM 2.5)

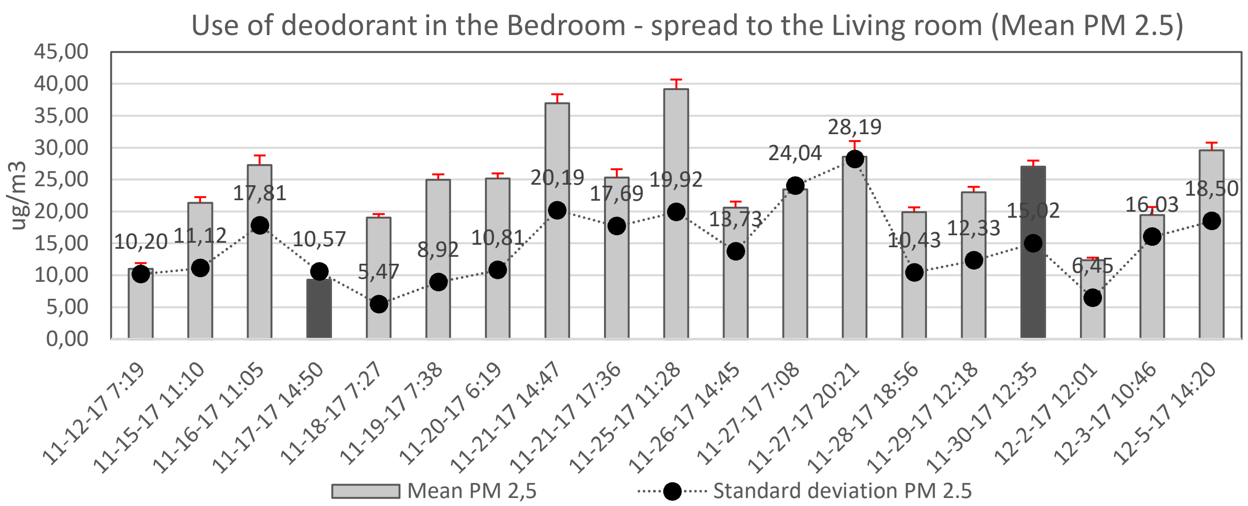


Figure 113 Use of deodorant in the Bedroom - spread to the Living room (Mean PM 2.5)

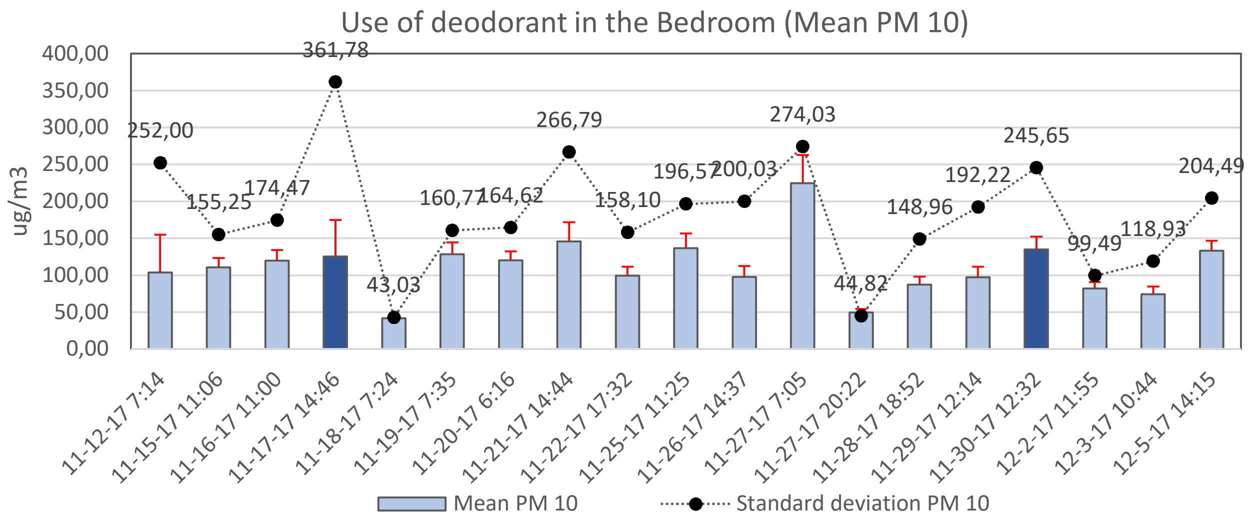


Figure 114 Use of deodorant in the Bedroom (Mean PM 10

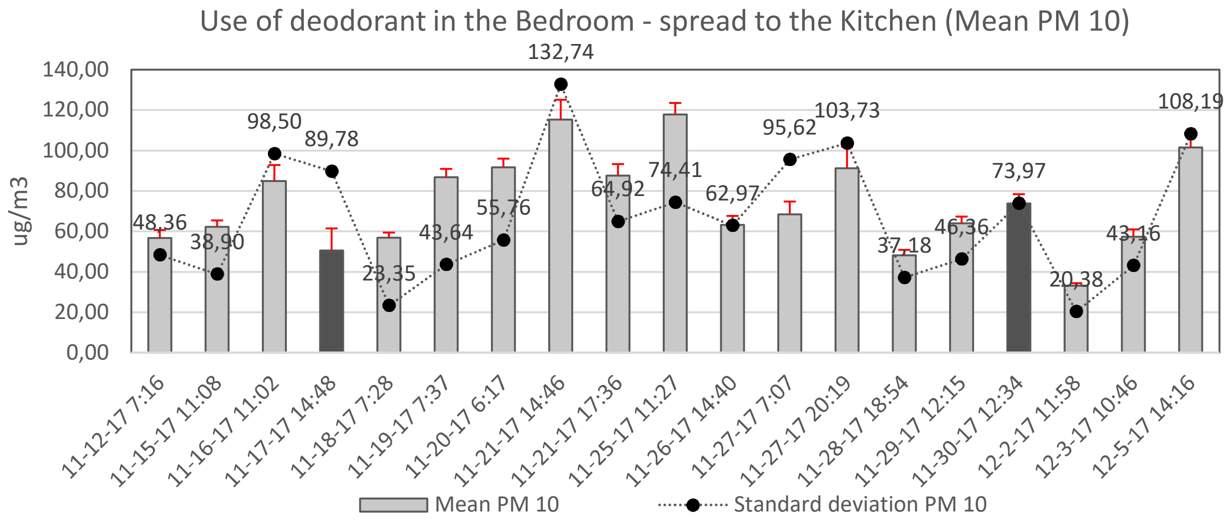


Figure 115 Use of deodorant in the Bedroom - spread to the Kitchen (Mean PM 10)

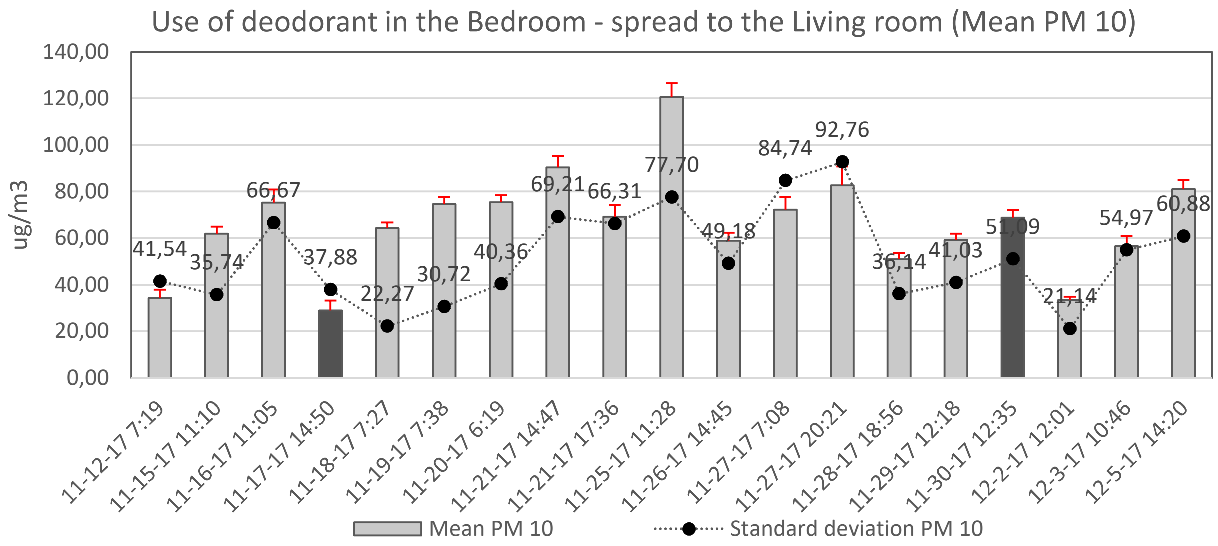


Figure 116 Use of deodorant in the Bedroom - spread to the Living room (Mean PM 10)

The mean levels of PM 2.5 and PM 10 from the use of deodorant in the bedroom (source) are displayed in the previous charts;
The blue colored charts represent the source room, and the grey colored charts represent the rooms where the particles spread; the spread seems to always follow the same order:

$$Bedroom \rightarrow Kitchen \rightarrow Living\ room$$

A standard deviation was calculated for each event, with the purpose of displaying the variation or dispersion of each set of data. Low and high standard deviations can be observed. High standard deviations can be seen in the source room, indicating that the data is spread out over a wider range of values; normally being represented by a quick increase, followed by a fast drop in particle concentration in a short period of time.
The standard deviation becomes lower as the particles spread more into the apartment, in most of the cases/events, the standard deviation becoming lower than the mean value of the event, indicating that more of the data becomes clustered around the mean value.
A standard error (represented with red color on top of each column) was calculated as well for each event; it normally indicates the accuracy of the mean value of each event, by showing how representative the mean for one specific event is, for the mean of all the events. In this case, the standard error also shows the sample size of each event; the smaller the sample size, the higher the standard error and the other way around.
Looking at the charts fig 114-fig 116, it is noticed that the standard error becomes lower and lower as the particles spread more and more.
Standard deviation and standard error, are therefore good indicators of dispersion and accuracy of each set of data/event.
As seen in the charts fig 111-fig 116, two of the events are colored with a darker color (dark blue/dark grey). The means of these two events (*event 4 17/11/2017 14.46*; *event 16 30/11/2017 12.32*) seem to be quite similar, but their standard deviation and standard error differ quite a lot. A closer look was taken at these two events.

EVENT 4 7/11/2017 14.4

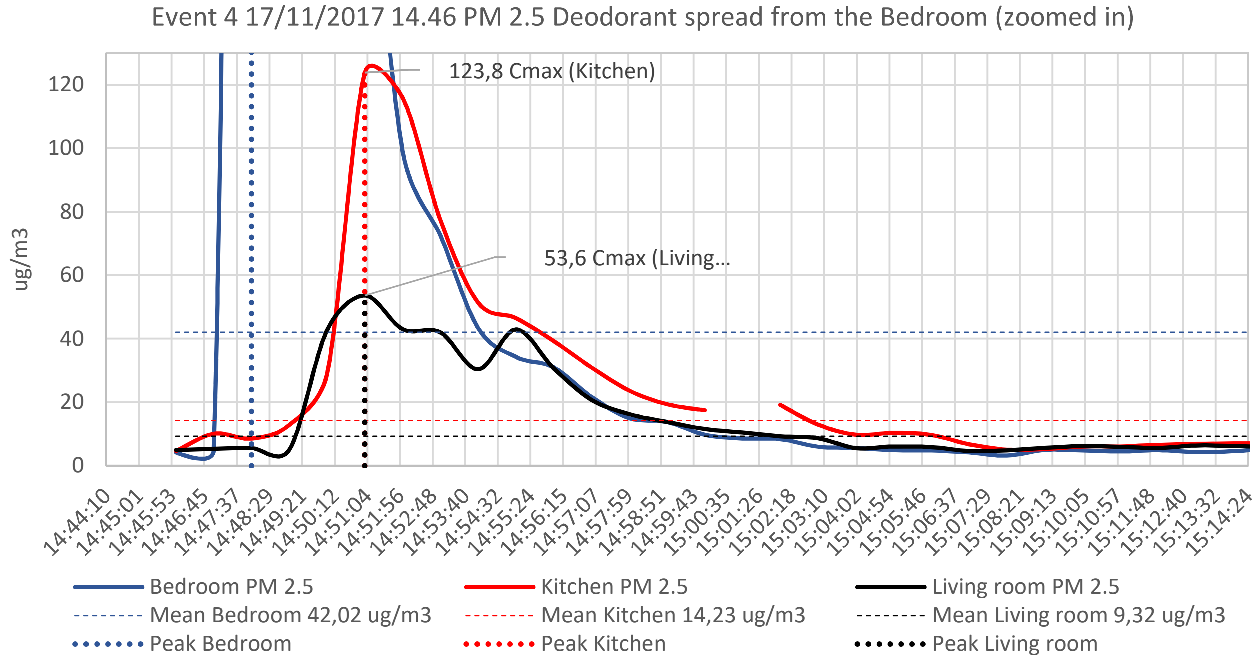


Figure 117 Event 4 17/11/2017 14.46 PM 2.5 Deodorant spread from the Bedroom (zoomed in)

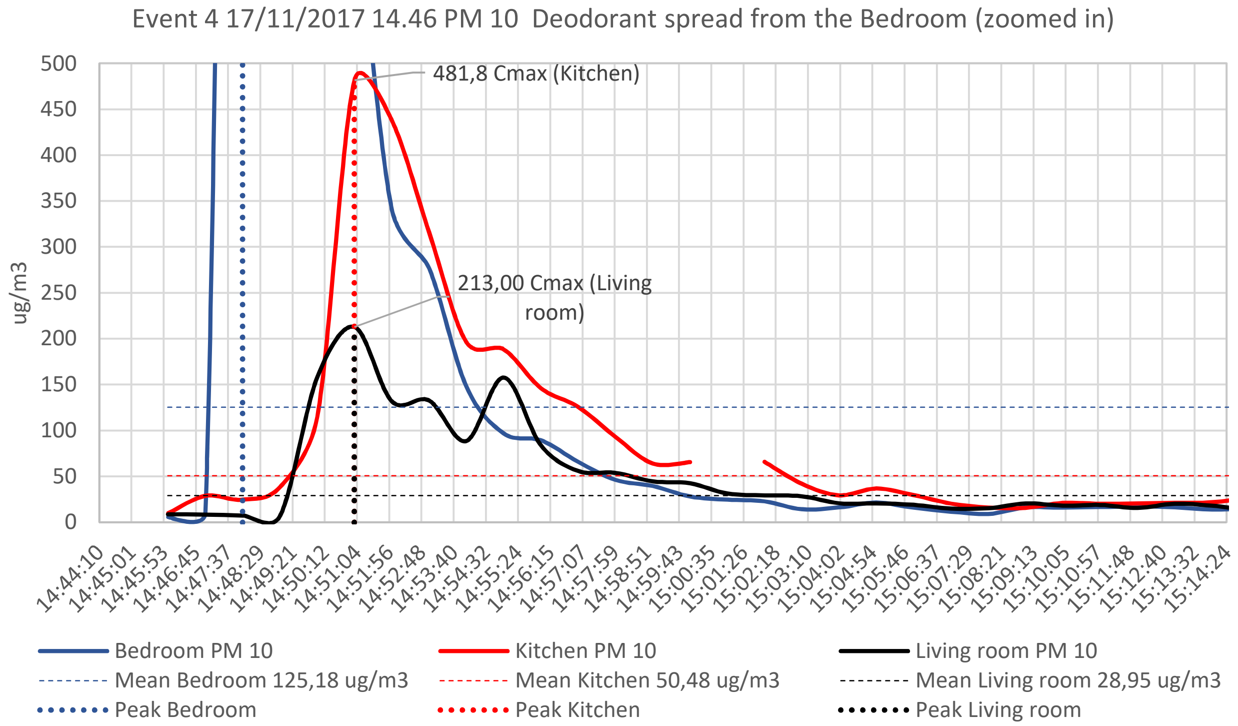


Figure 118 Event 4 17/11/2017 14.46 PM 10 Deodorant spread from the Bedroom (zoomed in)

EVENT 16 30/11/2017 12.32

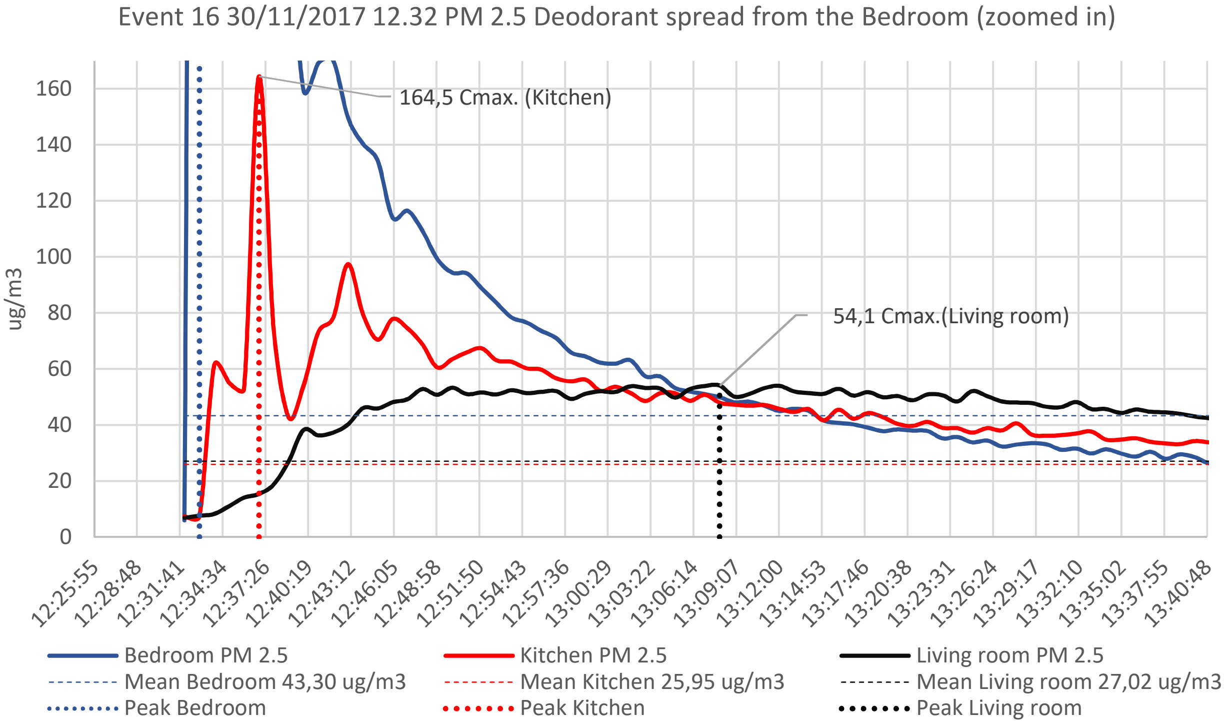


Figure 119 Event 16 30/11/2017 12.32 PM 2.5 Deodorant spread from the Bedroom (zoomed in)

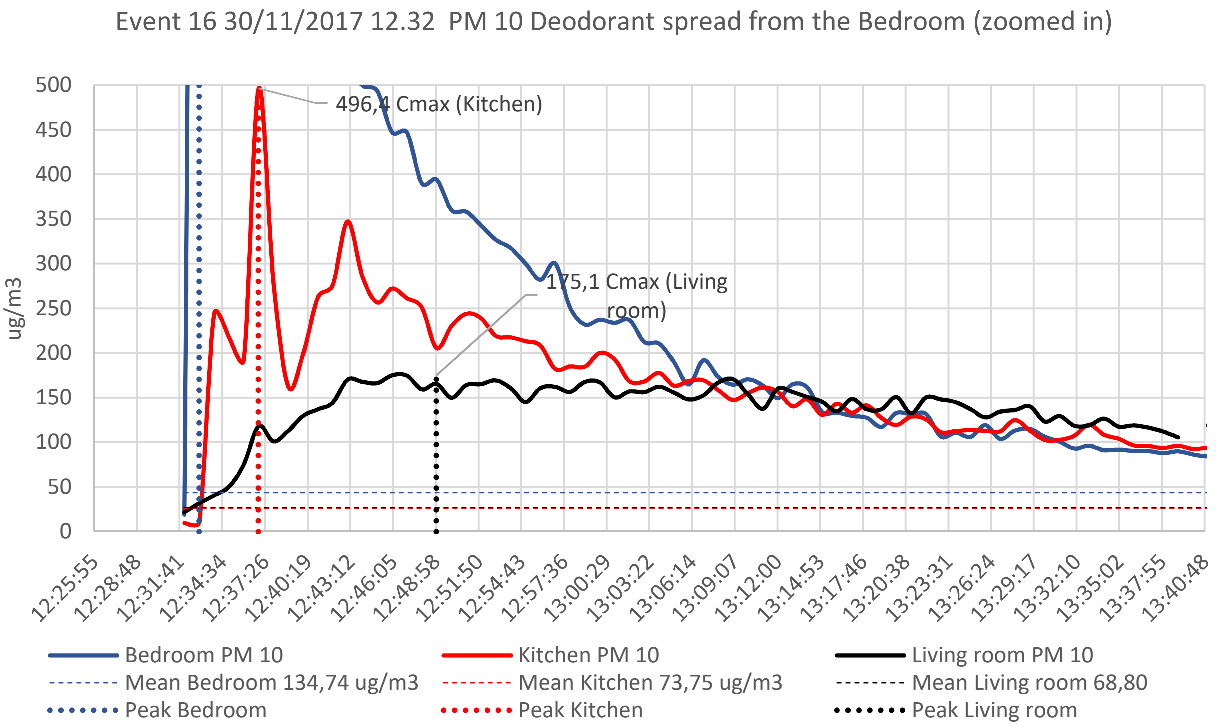


Figure 120 Event 16 30/11/2017 12.32 PM 10 Deodorant spread from the Bedroom (zoomed in)

Looking at the two events from another perspective can make a huge difference. The particle concentration (PM 2.5 and PM 10) in event 4 rises and drops quite fast to its initial concentration, compared to event 16, where it takes a substantial amount of time for the concentration to reach its initial value. As for the variation of data, event 4 contains a more dispersed set of data compared to event 16, therefore resulting in a higher standard deviation.

The spread of particle concentration is an important matter as well. The general idea is to have a "slow" spread from the source room to the other rooms or no spread at all, but in most cases spreading will occur.

The method of investigating the spreading of particle concentration was done by marking the peak values, and the time they occur at, in each room, for each of the events. See figure 117 and 120 (comparison of spreading for the two events). It took longer time for the spread to reach the living room in event 16, compared to event 4; it can only be assumed that the reason for that could be a closed door to the bedroom right after the use of deodorant. As for event 4, it can be assumed that the door to the bedroom was left open, thus the quick drop in particle concentration.

The general risk of human exposure due to particulate pollutant is another topic that was investigated. In order to do that, the intake fraction was estimated by using a one-compartment model. The one compartment model is based on a set of parameters that are needed to determine the intake fraction: ventilation rate of the building (Q, m^3/h^{-1}), the number of exposed individuals (P) and the average volumetric breathing rate (Q_B, m^3/h^{-1}/person). This model also implies that steady-state conditions are to be used if the pollutant release rate (E, $\mu g/h^{-1}$) and the ventilation rate are constant, the pollutant is nonreactive and the indoor air well mixed.

A few decisions were taken in regards to some of the parameters that were used for the estimation of intake fraction:

- The measuring unit of the particle sensors is µg/m3, and the required unit for the pollutant release rate is $\mu g/h^{-1}$; *(knowing that the sensor gives a reading for each minute*), the mean value for each event was multiplied by 60 (min) and then multiplied by the volume of the room.
- The volumetric breathing rate was adjusted so that it would match different metabolic rates in different rooms. For example: Bedroom: 0,8 MET, Kitchen 1,6 MET and Living room 1,2 MET.
- The occupancy of each room was assumed to be of one person.

$$C = \frac{E}{Q}$$

$$I = C * P * Q_B = \frac{E * P * Q_B}{Q}$$

$$iF = \frac{P * Q_B}{Q} = \frac{P * Q_B}{V * X}$$

Where:

C-concentration of the contaminant

E-pollutant release rate (µg/h^{-1})

Q-ventilation rate (m^3/h^{-1})

I-cumulative mass inhalation rate of pollutants

P-number of persons

Q_B-average volumetric breathing rate (m^3/h^{-1}/person)

iF-intake fraction (%)

V-volume of the room (m^3)

X-air change rate (h^{-1})

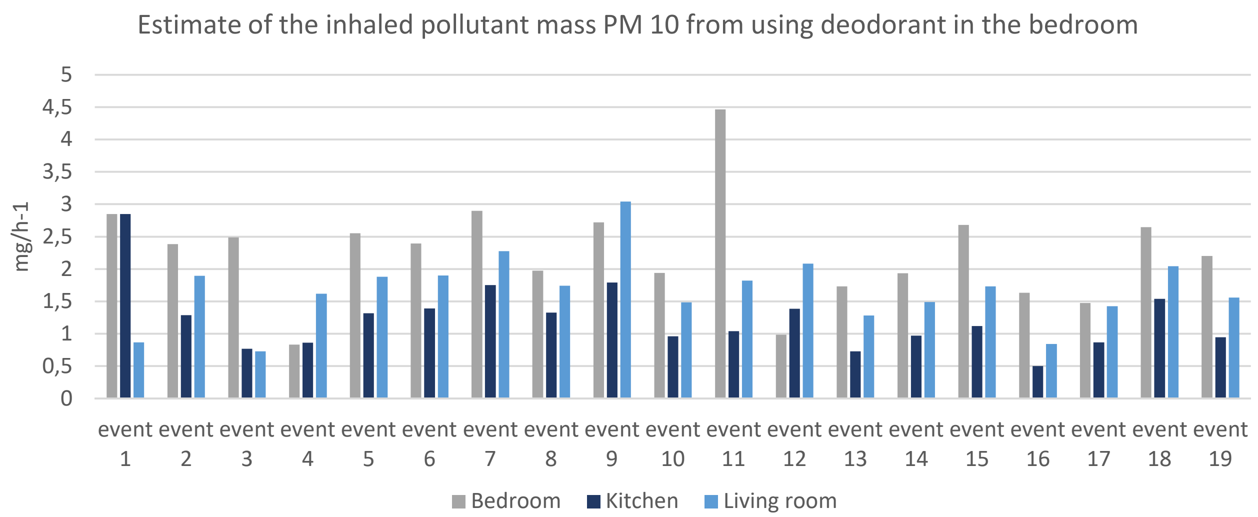


Figure 121 Inhaled pollutant mass PM 10 from using deodorant in the bedroom

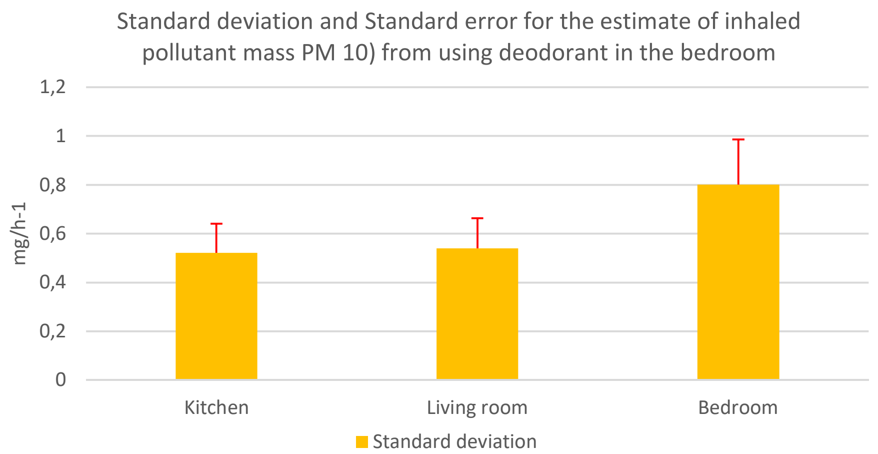


Figure 122 Standard deviation and Standard error for inhaled pollutant mass PM 10) from using deodorant in the bedroom

A standard deviation was calculated for each room, in order to show the dispersion of the estimate of inhaled pollutant. The standard error represents the statistical accuracy of the estimate for each of the rooms.

2. The use of deodorant in the bathroom

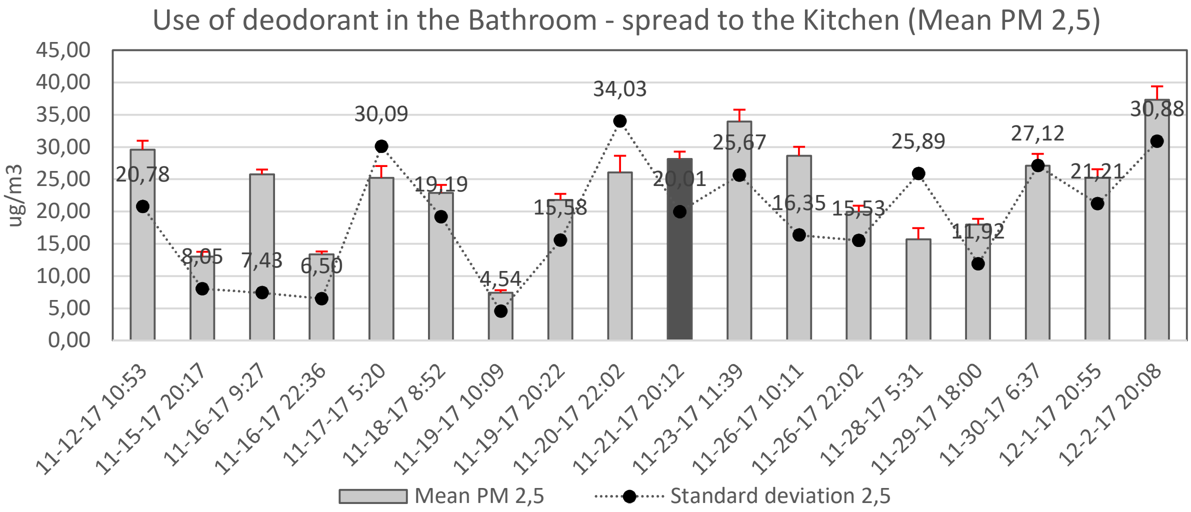


Figure 123 Use of deodorant in the Bathroom - spread to the Kitchen (Mean PM 2,5)

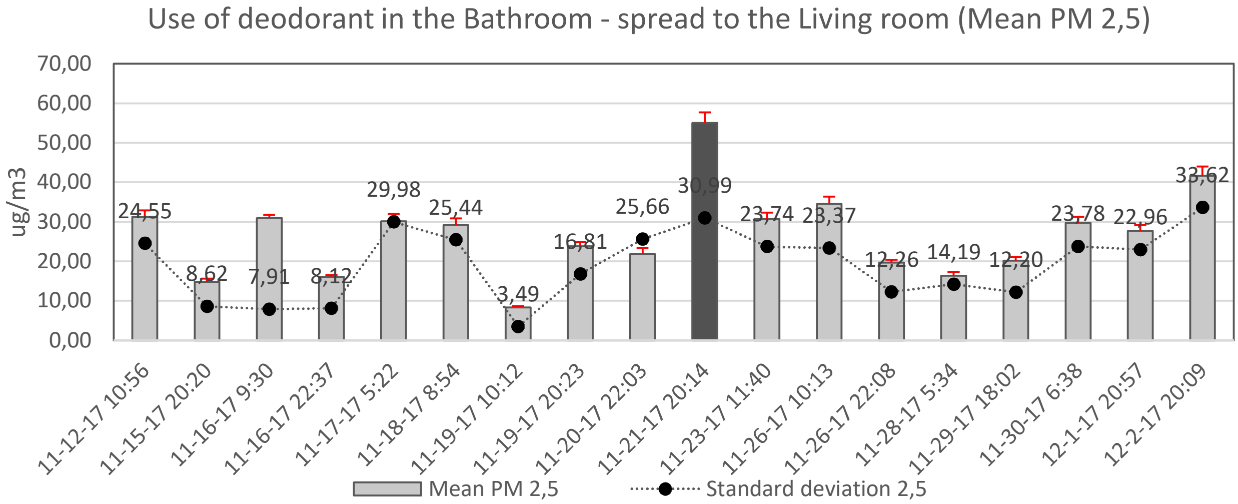


Figure 124 Use of deodorant in the Bathroom - spread to the Living room (Mean PM 2,5)

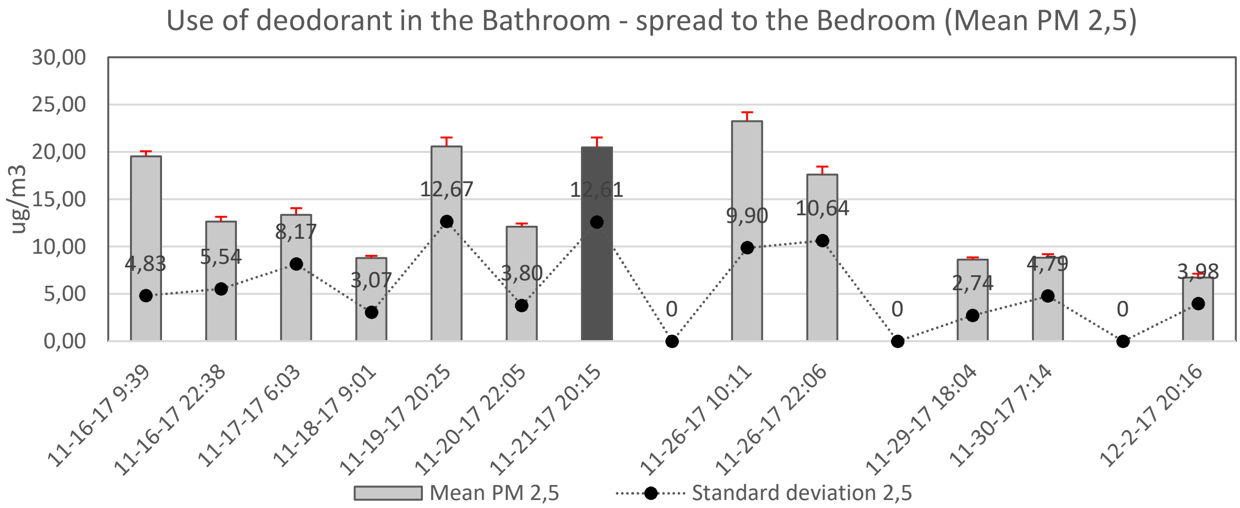


Figure 125 Use of deodorant in the Bathroom - spread to the Bedroom (Mean PM 2,5)

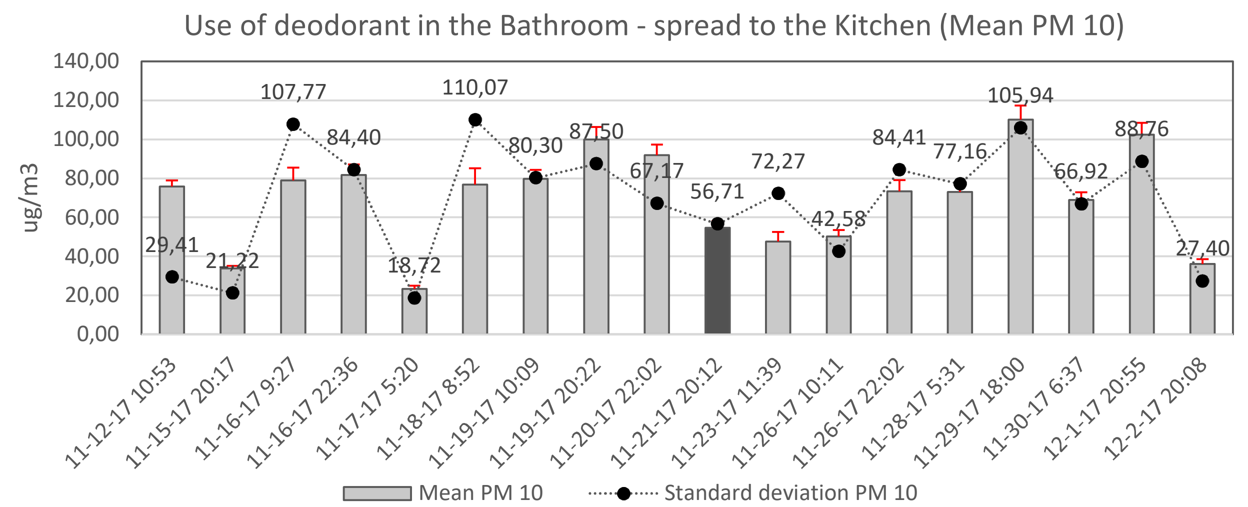


Figure 126 Use of deodorant in the Bathroom - spread to the Kitchen (Mean PM 10)

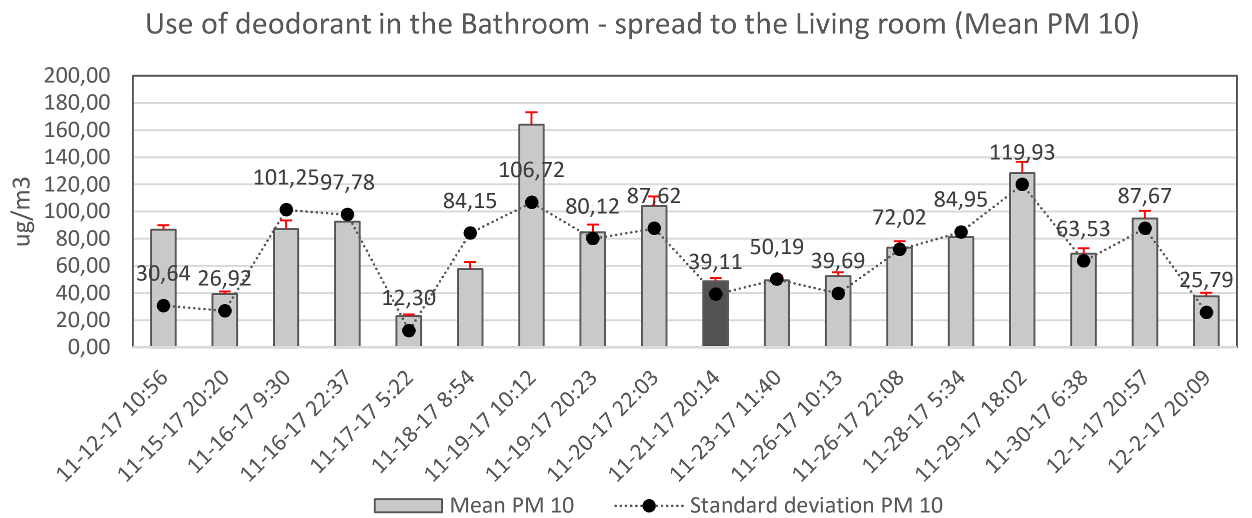


Figure 127 Use of deodorant in the Bathroom - spread to the Living room (Mean PM 10)

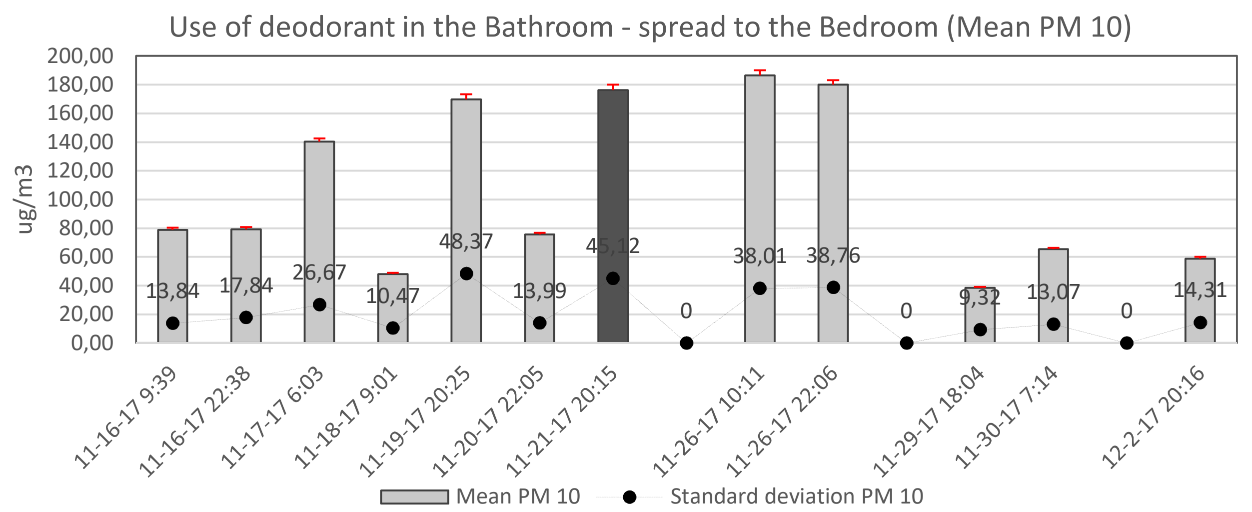


Figure 128 Use of deodorant in the Bathroom - spread to the Bedroom (Mean PM 10)

The spread of particle concentration seems to be substantially lower in the case of using the deodorant in the bathroom. It is observed that there is no spread to the bedroom for some of the events.

The standard deviation and standard error are lower than the mean value for most of the events, thus displaying a lower variation of the set of data.
A reason for having lower spread from the bathroom than from the bedroom could be the fact that the extraction hood from the ventilation system is placed in the bathroom. Another reason for that could be the fact that the door to the bathroom was always closed, blocking the spread.
In the charts fig125-fig 128, event 7 was highlighted. By doing so, a closer look was taken at the sequence of the particle spread for that event.

Event 7 21/11/2017 20.13

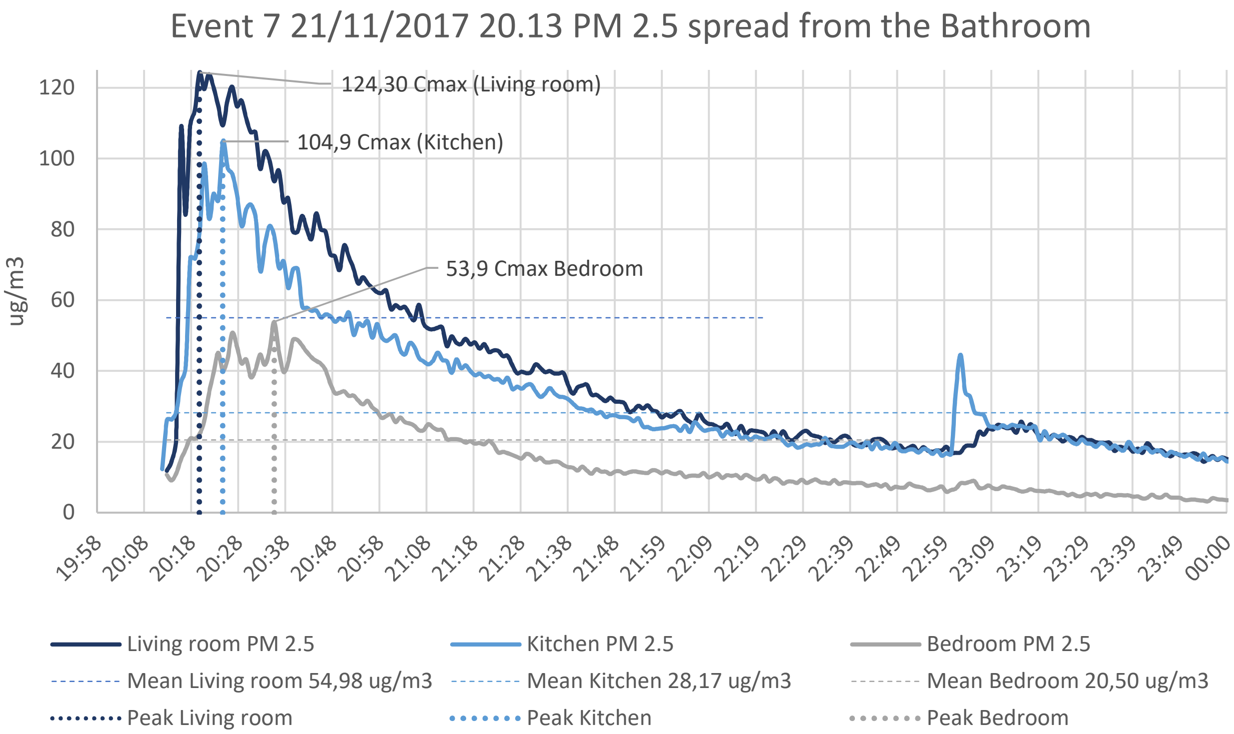


Figure 129 Event X 21/11/2017 20.13 PM 2.5 spread from the Bathroom

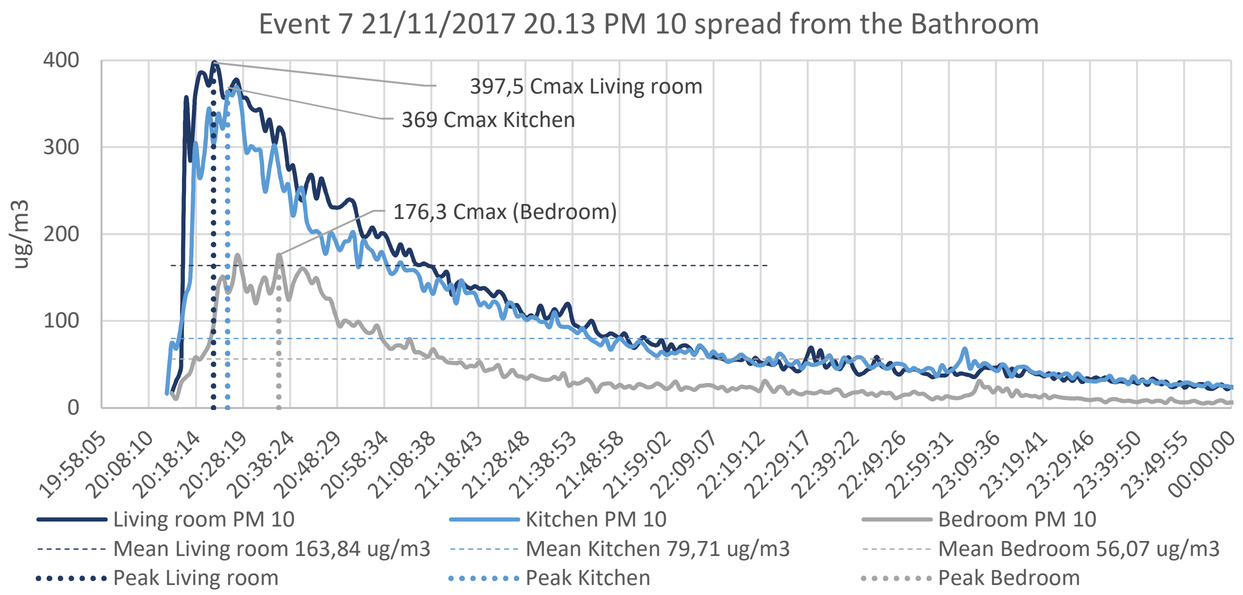


Figure 130 Event X 21/11/2017 20.13 PM 10 spread from the Bathroom

The first observation is that it takes almost 4 hours for the concentration to reach its initial value (as seen in figure 129 and 130.

More than that, the difference of time between the peaks is as well much bigger than in the case of deodorant use in the bedroom.

An interesting observation is that a higher mean of particle concentration is measured in the living room, even though the bathroom is accessed from the kitchen. More than that, the particles seem to spread quicker into the living room than into the kitchen; most probably the layout of the apartment being the reason for that. The fact that the particles are transported/spread in the living room, against the direction of the air flow supplied to the room, implies that the ventilation rate might not be sufficient in order to dilute the particle concentration.

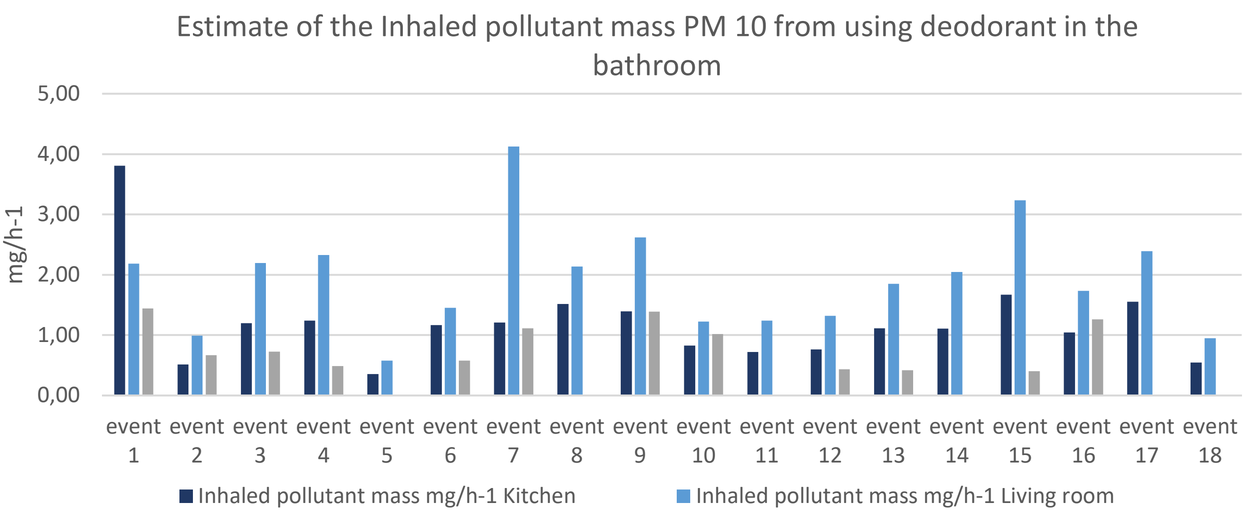


Figure 131 Estimate of the Inhaled pollutant mass PM 10 from using deodorant in the bathroom

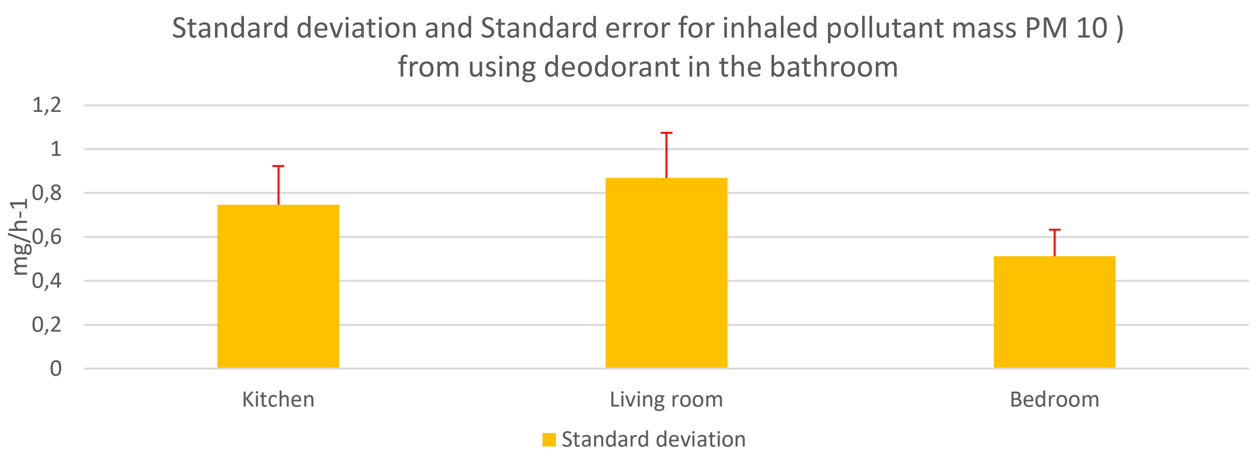


Figure 132 Standard deviation and Standard error for inhaled pollutant mass PM 10) from using deodorant in the bathroom

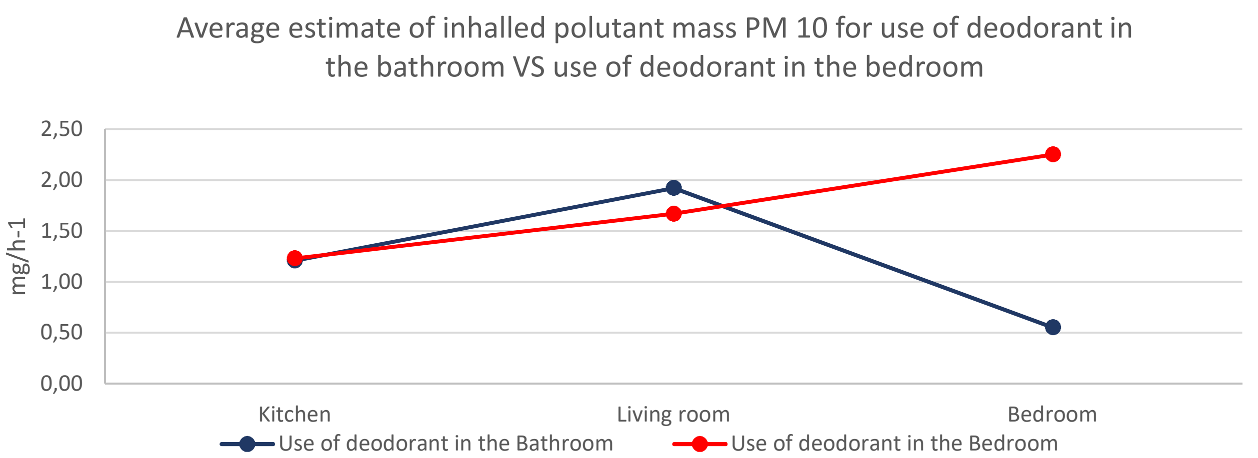


Figure 133 Average estimate of inhaled pollutant mass PM 10 for use of deodorant in the bathroom VS use of deodorant in the bedroom

Even though the general level of particle spread from the use of deodorant in the bedroom is slightly higher than the particle spread from the bathroom, by comparing the average estimate of inhaled pollutant, (see figure 133) a slightly higher estimate of inhaled pollutant can be noticed in the case of using the deodorant in the bathroom; 13% higher in the Living room. 2% lower estimate of inhaled pollutant in the Kitchen almost doesn't make a difference.

3. Cooking & making breakfast (third highest particle release)

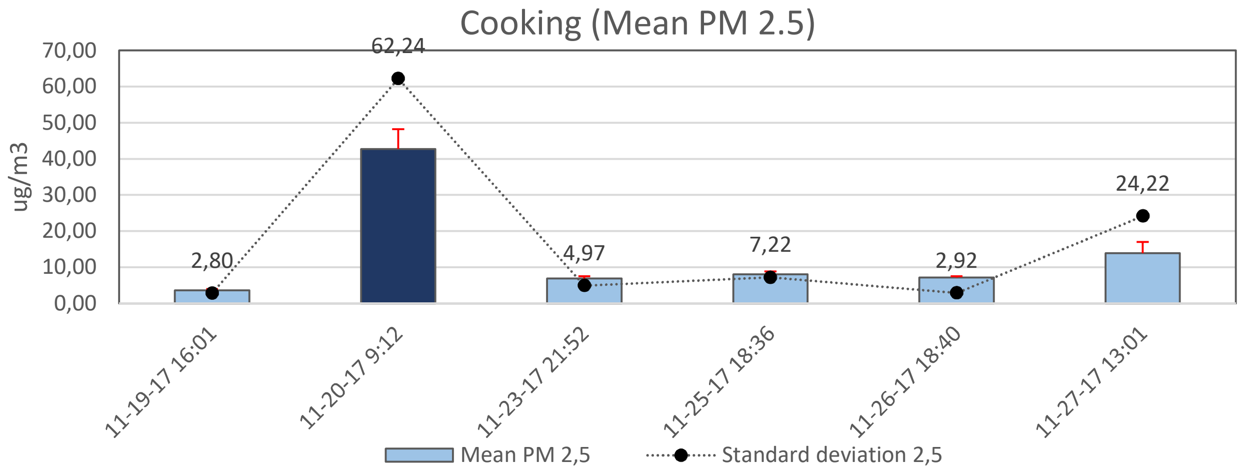


Figure 134 Cooking (Mean PM 2.5)

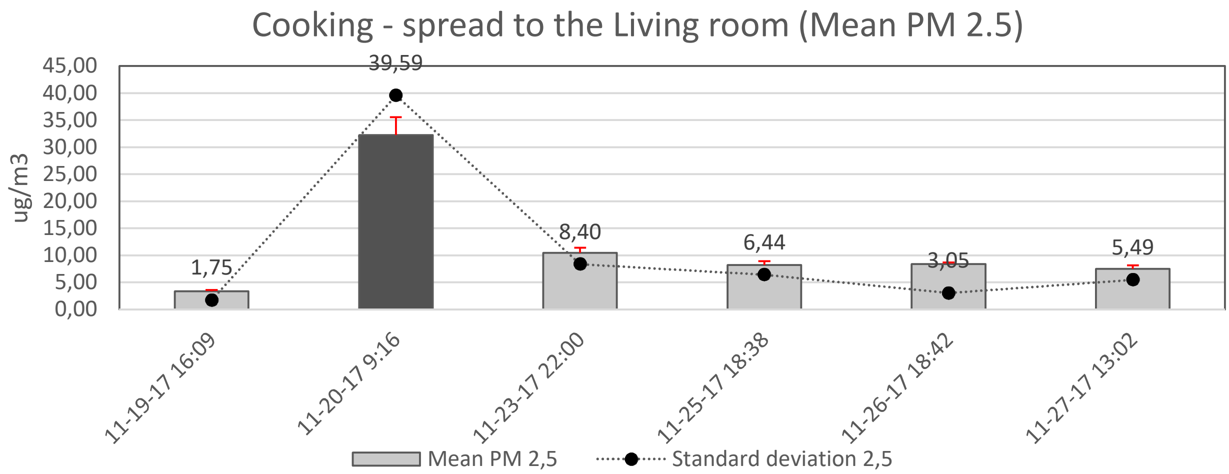


Figure 135 Cooking - spread to the Living room (Mean PM 2.5)

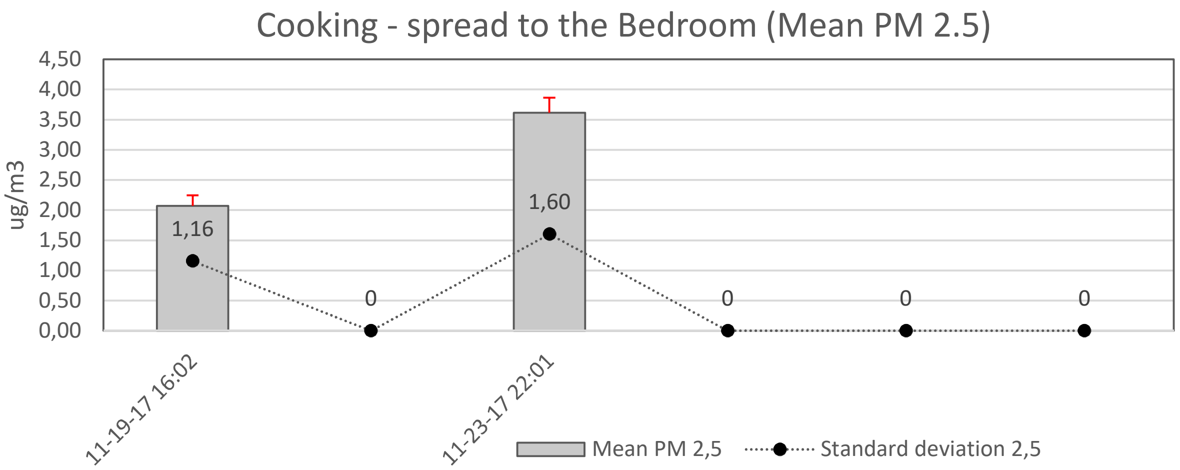


Figure 136 Cooking - spread to the Bedroom (Mean PM 2.5)

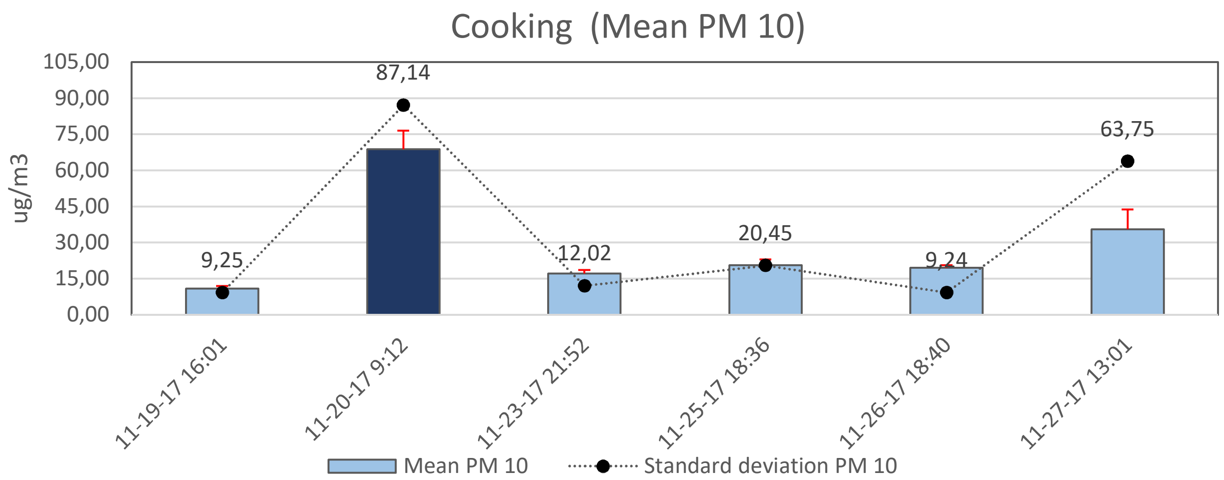


Figure 137 Cooking (Mean PM 10)

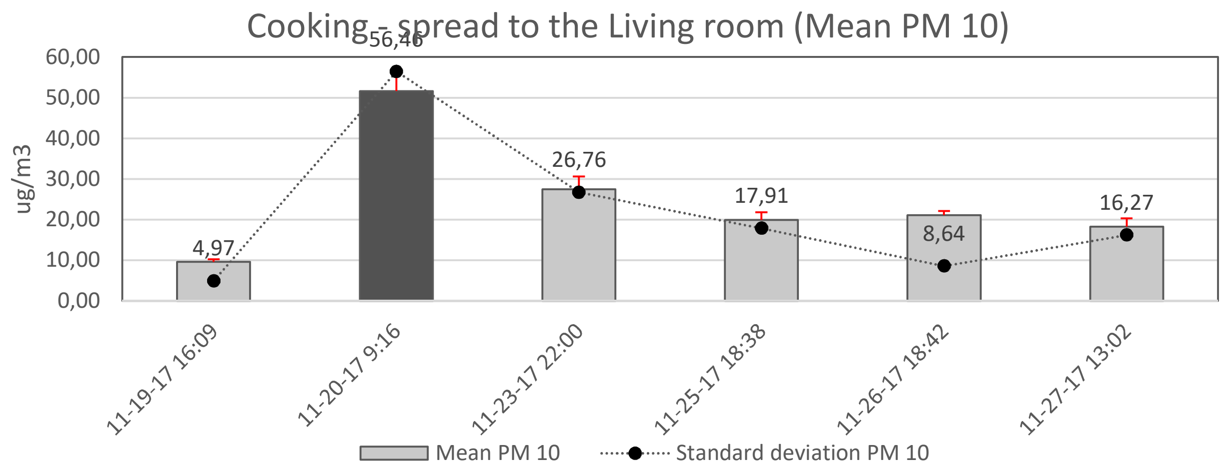


Figure 138 Cooking - spread to the Living room (Mean PM 10

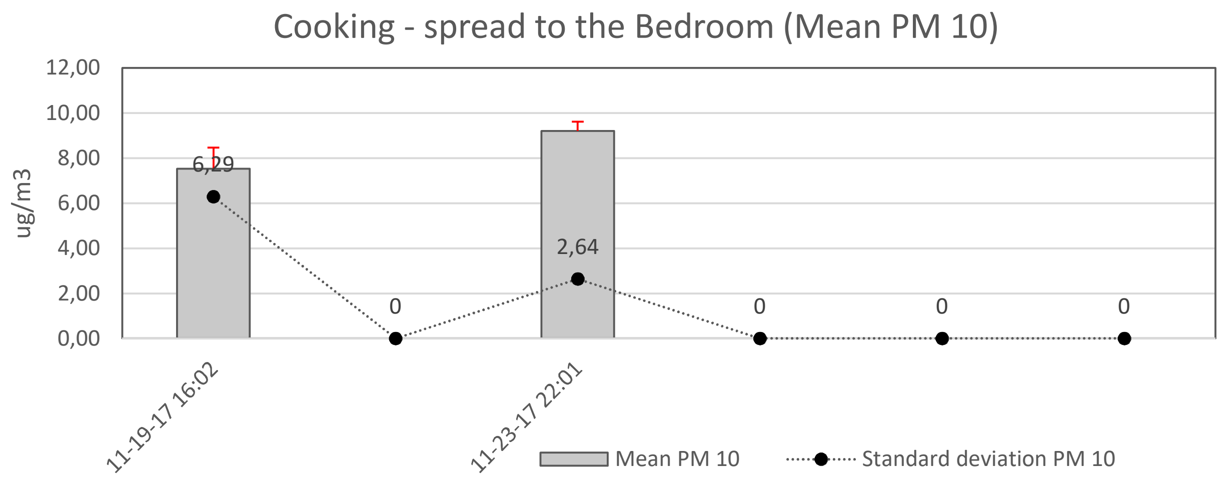


Figure 139 Cooking - spread to the Bedroom (Mean PM 10)

When it comes to cooking, not a very high concentration of particles was measured or spread. The fact that the kitchen hood was on whenever cooking was taking place, might have influenced the spread since in 4 out of 6 events there is no spread to the bedroom.

Event 2 20/11/2017 09.12

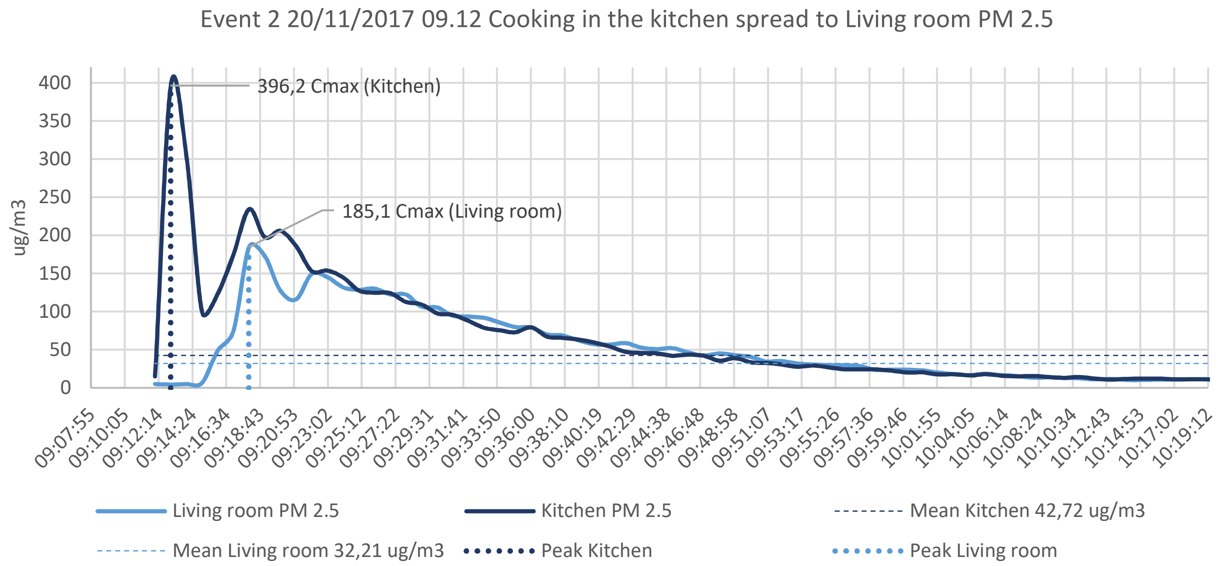


Figure 140 Event 2 20/11/2017 09.12 Cooking in the kitchen spread to Living room PM 2.5

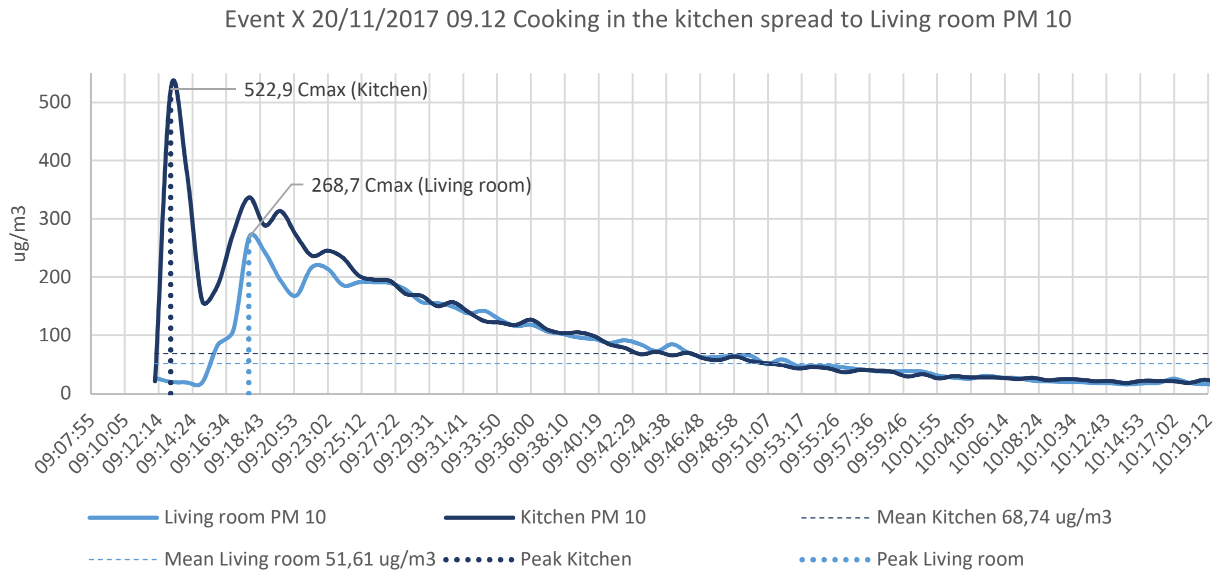


Figure 141 Event X 20/11/2017 09.12 Cooking in the kitchen spread to Living room PM 10

It is obvious that the layout of the apartment “plays an important role” in the spread of particles. With no door separating the living room form the kitchen, the particles have an easy way of spreading.

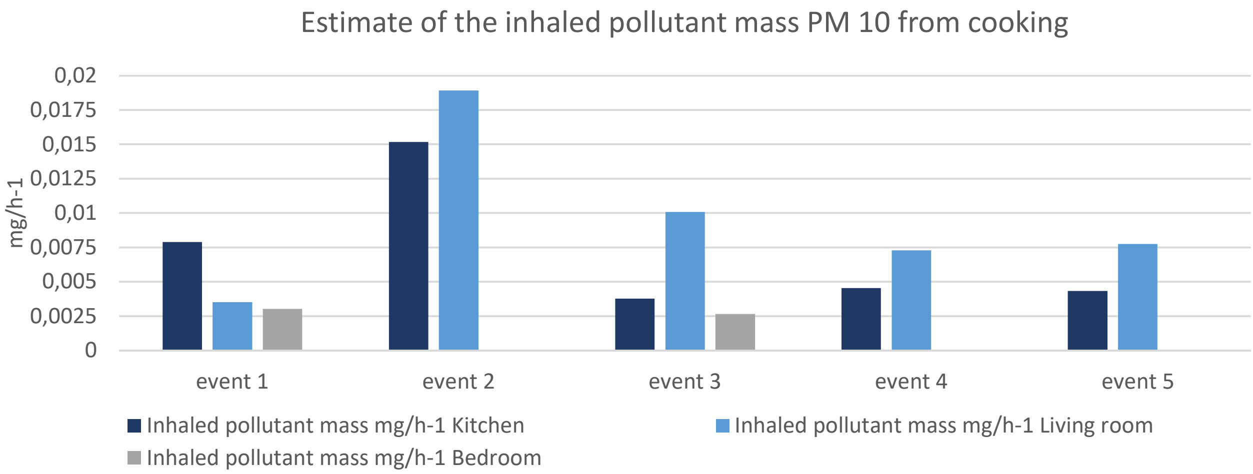


Figure 142 Estimate of the inhaled pollutant mass PM 10 from cooking

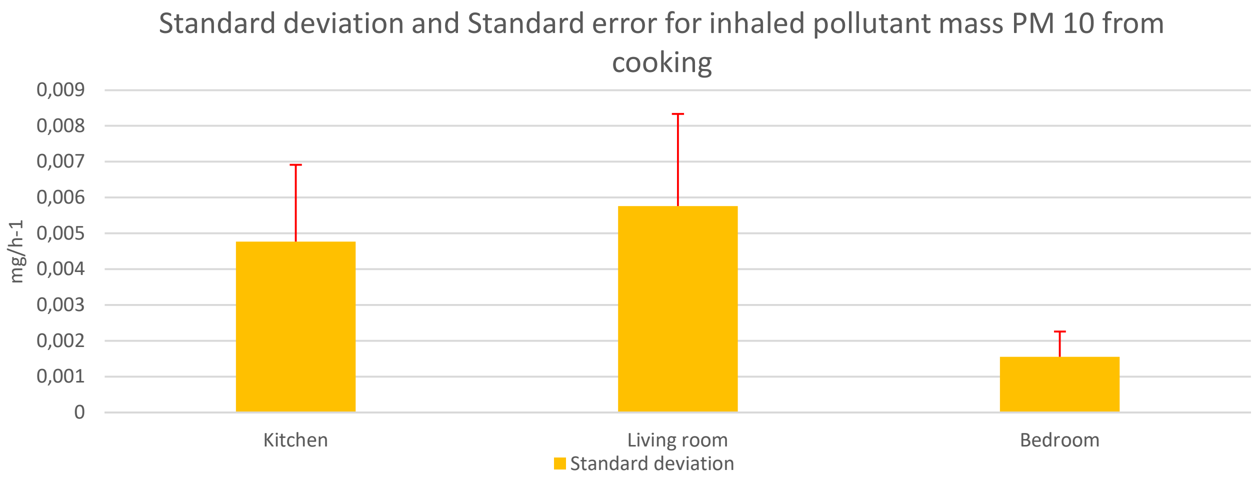


Figure 143 Standard deviation and Standard error for inhaled pollutant mass PM 10 from cooking

The estimate of the inhaled pollutant mass is significantly lower in case of cooking, compared to the case of deodorant use, mainly due to lower emissions of particles.

4.3.2 Location 2

A detailed description of the apartment can be found in chapter xx. Apartment in location 2 is situated on the ground floor with living-room facing the street and bedroom, kitchen – inner courtyard. The apartment is naturally ventilated with forced extraction in the bathroom and kitchen. However, the extraction has to be triggered manually.

Measurement period took place between 8th of November and 5th of December. Particle data has been logged in three main spaces of the dwelling (see picture below), with an extra sensor logging outdoor data whenever possible. Indoor particle sensors have been placed as close as possible to a reasonable breathing height for that particular space, depending on typical activities. The position of the particle sensors is indicated in the picture below.

Figure 144 Particle sensor placement in Location 2

A detailed description of the rooms is provided in the following table:

	**Living-room** Surfaces: Floor – Wood boards Walls – Solid brick construction, plaster, wallpaper painted white Ceiling – Plaster, painted white
	**Bedroom** Surfaces: Floor – Wood boards Walls – Solid brick construction, plaster, wallpaper painted white Ceiling – Plaster, painted white
	**Kitchen** Surfaces: Floor – Linoleum Walls – Solid brick construction, plaster, wallpaper painted white Ceiling – Suspended ceiling, a single layer of plasterboard painted white.
	**Bathroom** Surfaces: Floor – Concrete, wet room membrane, tiles Walls – Solid brick construction, wet room membrane, tiles Ceiling – suspended ceiling, a single layer of plasterboard painted white.

Table 69 Details about rooms of Location 2

Typical particle pollution

To get a quick overview of air quality in the apartment regarding particles, 24-hour mean values have been derived from measured data and compared with the World Health Organization recommendations.

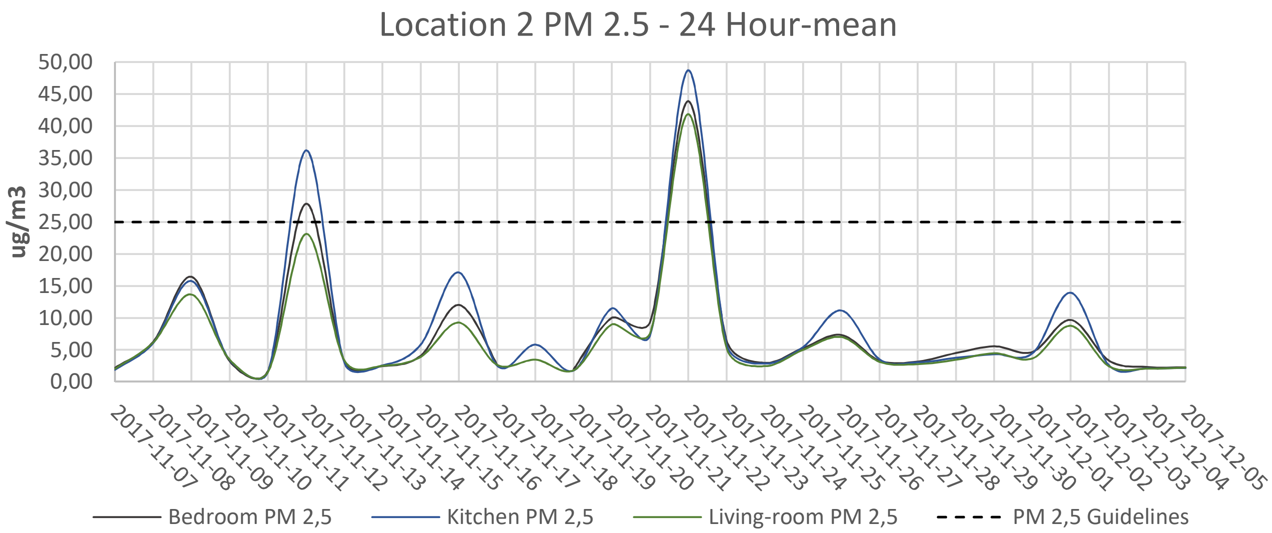


Figure 145 24-Hour mean for PM2.5 particle data at Location 2

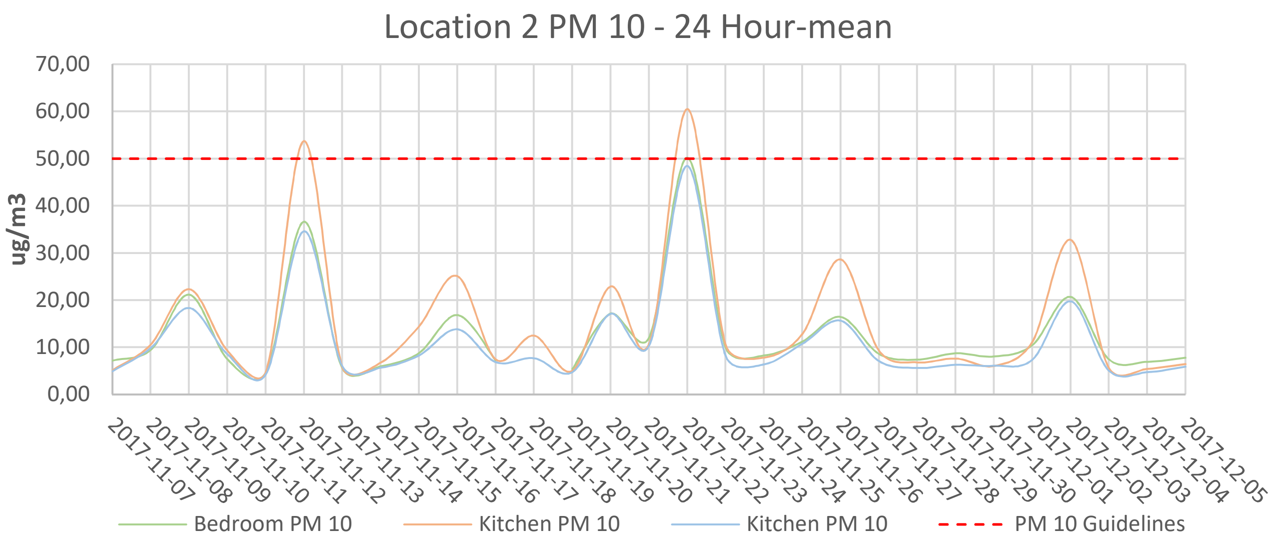


Figure 146 24-Hour mean for PM10 particle data at Location 2

For most of the time particle levels indoors are within recommended range. The 24-hour mean limit set by WHO has been exceeded only two times on 12th and 22nd of November (in this subchapter, the focus of the particle analysis will be directed to these days).
Particle concentration difference in the individual rooms is observed and indicates that kitchen is the leading source of particle pollution in the apartment (source room). Additionally, a clear relation between particle concentration in the kitchen and other rooms can be observed, suggesting that particles are spreading throughout the apartment from the source room.

In order to identify specific activities causing particle concentration increase a detailed activity log has been kept during the measurement period and later cross-checked with measured data. The log contained information like start and end times, occupancy, type and description of the activity.

Particle data has been treated and sorted into daily graphs where individual events could be identified based on the activity log, and outside influences recognized, as presented in the following example. (Most of the causes for particle concentration increase could be related to specific activities. However, a small number of peaks remains unidentified.) For remaining, daily graphs see digital appendix 2H.

Based on daily data a conclusion can be reached that outdoor particle levels play a relatively small part in influencing indoor particle pollution levels. Mean value for 24-hour PM 2.5 and PM 10 particle concentration level outdoors is respectively 5,9 and 11,9 µg/m³, which is well below recommended max limit. Moreover, in some instances, it has been observed, that when no activities are taking place pollution level indoor is even lower than outdoors. This can be explained by nature of infiltration. When air is infiltrating indoors, gaps in the constructions effectively act as filters, thus reducing the number of particles penetrating inside. Outdoor influences are observed only when the gap in the building envelope is sufficiently large (for example, open window).

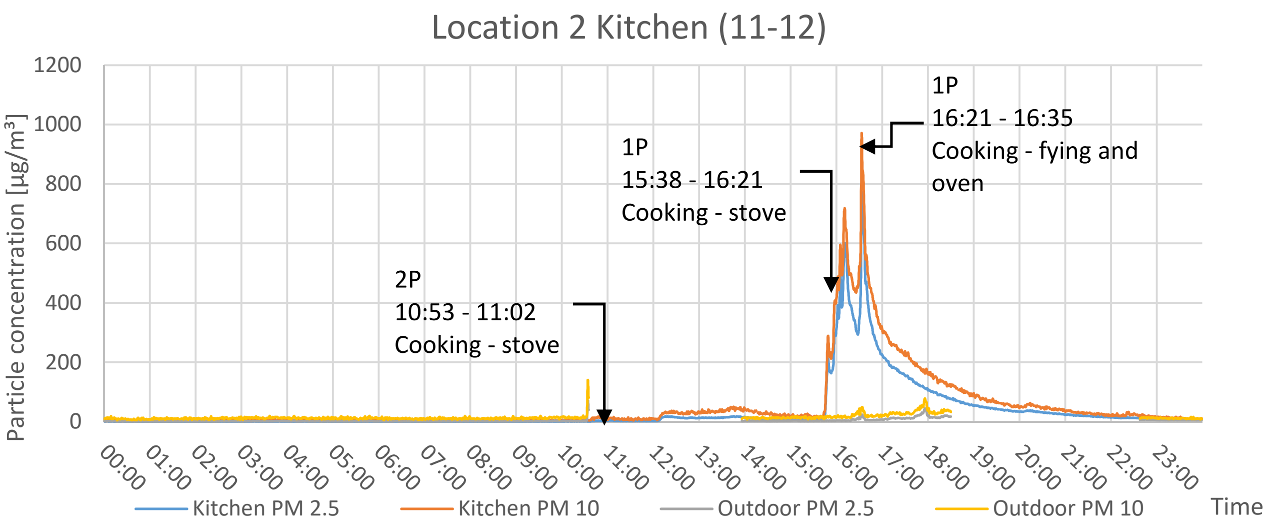


Figure 147 Daily chart of particle data treatment

Later, details of specific activities have been concentrated into a data table where activities have been sorted into different categories, and further analysis regarding standard deviation, peak values, and standard error presented. (See digital appendix 2G)

In the case of location 2, two dominating sources of particle pollution have been identified:

- Cooking (particularly frying)
- Burning candles

Cooking is the most significant source of particle pollution in location 2. Increase in particle concentration is often registered even in the other rooms when cooking activities are taking place in the kitchen. Such correlation indicates that even if airflows in the apartment are moving as intended, from liveable rooms into polluted zones (bathroom and kitchen), were extraction is present, particles are efficiently spreading against the air flow. Therefore, a more sophisticated or flexible ventilation system might be necessary in such homes, in order to deal with the pollution.

One of the main cooking activities causing substantial particle concentration increase is frying. These activities, their particle spread, and detail information are presented on the following pages.

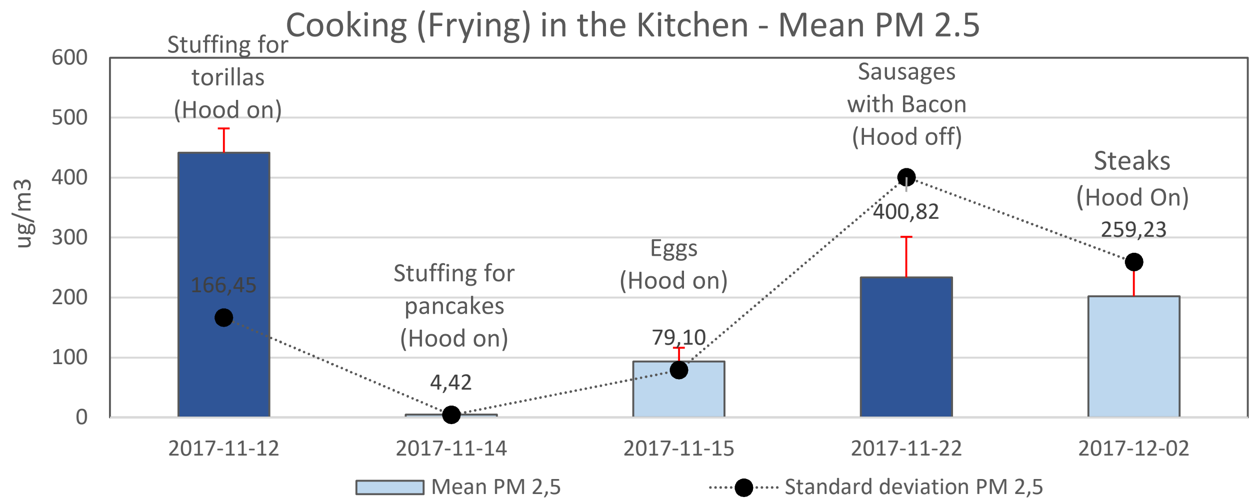


Figure 148 PM 2.5, Cooking (Frying) in the source room (Kitchen)

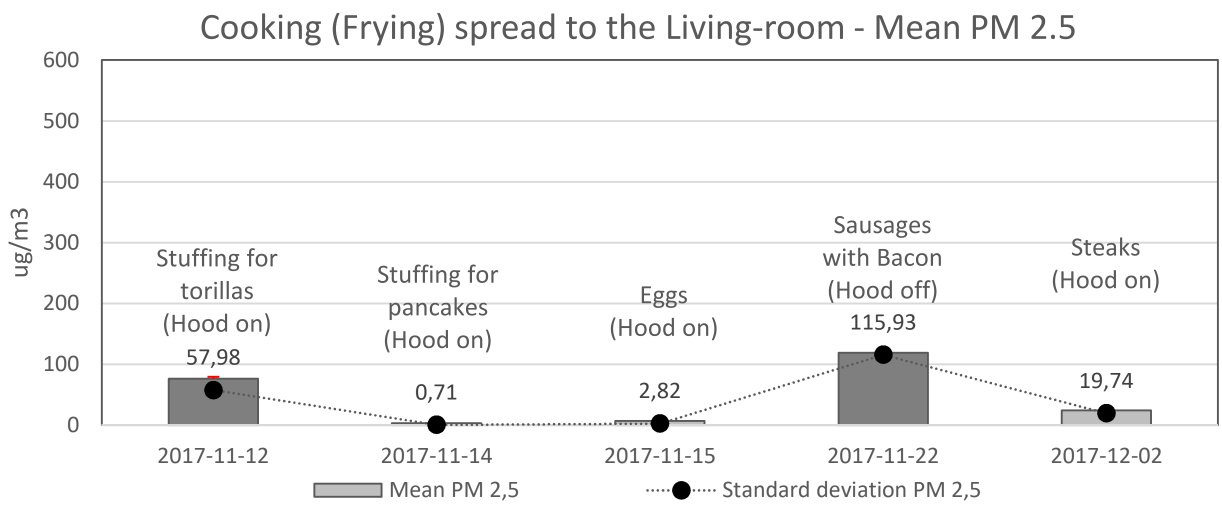


Figure 149 PM 2.5, Cooking (Frying) spreading to the Living-room

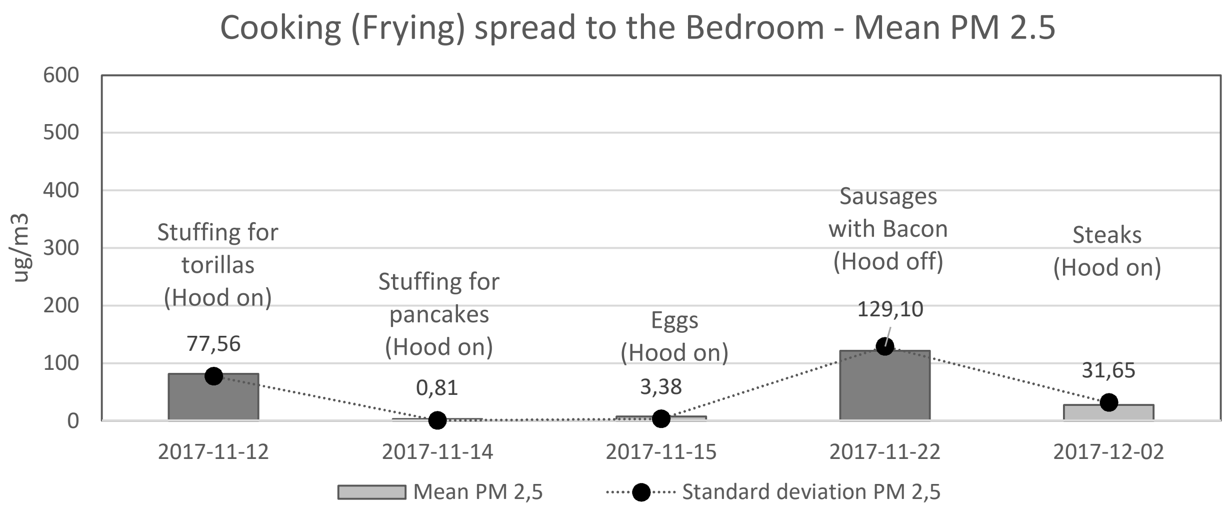


Figure 150 PM 2.5, Cooking (Frying) spreading to the Bedroom

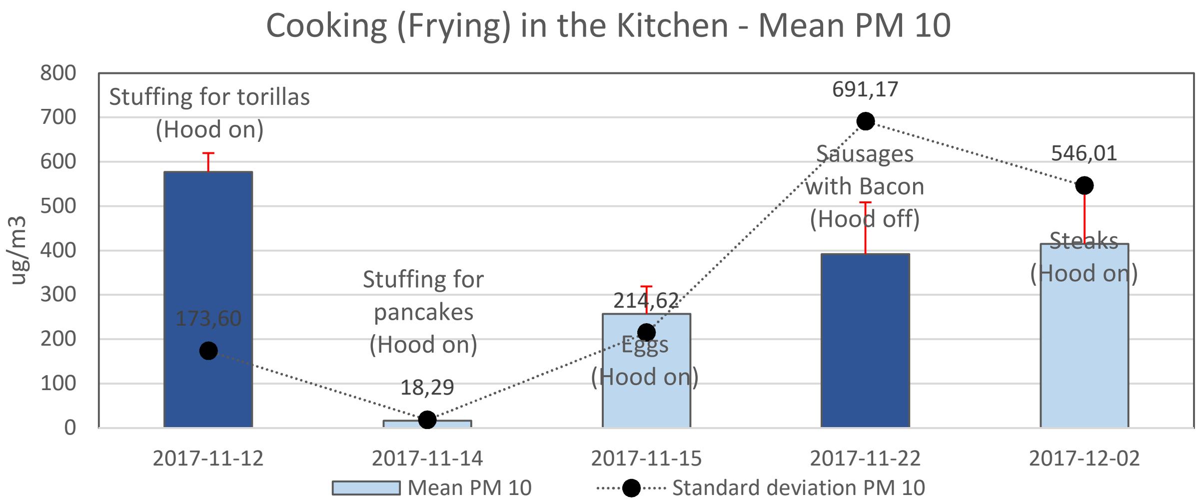


Figure 151 PM 10, Cooking (Frying) in the source room (Kitchen)

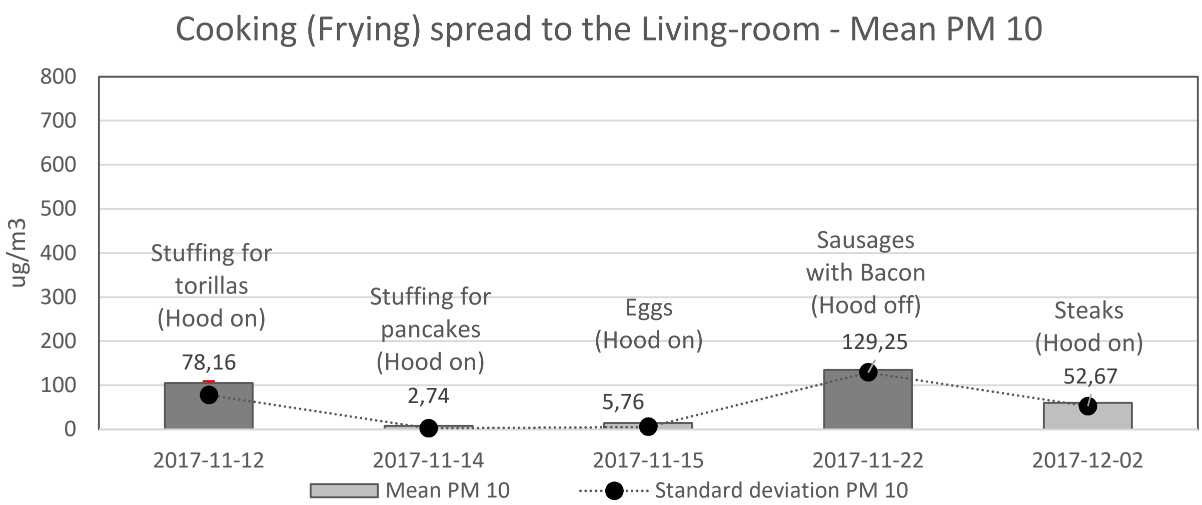


Figure 152 PM 10, Cooking (Frying) spreading to the Living-room

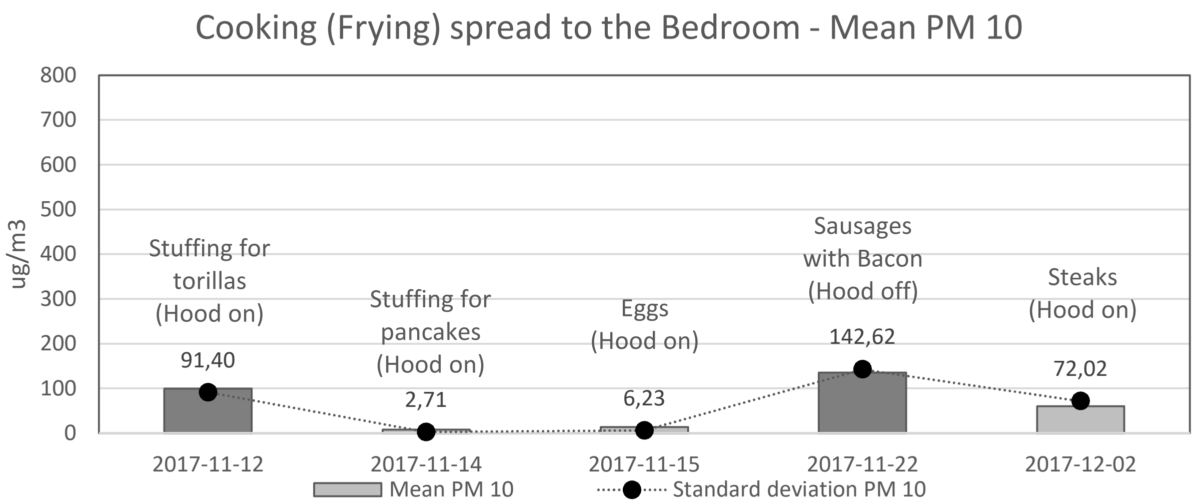


Figure 153 PM 10, Cooking (Frying) spreading to the Bedroom

Event Date	*Details*
2017-11-12 (Referred to as cooking event No. 1)	Two-part event: First peak – cooking pancakes (15:38 – 16:21) Exhaust hood turned on (16:20 – 16:37) Second peak – frying chicken and vegetables stuffing for tortillas, using olive oil. (16:21 – 16:35)
2017-11-14	Frying vegetables/stuffing for pancakes (20:22 – 21:05) Exhaust hood turned on (20:32 – 21:05)
2017-11-15	Frying eggs (16:34 – 16:47) Exhaust hood turned on (16:30 – 16:50)
2017-11-22 (Referred to as cooking event No. 2)	Frying sausages with bacon, using olive oil (14:14 – 14:27) Exhaust hood turned on (14:27 – 14:40)
2017-12-02	Frying pork chops, using olive oil and butter (15:56 – 16:09) Exhaust hood turned on (15:55 – 16:11)

Table 70 Description of cooking (frying) activities

Measurements suggest that highest particle emissions from frying activities are reached when browning[1] meat (cooking events number 1 and 2). That is especially evident when taking into account activity duration. For example, the average time of frying meat is 15min, while frying vegetables (event 2017-11-14) took 43 min and yet particle emissions were lowest of the 5 compared events.

[1] Browning is the process of partially cooking the surface of meat to help remove excessive fat and to give the meat a brown color crust and flavor through various browning reactions. (http://en.wikipedia.org)

However, this is only part of the issue. Major concern in this research project is spreading of particulate matter.
With the kitchen as a source room particles are spreading in this order:

$$Kitchen \rightarrow Bedroom \rightarrow Living-room$$

In some cases, when analyzing spreading of particles to other rooms, duration of the event had to be extended in order to make sure that peak value of the spread is within range. This must be taken into consideration, since describing parameters such as standard deviation and error are dependable on the number of samples. Thus longer time period is likely to affect these values. Additionally, when extending this period, there is a risk of different activities interfering with the result. These effects can be observed in the analysis of the spread. According to the apartment layout, one would expect that with source present in the kitchen second highest particle concentration would be reached in the bedroom and third in the living-room. However, that is not always the case. For example, an event on 12th of November presents a higher average particle concentration in the living-room rather than the bedroom. In this particular situation, after preparation, food has been moved into the living-room, where still steaming food affects particle concentration.
In order to better visualize activities and pollution spread, particle concentration over time has been analyzed in the following graphs for cooking events 1 and 2.

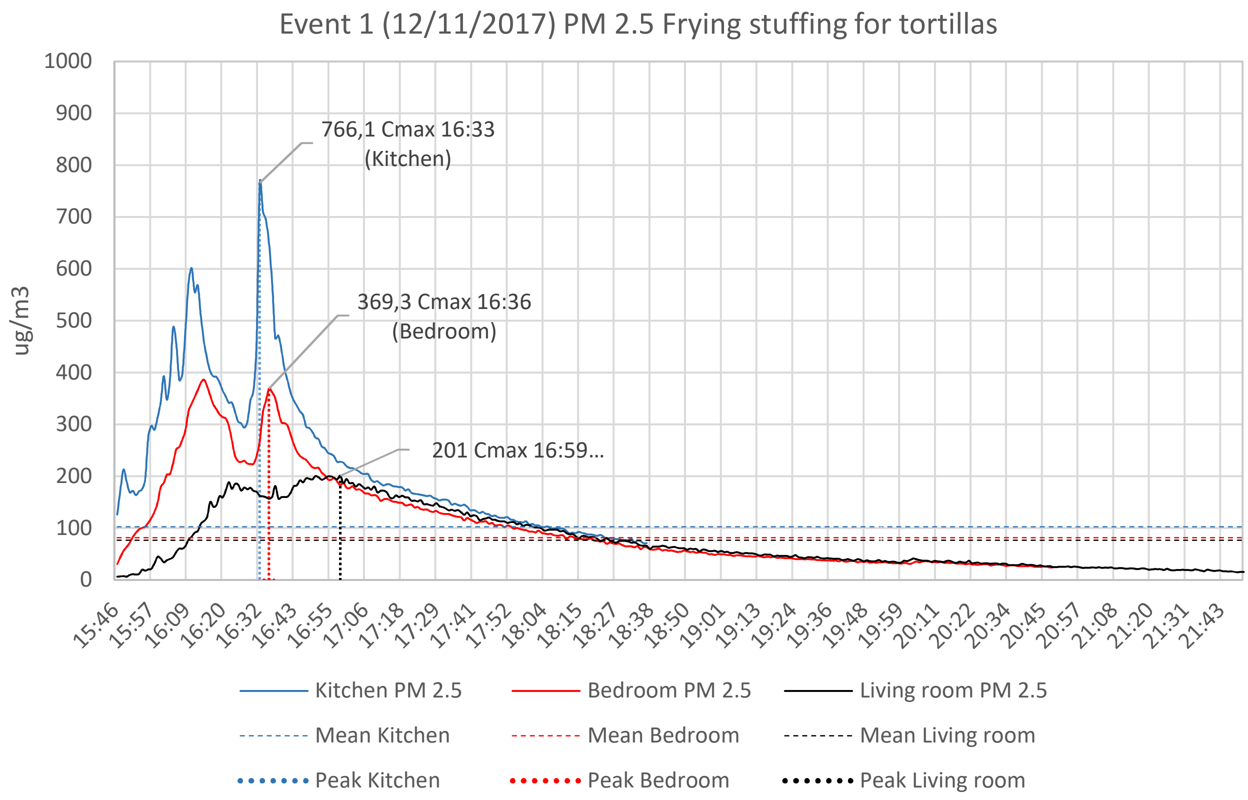


Figure 154 Event 12/11/2017 PM 2.5 particle spread

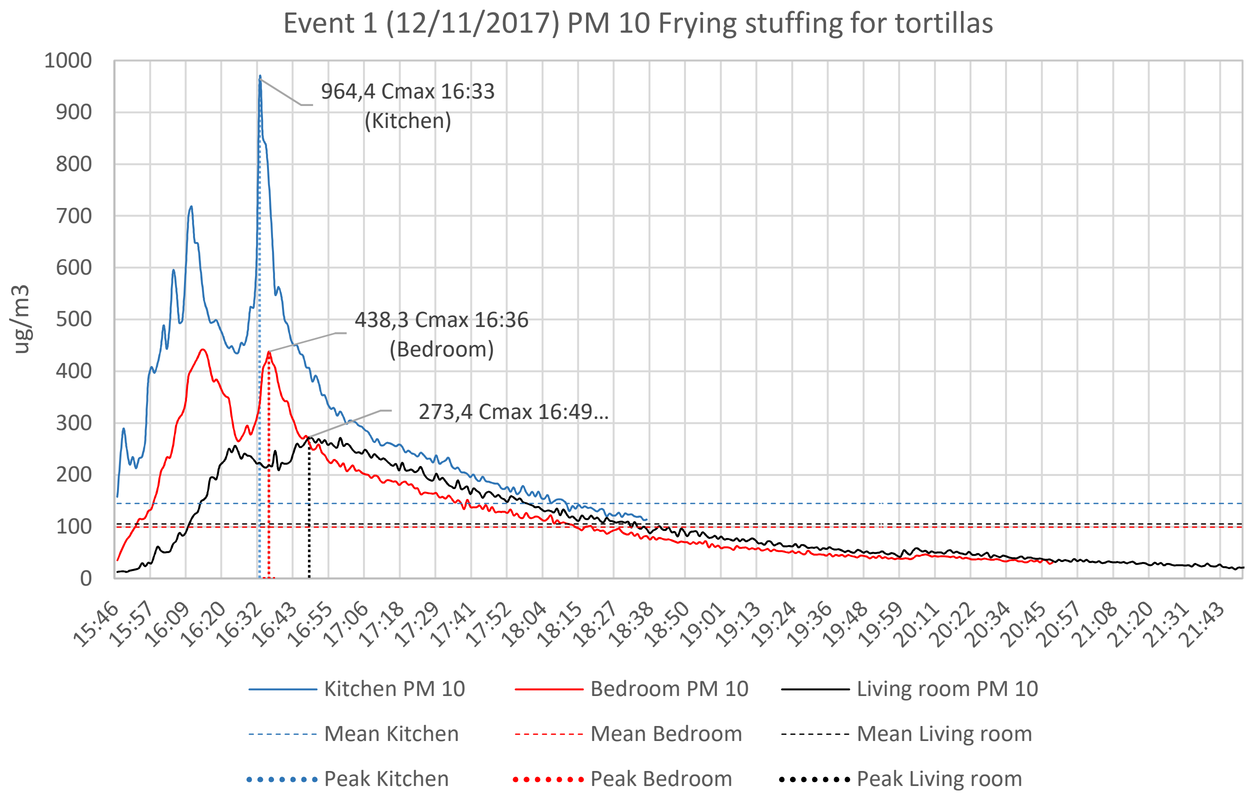


Figure 155 Event 12/11/2017 PM 10 particle spread

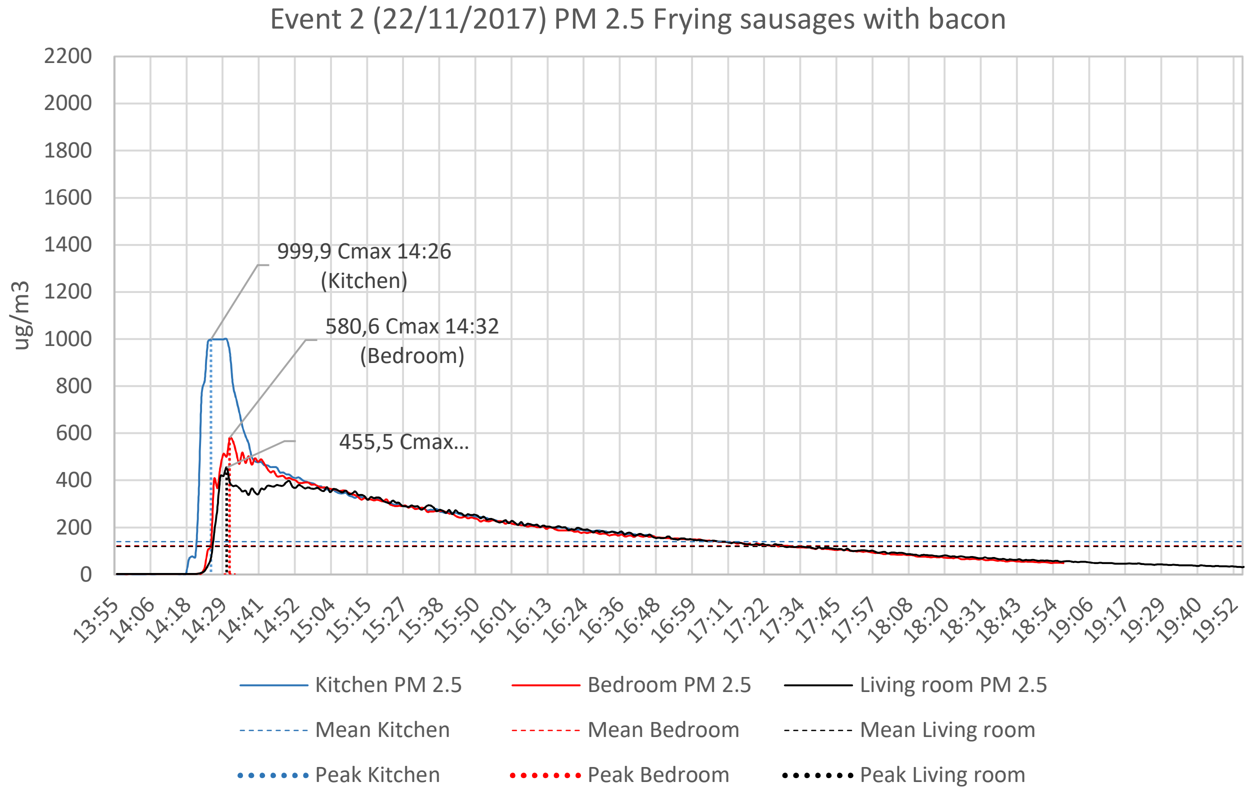


Figure 156 Event 22/11/2017 PM 2.5 particle spread

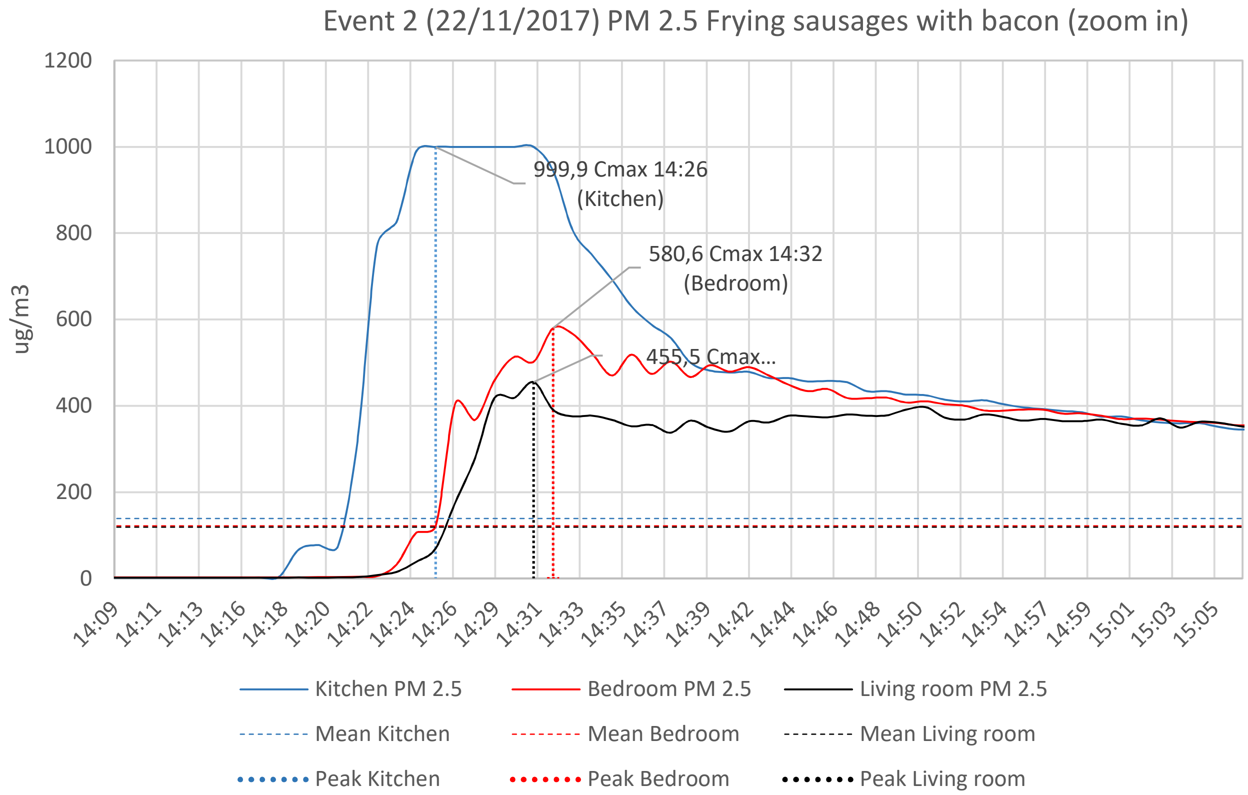


Figure 157 Event 22/11/2017 PM 2.5 particle spread (zoom in)

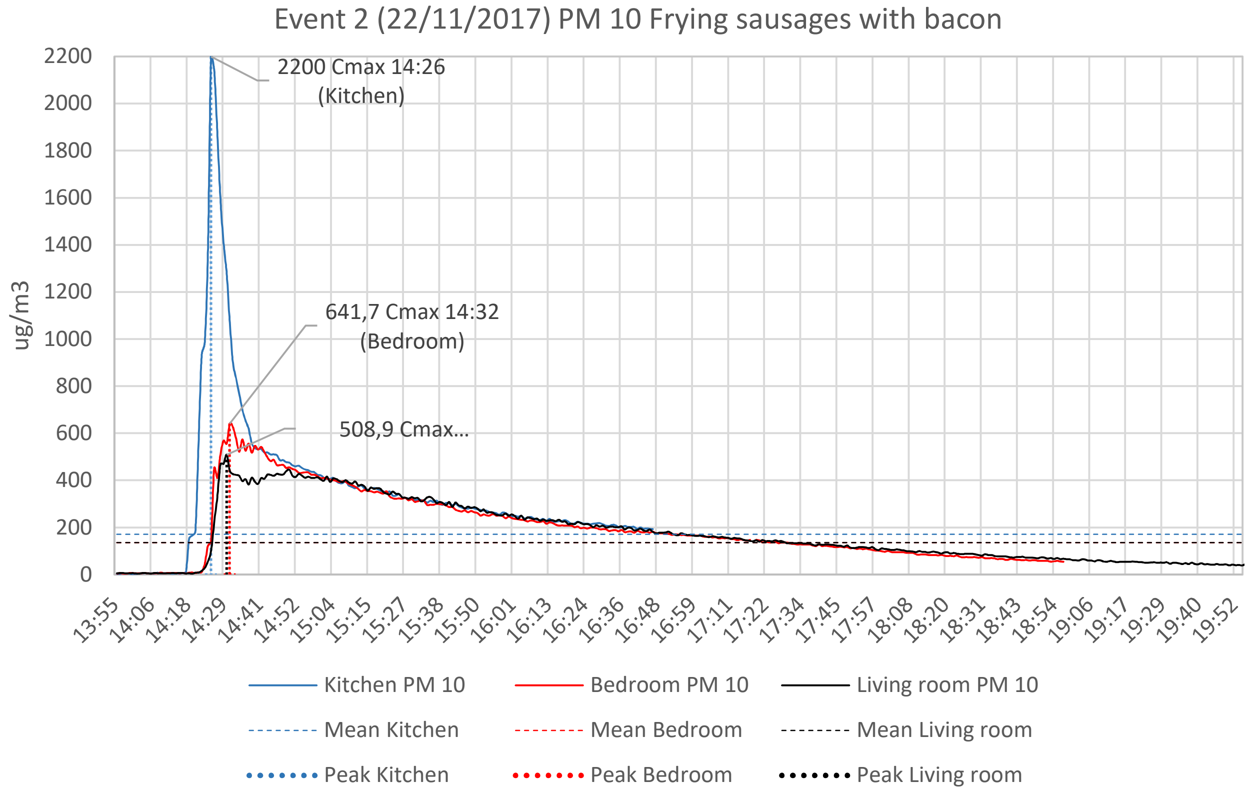


Figure 158 Event 22/11/2017 PM 10 particle spread

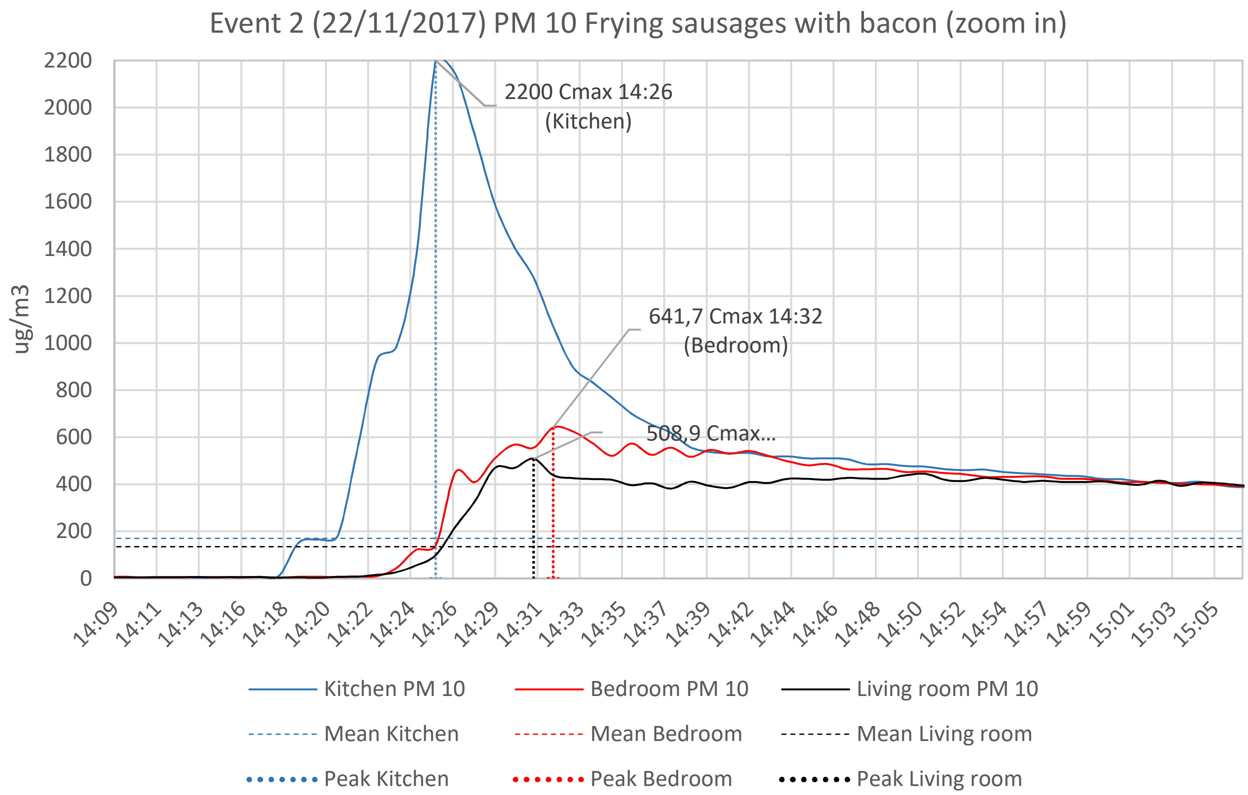


Figure 159 Event 22/11/2017 PM 10 particle spread

Investigated particle concentration distribution over time reveals additional findings. For instance, a suggestion of how to use kitchen exhaust hood, to maximize the benefit. In the first cooking event, kitchen hood has been activated during the second half of the cooking process, while in the second event cooking process had already ceased when exhaust hood was turned on. Here difference has been noticed in particle concentration decay curves. In the event 1 particle concentration is decaying at a slow, but steady rate. While in the event 2 (where particle concentration reached the equipment detection limit) concentration decay is very fast in the beginning, due to functioning exhaust hood. Only the moment when exhaust hood operation has been terminated the slope of particle concentration decay curve becomes similar to the cooking event no. 1. Such result suggests that kitchen exhaust hood should be used not only while cooking but for a certain amount of time after all cooking activities have stopped.

Furthermore, in order to determine a personal exposure to particles, an intake fraction method has been used. (Method description can be found on page 118)

In order to estimate intake fraction, an assumption of uniform particle distribution in the room has to be made. Ventilation rate for the kitchen has been estimated based on CO2 measurements using a dilution equation. In the graph below the inhaled mass of PM 10 particles can be seen for different events. Here the importance of using exhaust hood is visible once again since inhaled particulate matter mass in the kitchen is dominating, thus illustrating the level of exposure to particles experienced by people preparing food. Benefits of using kitchen hood can be estimated when comparing cooking events 1 and 2.

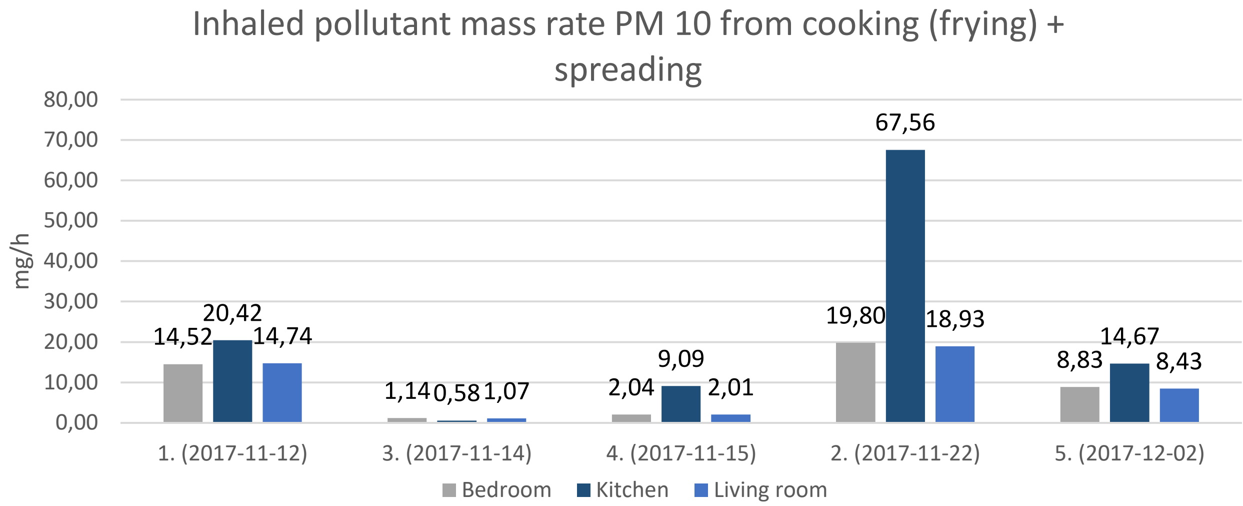


Figure 160 Inhaled pollutant mass rate for cooking events (frying)

However, actual inhaled particle mass can only be evaluated if time is taken into account. In the kitchen were highest particle pollution levels are present people typically do not spend that much time. By using activity log (where people presence is noted) analysis of inhaled particle mass has been updated.

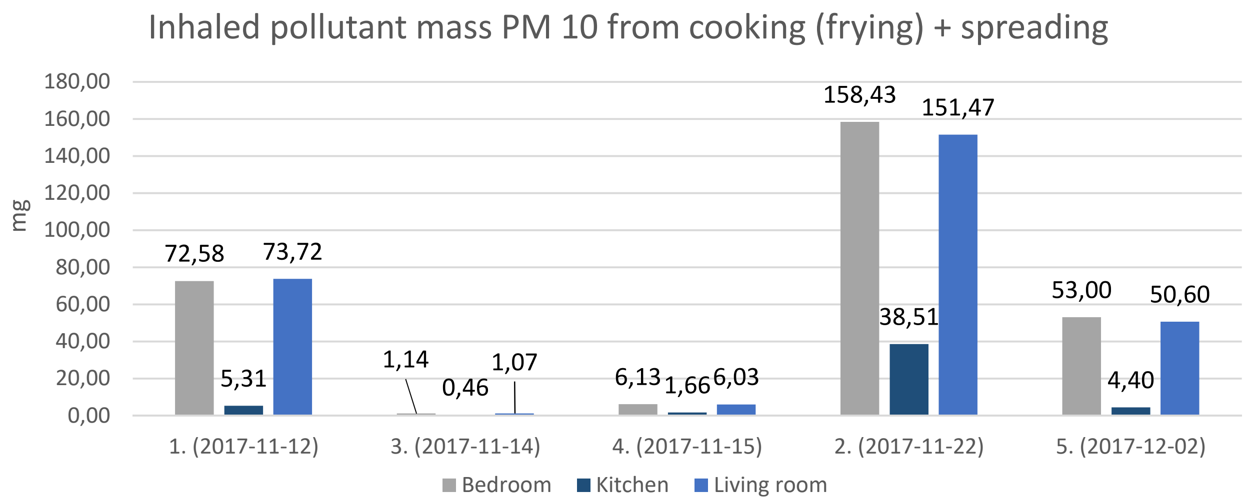


Figure 161 Inhaled particle mass from cooking activities (based on intake fraction and people presence)

This analysis shows the magnitude of the particle spread problem. While in the kitchen were particle level peaks are highest, actual exposure to particles is not that big, because of an overall small amount of time spent cooking. In the other rooms, where people are present for a prolonged period, inhaled particle pollution mass is dominating.

4.3.3 Location 3

This apartment was previously described in detail and can be found under Measurement Campaign chapter 2.1.3. It is located on the 5th floor, in the mansard of the block. The apartment has natural ventilation and radiator heating. Force extraction is placed in the bathroom but only active when the bathroom is used, being inactive the rest of the time, plus the kitchen hood.

The measurement campaign undergone in this specific apartment took place in between 11/11/2017 and 05/12/2017. There were 4 sensor boxes installed in each room except the bathroom. However, a few times the sensor placed in the hallway was taken outside, on both sides of the building, to measure the outdoor concentration. The sensors are built to capture PM 2.5 and PM 10 particle concentration. Sensor placement is done according to the usage of the room, bedroom and living room was set at sitting height while the kitchen sensor is placed at standing height. The position of these sensors can be seen in the following plan.

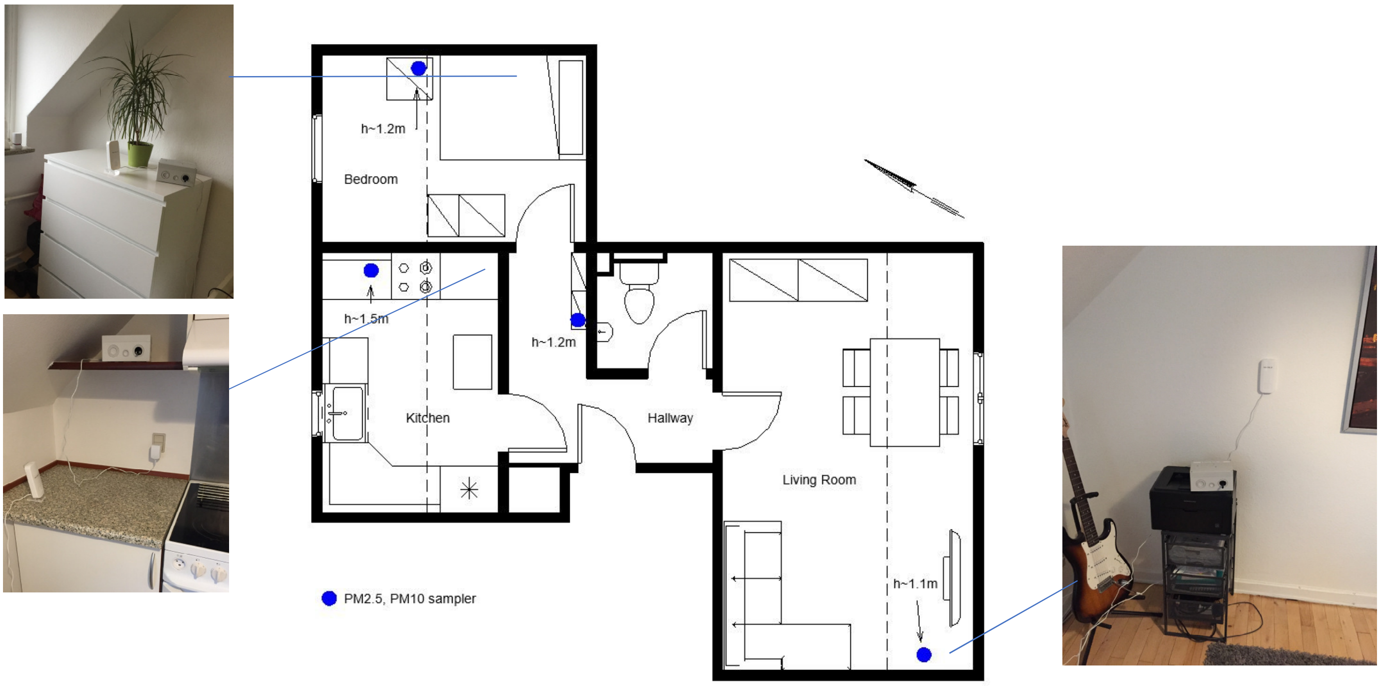


Figure 162 Vestre Ringgade 230, 5tv Particle Sensor Placement

Following, a table with different indoor surfaces is presented together with a picture of each room:

	**Hallway** Surfaces: Floor - Wooden Parquet Walls – Wall Paper + White Paint Ceiling – Plaster + White Paint

	**Kitchen** Surfaces: Floor – Vinyl Surface Walls – Wall Paper + White Paint Ceiling – Plaster + White Paint
	**Bedroom** Surfaces: Floor - Wooden Parquet + Small Carpet Walls - Wall Paper + White Paint Ceiling - Plaster + White Paint
	**Living-Room** Surfaces: Floor - Wooden Parquet + Small and Big Carpet Walls - Wall Paper + White Paint Ceiling - Plaster + White Paint
	**Bathroom** Surfaces: Floor – Tiles + Small Synthetic Cover Walls - Plaster + White Paint Moisture Resistant Ceiling - Plaster + White Paint Moisture Resistance

Table 71 Surfaces - Vestre Ringgade 230

Typical particle pollution

The starting point of the particle analysis is directed towards comparison of the mean 24h measured indoor particle concentration, with the World Health Organization advisement over the indoor particulate matter pollution levels.

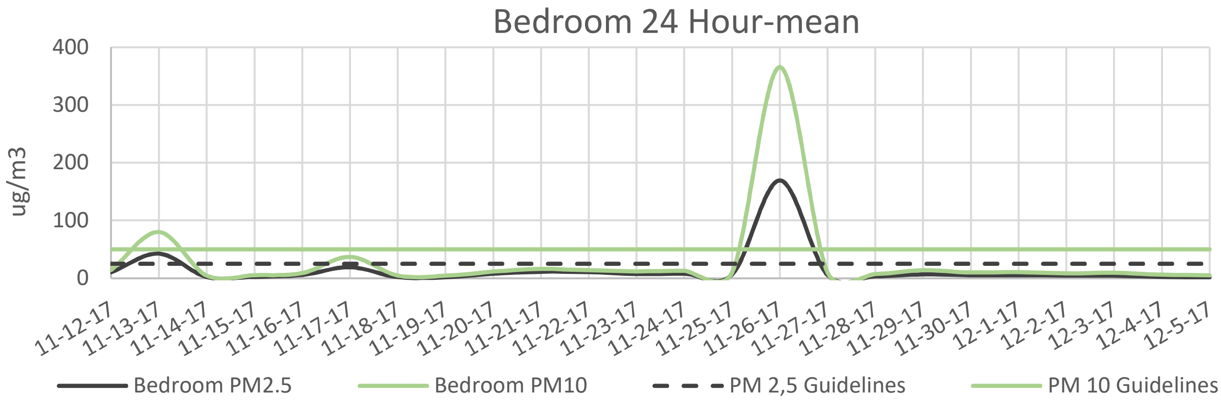


Figure 163 Bedroom 24h mean - Location 3

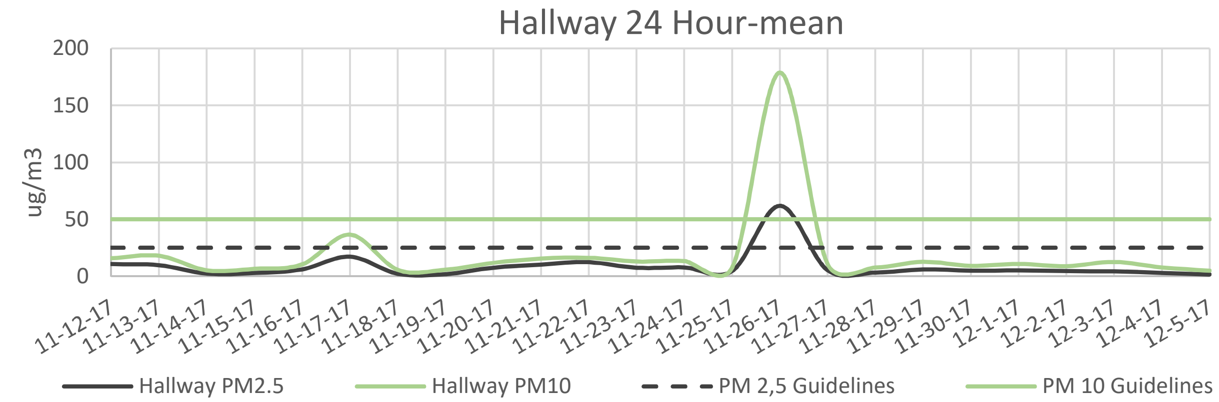


Figure 164 Hallway 24h mean - Location 3

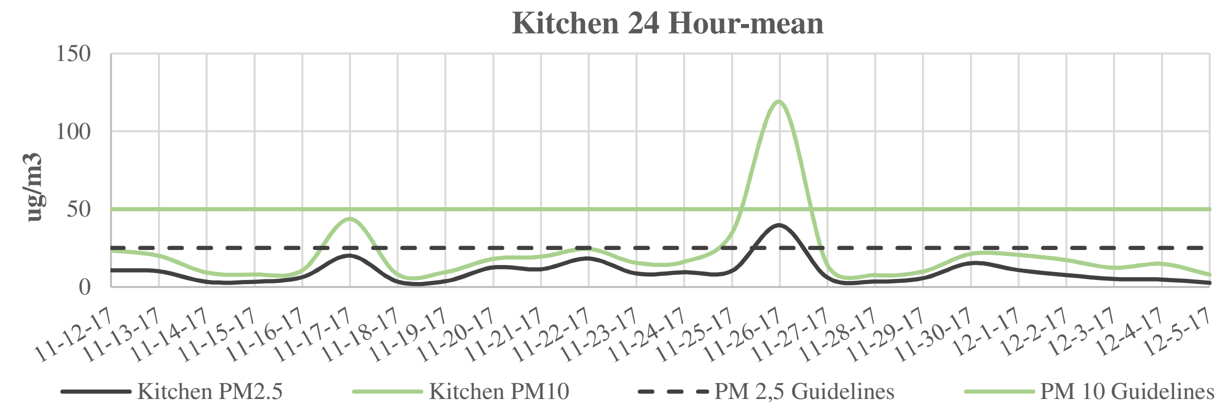


Figure 165 Kitchen 24h mean - Location 3

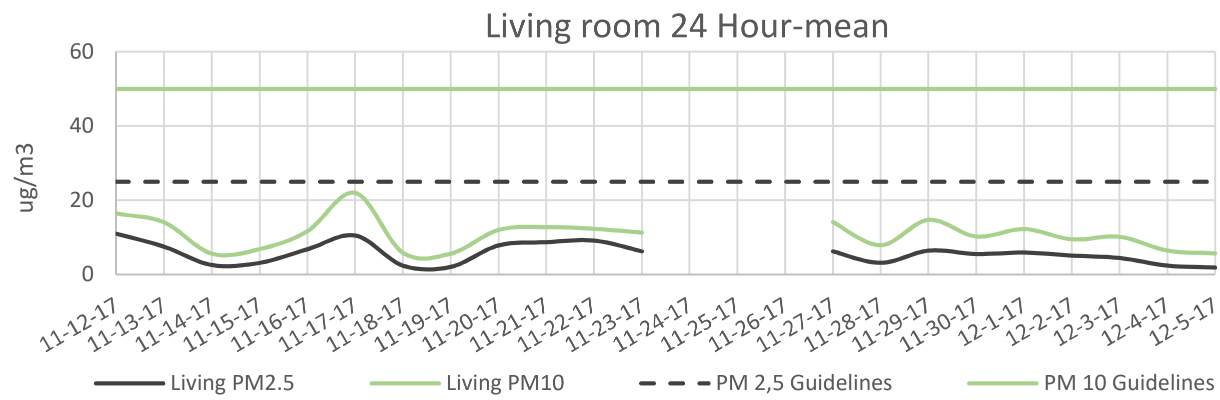


Figure 166 Living Room 24h mean - Location 3

Overall, the concentration of the particulate matter is within the recommended guideline values for both PM2.5 and PM10. However, the issue emerges in some nights when the indoor pollutant reaches extraordinary high concentrations, considering that this is a mean 24h value. This issue is first investigated. The following graph is showing the particle concentration during such an event on 26/11, the rest of the graphs can be seen in the appendix.

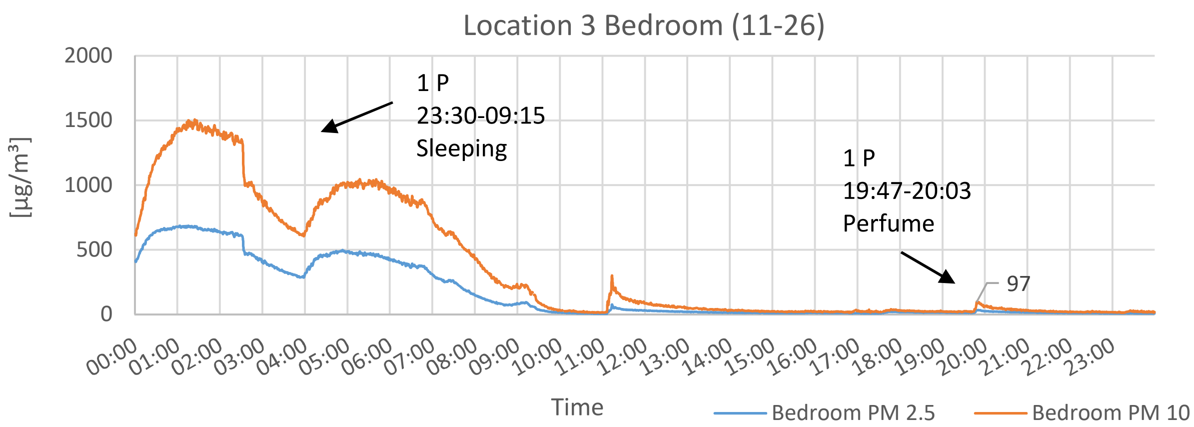


Figure 167 Start of High Concentration - Bedroom

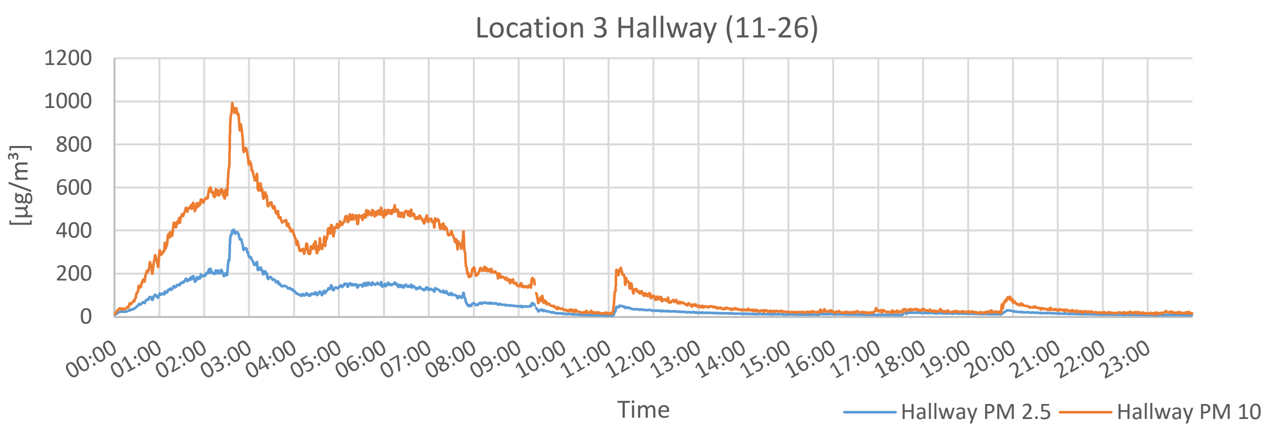


Figure 168 Spread of High Concentration - Hallway

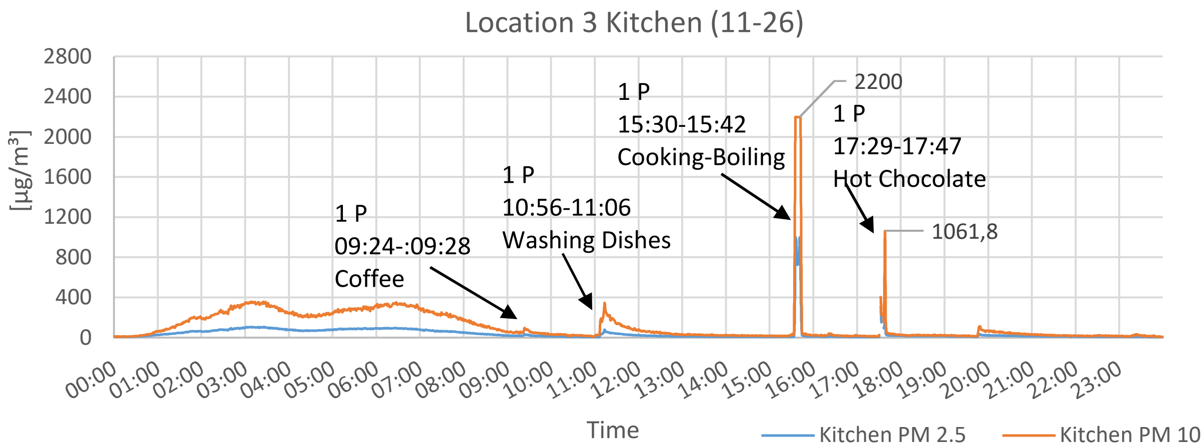


Figure 169 Spread of High Concentration - Kitchen

The particles develop over the entire night; the starting point is in the bedroom. The pollutant starts to increase around midnight and spreads to the hallway, from there, part goes to the kitchen and assuming, the part will go to the living room area. However, the sensor in the living room malfunctioned this specific night.

It is noticed that around 2.30 am, the levels are dropping until 4 am when they start increasing again. The charts have descriptions of activities that took place at this specific time. There is no activity observed during the production of the pollutant. Further, the area was checked for any kind of factory/restaurant or any facility that could produce such high contaminations. As expected, since this is just a residential area, there are no such places.

The phenomena cannot be explained and would need testing in order to accurate find and trace this specific particulate matter production.

It is important to note that a theory may exist. For example; The sensor in the bedroom was placed on top of a drawer that had the targeted height. In addition, the drawer is filled with makeups, perfumes and different body lotions and creams. The theory is that this could serve as a pollutant addition in the room, however, the parameters of this exact cause are unknown thus there is no knowledge of how this further influenced the pollutant concertation.

During the measurement campaign, a detailed log of all the activities in all the rooms was registered. For a better overview, the next graph indicates a regular day with different activities that took place in the kitchen area, in the appendix can be found the rest of the graphs.

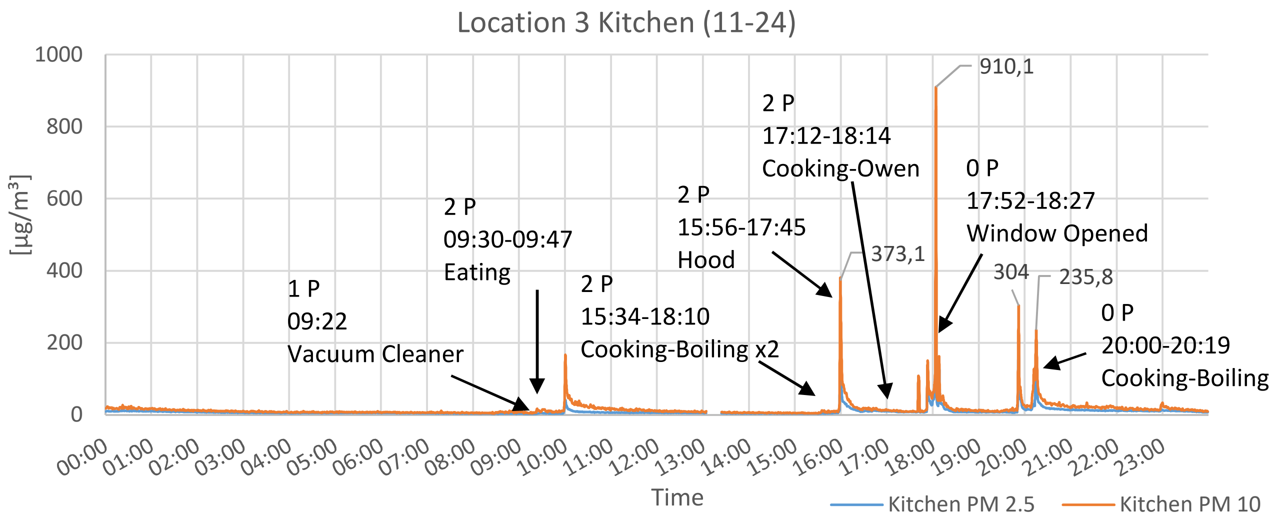


Figure 170 Daily chart with activities for particle data treatment

Each day was created a resembling chart like the one above, for each room. The data treatment is based on identified activities and their particle emission, both PM2.5 and PM10. The peaks that have no activity written means that the schedule is incomplete, and the source of the particle emission is unidentified.

All the activities are transposed into a general table that contains all the necessary information, such as, type of activity, duration, average emission, peak emission, standard deviation/error and more. This presents a good overview of which activities need to be further investigated due to their spread or high particulate matter emissions.

1. Activities that result in spreading – usage of perfume in bedroom

The activity that results in spreading is specifically the usage of perfume, in this case, the source room is the bedroom. Further, the mean value for this specific activity is presented for both, PM2.5 and PM10 with standard deviation and standard error for each independent event. The colored chart indicates the source room while the grayed ones represent spreading of pollutant. See following graphs.

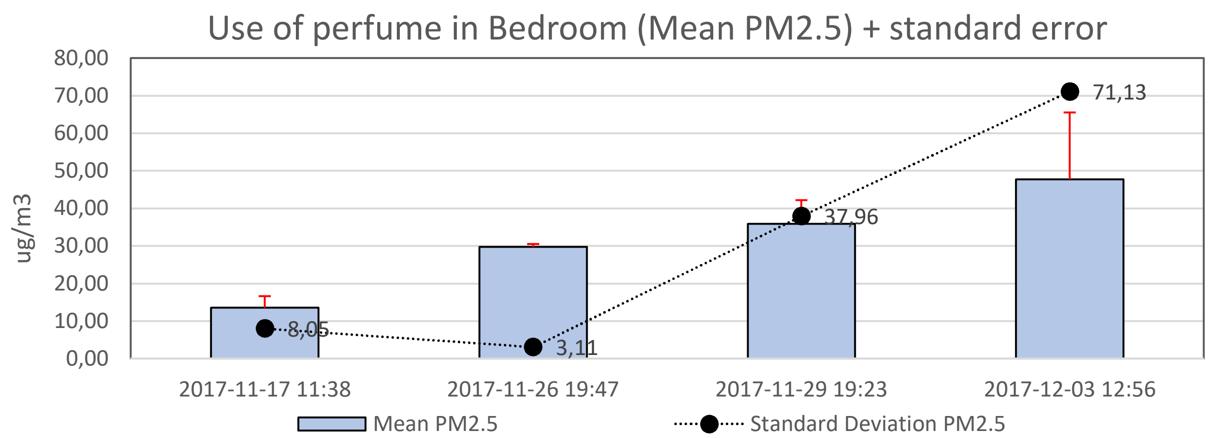


Figure 171 PM2.5 Use of perfume in Bedroom

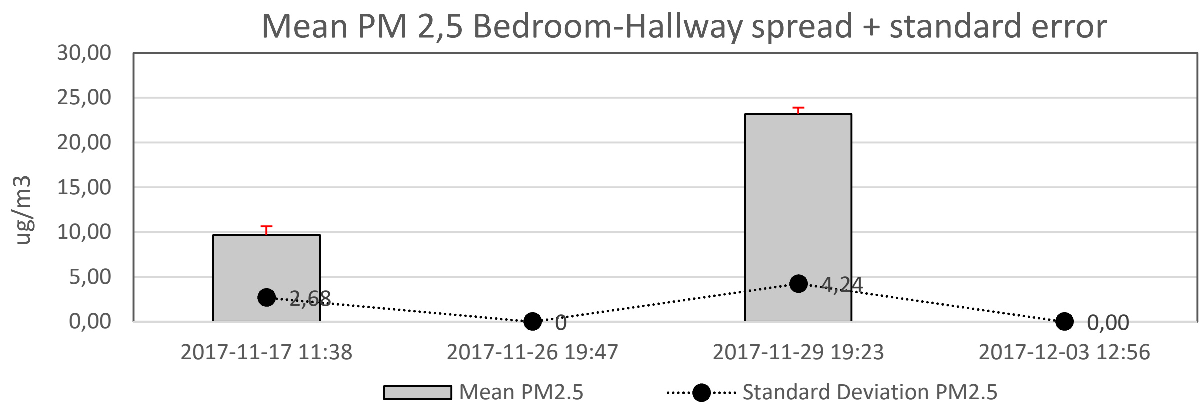


Figure 172 PM2.5 Use of perfume in Bedroom- Hallway Spread

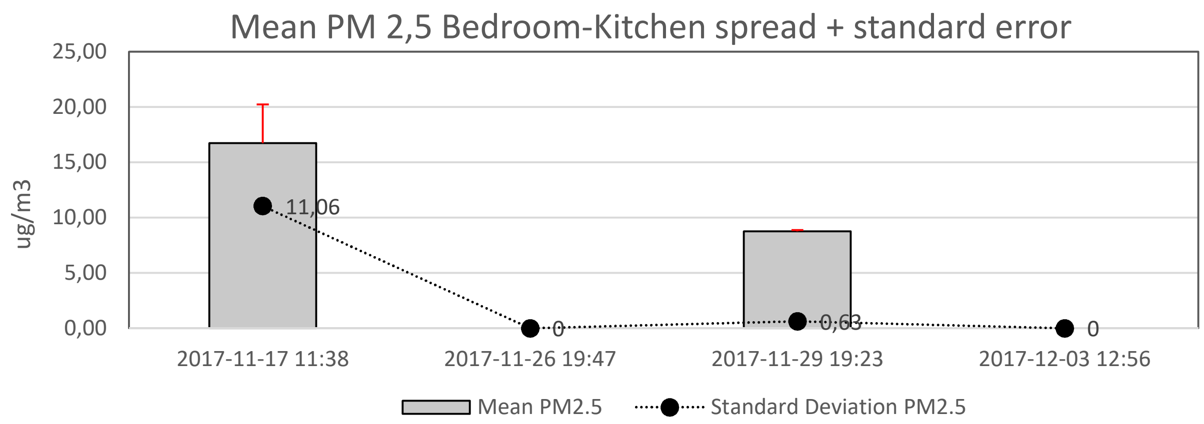


Figure 173 PM2.5 Use of perfume in Bedroom - Kitchen Spread

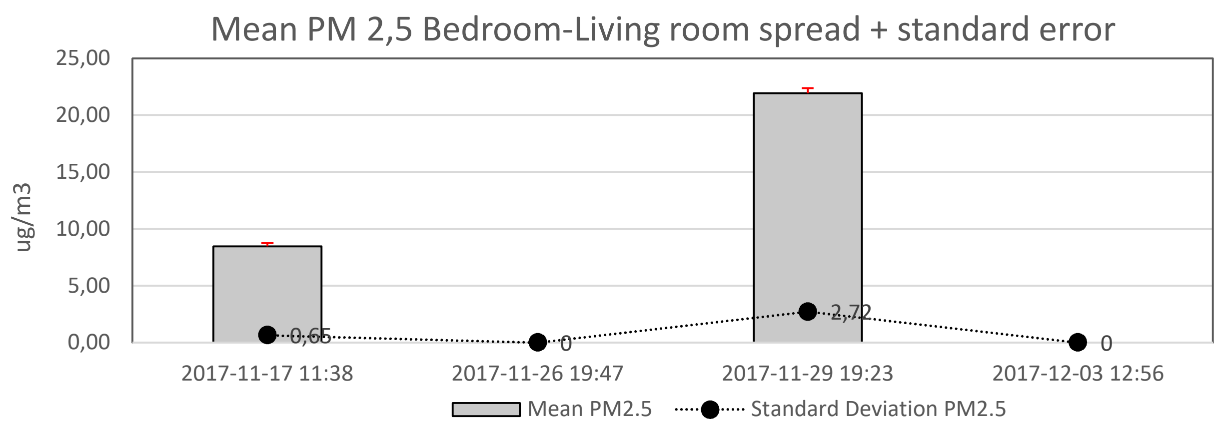


Figure 174 PM2.5 Use of perfume in Bedroom- Living Room Spread

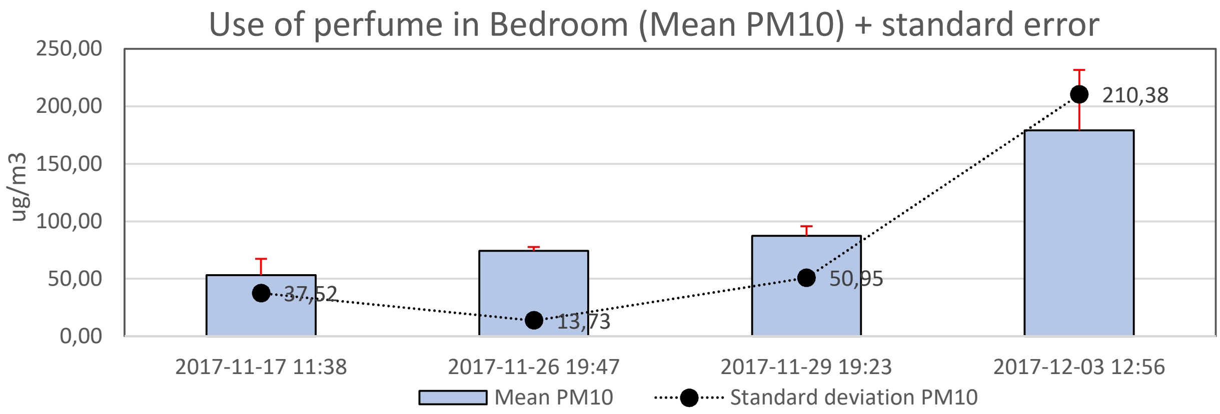


Figure 175 PM10 Use of perfume in Bedroom

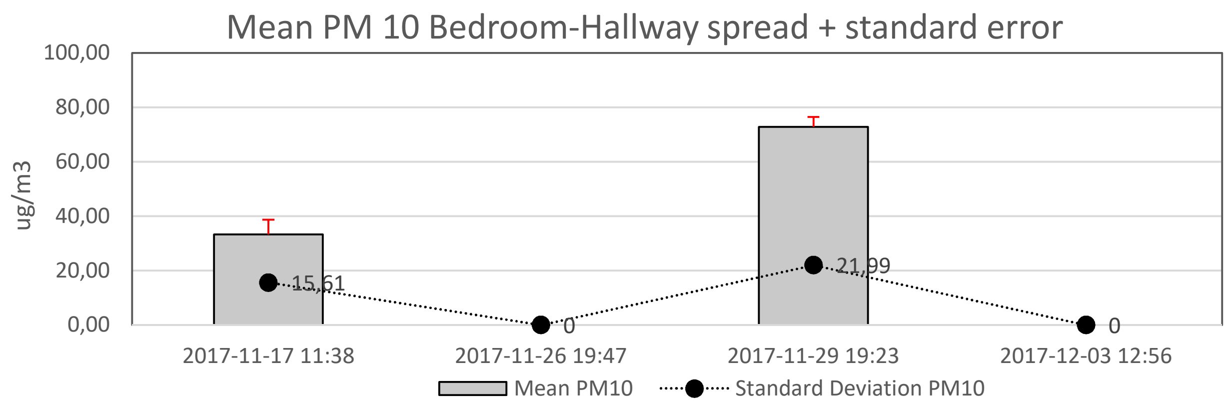


Figure 176 PM10 Use of perfume in Bedroom- Hallway Spread

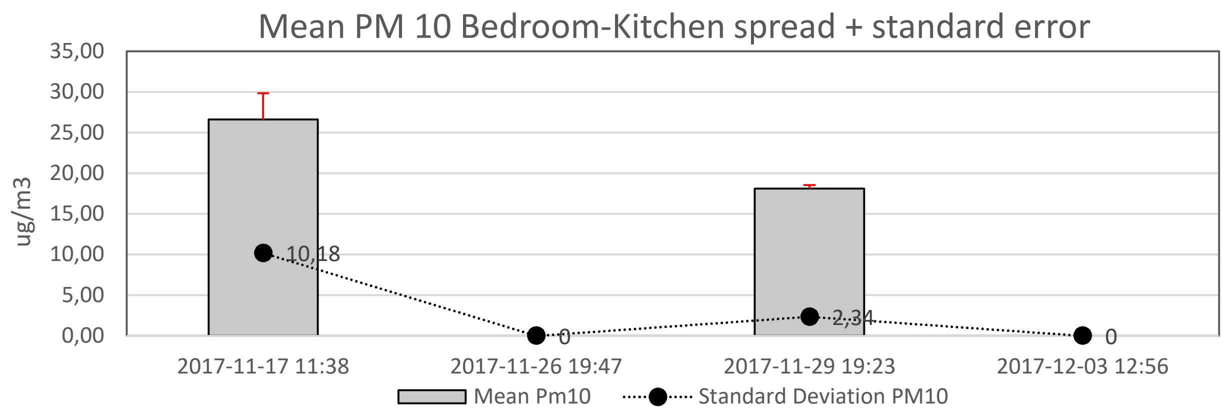


Figure 177 PM10 Use of perfume in Bedroom - Kitchen Spread

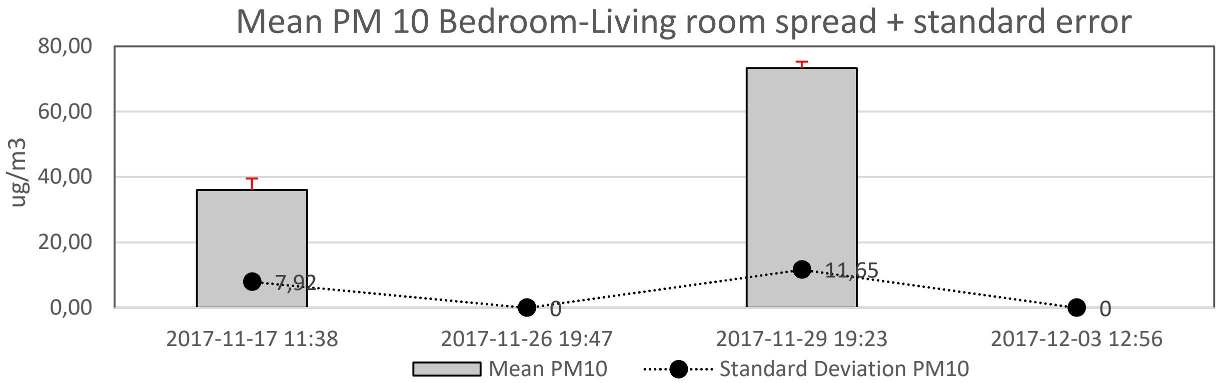


Figure 178 PM10 Use of perfume in Bedroom- Living Room Spread

Considering the above visual data regarding PM2.5, the spreading does not always occur, and when it does, it is shallow and inconsistent. The source concentration varies as well, with the highest mean value from the event that has spread of 35,93 µg/m^3, to the first room it reaches, hallway, the value drops down to 23,18 µg/m^3. Further, the values are too small that other indoor activities like walking or moving around is noticeable and already interfere with results.

The standard deviation is generally low, thus indicating that the data was not increasing from a moment to another, but its range is more within the mean values. The difference can be observed in the source room but to only some extent, the last two events from 29/11 and 03/12. The peak values are higher than the other two events, hence the rapid increments and higher standard deviation. As a direct influence, the standard error is low as well, making the data trustworthy and accurate.

On the other hand, PM10 values are easier noticed, with mean values from the smallest to the highest event emission of 53,27 µg/m^3 up to 179,05 µg/m^3. The spreading, however, occur in the same 2 events.

For a better overview, the following graphs show the full events when spreading takes place, in 17/11/2017 at 11:38 and the event from 29/11/2017 19:26.

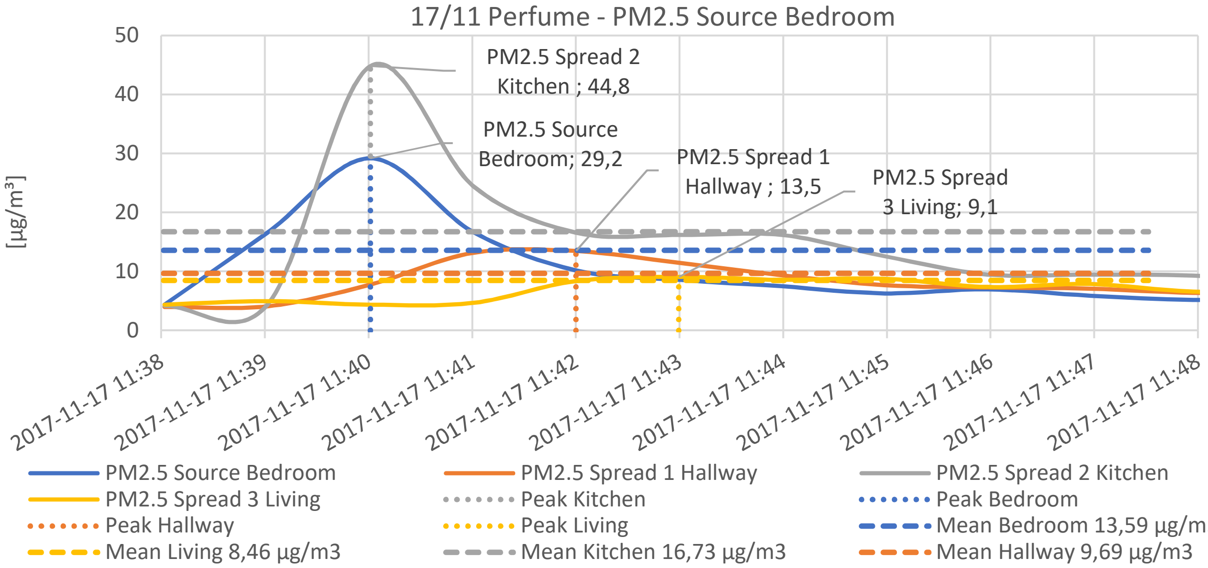


Figure 179 17/11/2017 11:38 Perfume usage in Bedroom + Spread PM2.5

The blue line indicates the source room, Bedroom, while the gray line is the kitchen. Since the kitchen line is higher, means that there is an unrecorded event or simply resuspension that interfere with the spreading. The variation in PM2.5 is noticeable in the other rooms but with a slight increase. However, the pattern of the spread seems logical, with peaks starting in the source room and distributing towards the hallway and the rest of the apartment.

Bedroom ➔ Hallway ➔Kitchen & Living Room

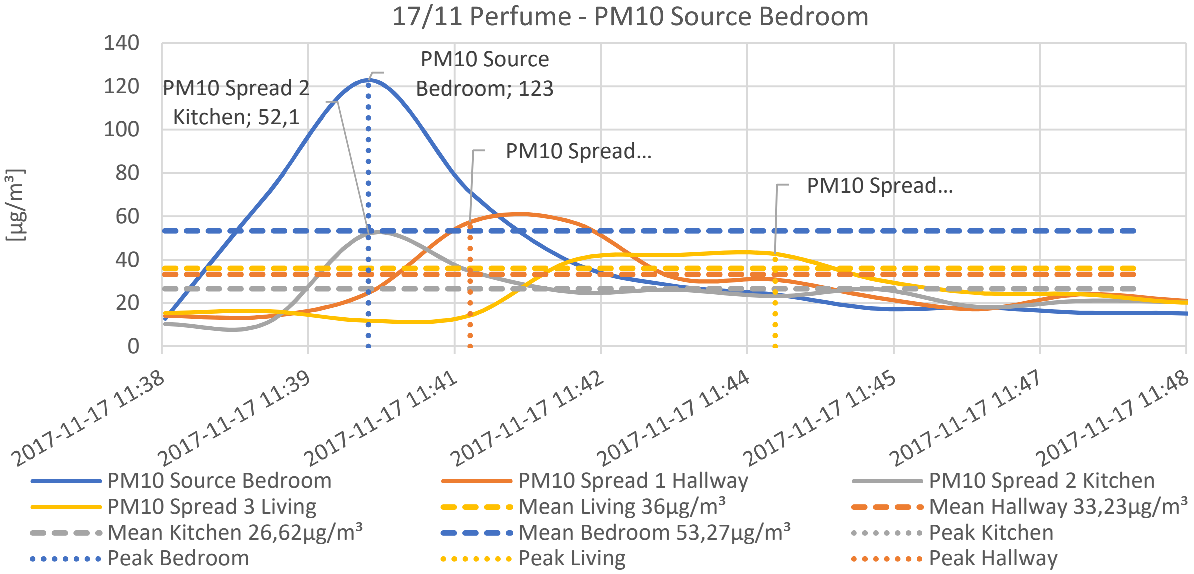


Figure 180 17/11/2017 11:38 Perfume usage in Bedroom + Spread PM10

The vertical dotted lines indicate the time when the values reached the peak moment. The variation in peaks is quite diverse, by the time it reaches the hallway it already lost half of its concentration, but no doubt that it follows the specific apartment layout.

Further, for a better comparison, the second spread from perfume on 29/11 is analyzed.

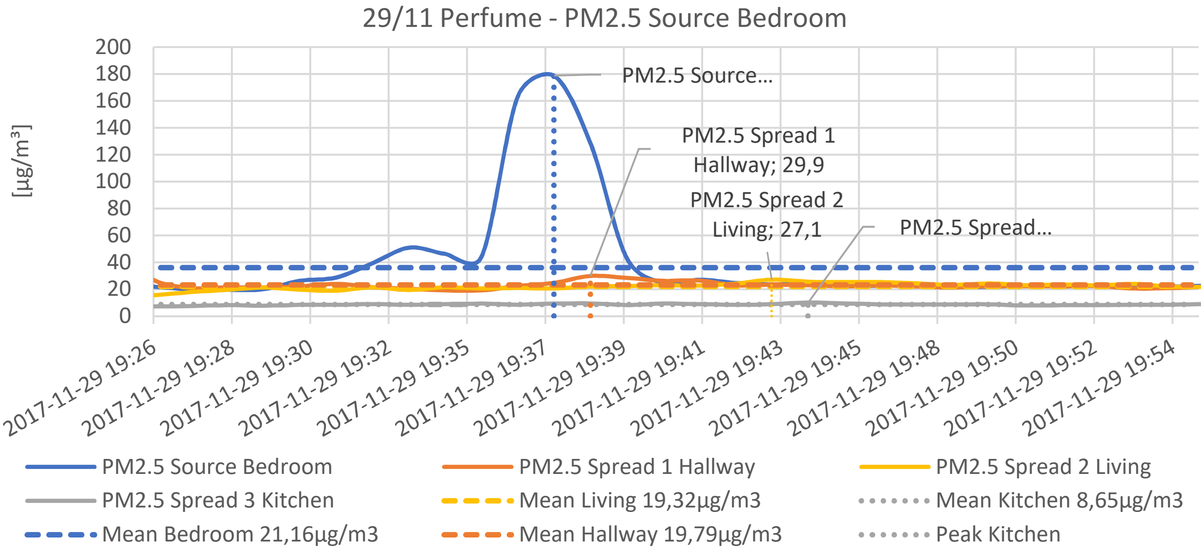


Figure 181 29/11/2017 19:26 Perfume usage in Bedroom + Spread PM2.5

This event is rather different in spread and peaks. If before the max peak for PM2.5 was 29,2 µg/m^3, in this specific event the peak goes up to 178,7 µg/m^3. When it comes to spreading, only a fraction goes further to the other rooms. As if there is almost no spreading for PM2.5 in both events.

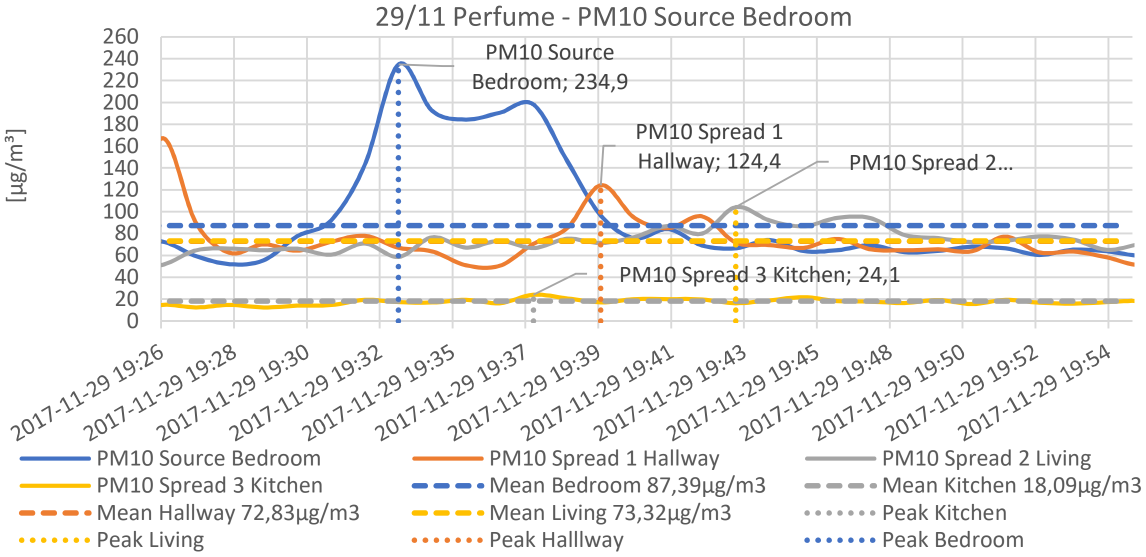


Figure 182 29/11/2017 19:26 Perfume usage in Bedroom + Spread PM10

On the other hand, PM10 has quite high values and clear spread to the other rooms, except the kitchen. The spread is first noticed in the hallway with rather high concentrations as well as in the living room area with resembling results.
From the highest peak that occurs around 19:32 in the source room, until it reaches substantial lower concentrations it takes around 30 minutes. This can be assumed and conclude, that only infiltration as well as natural ventilation based on people behavior, with no active mechanical extraction, keep the pollutant level quite high for long period of time, giving it time to spread to other areas.

Each of these theories based on the gathered data make an important contribution to our understanding of the particulate pollutant behavior in such types of apartments. However, it is important to see what would be the general risk of human exposure. To accomplish this step, intake fraction calculations were made for these specific events, with or without spreading.

The intake fraction calculation methodology can be found at page 118. It is based on the concentration of the pollutant, the pollutant release, cumulative mass inhalation rate of the pollutant, ventilation rate, number of people that are exposed during an event and their activity level that transposes into breathing fraction as well as the room volume that the event takes place. The assumptions made regarding the intake fraction is that the pollutant release is nonreactive, as well as the indoor air is mixed with a constant ventilation/infiltration rate.

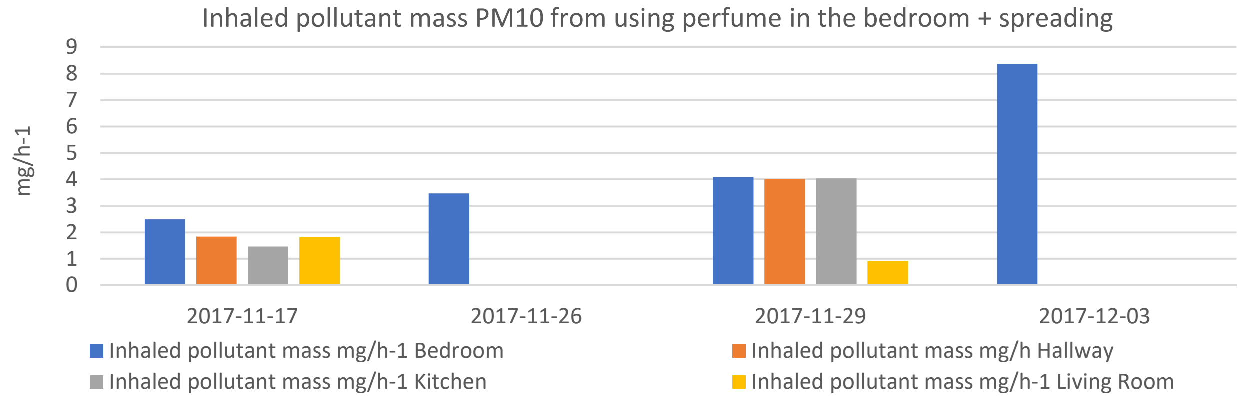


Figure 183 Inhaled pollutant mass PM 10 from using perfume in the bedroom

Moreover, the standard deviation together with the standard error was calculated to indicate how scattered and how accurate are the intake fraction results based on the calculation of each event in each specific room, being a source or spread.

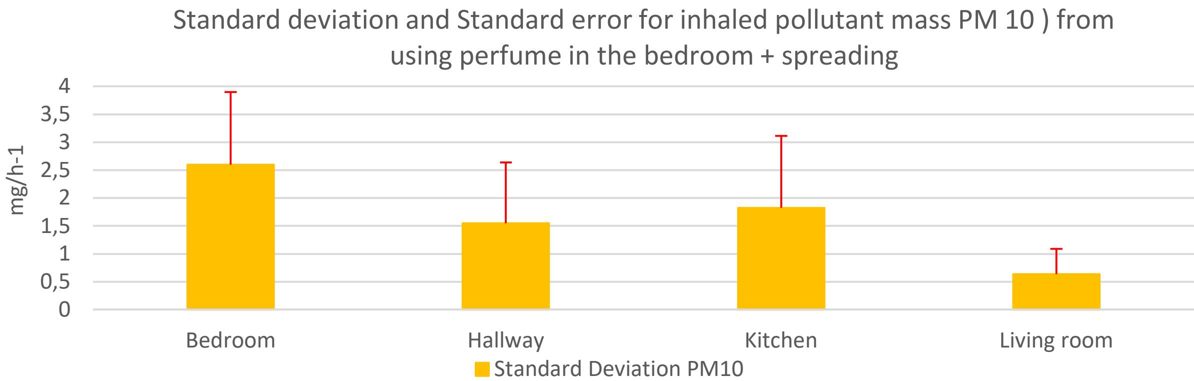
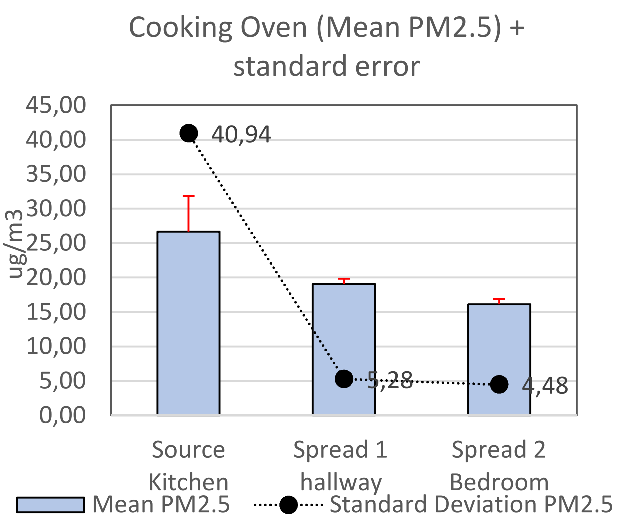


Figure 184 Standard deviation and Standard error for inhaled pollutant mass PM 10 from using perfume in the bedroom

2. Activities that result in spreading – cooking (oven)

Next activity that results in spreading is cooking, in this case using the oven on 24/11/2017 from 17:12 to 18:14. This single activity was investigated due to signs of emission dispersion throughout the apartment. Based on the source room, kitchen, the mean values have a high standard deviation. This specific issue is expected as a result of particle emission frequency, as in the time of particle release.



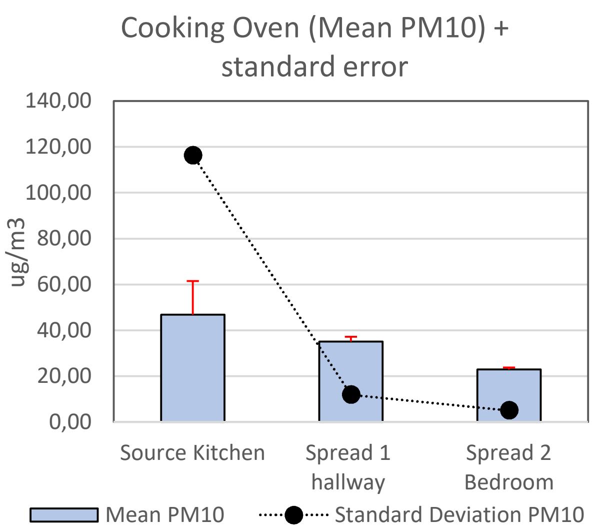


Figure 185 Cooking using the Oven - Spread PM2.5 / Cooking using the Oven - Spread PM10

Graphically, it was possible to determine the particle emanation that correlates with the opening of the oven during cooking, as well as retrieving the food from the oven. Even though the activity itself lasted for 01:12 (hh:mm), there are sharp spikes that reach high concentrations, but only for a short time period, when average values are made, the range of particles are quite different, hence the high standard deviation. In this individual activity, the hood was turned on as well as the window was opened. Even though there was a lot of air coming into the room, spreading still occurred.

Further, the peaks of this activity are presented in all rooms where spreading exist. This can prove that the actual spreading in PM2.5 range is generally low with small increments. It can be neglected since their peak values are not much different from regular particle pollution.
On the other hand, PM10 pollution is higher as expected since they comprise the PM2.5 as well. Max values for spreading is not that high to be treated as an issue but more as an observation.

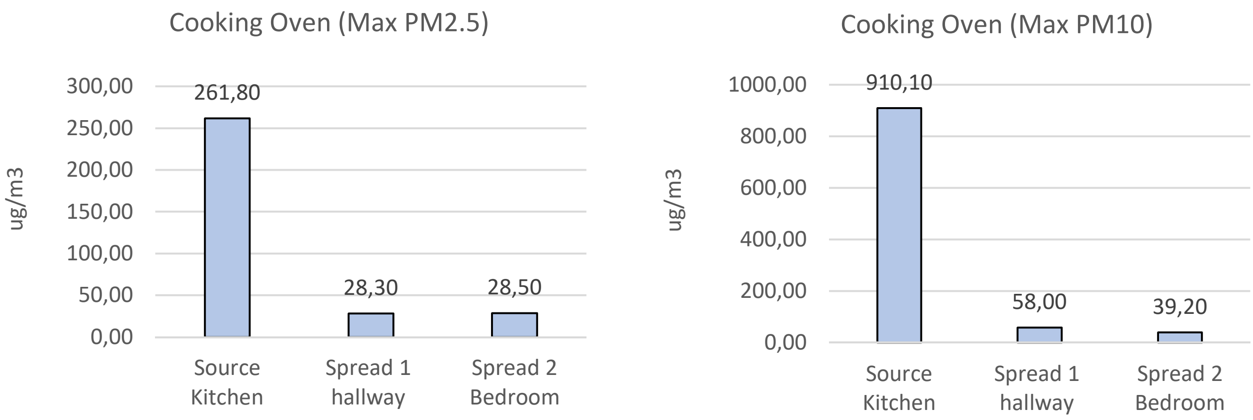


Figure 186 Max PM2.5 Values / Max PM10 values

Intake fraction was calculated for this event and each room it spread over time. The results are presented in the following chart.

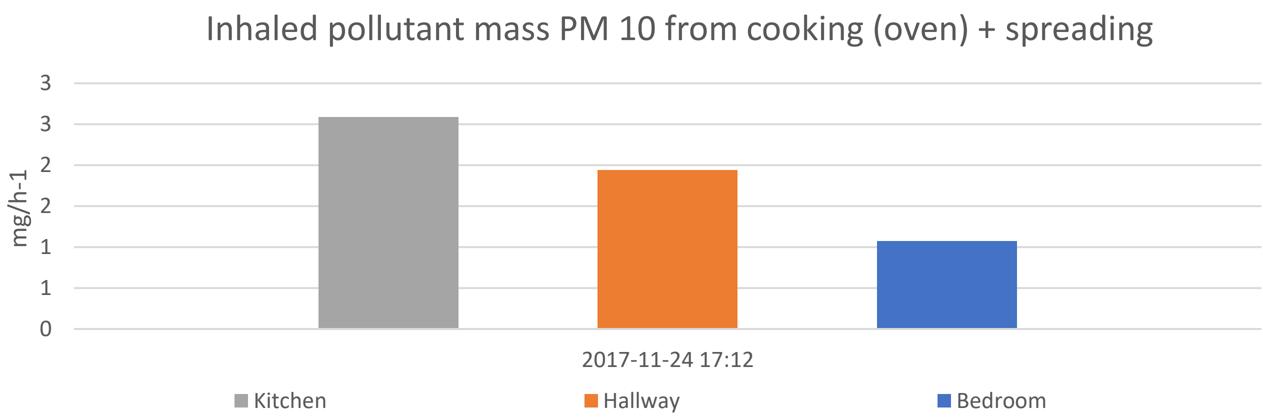


Figure 187 Inhaled pollutant mass PM 10 from cooking (oven) + Spreading

Even though there are many ongoing activities during the measurement campaign, planned or not, the spreading, in general, is shallow and neglectable. There are many parameters that influence this matter. For instance, it can be assumed that the apartment layout is playing an important role in particle distribution and therefore, spreading occurs mostly from activities like perfume usage in the bedroom since the door is opened all the time there.

Particle release is generally high in the kitchen but parameters such as high infiltration, usage of kitchen hood/opening the window and keeping the door closed, are playing an important role that will be described in the next point.

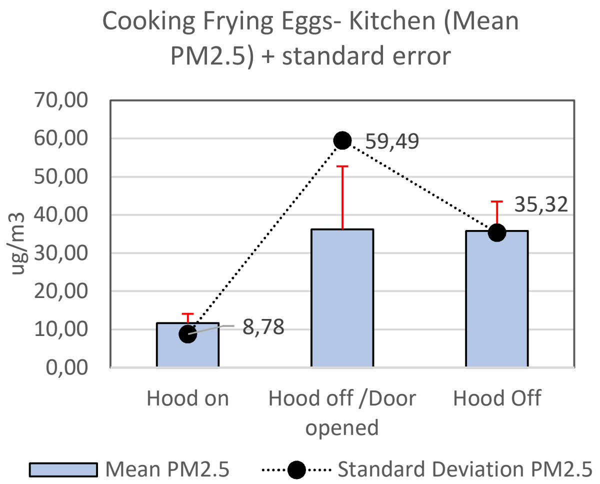
3. Frying Test

Intentions of this test are directed towards usage of kitchen hood and its efficiency as well as a spread possibility due to opened doors. Therefore, in 3 different days, the same activity type was repeated, frying eggs, but with different boundary conditions. First, frying is done with the hood turned on, and the door is closed. Secondly, the eggs are fried with the kitchen hood off but with an open door. Last but not least, the kitchen hood was off as well as the door was closed, the period of frying was kept longer, and the eggs are scrambled and not just simply fried.

Date	Activity	Duration (min)	Comments
15/11/2017 09.34	Frying Eggs (6) Event 1	12	Door closed, Hood on
19/11/2017 10.16	Frying Eggs (6) Event 2	12	Door Opened, Hood off
20/11/2017 13.21	Frying Eggs (6) Event 3	20	Door Closed, Hood off

Table 72 Frying test - activity description

The test results are being presented through mean values of PM2.5 and PM10. From beginning is noticed that when the hood is on, the mean value is lower compared with the other two cases. Furthermore, When the hood is off, and the doors are opened, the standard deviation increased. Further analysis is made in this case.



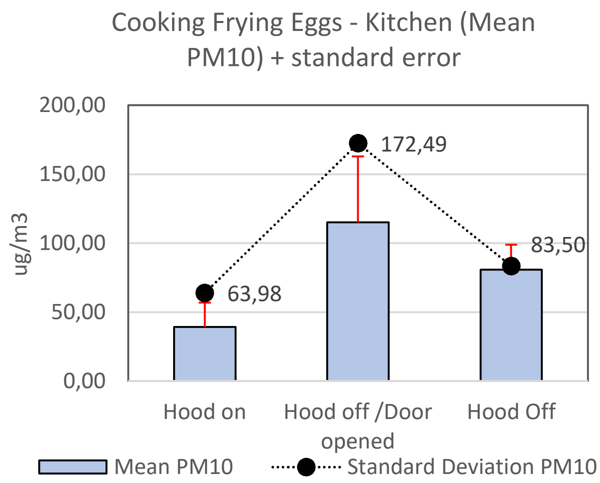
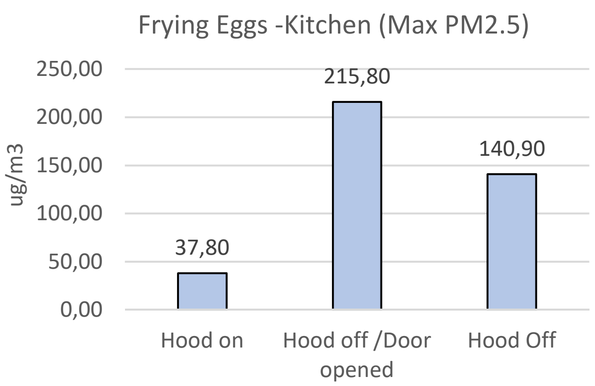


Figure 188 Mean PM2.5 - Frying Eggs / Mean PM10 - Frying Eggs

To have a better overview, graphs with max concentration is presented.



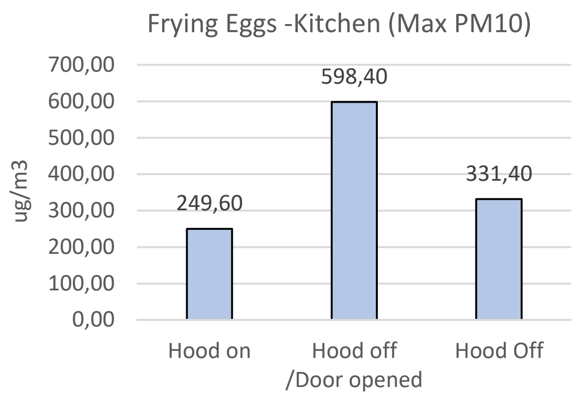


Figure 189 MaxPM2.5 - Frying Eggs / MaxPM10 - Frying Eggs

Max values offer a good overview of the kitchen hood usage. In event 1, the kitchen hood was on, and the max concentration was reaching 249,60 $\mu g/m^3$. In event 2, where the same frying conditions were maintained the difference being in the hood that was off, and the doors were opened, is visible a substantial increment in particle generation. Such a correlation is to be expected, part of the particle production is directly removed by the forced extraction. From here, it is safe to assume that cooking activities should always be done while extraction is active.

The third experiment was made for a longer period of time, for 20 minutes. The hood was off as well; this can be noticed in the peak and in the mean value that is higher compared to the event 1. This again leads to the conclusion that forced extraction should be used when cooking.
It is important to note, however, that the time used for cooking differ from event 1&2 to event 3. Even though the event 3 has 8 minutes in addition to frying, the mean and peak values do not exceed the event 2 values. For both events the hood was off, the difference is the door which was closed in case of event 3. One of the reasons could be that the procedure of cooking was different, event 3 is scrambled eggs at a lower temperature for a longer period of time compared with normal frying a higher temperature for the shorter time period.

Further, two graphs of the event 2, PM2.5 and Pm10, is placed to prove or disprove the existence of particle distribution due to the opened door while frying.

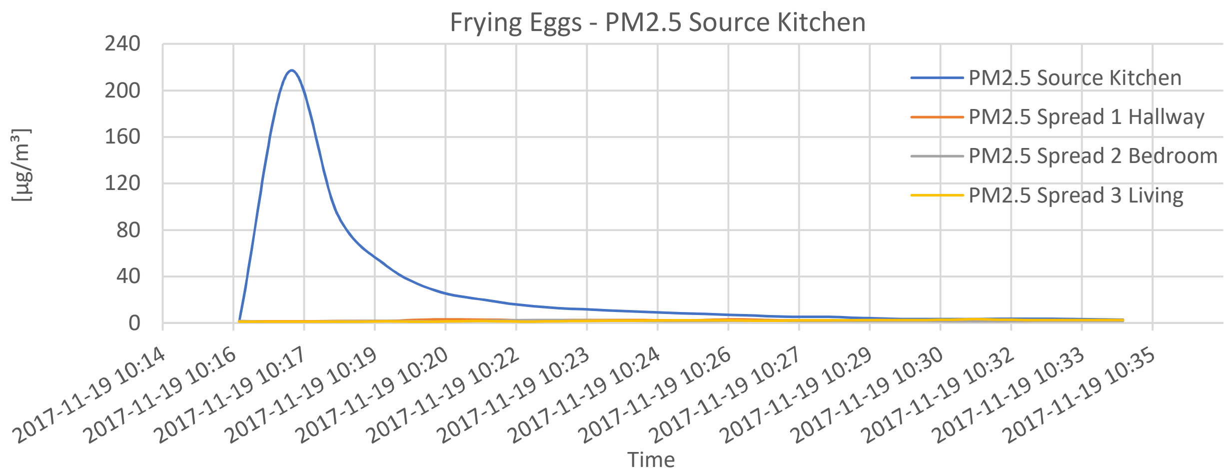


Figure 190 Frying Test - Event 2 - PM2.5

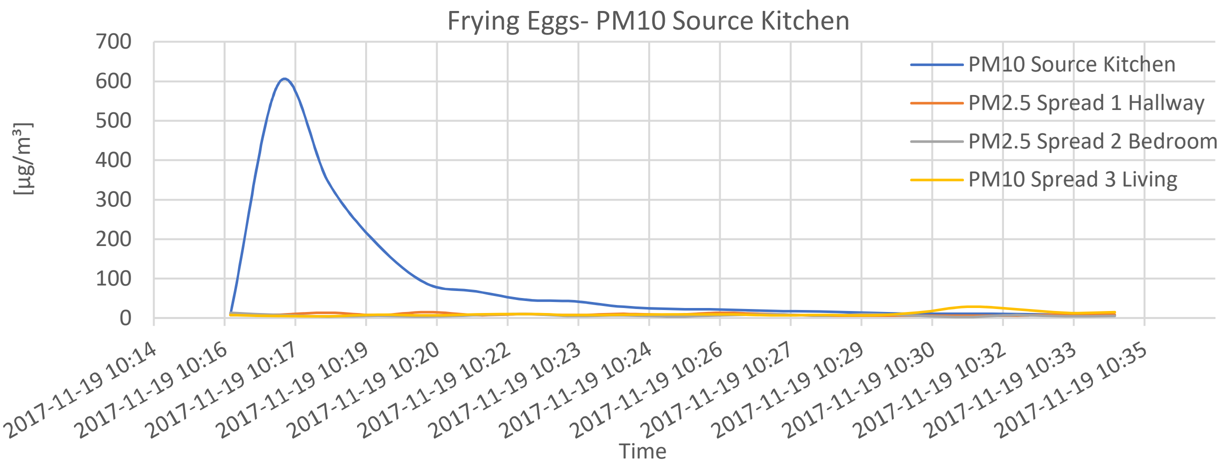


Figure 191 Frying Test - Event 2 - PM10

It can be seen from the above analysis that even though one test is done with the door opened, spreading did not occur. This matter is mostly dependent on the airflow pattern and apartment layout, which in this case, is not favorable for dispersing particle production to the neighboring rooms.

In addition, intake fraction for these activities was calculated. The following chart presents the results found.

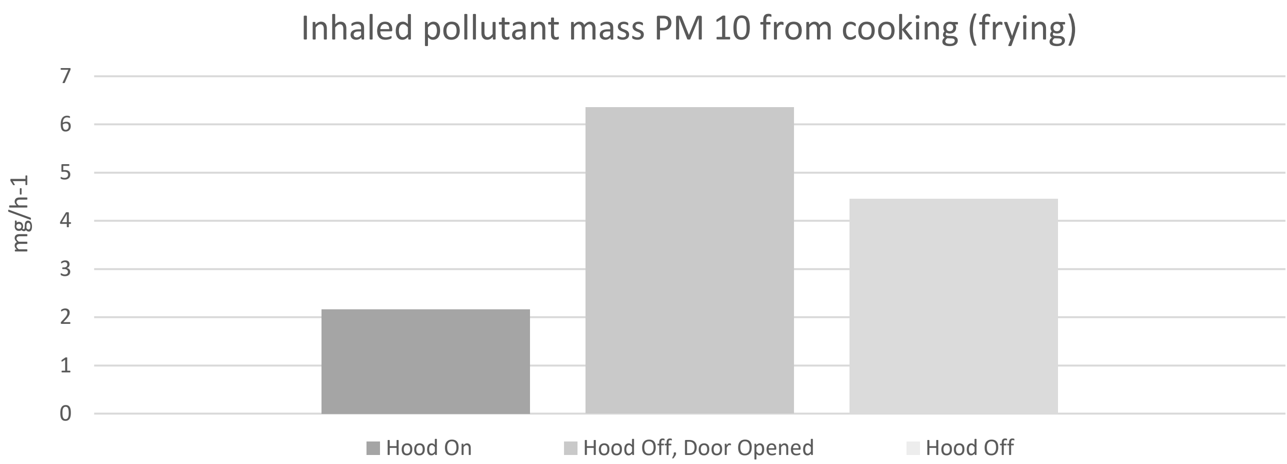


Figure 192 Inhaled pollutant mass PM 10 from cooking (frying)

Exposure risk to the pollutant inhalations is diminishing considerably when the kitchen hood is used, compared with the other events.

4. Activities with high particle release

From all the indoor activities performed during the measurement campaign, no doubt that the cooking part has the highest particulate pollutant emission. Further, cooking is compared in different graphs based on boiling/frying with the hood on/off.

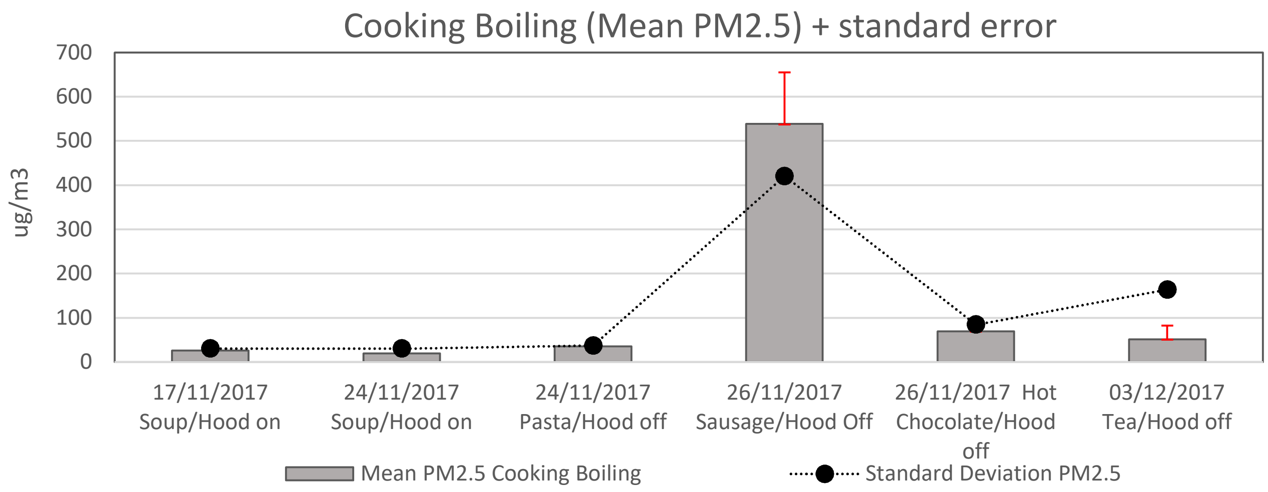


Figure 193 Cooking Boiling Mean PM2.5

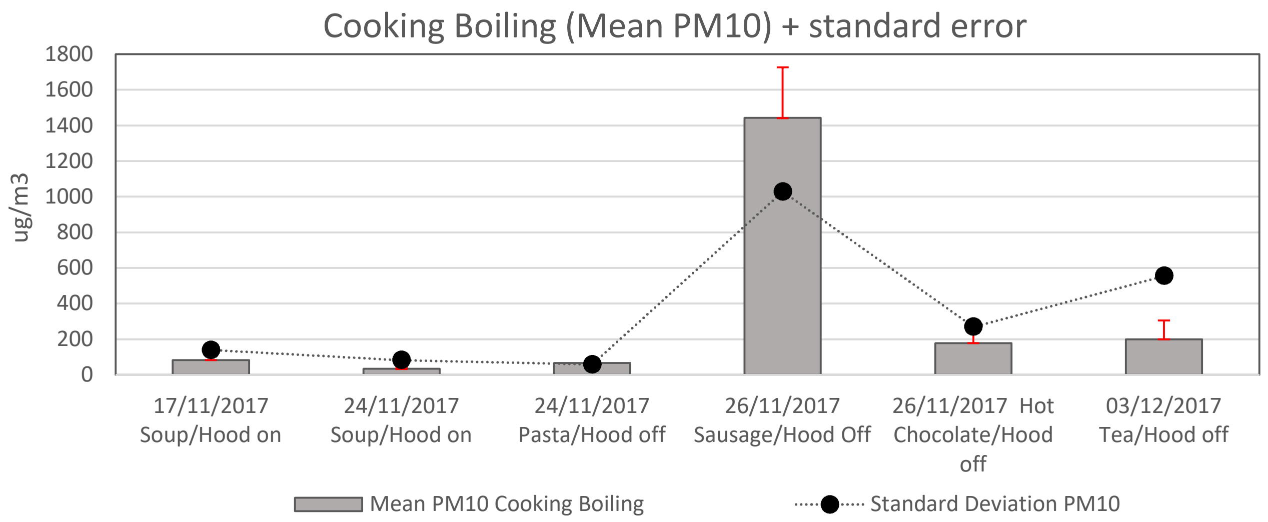


Figure 194 Cooking Boiling Mean PM10

Further, the same activities are presented, but in this case, max concentration (peak values) are used.

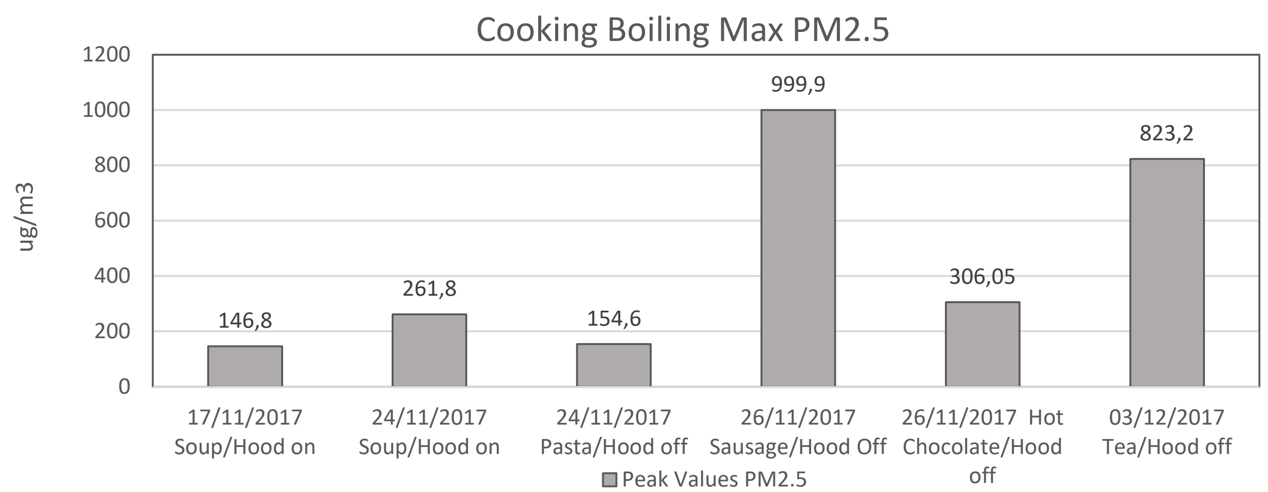


Figure 195 Cooking Boiling Max Values PM2.5

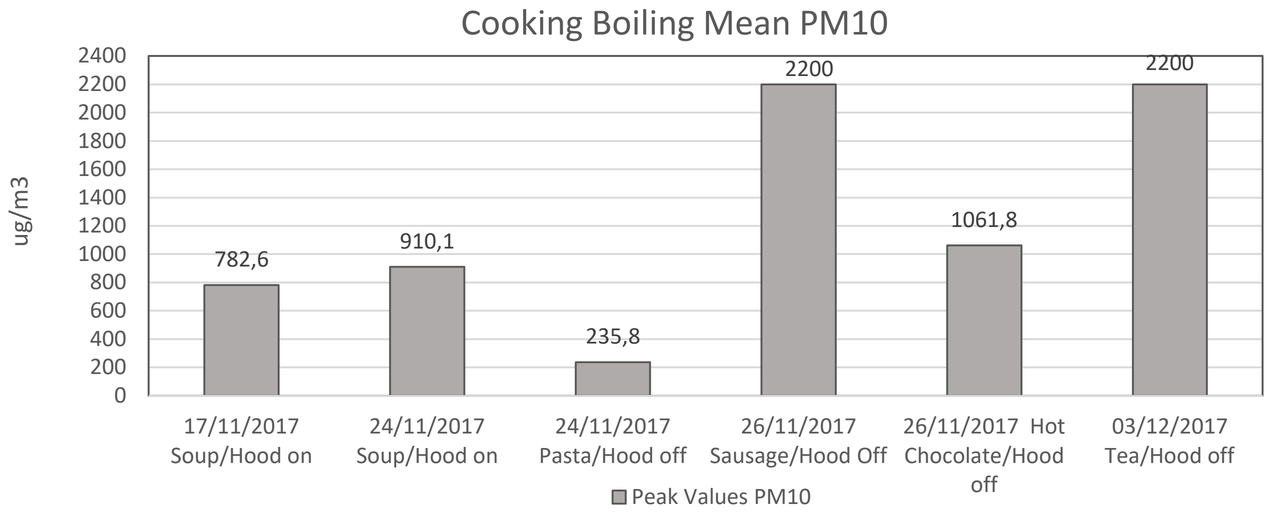


Figure 196 Cooking Boiling Max Values PM10

Noting the compelling nature of the above graphs with evidence indicating the importance of forced extraction usage that alternates in between the different activities, thus leading to one key result, it should always be used when cooking. Even though for this specific apartment spreading is not an issue, long-term exposure to such high concentrations of pollutant matter could become a potential health risk.

Further, the pollutant inhalation exposure is presented for each individual activity.

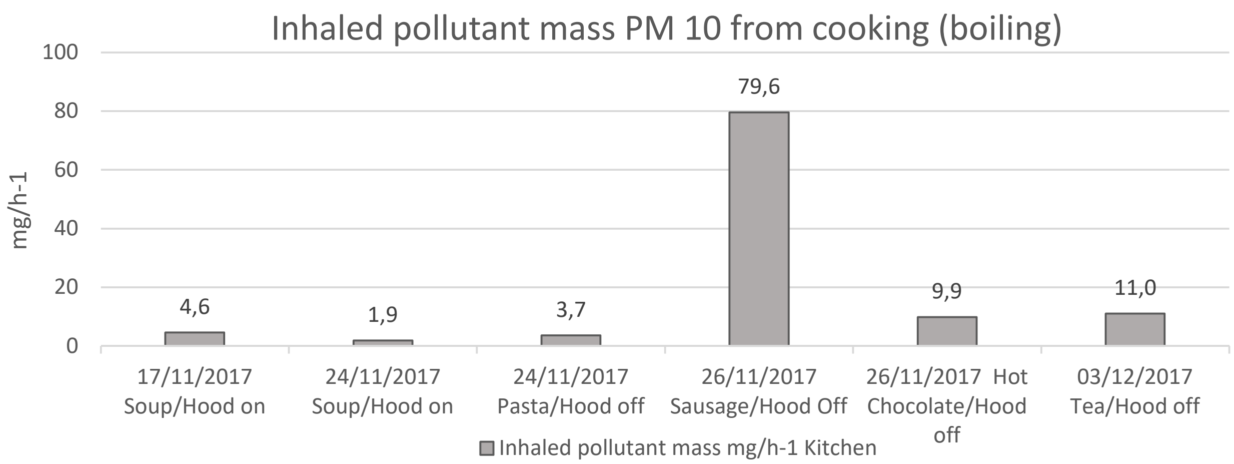


Figure 197 Estimate of the inhaled pollutant mass PM 10 from cooking (boiling)

The general tendency of the exposure risk is to diminish while using the kitchen hood. However, there is the event from the 26/11 when the exposure risk is immense. After further investigations, it turned out that is due to the mean value of the particulate pollutant which is higher than 1400 µg/m^3. The raw data was checked for flaws and errors, but none was found. It is surprising having a maximum concentration from almost the beginning of the event. It appears that this specific event is boiling homemade smoked sausages, as a consequence of putting them straight into boiling water, the emissions are instant to max levels. Over the entire period of the boiling, the emissions stayed at max levels of 2200 µg/m^3 (PM10) and only decreased in the last 2 minutes. As a result, the mean value is very high, hence the elevated inhalation risk.

Further, cooking on the stove like frying, soups and stews are presented.

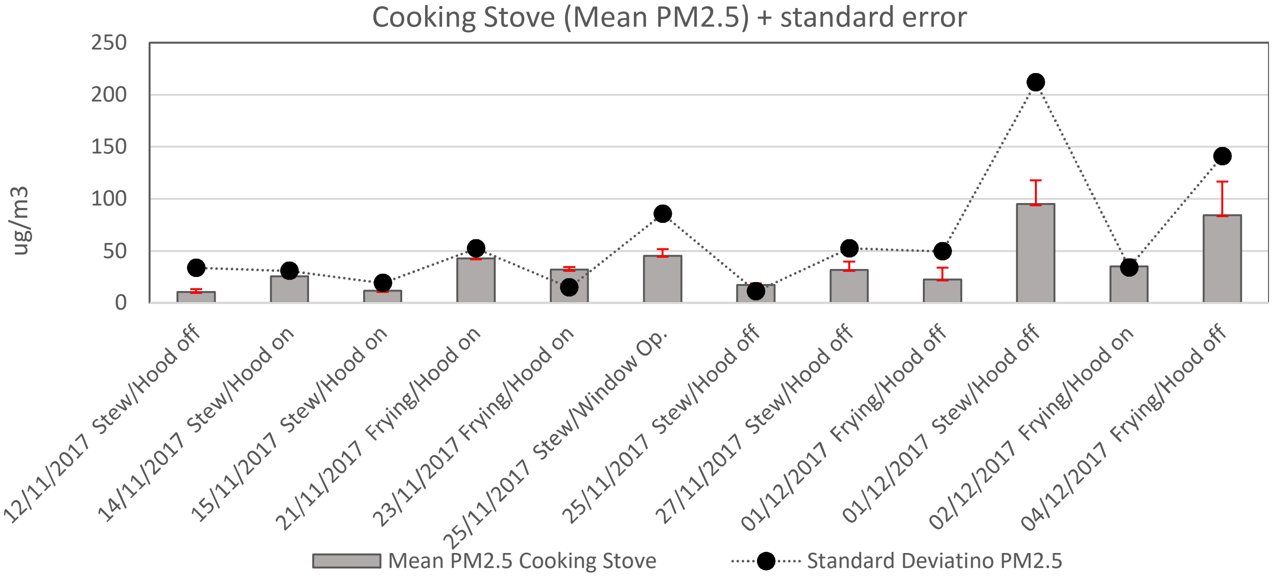


Figure 198 Cooking Stove Mean PM2.5

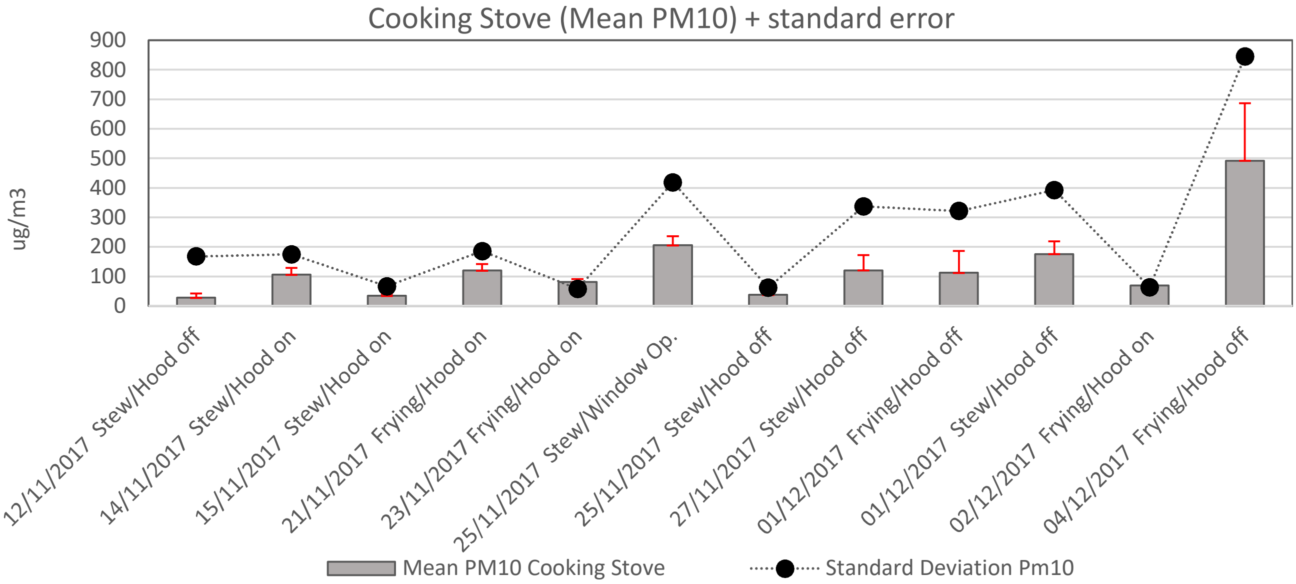


Figure 199 Cooking Stove Mean PM10

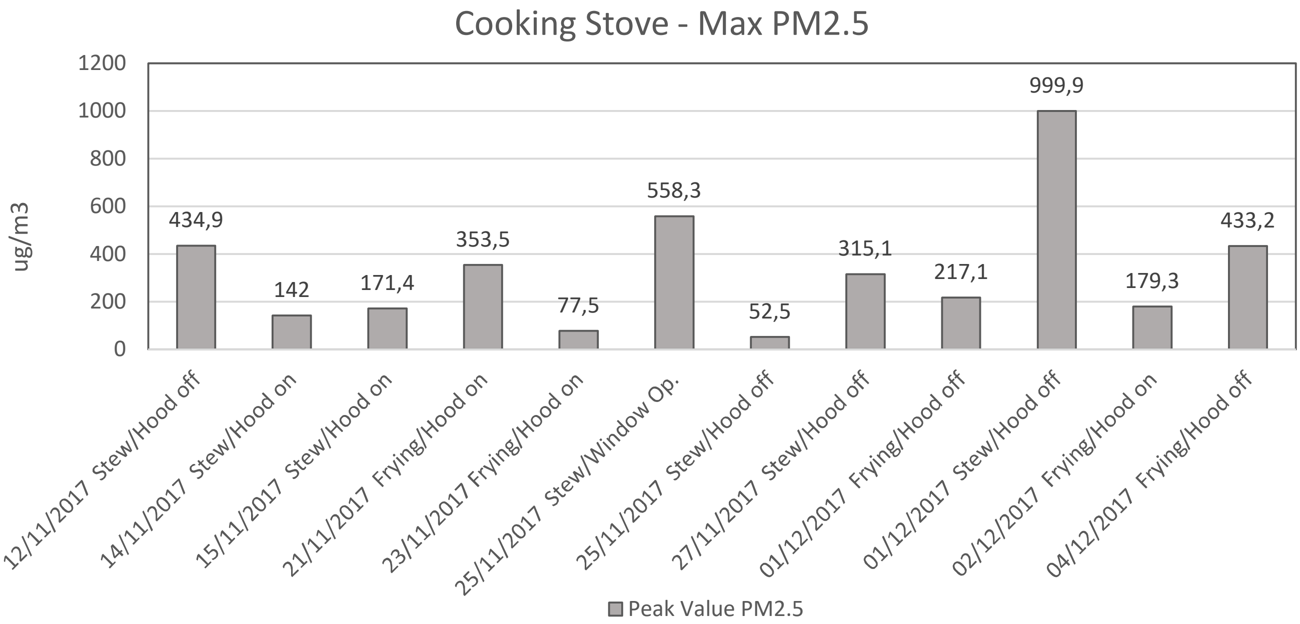


Figure 200 Cooking Stove Max Value PM2.5

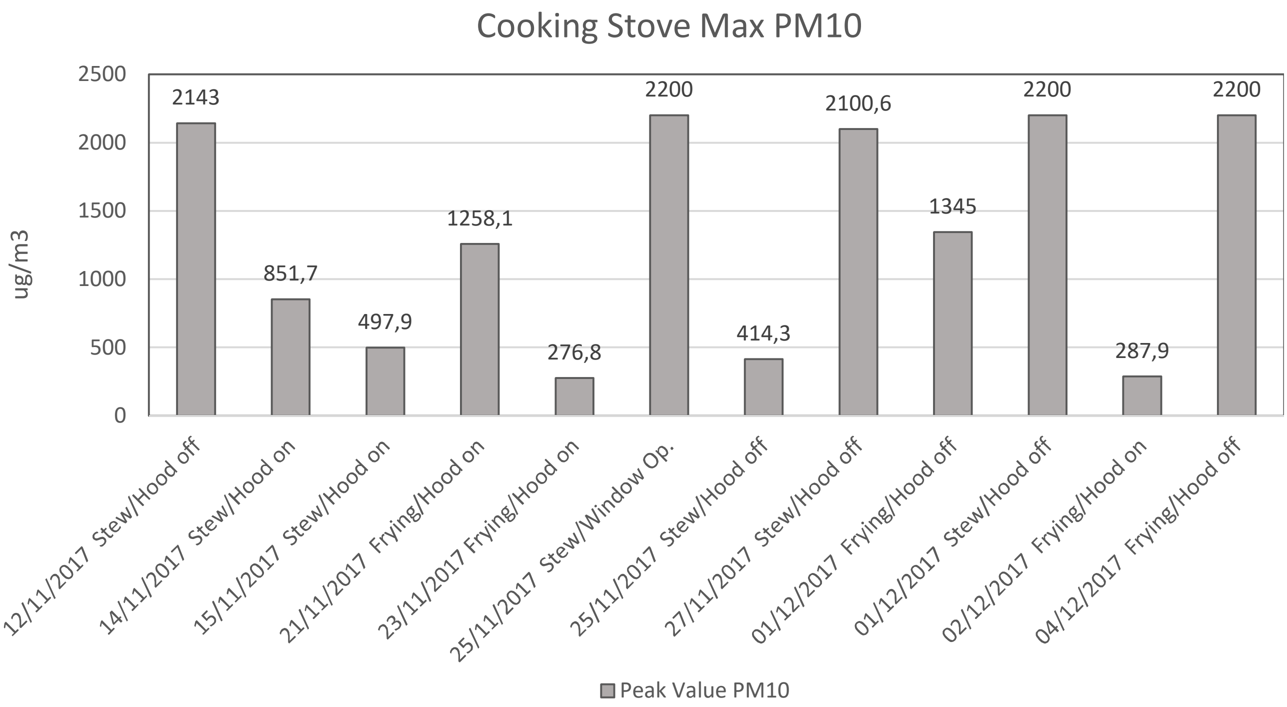


Figure 201 Cooking Stove Max Value PM10

In contrast to forced extraction, having the window opened during the cooking activity does not lower the values. As can be seen in the above graphs, on 23/11 the window was opened during the entire process of cooking. However, the max reading value was reached by the measurement equipment. If we compare this event with other similar events but when extraction is active, and the window is closed, the difference is significant.

Further, estimation of the inhalation risk is presented for the above activities, cooking on the stove.

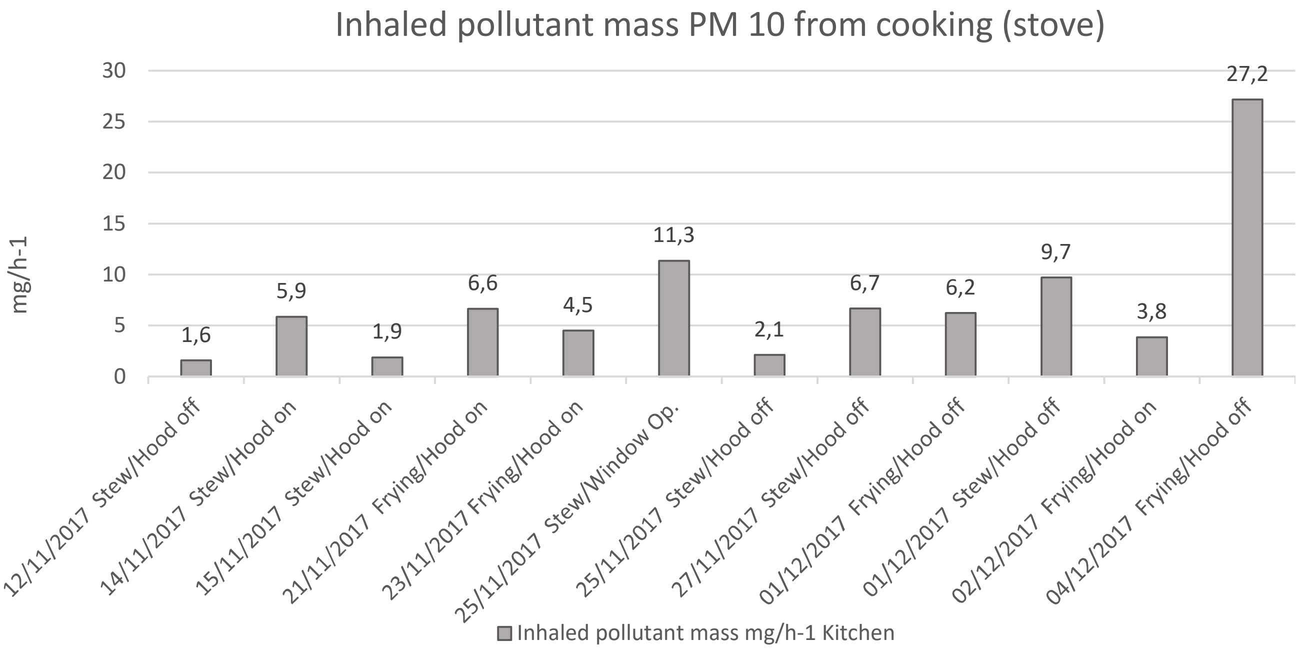


Figure 202 Estimate of the inhaled pollutant mass PM 10 from cooking (stove)

Comparing the exposure risk in between cooking boiling and cooking on the stove(frying), there is significant increment when frying. The particle emissions from these types of activities are higher, thus the higher exposure risk.

Discussion

Evidence support the conclusion that particulate matter emissions are well bellow the 24h mean guidelines offered by the World Health Organization. However, keeping in mind that on two occasions the indoor environment was polluted by an unknown source, while a specific night on 26/11pollution reached extreme levels.

The main particulate pollutant production in a typical apartment like this would strictly be from cooking. There are high-level emissions while performing such activities. There is also, however, a further point to be examined and it refers to the forced kitchen extraction usage. All the analysis shows a substantial reduction in peaks and general mean values during the entire activity emission if such is used. It appears that opening the window is not enough and the kitchen hood can make a difference.

The spread in this specific apartment layout only takes place from activities like perfume usage in the bedroom, even so, the particulate pollutant amount that travels to the neighboring rooms is shallow and not an apparent issue. There is one time when spreading occurred from the kitchen while cooking in the oven, but the levels are too small to be considered problematic.

The general human exposure towards particulate emissions is strictly constrained by human behavior. For instance, since spreading is not an issue in this apartment type, cooking is the main activity that produces affects particle concentration, the overall exposure can be limited by simply using the kitchen hood. It was clear when the same type of activity was compared, with and without extraction, the human exposure would diminish considerably if using the kitchen hood.

4.4 Interplay between IAQ parameters

4.4.1 Location 2

In order to improve indoor air quality, particle concentration levels must be controlled. Unfortunately, it is rather new, for the building industry, to control building systems based on particle pollution. One of the reasons is the high cost of particle sensors. Much more efficient and simpler way would be to control particle level, based on other parameters like temperature, relative humidity and CO2 which are already measured in new buildings. However, the correlation between aforementioned IAQ parameters and particle concentration has to be established first.

For this purpose, the interaction between different parameters registered during measurement campaign has been investigated.

As a first step, a number of graphs illustrating particle concentration and IAQ parameters have been made (see example below). This information while enlightening presents many contradicting results, and no clear relationship between different parameters can be identified. (Rest of the graphs can be found in digital appaendix 2J).

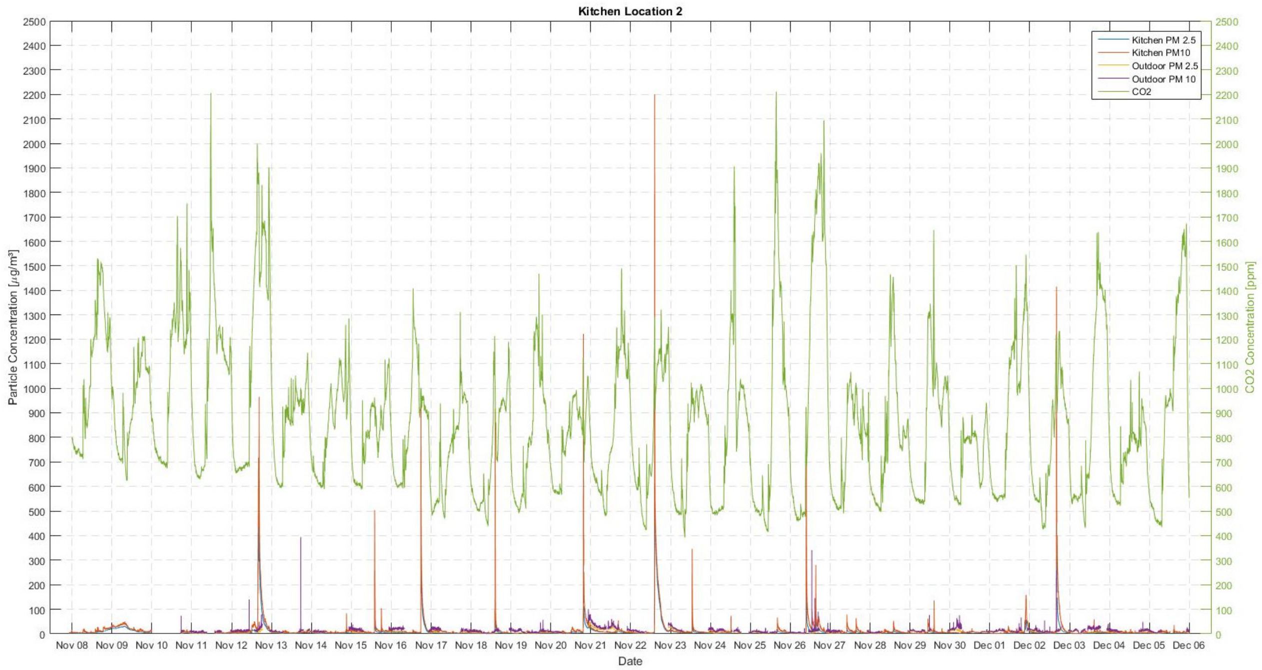


Figure 203 Particle concentration and CO2 levels in Kitchen (Location 2)

The second test has been performed by plotting particle data against different parameters. First, measured particle data has been treated and running 5 min averages calculated, so that timestamps from particle sensors and IC meters would be normalized. Then data can be analyzed graphically, by plotting different parameters against each other and determining a trend line and coefficient of determination to describe its accuracy.

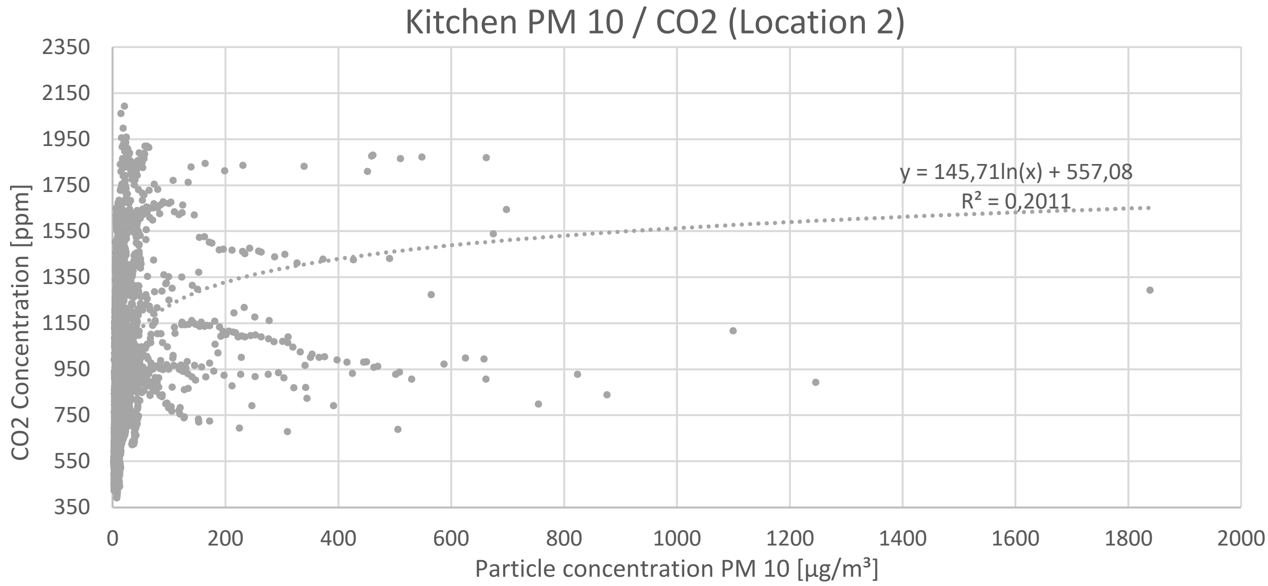


Figure 204 CO2 Concentration vs.PM 10 Concentration in the Kitchen (Location 2)

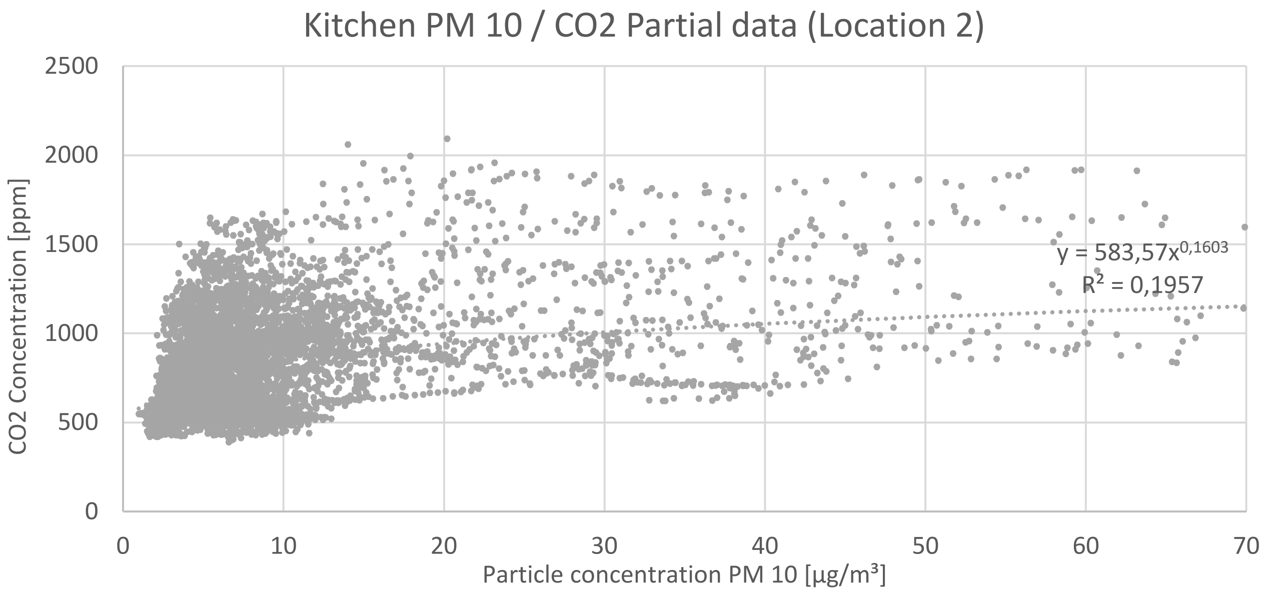


Figure 205 CO2 Concentration vs.PM 10 Concentration, partial data in the Kitchen (Location 2)

Data analysis reveals that in lower ranges variables present a small level of correlation. However, it quickly disappears when values get higher. Overall data looks sporadic without any clear correlation. R^2 values reach maximum of 0,2, implying that only 20% of data can be expressed or related to a modeling equation.

Another method used to determine if a correlation exists is calculation of correlation factor.
For this purpose, Pearson's correlation coefficient has been used. Calculations have been carried out using following formula.

$$Pearson's\ correlation\ factor = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Results of the calculations for location 2 are presented the table below.

Correlation factors (Particles / IAQ Parameter) Location 2				
Room	**Particle Size**	**Temperature**	**Relative Humidity**	**CO2**
Living-room	PM 2.5	0,10	0,11	0,21
	PM 10	0,12	0,08	0,24
Bedroom	PM 2.5	0,09	0,21	0,20
	PM 10	0,10	0,21	0,22
Kitchen	PM 2.5	0,09	0,22	0,18
	PM 10	0,08	0,23	0,20

Table 73 Correlation factors between particle concentration and IAQ parameters (Location 2)

Statistical data treatment provides no evidence that correlation between particulate matter concentration and indoor air quality parameters exists.
However, an argument can be made that specific cases/events should be further analyzed. For there is a chance of correlation between changes in particle concentration and IAQ parameters in the limited time span of specific activity (for example moisture increase due to cooking).

4.4.2 Location 3

Firstly, the indoor air quality parameters and particle concentrations will be explored regarding correlation. The matter is focused on the interplay that could exist by comparing the measured values like air temperature, relative humidity, and Co2 concentrations with particle emissions PM2.5 and PM10. The different parameters were visually investigated by analyzing plots made with the particle concentration and one parameter fx. temperature. However, there was vague evidence supporting their correlation. As such, supplementary analysis was made.

Secondly, graphs were made by taking two parameters such as Co2 and PM2.5 and create a plot where patterns could be identified. The procedure used was the same as for the above apartments analyzed. See following graphs.

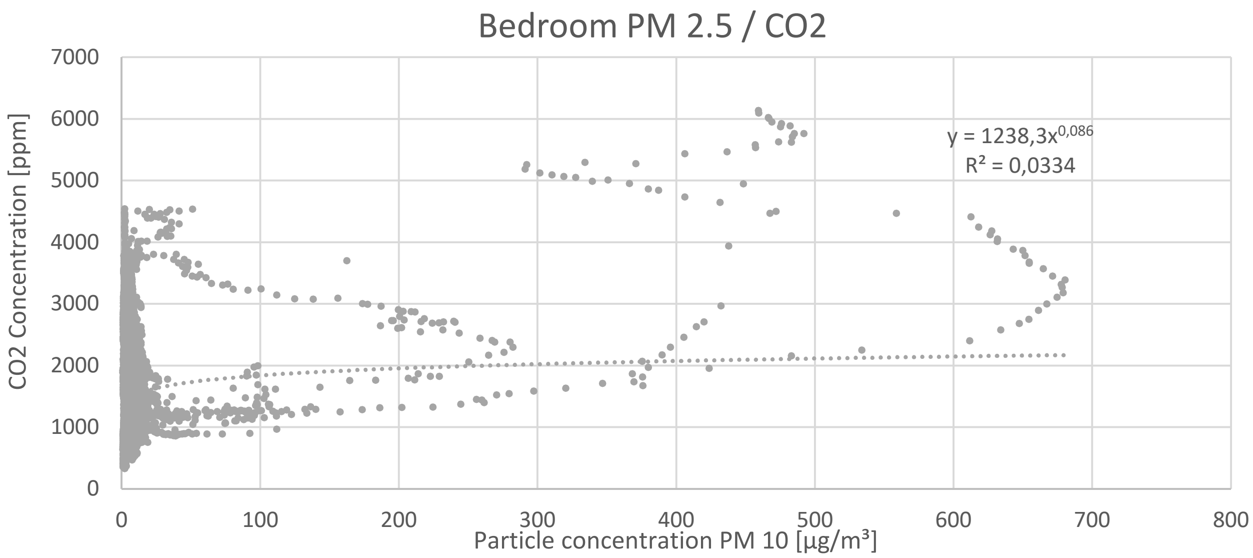


Figure 206 Bedroom CO2 / PM2.5 Location 3

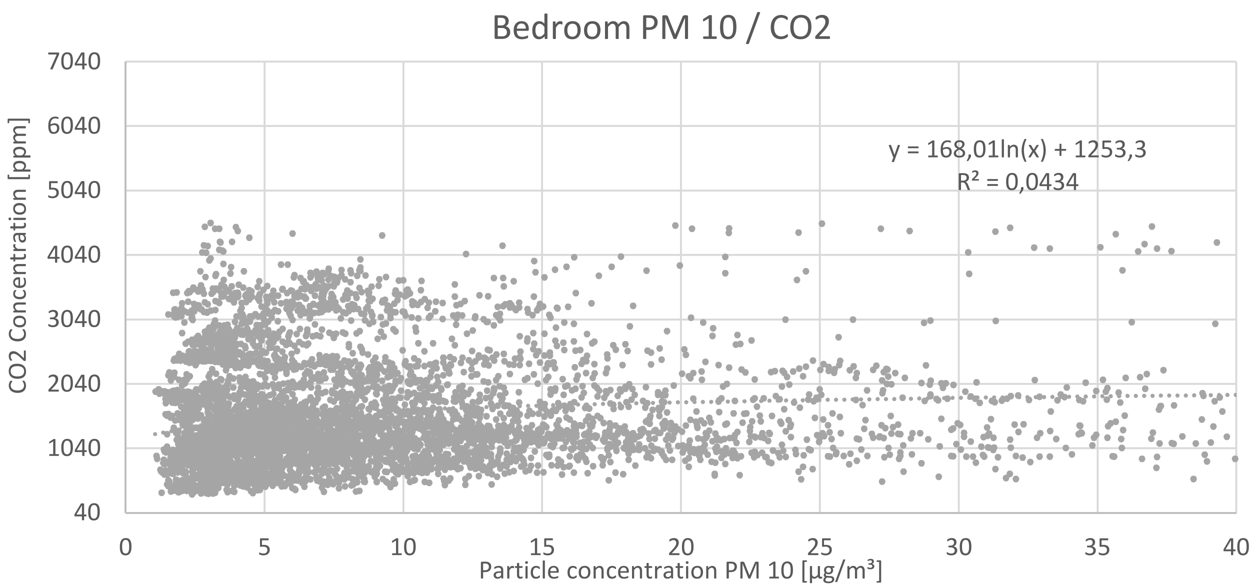


Figure 207 Bedroom CO2 / PM10 Location 3

It can be seen, in the above graphs, that there is no clear pattern of the data correlation and they are rather scattered.

The last method used to check for any interaction between the different indoor parameters is the Pearson correlation. By finding the Pearson correlation coefficient is possible to test the robustness of the two targeted linear relationships. The correlation factor calculation is described in the earlier chapter.

Further, the result of the calculations made for Location 3 is presented.

Correlation factors (Particles / IAQ Parameter) Location 3				
Room	**Particle Size**	**Temperature**	**Relative Humidity**	**CO2**
Living-room	PM 2.5	0,10	0,11	-0,06
	PM 10	0,09	0,12	-0,03
Bedroom	PM 2.5	0,20	0,19	0,30
	PM 10	0,21	0,19	0,30
Kitchen	PM 2.5	0,11	0,07	-0,02
	PM 10	0,11	-0,01	-0,01

Table 74 Correlation factors between particle concentration and IAQ parameters (Location 3)

To summarize, the result is mainly showing no valid correlation throughout the data set. However, there is this particular room, bedroom, where the particle correlates in the proportion of 30% with the CO_2 concentration. Further investigations performed on the data revealed the matter. The issue is with the unknown source of a pollutant that reaches very high concentrations during a few nights in the period of the measurement campaign. At the same time, since it is during the night, 2 persons are also sleeping, thus generating CO_2. This creates a small correlation between the different parameters but it is not representative since the source of pollutant is not determined.

4.5 Conclusion

1. What is the main source of particles in the indoor environment?

It has been previously shown that there are 3 main activity categories causing a significant increase in particle concentration. Though they depend on the individual preferences. Location 1 had deodorant spray usage resulting in very high particle release plus cooking. Location 2 had the main activities like cooking, in particular, frying, plus candle burning, while Location 3 is dominated by particle released from cooking. In summary, cooking is present in all apartments and can be classified as one of the leading activities influencing particle concentration. Even though usage of deodorant spray and candle result in high pollution added to the indoor environment, they cannot be classified as the main sources of pollution since they depend very much on personal choices.

a) What is the level of particles pollution in typical apartment buildings, in Denmark?

Further, based on the investigation done, the indoor pollution level is within limits stated by the World Health Organization, 25 µg/m3 24-hour mean and 50 µg/m3 24-hour mean. On the other hand, in two apartments, location 2&3, the 24h mean guidelines are exceeded a couple of times. This issue occurs 2 times in both apartments. The source of this pollution is simply cooking, and candle burning for location 2. However, in location 3 pollutant could not be traced and remains unidentified. During these events (location 3) concentrations are extremely high and occur during the whole period of the night.
Besides these events, the indoor particle concentration is generally at a low level.

b) How are particles transported inside the apartment?

During the high particle release from aforementioned activities spreading to the neighboring rooms occur. An essential point to understand the spreading is that even when cooking takes place with the kitchen hood turned on, spreading still takes place in location 1&2. This further indicates that particles have the capability of moving against the direction of the air pattern caused by the forced extraction.
Findings point out that even when the door is closed, particles still pollute and spread to the next room. This is demonstrated by deodorant usage in location 1 - the particles require more time to spread, but there is no doubt that it happens.

There is limited evidence for spreading in location 3, the only times when spreading occur due to perfume usage in the bedroom, and particle spread is almost insignificant and can be neglected. Cooking rarely influences spreading, regardless if the hood is used or not. A major factor could be the apartment layout that interferes with spreading, thus improving the overall risk exposure from activities like cooking.

2. What is the general risk of human exposure due to the particulate pollutant in typical apartment buildings, in Denmark?

The exposure risk was calculated for all events investigated. Findings reveal that usage of kitchen hood lowers the risk and the amount of the inhaled pollutants considerably. For example, frying with the hood on for 12 minutes had a value of 2,16 mg/h of inhaled particles, while in the similar event, but this time keeping the hood off, this value increased up to 6,35 of mg/h^{-1}. At the same time, good ventilation/extraction lowers the risk of inhaling particles due to spreading.

3. How can indoor particulate pollutants be better controlled?

As the analysis shows, the most problematic particulate emissions are from cooking activities. During the events in location 2, it was noted that by keeping kitchen hood on during and especially, for a small amount of time, after cooking activities have ceased a significant reduction in airborne particle exposure can be achieved. This indicates, that kitchen hood, when used in a particular way, could be a cheap and effective way of controlling particulate matter concentration.
On the other hand, after particles have already spread throughout the apartment more sophisticated control system would be necessary. For example, particle sensors warning the occupant when windows should be opened and room aired.

c) Is there a correlation between particle concentration and IAQ parameters?

The interplay between the IAQ parameters and the particle concentration has been investigated in multiple ways. No meaningful results have been achieved by trying to solve it graphically; no clear patterns have been observed. Therefore, Pearson's correlation factor has been used in the end. The final result implies that there is no certain and substantial correlation between the parameters. Highest correlation factor has been found at location 3. There CO2 levels and the particle concentration reached a correlation factor of 30%. However, this is simply due to high unknown particle emission during the night when, as well 2 persons were sleeping. Hence CO2 increment plus particle emissions. Even so, it provides no basis for any affirmation of certain correlation. The outcome is clear; there is very little evidence to support a correlation between IAQ parameters and particles.

d) Should ventilation systems be controlled based on indoor particle concentration?

The indoor environment is well within WHO guidelines regarding the 24h mean particle concentration levels. However, in a few instances, it would be reasonable to control ventilation system based on particle pollution. While cooking events can be reasonably controlled via exhaust hood, another type of events taking place in other rooms cannot (e.g., candle burning). In these cases, ventilation control based on particle concentration could be justified. Although it does not make much sense to invest in high tech, expensive mechanical ventilation system with particle sensors. It would be much more reasonable to design a simple alarm system, warning occupants to air the rooms by simply opening the window when particle concentration approaches high values.

5. Micro-Plastic

5.1 Background Information

Plastic pollution is nowadays recognized as a global concern, affecting both marine and terrestrial environment. Despite the durability of polymers, plastic items undergo degradation phenomena triggered by physical and photochemical processes which lead to fragmentation of larger items into smaller ones. Microplastics (MP) are small plastic particles smaller than 5 mm (Thompson et al., 2004). Their presence has been widely documented both in marine and freshwater environments and resulted almost ubiquitous. Most of the plastic pollution sources are suspected to be land-based sources, with around 8 MT/year of plastic waste entering the oceans (Jambeck et al., 2015). Among the potential MP sources also atmospheric fallout, outdoor and indoor air pollution has been recently investigated (Dris et al., 2016; Dris et al., 2017), highlighting 33% of recovered fibers contain from petrochemical.

5.2 Method of Investigation

5.2.1 Sampling set up

This part of the investigation required a more complex set of equipment that had to be put together so that eventual plastic fibers in the indoor environment could be trapped and afterwards analyzed.

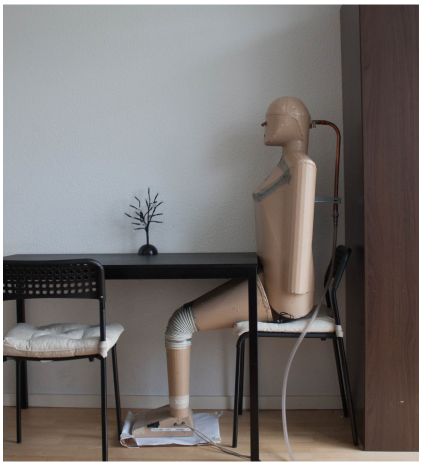


Figure 208 The manikin

Figure 209 VarioTransformer

Figure 210 Legs of the manikin (power supply for the heating and ventilation of the manikin)

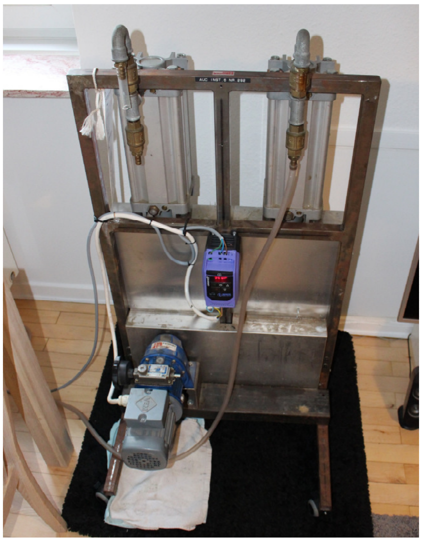


Figure 211 The lungs

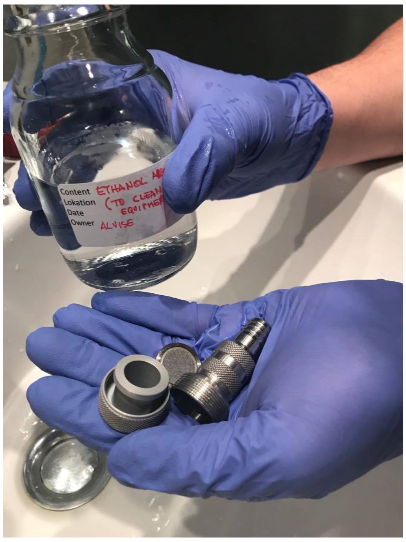


Figure 212 Filter holder

Figure 213 Silver coated filter maneuvered with the help of tweezers

Description of equipment and setup diagram

The manikin, see figure 209, is basically a human size manikin, made out of aluminium and glass fiber, having the purpose of simulating the presence of a person. It is able to produce heat and simulate breathing in and out, depending on its metabolic rate. For the measurements, in a sitting position with light activity, the metabolic rate would be 1.2 met or the equivalent of approximately 120W (assuming a Dubois area of approx. 1.7-1.8 m^2).
120W represents the power that the manikin requires so that the same amount of heat production can be released.
The manikin is therefore powered by two cables, see figure 211: one of them powering the heating element inside the manikin, and the other one powering a ventilator. The ventilator has the purpose of distributing the heat uniformly throughout the manikin's internal space.
Since the measurements were done inside an apartment, and the standard voltage output of a socket in Denmark is 230 V, by plugging in the heating unit of the manikin directly in the socket, it would mean that the manikin would release the maximum power of the heating unit and that is not correct.
Instead, a variotransformer was used, see figure 210, with the purpose of reducing the power input to the heating unit of the manikin to the desired value.
The adjustment of the power is made via the red knob placed on the variotransformer; by doing that, the volts and amperes are changed. Therefore the power is changed.

$$W(power) = V(volts) \times I(amperes)$$
$$\mathbf{103.5\ W}(power\ supplied\ to\ heating\ unit) = 115\ volts\ \times\ 0.9\ ampers$$

The supplied power of 103.5 W is the closest value to the target of 120 W; and that is due to the fact that on the variotransformer, the two values (volts and amperes) move independently from one another when rotating the knob.

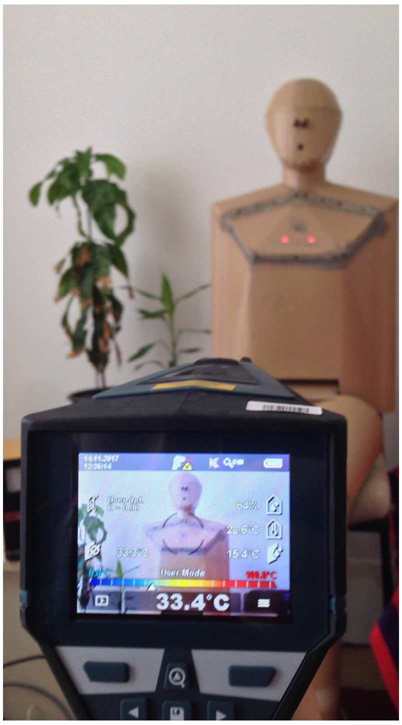


Figure 214 Laser thermometer

The temperature on the surface of the manikin was afterwards accurately measured with the help of a Bosch GIS 1000 C Thermo Detector.
The manikin's temperature was measured periodically until it was observed that the temperature stabilized at around 33.4°C.
The temperature measurements were done for three consecutive times, and the temperature stabilized at around 33.4°C each time.

Specification overview of the Thermo Detector relevant to the performed measurement:
Measurement range -40°C … +1000°C
Measuring accuracy of IR ± 1.0°C

Meanwhile, the cable powering the ventilator was plugged directly into the socket.
Now that the manikin was able to produce/release heat according to its metabolic rate, it was time to make sure that the breathing function is also working accordingly; for that to happen, the lungs see figure 212, had to be "attached."
The lungs consist of two pneumatic cylinders which are moved with the help of a motor. The movement of the pistons creates a flow of air which is directly linked to the size of the cylinder, speed of the motor and stroke length of the piston. Therefore, the volume flow and the breathing frequency can be adjusted.

As there is a difference between the male and female respiration rates, a decision had to be taken in the direction of the gender of the manikin. Male respiration rates were chosen for this study.
Based on this decision, the stroke length of the piston and the breathing frequency had to be calculated according to the following equations:

$$S_{male} = \frac{N \times (9.4318 \times M - 0.4675)}{1.25^2 \times \frac{\pi}{4} \times (2.8747 \times M + 10.816)} \times 100 = 61.97\, mm$$

$$BF_{male} = 2.8748 \times M + 10.816 = 14.26\, min^{-1}$$

Where: S_{male} = stroke length (mm),
N = Number of manikins,
M = Activity level (met),
BF_{male} = Breathing frequency

The stroke length and the breathing frequency can be used to calculate the volume of air that was inhaled throughout the entire extent/span of each measurement (24 hours/filter).

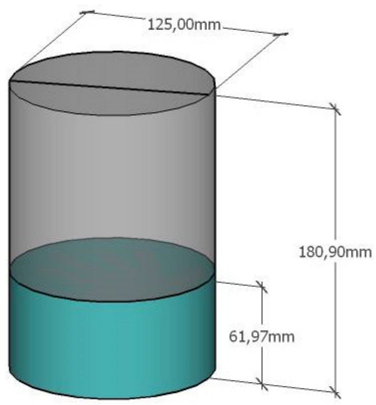


Figure 215 Cylinder size

Cylinder data (one cylinder):
Max. Volume of the cylinder is 2.4 l.
Diameter is 125 mm.

$$V(max.volume) = \pi \times r^2 \times h$$

Height (h) of the cylinder is 180.9 mm.
To calculate the displaced volume of air for one breathing cycle the same formula is used, but with a cylinder height (stroke length) of 61.97 mm.

$$V(cycle) = 0.82\, l$$

$$\boldsymbol{V(24h) = 16.8\, m^3}$$

As for the filters that were used, they are silver metal membrane filters (99,9%) from Sterlitech (http://www.sterlitech.com/silver-membranes.html), originally 47 mm in diameter with a 0,8 µm pore size. The filters have been custom cut to 20 mm outer diameter.
The filter holder seems to consist of a mix of steel and aluminium parts, with a filtration surface of 132,67 mm^2 (13 mm in diameter).

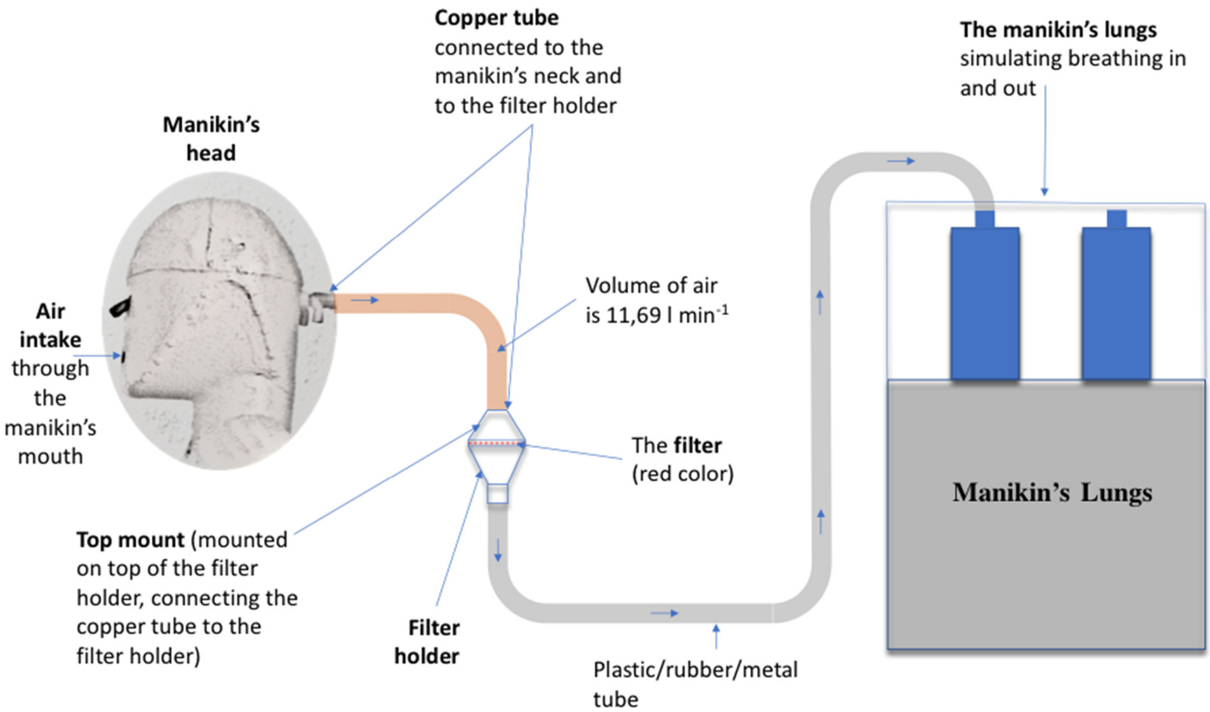


Figure 216 Diagram of the Micro plastic measurement

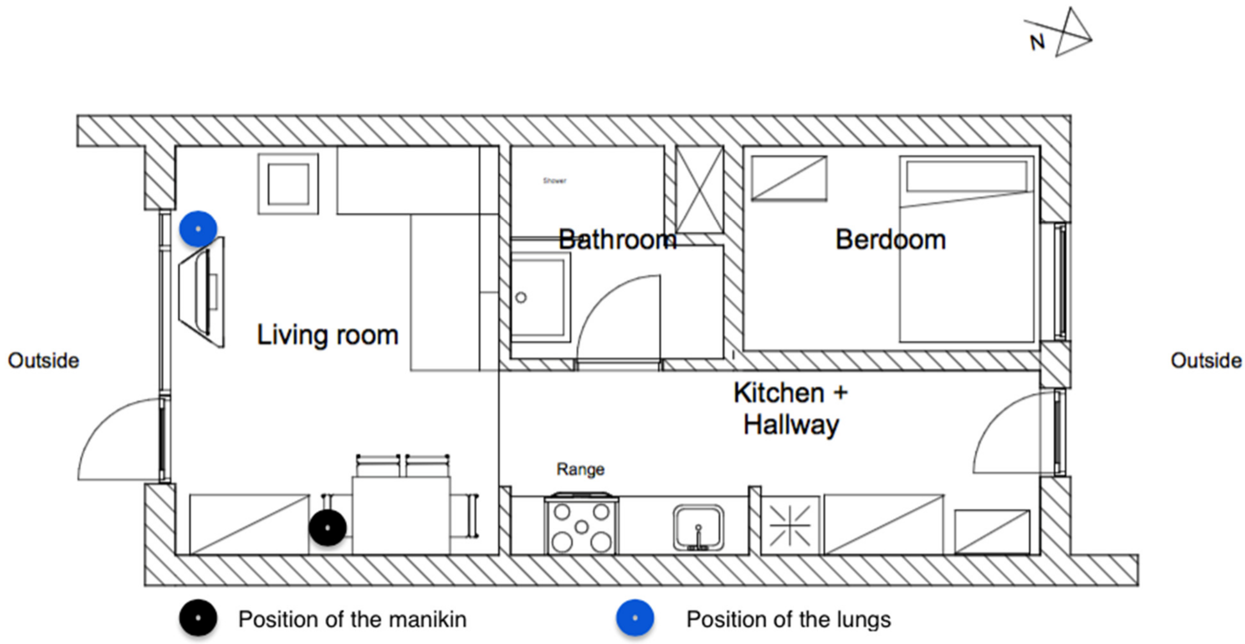


Figure 217 Manikin and mechanical lung placement. Location 1.

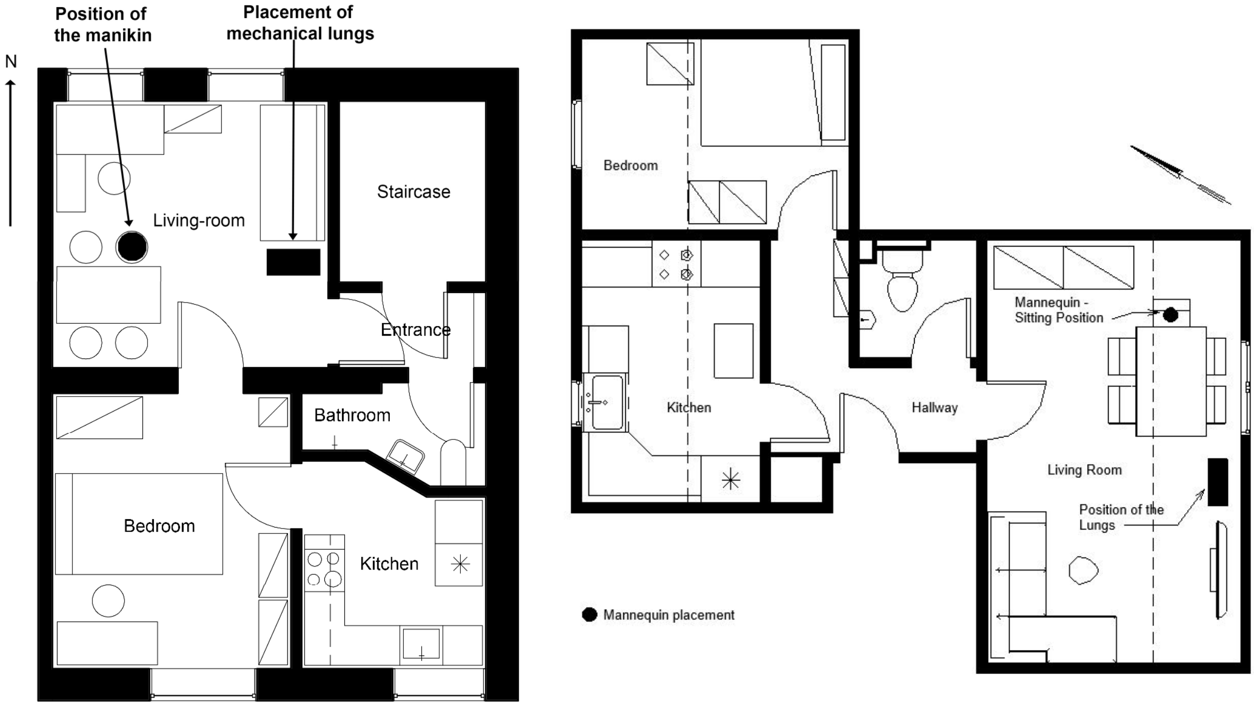


Figure 218 Manikin and mechanical lung placement. Location 2 – Brammersgade 12, st (left), Location 3 - Vestre Ringgade 230, 5tv (right)

5.3 Analysis

FPA-µFTIR-Imaging MP analysis

MP analysis was carried out using FPA-µFTIR-Imaging spectroscopy (Focal Plane Array-Fourier Transform-Micro-Spectroscopy), which is recognized as one of the most suited analytical techniques for identification and characterization of microplastics (Rocha-Santos & Duarte, 2014; Loder et al., 2015). Particles and fibers were identified by InfraRed imaging applying a micro-FTIR imaging system with a focal plane array detector (FPA). The instrument was an Agilent's 620 FTIR microscope combined with its Cary 670 FTIR spectrometer equipped with a 128x128 pixel FPA). It can operate in transmission, reflection and ATR mode. The FTIR creates a FTIR spectrum for each pixel, which, in combination with a spectrum library, allows identification of a wide range of organic and inorganic materials. This identification method is for example used in forensic science to identify car paints from crime scenes, or to identify the authenticity of old paintings. The imaging system creates two types of images – a traditional microscope image and a corresponding IR-spectrum image. The pixel resolution of the latter can be set as low as few micrometers. The imaging system creates tiles of 128x128 pixels co-adding several scans. These tiles are combined into a mosaic of the total surface scanned. This technique allows rapid scanning of extended surfaces for material composition at very fine resolution.

Experimental

A first test analysis was carried out directly on one enriched silver membranes to check the feasibility of direct analysis, to avoid sample preparation and manipulation. This analysis was performed in reflection mode, acquiring a background tile (to subtract the air and the filter material IR signal) on a clear (no particles) spot of the silver filter. The obtained results from this preliminary test were not encouraging mainly because of the filter, after being sampled, was not flat enough to perform a large area Imaging scan keeping the focus of the IR beam during the whole analysis. This led to poor spectral quality and therefore to uncertain identification.
To overcome the aforementioned issue, the enriched filters were placed in pre-cleaned small glass beakers adding few mL of 100% ethanol (HPLC grade) and sonicated for 10 minutes. The filters were then flushed with ethanol, and the liquid phase was deposited by multiple micro-additions on a heated ZnSe (Zinc Selenide) windows using a glass capillary micro-pipette and evaporated (55 ˚C) on a heating plate.
The enriched ZnSe windows were then submitted to FTIR-Imaging analysis.
The analysis was performed in transmission mode, as ZnSe is an IR transparent material in this spectral range. Instrumental parameters were:

- spectral range 3750 – 850 cm^{-1}
- spectral resolution 8 cm^{-1},
- 30 co-added scans for sample scan, 120 co-added scans for the background,
- FPA size 128X128 pixel,
- visible objective 15X, IR objective 15X,
- pixel size 5.5 µm, with reliable spatial resolution around 5-10 µm (these are also the Limit of detection in term of size).

The analysis time was around 4.5h per sample. After the acquisition, data were managed using MPHunter, a software developed at AAU which allows to identify and quantify the particles in the sample by spectral correlation (Pearson's correlation coefficient) comparing the unknown sample spectra with a custom spectral library.

5.4 Results

Preliminary results on the first three filters showed all the sampling sites were contaminated by MP (Table XX).

		PE	PP	PEst	PA (nylon)	PS	PAcr	PU	Acrylic Coat.	TOT
#5 Åbyhøjgård 40 (Location 1)	N/m³	0.42	0.54	4.46	0.00	0.00	0.00	0.00	0.06	5.48
	N/h	0.29	0.38	3.13	0.00	0.00	0.00	0.00	0.04	3.83
#16 Brammersgade 12 (Location 2)	N/m³	0.54	0.48	10.30	0.12	0.12	0.24	0.18	0.00	11.96
	N/h	0.38	0.33	7.21	0.08	0.08	0.17	0.13	0.00	8.38
#10 Vestre Ringgade 230 (Location 3)	N/m³	0.30	0.89	9.23	0.18	0.18	0.12	0.06	0.00	10.95
	N/h	0.21	0.63	6.46	0.13	0.13	0.08	0.04	0.00	7.67

Table 75 Results of microplastic analysis

The most abundant polymer identified by FTIR analysis was polyester (PEst) which ranged from 82 (site 1) to 86% (site 3) (check the Excel GENERAL RESULTS for a detailed overview) of the identified MP. The other main polymers identified were polypropylene (PP), (4% site 3 - 10% site 1) and polyethylene (PE) (3% site 2 - 8% site 1). Other identified polymers were polystyrene, polyamide (nylon), poly-acrylate, polyurethane and acrylic coating (paint). MP was mainly present as fragments (68% - 77% of the identified MP), while fibers accounted for 23% to 32% of the MP.

As all the identified MP's were also measured in terms of area and main particle axis (length and width, diameter for the fibers), a particle size distribution was carried out, considering both the total amount of MP (fragments and fibers) and dividing fragments from fibers.

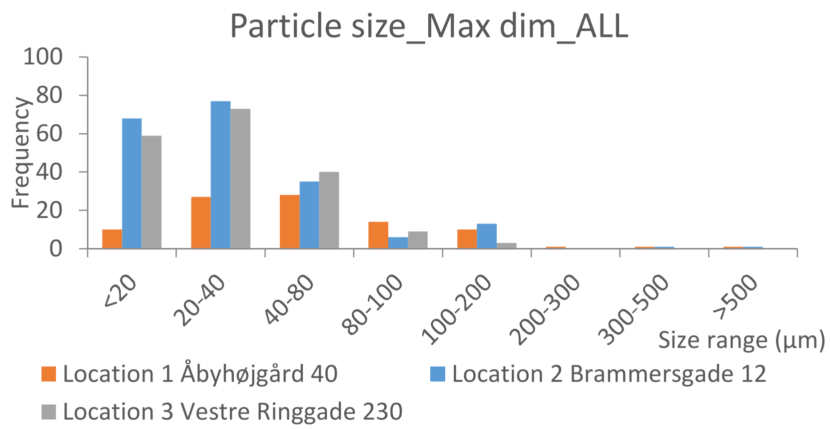


Figure 219 Microplastic fiber and particle size distribution (bigger axis)

Considering the MAX dim, the most abundant size range for fragments was 20-40 µm for site 2 and 3, while site 1 was more abundant in the range 40-80 µm. If considering the min dim, the three sites were more abundant in the range < 20 µm. Particle size distribution using area showed a distribution with a maximum in the range 300-500 µm^2 for sites 2 and 3, while site 1 showed higher frequency in the range 1000-3000 µm^2.

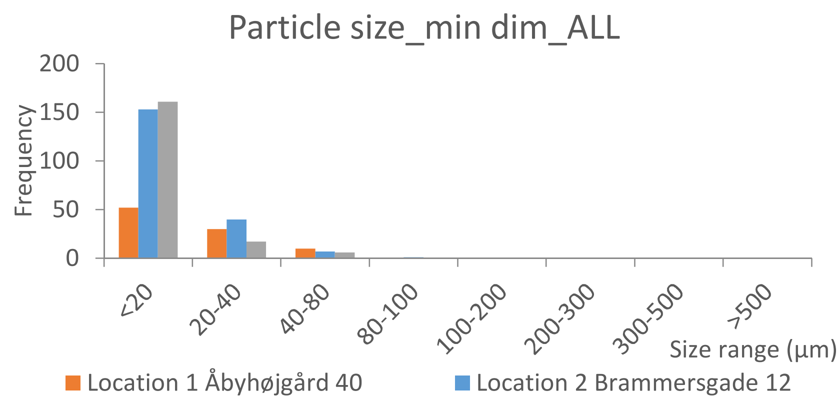


Figure 220 Microplastic fiber and particle size distribution (smaller axis)

The most abundant fiber length was in the range 200-400 µm for site 1 and 3, while site 2 showed a higher frequency in the range 600-800 µm. The most frequent fiber diameter was in the range <10 µm for sites 2 and 3 and in the range 10-20 µm for site 1.
Particle size distribution considering fibers' area showed a similar frequency for sites 2 and 3, with a maximum in the range 1000-3000 µm^2. Site 1 also showed the highest frequency in the same range, but with lower values. Site 2 also showed a quite high frequency in the range 500-700-1000 µm^2, while site 3 highlighted a quite high frequency also in the range 100-300 µm^2.

Rest of information regarding micro plastic investigation can be found in appendix F. FPA-µFTIR-Imaging maps can be found in digital appendix 2K.

5.5 Conclusion

Since no particular guidelines exist for microplastic inhalation, one way of understanding potential harm is to put size and polymer composition results into perspective.

According to ISO 7708: 1995 particles are separated into four conventions based on their size and how deep they can penetrate into the respiratory tract:

1 – Inhalable convention (mass fraction of total inhaled particles).
2 – Thoracic convention (mass fraction of inhaled particles that penetrates beyond larynx).
3 – Respirable convention (mass fraction of inhaled particles that penetrates to the unciliated airways):

a) "Healthy" adult respirable convention (healthy is defined as the percentage of inhalable convention given by a cumulative log-normal distribution with a median of 4,25 µm and is calculated from the inhalable convention).
b) "High risk" respirable convention (high risk is defined as the percentage of the inhalable convention given by a cumulative log-normal distribution with a median of 2,5 µm and is calculated from inhalable convention).

(Morawska & Salthammer, 2003); (ISO 7708, 1995)

Most of the discovered microplastic fibers and particles fall into respirable convention range, suggesting that it can penetrate deep into the human respiratory tract and cause serious harm. Additionally, while overall exposure to other particle types could be greater, MP is dangerous because of its properties:

- It can influence a wide range of conditions, from cytotoxicity to inflammation and necrosis.
- Due to a large surface area to volume ratio, MP particles are very efficient at transporting hydrophobic organic contaminants (like DDT's, PCB's and PAH's).
- Leaching of unbound chemicals from polymers themselves.

This is only a small number of possible harmful effects caused by microplastic inhalation. (Wright and Kelly, 2017) Furthermore, there can potentially be smaller MP particles which couldn't be identified using this instrumental resolution.

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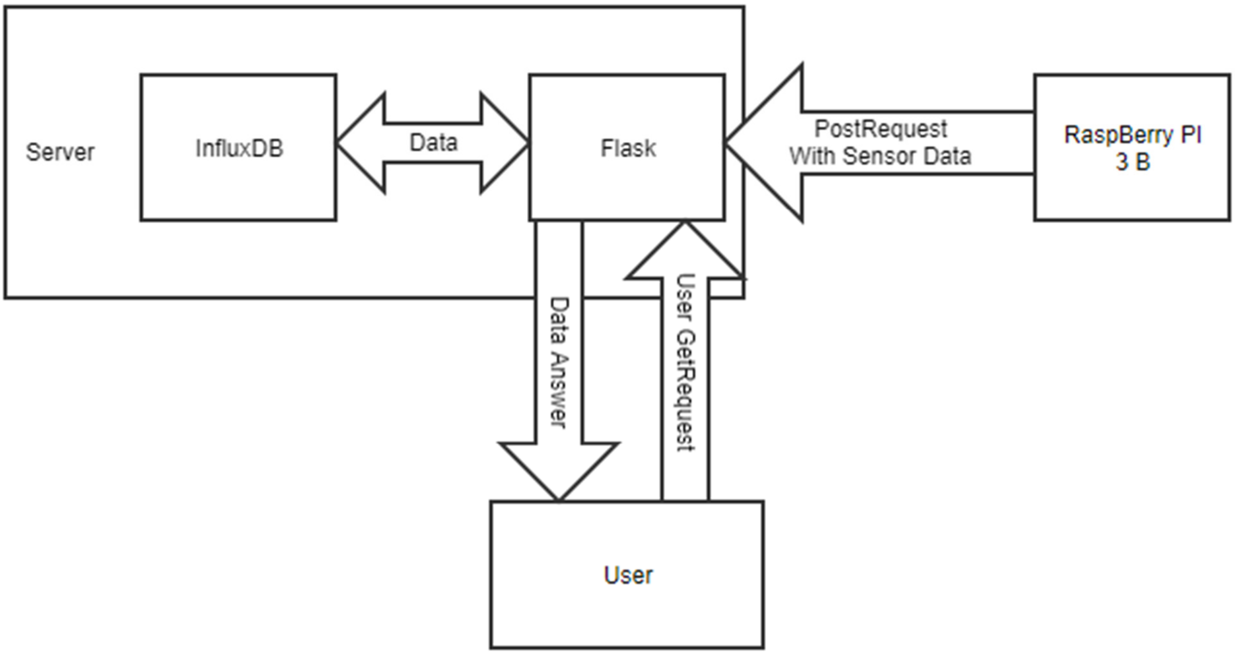
Appendix A

Particle sensor working principle.



Flowchart of particle sampler

The server contains an Influx database which is a time-based database and the Flask web framework which is used to communicate with the server.
The RaspBerry Pi sends a post request with sensor data, flasks take this data and give it to the influx database.
For security reasons, each sensor setup has a token which flask checks if it is valid.
To download data the user sends a “get” request to the flask. Flask then takes the information and get all the data from the influx and return that to the user.
Both Post and “Get” request is methods to get data via websites.

Joakim Levi Haslund

Appendix B

Activity	Before [g]	After [g]	Moisture Emission [g]	Area [m²]	Moisture [g/m²]
Cleaning					
Cleaning with wet cloth	56,28	51,42	4,86	1,125	4,32
Cleaning with wet cloth	49,28	46,77	2,51	1,449	1,73
Cleaning with wet cloth	61,94	58,02	3,92	1,152	3,40
Cleaning with wet cloth	57,81	51,25	6,56	1,4214	4,62
Average			4,4625		3,52
Dishwashing					
Small plate ø 19cm	80,8	83,85	3,05		
Saucepan	83,63	85,83	2,20		
Spatula (wooden)	85,48	85,93	0,45		
Bowl	5,6	6,77	1,17		
Cutlery (knive+fork)	4,33	4,52	0,19		
Small glass	4,7	5,41	0,71		
Small plate ø 19cm	4,49	5,6	1,11		
Cup	4,53	5,77	1,24		
Tea spoon	2,98	3,11	0,13		
Regular glass	4,5	5,7	1,20		
Frying pan	5,96	7,19	1,23		
Small plate ø 19cm	4,49	6,62	2,13		
Fork	2,99	3,36	0,37		
Large plate	6,15	9,86	3,71		
Large plate	7,64	11,64	4,00		
			22,89		
Remains in a sink	13,56	42,64	29,08		
Remains in a sink	13,83	30,43	16,60		
Bowl	76,34	80,59	4,25		
Bowl	80,59	84,9	4,31		
Spoon	84,9	86,22	1,32		
Spoon	86,22	87,2	0,98		
Pot Lid	87,15	90,24	3,09		

Pot	90,09	94,55	4,46
Large drain bowl	94,16	97,58	3,42
Mixing bowl	97,33	100,82	3,49
Cup	100,66	101,76	1,1
Glass	101,62	102,31	0,69
Glass	102,19	102,95	0,76
			27,87

Personal Hygiene

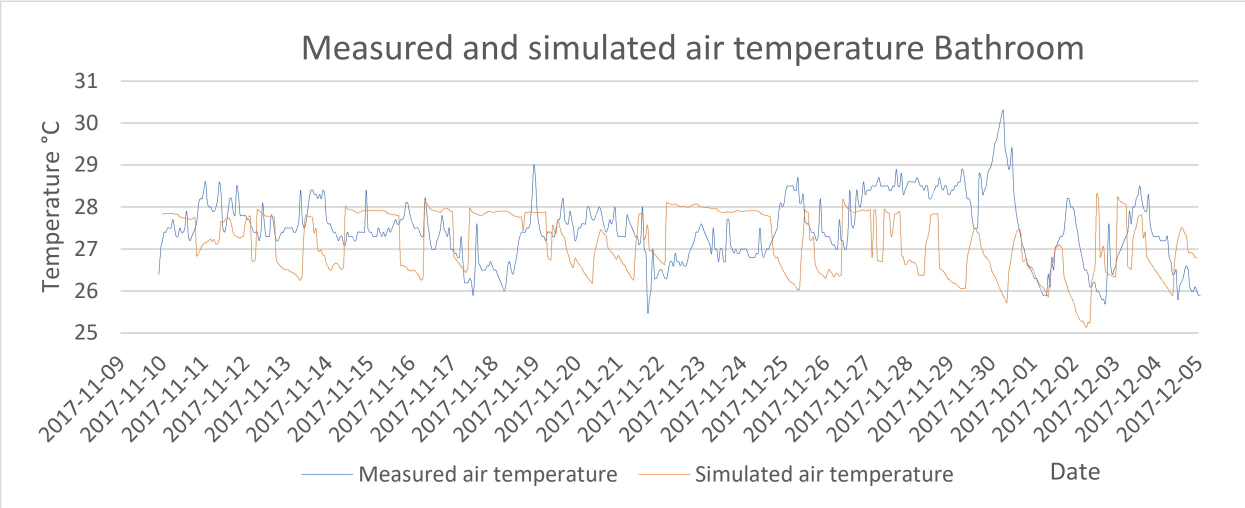
Washing hands (deposit in towel)	102,96	105,93	2,97
Washing hands (deposit in towel)	105,33	107,67	2,34
Deposit in the sink (after handwashing)	5,99	8,32	2,33
Deposit in the sink (after handwashing)	9,15	11,37	2,22
Water deposited in the towel after a shower	591,48	642,56	51,08
Water deposited in the towel after a shower	630,56	650,15	19,59
Water deposited in the towel after a shower	585,7	621,11	35,41
Water deposited in the towel after a shower	582,64	644,45	61,81
Average			41,97

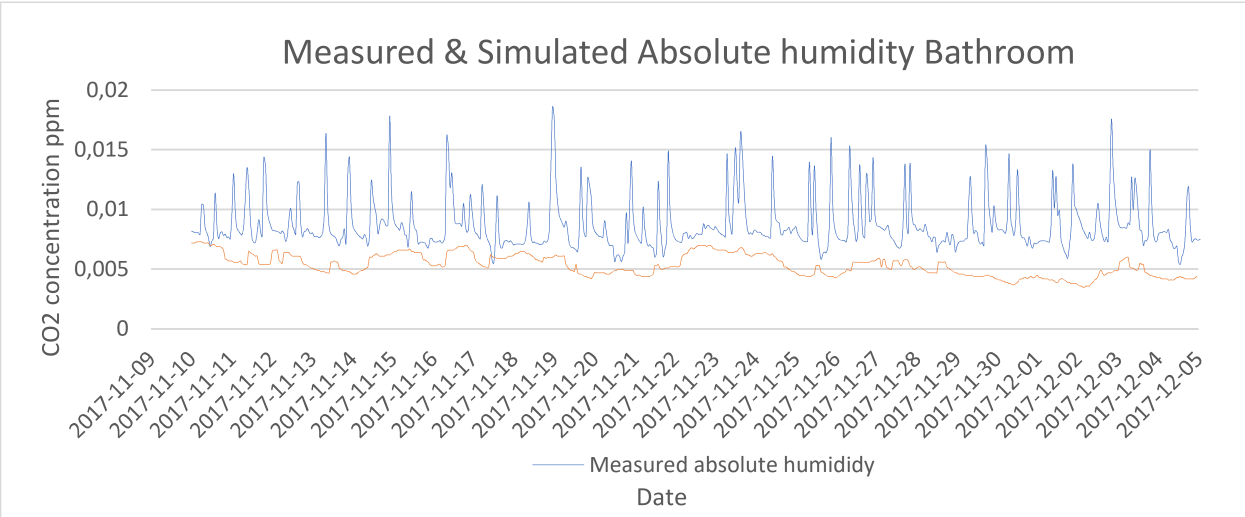
Cooking

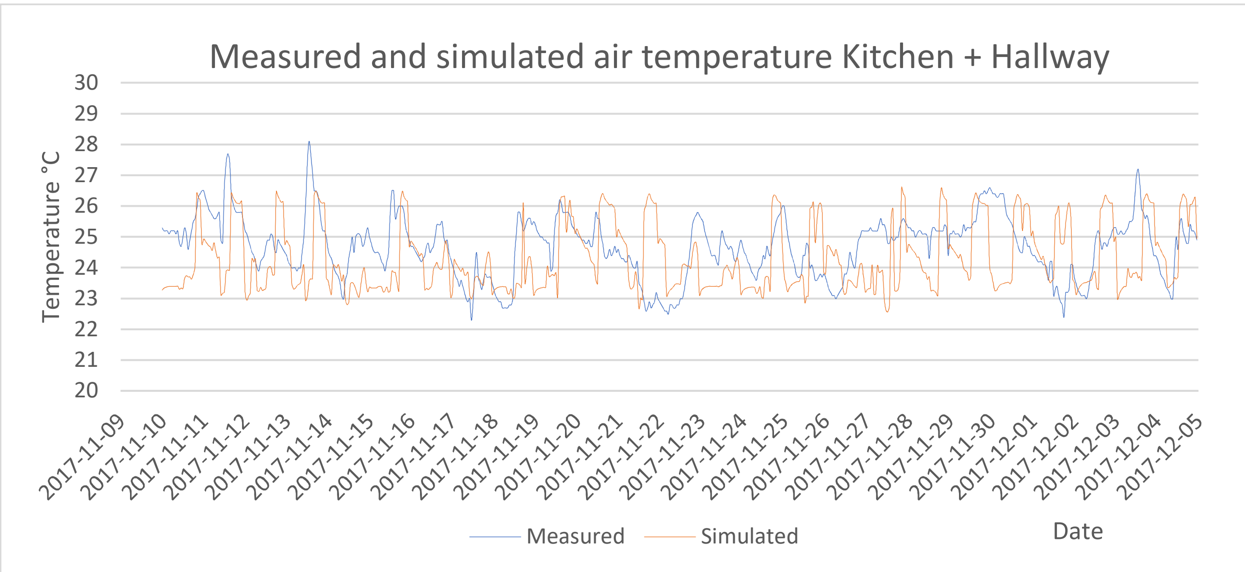
Moisture release from water kettle (boiling)	2096,75	2085,5	11,25
Moisture release from water kettle (boiling)	2183,18	2173,05	10,13
Moisture release from water kettle (cooling off)	1895,65	1883,91	11,74
Boiling 3 eggs	763,72	611,01	152,71
Spaghetti 250g	1845,59	1458,6	386,99
Cooking rice (125g)	575,78	562,78	13
Cooking rice	881,73	871,29	10,44
Cooking rice	1338,26	1310,82	27,44

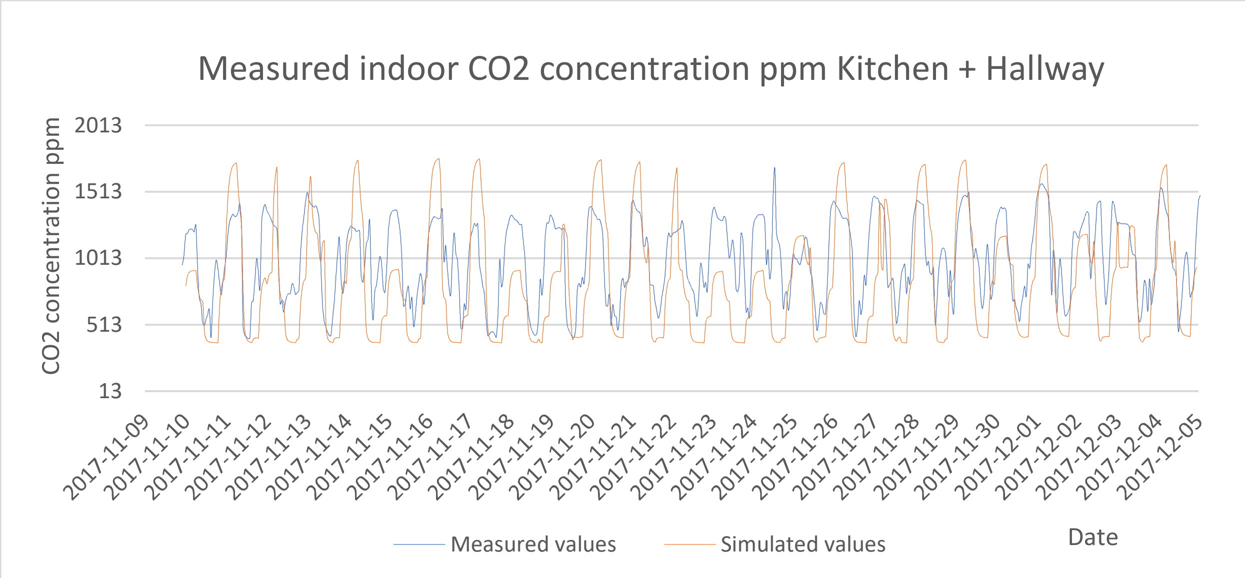
Appendix C

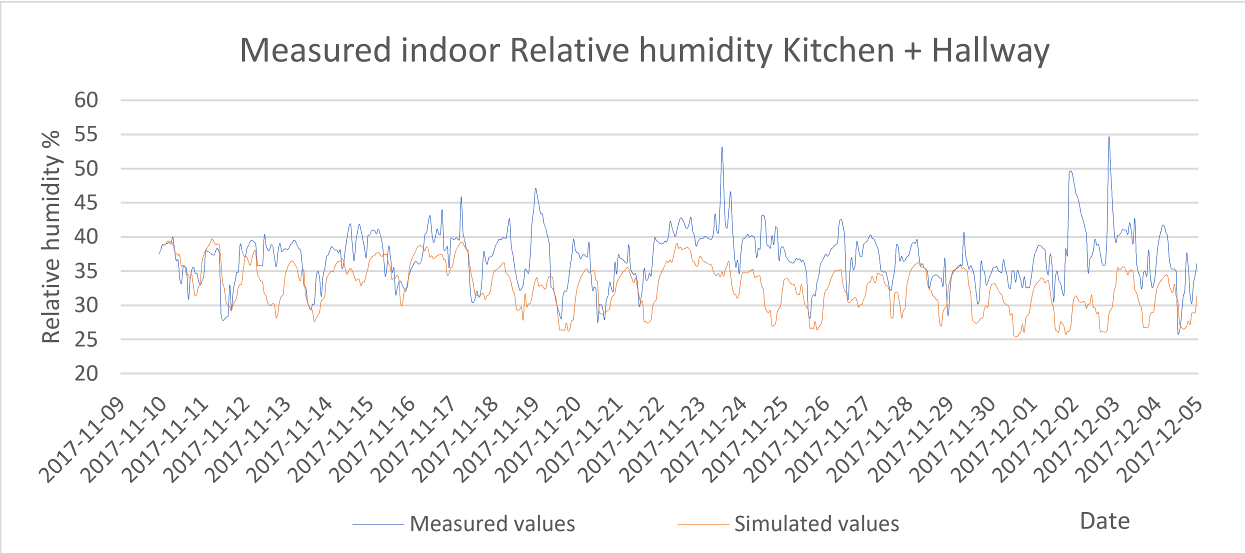
C 1 - Bsim Location 1 validation of bathroom and kitchen








Measured indoor CO2 concentration ppm Kitchen + Hallway
CO2 concentration ppm
2013
1513
1013
513
13
2017-11-09
2017-11-10
2017-11-11
2017-11-12
2017-11-13
2017-11-14
2017-11-15
2017-11-16
2017-11-17
2017-11-18
2017-11-19
2017-11-20
2017-11-21
2017-11-22
2017-11-23
2017-11-24
2017-11-25
2017-11-26
2017-11-27
2017-11-28
2017-11-29
2017-11-30
2017-12-01
2017-12-02
2017-12-03
2017-12-04
2017-12-05
Measured values
Simulated values
Date


Measured indoor Relative humidity Kitchen + Hallway
Relative humidity %
60
55
50
45
40
35
30
25
20
2017-11-09
2017-11-10
2017-11-11
2017-11-12
2017-11-13
2017-11-14
2017-11-15
2017-11-16
2017-11-17
2017-11-18
2017-11-19
2017-11-20
2017-11-21
2017-11-22
2017-11-23
2017-11-24
2017-11-25
2017-11-26
2017-11-27
2017-11-28
2017-11-29
2017-11-30
2017-12-01
2017-12-02
2017-12-03
2017-12-04
2017-12-05
Measured values
Simulated values
Date

C 2 - Moisture emission tables

Åbyhøjgård 40 data analysis for moisture generation profile

- Kitchen

Weekday 10/11/2017				Duration	Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
06:25		Washing hands	1		5.00			5.00
06:26	06:32	Breackfast	1	12:06:00 AM	35.00	5.50		40.50
12:35	12:40	Washing dishes	1	12:05:00 AM	50.00	4.58	6.00	60.58
17:42	17:47	Boiling water tea	1	12:05:00 AM	135.00	4.58		139.58
20:03		Washing hands			5.00			5.00
20:04	20:31	Cooking/oven	1	12:27:00 AM	42.00	24.75		66.75
20:32		Washing hands			5.00			5.00
							Total [g/day]	**312.42**

Weekend 11/11/2017				Duration	Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
07:25	07:33	Boiling water/tea	1	00:08	216.00	7.33		223.33
10:29	10:35	Make coffee	1	00:06	12.00	5.50		17.50
15:00	15:15	Wash dishes	1	00:15	50.00	13.75	6.00	69.75
15:15		Washing hands	1		5.00			5.00
15:15	15:25	Cooking	2	00:10	166.00	11.00		177.00
15:34	15:38	Dishwashing	1	00:04	50.00	3.67	6.00	59.67
19:05	19:20	Cooking/oven	2	00:15	42.00	27.50		69.50
19:20	20:15	Cooking/oven	1	00:55	42.00	50.42		92.42
20:16		Washing hands	1		5.00			5.00
21:18	21:28	Dishwashing	1	00:10	50.00	9.17	6	65.17
							Total [g/day]	**784.33**

Weekend 12/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporat	Total Moisture
hh:mm	hh:mm	Activity	People					
07:19	07:27	Make coffee	1	00:08	12.00	7.33		19.33
07:52	07:56	Dishwashing	1	00:04	50.00	3.67	6.00	59.67
08:00		Washing hands	1		5.00			5.00
08:00	08:11	Breackfast	1	00:11	35.00	10.08		45.08
15:01	15:33	Cooking/stove	1	00:32	166.00	29.33		195.33
16:08	16:15	Dishwashing	1	00:07	50.00	6.42	6.00	62.42
18:40		Washing hands	1		5.00			5.00
18:40	19:26	Cooking/stove	1	00:46	166.00	42.17		208.17
20:05	20:17	Dishwashing	1	00:12	50.00	11.00		61.00
							Total [g/day]	**661.00**

Weekday 13/11/2017				Duration	Moisture Emission	Moisture People	Extra Evapora	Total Moisture
hh:mm	hh:mm	Activity	People					
08:22	08:27	Dishwashing	1	00:05	50.00	4.58	6.00	60.58
08:28	09:00	breackfast	1	00:32	35.00	29.33		64.33
09:05		Washing hands	1		5.00			5.00
09:05	09:13	Coffee	1	00:08	12.00	7.33		19.33
09:37	09:43	Dishwashing	1	00:06	50.00	5.50	6.00	61.50
16:50		Washing hands	1		5.00			5.00
16:50	17:00	Cooking/stove	1	00:10	166.00	9.17		175.17
17:00	17:29	Cooking/stove	2	00:29	166.00	53.17		219.17
18:01	18:04	Dishwashing	1	00:03	50.00	2.75	6.00	58.75
21:25	21:50	Cooking/stove	1	00:25	166.00	22.92		188.92
							Total [g/day]	**857.75**

Weekday 14/11/2017				Duration	Moisture Emission	Moisture People	Extra Evapora	Total Moisture
hh:mm	hh:mm	Activity	People					
09:29	09:56	Breackfast	2	00:27	35.00	49.50		84.50
10:33	10:38	Coffee	1	00:05	71.00	4.58		75.58
10:40	10:50	Dishwashing	1	00:10	50.00	9.17	6.00	65.17
09:05		Washing hands	1		5.00			5.00
11:32	12:07	Cooking/stove	1	00:35	166.00	32.08		198.08
16:50		Washing hands	1		5.00			5.00
13:40	14:13	Cooking/stove	1	00:33	166.00	30.25		196.25
17:00		Washing hands	1		5.00			5.00
14:24	15:49	Cooking/oven	1	01:25	42.00	77.92		119.92
15:06	15:11	Dishwashing	1	00:05	50.00	4.58	6.00	60.58
16:12	16:41	Cooking/stove	1	00:29	166.00	26.58		192.58
22:22	22:35	Washing dishes	1	00:13	50.00	11.92	6.00	67.92
22:50	22:55	Washing dishes	1	00:05	50.00	4.58	6.00	60.58
							Total [g/day]	**1136.17**

Weekday 15/11/2017				Duration	Moisture Emission	Moisture People	Extra Evapora	Total Moisture
hh:mm	hh:mm	Activity	People					
05:16	05:22	Boiling water	1	00:06	35.00	24.75		59.75
08:49	09:00	Dishwashing	1	00:11	50.00	4.58	6.00	60.58
09:01	09:06	Making coffee	1	00:05	12.00	4.58		16.58
09:51	09:56	Making coffee	1	00:05	12.00	4.58		16.58
15:02	15:05	Dishwashing	1	00:03	50.00	2.75	6.00	58.75
15:07	15:18	Cooking/oven	1	00:11	42.00	10.08		52.08
15:20	15:54	Cooking/oven	1	00:34	42.00	31.17		73.17
15:54	16:23	Cooking/oven	1	00:29	42.00	26.58		68.58
16:23		Washing hands	1		5.00			5.00
							Total [g/day]	**411.08**

Weekday 16/11/2017				Duration	Moisture Emission	Moisture People	Extra Evapora	Total Moisture
hh:mm	hh:mm	Activity	People					
06:51	07:00	Boiling water	1	00:09	243.00	8.25		251.25
08:41	09:22	Making breakfast	1	00:41	35.00	37.58		72.58
09:50	09:59	Washing dishes	1	00:09	50.00	8.25		58.25
11:12	11:15	Washing dishes	1	00:03	50.00	4.58	6.00	60.58
13:10		Washing hands	1		5.00		6.00	11.00
13:10	13:15	Cooking/stove	1	00:05	166.00	4.58		170.58
15:20		Washing hands	1		5.00			5.00
14:05	14:25	Cooking/oven	1	00:20	42.00	18.33		60.33
20:35		Washing hands	1		5.00			5.00
20:35	21:51	Cooking/stove	1	01:16	166.00	14.67		180.67
22:16	22:18	Washing dishes	1	00:02	50.00	1.83	6.00	57.83
							Total [g/day]	**933.08**

Weekday 17/11/2017				Duration	Moisture Emission	Moisture People	Extra Evapora	Total Moisture
hh:mm	hh:mm	Activity	People					
05:10	05:39	Breackfast	1	00:29	35.00	26.58		61.58
10:20	10:28	Coffee	1	00:08	12.00	7.33		19.33
11:20	12:00	Cooking/stove	1	00:40	166.00	36.67		202.67
17:21	17:29	Boiling water	1	00:08	216.00	7.33		223.33
17:31	17:38	Dishwashing	1	00:07	50.00	6.42	6.00	62.42
17:38	17:40	Preparing tea	1	00:02	54.00	1.83		55.83
18:41		Washing hands	1		5.00			5.00
18:41	19:16	Cooking/oven	1	00:35	42.00	32.08		74.08
18:41	18:49	Dishwashing	1	00:08	50.00	7.33	6.00	63.33
							Total [g/day]	**767.58**

Weekend 18/11/2017				Duration	Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission
hh:mm	hh:mm	Activity	People					
07:50	07:55	Making tea	1	00:05	135.00	4.58		139.58
08:58	09:08	Breackfast	1	00:10	35.00	3.67		44.67
17:58		Washing hands	1		5.00			5.00
17:58	19:47	Cooking/stove	2	01:49	166.00	273.17		439.17
20:13	20:23	Dishwashing	1	00:10	50.00	9.17	6.00	65.17
							Total [g/day]	**693.58**

Weekend 19/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporat	Total Moisture
hh:mm	hh:mm	Activity	People					
09:26	09:40	Breackfast	1	00:14	35.00	12.83		47.83
09:40	09:45	Dishwashing	1	00:05	50.00	4.58	6	60.58
16:15		Washing hands	1		5.00			5.00
16:15	16:40	cooking/stove	2	00:25	166.00	45.83		211.83
18:18		Washing hands	1		5.00			5.00
18:18	18:36	cooking/stove	1	00:18	166.00	16.50		182.50
19:13	19:17	dishwashing	2	00:04	50.00	7.33	6.00	63.33
19:17	19:53	cooking/stove	1	00:36	166.00	33.00		199.00
19:53	20:00	dishwashing	1	00:07	50.00	6.42	6	62.42
							Total [g/day]	**837.50**

Weekday 20/11/2017				Duration	Moisture Emission	Moisture People	Extra Evapora	Total Moisture
hh:mm	hh:mm	Activity	People					
13:18	13:21	Making coffee	1	00:03	12.00	2.75		14.75
18:32	18:59	Cooking/stove	2	00:27	12.00	49.50		61.50
21:50		Washing hands	1		5.00			5.00
21:50	22:18	Cooking/stove	1	00:28	216.00	25.67		241.67
22:23	22:24	Washing dishes	1	00:01	50.00	0.92	6.00	56.92
							Total [g/day]	**379.83**

Weekday 21/11/2017				Duration	Moisture Emission	Moisture People	Extra Evapora	Total Moisture
hh:mm	hh:mm	Activity	People					
05:40	06:06	Breackfast	1	00:26	35.00	23.83		58.83
09:17	09:20	Coffee	2	00:03	12.00	5.50		17.50
09:50	09:55	Dishwashing	1	00:05	50.00	4.58	6.00	60.58
10:33	10:55	Cooking/stove	1	00:22	166.00	20.17		186.17
11:14	11:20	Coffee	1	00:06	12.00	5.50	6.00	23.50
17:10		Washing hands	1		5.00			5.00
17:10	17:50	Cooking/stove	1	00:40	166.00	36.67		202.67
20:45		Washing hands	1		5.00			5.00
20:45	20:53	Cooking/oven	1	00:08	42.00	7.33		49.33
22:28	22:29	Dishwashing	1	00:01	50.00	0.92		50.92
							Total [g/day]	**659.50**

Weekday 22/11/2017				Duration	Moisture Emission	Moisture People	Extra Evapora	Total Moisture
hh:mm	hh:mm	Activity	People					
06:03	06:17	Breackfast	1	00:14	35.00	12.83		47.83
12:04	12:08	Washing dishes	2	00:04	50.00	7.33	6.00	63.33
12:57	13:00	Making coffee	1	00:03	12.00	2.75		14.75
14:25	14:45	Cooking/stove	1	00:20	166.00	18.33		184.33
14:55	15:00	Washing dishes	1	00:05	50.00	4.58	6.00	60.58
17:54		Washing hands	1		5.00			5.00
17:54	18:30	Cooking/stove	2	00:36	166.00	66.00		232.00
18:47	18:55	Washing dishes	1		50.00		6.00	56.00
18:59	19:05	Boiling water	1	00:06	162.00	5.50		167.50
19:57	20:45	Cooking/oven	1	00:48	42.00	44.00		86.00
20:45		Washing hands	1		5.00			
							Total [g/day]	**917.33**

Weekday 23/11/2017				Duration	Moisture Emission	Moisture People	Extra Evapora	Total Moisture
hh:mm	hh:mm	Activity	People					
07:15	07:27	reackfast and eatin	1	00:12	35.00	11.00		46.00
07:56	08:05	Coffee	2	00:09	12.00	16.50		28.50
10:20	10:26	Washing dishes	1	00:06	50.00	5.50	6.00	61.50
14:15	14:17	Coffee	1	00:02	12.00	1.83		13.83
14:15	14:27	Cooking/oven	1	00:12	42.00	11.00		53.00
19:55		Washing hands	1		5.00			5.00
19:55	20:44	Cooking/oven	1	00:49	42.00	44.92		86.92
20:44		Washing hands	1		5.00			5.00
21:08	22:10	Cooking/stove	2	01:02	166.00	187.00		353.00
23:07	23:14	Washing dishes	1	00:07	50.00	6.42	6.00	62.42
							Total [g/day]	**715.17**

Weekday 24/11/2017				Duration	Moisture Emission	Moisture People	Extra Evapora	Total Moisture
hh:mm	hh:mm	Activity	People					
08:45	08:51	Coffee	1	00:06	35.00	5.50		40.50
09:02	09:23	Breackfast and eating	2	00:21	12.00	38.50		50.50
09:23	09:24	Washing dishes	1	00:01	50.00	0.92	6.00	56.92
10:02	10:26	Cooking/stove	1	00:24	166.00	22.00		188.00
11:05	11:09	Boiling water	1	00:04	108.00	3.67		111.67
13:45	13:48	Washing dishes	1		5.00			5.00
13:48	13:53	Boiling water	1	00:05	135.00	4.58		139.58
17:25		Washing hands	1		5.00			5.00
17:25	17:30	Boiling water	2	00:05	135.00	9.17		144.17
20:30	20:56	Cooking/stove	1	00:26	166.00	23.83	6.00	195.83
							Total [g/day]	**937.17**

Weekend 25/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporat	Total Moisture
hh:mm	hh:mm	Activity	People					
08:39	08:55	Breackfast and eating	1	00:16	35.00	14.67		49.67
09:40		Washing hands	1		5.00			5.00
18:45	19:32	Cooking/stove	2	00:47	166.00	86.17		252.17
21:40	21:43	Boiling water	1	00:03	81.00	2.75		83.75
							Total [g/day]	**390.58**

Weekend 26/11/2017				Duration	Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
07:44	07:53	Boiling water	1	00:09	243.00	8.25		251.25
08:45	08:55	Breackfast and eating	1	00:10	35.00	9.17		44.17
08:55	09:00	Boiling water	1	00:05	135.00	4.58		139.58
10:48	10:55	Coffee	1	00:07	12.00	6.42		18.42
12:08		Washing hands	1		5.00			5.00
12:08	12:38	Cooking/stove	1	00:30	166.00	27.50		193.50
18:13		Washing hands	1		5.00			5.00
18:13	18:49	Cooking/stove	1	00:36	166.00	33.00		199.00
18:49		Washing hands	1		5.00	14.67		19.67
							Total [g/day]	875.58

Weekday 27/11/2017				Duration	Moisture	Moisture	Extra	Total
hh:mm	hh:mm	Activity	People		Emission	People	Evapora	Moisture
07:01	07:20	Boiling water	1	00:19	12.00	17.42		29.42
12:35	12:45	Washing dishes	2	00:10	50.00	18.33	6.00	74.33
12:46	12:55	Cooking/stove	1	00:09	166.00	8.25		174.25
15:30	15:33	Coffee	1	00:03	12.00	2.75		14.75
18:49	19:25	Cooking/stove	1	00:36	166.00	33.00		199.00
19:50	19:55	Washing dishes	1		50.00		6.00	56.00
20:25	21:01	Cooking/stove	1	00:36	166.00	4.58		170.58
21:01		Washing hands	1		5.00			5.00
							Total [g/day]	**723.33**

Weekday 28/11/2017				Duration	Moisture	Moisture	Extra	Total
hh:mm	hh:mm	Activity	People		Emission	People	Evapora	Moisture
05:30	05:47	Breackfast & eating	1	00:17	35.00	15.58		50.58
10:30	10:33	Coffee	2	00:03	12.00	5.50		17.50
11:50		Washing hands	1		5.00			5.00
11:50	12:28	Cooking/oven	1	00:38	42.00	34.83		76.83
12:28	12:32	Washing dishes	1	00:04	50.00	3.67	6.00	59.67
15:35	15:40	Coffee	1	00:05	12.00	4.58		16.58
20:30	20:35	Washing dishes	1	00:05	50.00	4.58		54.58
09:00	09:45	Cooking/stove	1	00:45	166.00	38.50		204.50
		Washing hands	1		5.00			5.00
22:10	22:26	Cooking/stove	1	00:16	166.00	14.67		180.67
		Washing hands	1		5.00			5.00
							Total [g/day]	**675.92**

Weekday 29/11/2017				Duration	Moisture	Moisture	Extra	Total
hh:mm	hh:mm	Activity	People		Emission	People	Evapora	Moisture
07:54	08:11	Breackfast & eating	1	00:17	35.00	15.58		50.58
10:18	10:25	Washing dishes	1	00:07	50.00	6.42	6.00	62.42
15:05		Washing hands	1		5.00			5.00
15:05	16:00	Cooking/oven	1	00:55	42.00	50.42		92.42
19:49	21:49	Cooking/oven	1	02:00	42.00	110.00		152.00
		Washing hands	1		5.00			5.00
21:15	21:20	Dishwashing	2	00:05	50.00	9.17	6.00	65.17
21:50	21:56	Dishwashing	1	00:06	50.00	5.50	6.00	61.50
							Total [g/day]	**494.08**

Weekday 30/11/2017				Duration	Moisture	Moisture	Extra	Total
hh:mm	hh:mm	Activity	People		Emission	People	Evapora	Moisture
06:50	07:12	Breackfast	1	00:22	35.00	20.17		55.17
08:01	08:08	Coffee	1	00:07	12.00	6.42		18.42
09:44	10:02	Cooking/stove	1	00:18	166.00	16.50		182.50
17:50		Washing hands	1		50.00			50.00
17:50	18:48	Cooking/stove	1	00:58	42.00	53.17		95.17
18:48		Washing hands	1		5.00			5.00
							Total [g/day]	**406.25**

Kitchen overview of investigated days and result

Kitchen Day/Date		Total Moisture Generation [g/day]	Average Daily Emission [g]	Hourly Average Week/Weekend [g/h]	Standard Deviation	Standard Error	Total Average [g/day]	Total Hourly Average [g/h]
	11/10/2017	312.42						
	11/13/2017	857.75						
	11/14/2017	1136.2						
	11/15/2017	411.08						
	11/16/2017	933.1						
	11/17/2017	767.6						
	11/20/2017	379.8						
	11/21/2017	659.50						
Weekday	11/22/2017	917.3	**688.4**	**28.69**	**245.44**	**63.37**		
	11/23/2017	715.2						
	11/24/2017	937.17						
	11/27/2017	723.33						
	11/28/2017	675.92					**697.77**	**29.07**
	11/29/2017	494.08						
	11/30/2017	406.25						
	11/11/2017	784.33						
	11/12/2017	661						
	11/18/2017	693.58						
Weekend	11/19/2017	837.5	**707.095**	**29.46229167**	**175.412117**	**71.61169689**		
	11/25/2017	390.58						
	11/26/2017	875.58						

Standard Daily Profile - Kitchen			
Hours	Activity	Emissions [g]	Percentage [%]
0	-	-	-
1	-	-	-
2	-	-	-
3	-	-	-
4	-	-	-
5	-	-	-
6	-	-	-
7	-	-	-
8	Washing Hands	10	5.08
9	Brakfast	67	34.01
10	Washing Dishes	50.3	25.53
11	-	-	
12	-	-	
13	Washing Hands	10	5.08
14	Cooking	197	100.00
15	Washing Dishes	50.3	25.53
16	-	-	
17	Washing Hands	10	5.08
18	Cooking	197	100.00
19	Washing Dishes	50.3	25.53
20	-	-	-
21	-	-	-
22	-	-	-
23	-	-	-
	Total	**641.9**	

- Bathroom

Weekday 10/11/2017				Duration	Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
06:07	06:14	Morning routine	3	12:07:00 AM	147.00	6.42	4.00	157.42
06:38	06:56	Shower	1	12:18:00 AM	531.00	16.50	79.00	626.50
14:24	14:40	Shower	1	12:16:00 AM	470.40	14.67	79.00	564.07
21:56	22:00	Evening routine	1	12:04:00 AM	147.00	3.67	4.00	154.67
00:45	00:59	Shower	3	12:14:00 AM	411.60	12.83	79.00	503.43
							Total [g/day]	**1502.65**

Weekend 11/11/2017				Duration	Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
10:16	10:28	Morning routine	3	12:12:00 AM	147.00	11.00	4.00	162.00
08:33	09:12	Shower	1	12:39:00 AM	1150.50	35.75	79.00	1265.25
09:49	10:00	Shower	1	12:11:00 AM	323.40	10.08	79.00	412.48
11:04	11:28	Shower	1	12:24:00 AM	705.60	22.00	79.00	806.60
19:20	19:56	Shower	1	12:36:00 AM	1058.40	33.00	79.00	1170.40
22:34	22:38	Evening routine	3	12:04:00 AM	147.00	3.67	4.00	154.67
							Total [g/day]	**2646.33**

Weekend 12/11/2017				Duration	Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission
hh:mm	hh:mm	Activity	People					
06:24	06:29	Morning routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
10:45	10:53	Shower	1	12:08:00 AM	236.00	7.33	79.00	322.33
15:25	15:52	Shower	1	12:27:00 AM	793.80	24.75	79.00	897.55
21:18	21:21	Evening routine	3	12:03:00 AM	147.00	2.75	4.00	153.75
							Total [g/day]	**1529.22**

Weekday 13/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
06:34	06:44	Morning routine	3	12:10:00 AM	147.00	9.17	4.00	160.17
07:39	08:04	Shower	1	12:25:00 AM	737.50	22.92	79.00	839.42
08:08	08:25	Shower	1	12:17:00 AM	499.80	15.58	79.00	594.38
21:24	21:38	Shower	1	12:14:00 AM	705.60	12.83	79.00	797.43
21:51	22:03	Shower	1	12:12:00 AM	352.80	11.00	79.00	442.80
22:27	22:29	Evening routine	3	12:02:00 AM	147.00	1.83	4.00	152.83
							Total [g/day]	**2391.40**

Weekday 14/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
07:34	07:40	Morning routine	3	12:06:00 AM	147.00	5.50	4.00	156.50
11:17	11:45	Shower	1	12:28:00 AM	826.00	25.67	79.00	930.67
13:07	13:13	Shower	1	12:06:00 AM	176.40	5.50	79.00	260.90
21:50	22:17	Shower	1	12:27:00 AM	793.80	24.75	79.00	897.55
22:27	22:29	Evening routine	3	12:02:00 AM	147.00	1.83	4.00	152.83
							Total [g/day]	**2245.62**

Weekday 15/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
05:00	05:16	Morning routine	3	12:16:00 AM	147.00	14.67	4.00	165.67
10:42	11:04	Shower	1	12:22:00 AM	649.00	20.17	79.00	748.17
22:27	22:29	Evening routine	3	12:02:00 AM	147.00	1.83	4.00	152.83
							Total [g/day]	**913.83**

Weekday 16/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
6:44	6:49	Morning routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
07:53	08:15	Shower	1	12:22:00 AM	649.00	20.17	79.00	748.17
09:04	09:27	Shower	1	12:23:00 AM	676.20	21.08	79.00	776.28
10:45	10:50	Shower	1	12:05:00 AM	147.00	4.58	79.00	230.58
18:00	18:05	Shower	1	12:05:00 AM	147.00	4.58	79.00	230.58
22:22	22:35	Shower	1	12:13:00 AM	382.20	11.92	79.00	473.12
22:27	22:32	Evening routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
							Total [g/day]	**1910.62**

Weekday 17/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
5:00	5:08	Morning routine	3	12:08:00 AM	147.00	7.33	4.00	158.33
05:30	05:39	Shower	1	12:09:00 AM	265.50	8.25	79.00	352.75
13:29	14:46	Shower	1	1:17:00 AM	499.80	15.58	79.00	594.38
22:27	22:32	Evening routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
							Total [g/day]	**1105.47**

Weekend 18/11/2017				Duration	Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
7:14	7:24	Morning routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
22:24	23:13	Shower	1	12:22:00 AM	646.80	20.17	79.00	745.97
00:00	00:15	Shower	1	12:23:00 AM	676.20	21.08	79.00	776.28
22:27	22:32	Evening routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
							Total [g/day]	**1833.42**

Weekend 19/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporation	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
09:16	09:22	Morning routine	3	12:06:00 AM	147.00	5.50	4.00	156.50
15:45	15:58	Shower	1	12:13:00 AM	383.50	11.92	79.00	474.42
20:08	20:21	Shower	1	12:13:00 AM	382.20	11.92	79.00	473.12
21:35	21:45	Shower	1	12:10:00 AM	294.00	9.17	79.00	382.17
22:34	22:38	Evening routine	3	12:04:00 AM	147.00	3.67	4.00	154.67
							Total [g/day]	**1486.20**

Weekday 20/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
06:16	06:43	Morning routine	3	12:27:00 AM	147.00	24.75	4.00	175.75
19:00	19:10	Shower	1	12:10:00 AM	295.00	9.17	79.00	383.17
21:31	21:45	Shower	1	12:14:00 AM	411.60	12.83	79.00	503.43
21:49	22:02	Shower	1	12:13:00 AM	382.20	4.58	79.00	465.78
22:24	22:27	Evening routine	3	12:03:00 AM	147.00	2.75	4.00	153.75
							Total [g/day]	**1528.13**

Weekday 21/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
5:11	5:16	Morning routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
5:11	5:36	Shower	1	12:25:00 AM	737.50	22.92	79.00	839.42
13:37	14:00	Shower	1	12:23:00 AM	676.20	21.08	79.00	776.28
19:50	20:12	Shower	1	12:22:00 AM	646.80	20.17	79.00	745.97
22:57	23:02	Evening routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
							Total [g/day]	**2517.25**

Weekday 22/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
6:44	6:49	Morning routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
22:31	22:35	Evening routine	3	12:04:00 AM	147.00	3.67	4.00	154.67
							Total [g/day]	**155.58**

Weekday 23/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
6:44	6:49	Morning routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
06:52	07:12	Shower	1	12:22:00 AM	646.80	20.17	79.00	745.97
11:45	11:54	Shower	1	12:23:00 AM	676.20	21.08	79.00	776.28
14:58	15:12	Shower	1	12:05:00 AM	147.00	4.58	79.00	230.58
15:15	16:12	Shower	1	12:05:00 AM	147.00	4.58	79.00	230.58
23:23	23:27	Evening routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
							Total [g/day]	**2294.58**

Weekday 24/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
07:34	07:36	Morning routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
09:56	10:24	Shower	1	12:22:00 AM	646.80	20.17	79.00	745.97
10:37	10:50	Shower	1	12:23:00 AM	676.20	21.08	79.00	776.28
22:45	22:47	Evening routine	3	12:05:00 AM	147.00	1.83	4.00	152.83
							Total [g/day]	**1830.67**

Weekend 25/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporation	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
07:49	07:50	Morning routine	3	12:01:00 AM	147.00	5.50	4.00	156.50
8:05	8:37	Shower	1	12:32:00 AM	944.00	29.33	79.00	1052.33
11:00	11:23	Shower	1	12:23:00 AM	676.20	21.08	79.00	776.28
20:43	21:12	Shower	1	12:29:00 AM	852.60	26.58	79.00	958.18
23:30	23:40	Evening routine	3	12:10:00 AM	147.00	2.75	4.00	153.75
							Total [g/day]	**2943.30**

Weekend 26/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporation	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
7:45	7:50	Morning routine	3	12:05:00 AM	147.00	5.50	4.00	156.50
08:50	08:59	Shower	1	12:09:00 AM	265.50	8.25	79.00	352.75
09:09	09:14	Shower	1	12:05:00 AM	147.00	4.58	79.00	230.58
14:09	14:37	Shower	1	12:28:00 AM	823.20	25.67	79.00	927.87
18:15	18:35	Shower	1	12:20:00 AM	588.00	18.33		
23:30	23:40	Evening routine	3	12:10:00 AM	147.00	9.17	4.00	160.17
							Total [g/day]	**1667.70**

Weekday 27/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
06:32	06:52	Morning routine	3	12:20:00 AM	147.00	18.33	4.00	169.33
16:40	17:15	Shower	1	12:35:00 AM	1029.00	32.08	79.00	1140.08
20:03	20:20	Shower	1	12:17:00 AM	499.80	15.58	79.00	594.38
22:26	22:30	Evening routine	3	12:04:00 AM	147.00	3.67	4.00	154.67
							Total [g/day]	**2058.47**

Weekday 28/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
05:11	05:30	Morning routine	3	12:19:00 AM	147.00	17.42	4.00	168.42
22:28	22:30	Evening routine	3	12:02:00 AM	147.00	1.83	4.00	152.83
							Total [g/day]	**321.25**

Weekday 29/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
7:23	7:32	Morning routine	3	12:09:00 AM	147.00	8.25	4.00	159.25
07:37	07:53	Shower	1	12:16:00 AM	470.40	14.67	79.00	564.07
16:49	18:00	Shower	1	1:11:00 AM	323.40	10.08	79.00	412.48
21:59	22:17	Evening routine	3	12:18:00 AM	147.00	16.50	4.00	167.50
							Total [g/day]	**1303.30**

Weekday 30/11/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
06:16	06:37	Morning routine	3	12:21:00 AM	147.00	19.25	4.00	170.25
06:50	07:05	Shower	1	12:15:00 AM	441.00	13.75	79.00	533.75
11:15	12:30	Shower	1	1:15:00 AM	441.00	13.75	79.00	533.75
22:23	22:29	Evening routine	3	12:06:00 AM	147.00	5.50	4.00	156.50
							Total [g/day]	**1394.25**

Weekday 1/12/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
07:47	07:49	Morning routine	3	12:02:00 AM	147.00	1.83	4.00	152.83
8:45	8:55	Shower	1	12:10:00 AM	294.00	9.17	79.00	382.17
09:02	09:17	Shower	1	12:15:00 AM	441.00	13.75	79.00	533.75
10:48	11:08	Shower	1	12:20:00 AM	588.00	18.33	79.00	685.33
12:27	12:41	Shower	1	12:14:00 AM	411.60	12.83	79.00	503.43
20:47	20:55	Shower	1	12:08:00 AM	235.20	7.33	79.00	321.53
22:23	22:29	Evening routine	3	12:06:00 AM	147.00	5.50	4.00	156.50
							Total [g/day]	**2735.55**

Weekend 2/12/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporation	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
7:19	7:23	Morning routine	3	12:04:00 AM	147.00	3.67	4.00	154.67
11:38	11:53	Shower	1	12:15:00 AM	442.50	13.75	79.00	535.25
19:32	20:10	Shower	1	12:38:00 AM	1117.20	34.83	79.00	1231.03
23:12	23:14	Evening routine	3	12:02:00 AM	147.00	1.83	4.00	152.83
							Total [g/day]	**1920.95**

Weekend 3/12/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporation	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	People					
7:35	7:40	Morning routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
08:14	08:21	Shower	1	12:07:00 AM	206.50	6.42	79.00	291.92
10:23	10:42	Shower	1	12:19:00 AM	558.60	17.42	79.00	655.02
19:06	19:15	Shower	1	12:09:00 AM	264.60	8.25	79.00	351.85
23:12	23:14	Evening routine	3	12:02:00 AM	147.00	1.83	4.00	152.83
							Total [g/day]	**1454.37**

Weekday 4/12/2017				Duration	Moisture Emission	Moisture People [g]	Extra Evaporati	Total Moisture
hh:mm	hh:mm	Activity	People					
07:07	07:14	Morning routine	3	12:07:00 AM	147.00	6.42	4.00	157.42
16:23	16:45	Shower	1	12:22:00 AM	646.80	20.17	79.00	745.97
17:44	17:55	Shower	1	12:11:00 AM	323.40	10.08	79.00	412.48
21:55	22:00	Evening routine	3	12:05:00 AM	147.00	4.58	4.00	155.58
							Total [g/day]	**1471.45**

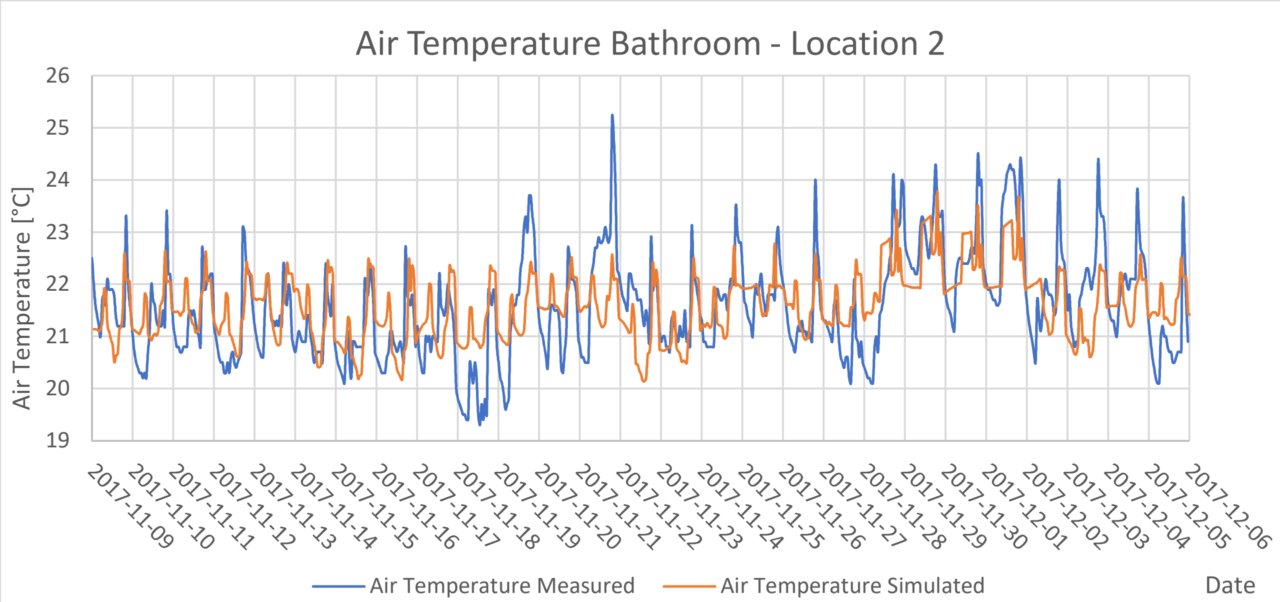
Kitchen overview of investigated days and result

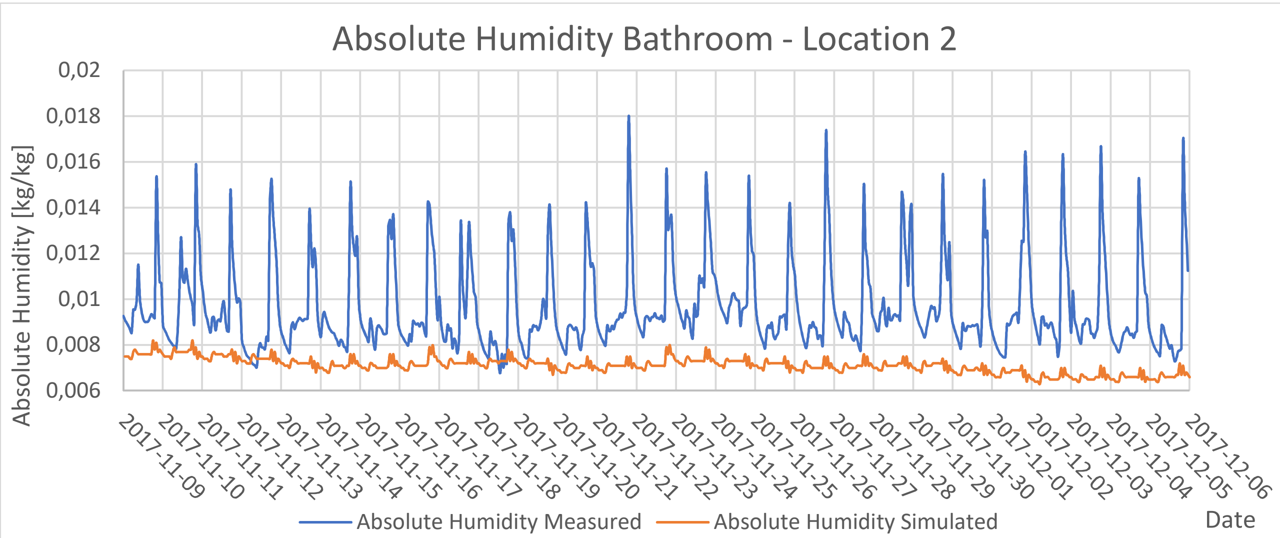
Bathroom Day/Date		Total Moisture Generation [g/day]	Average Daily Emission [g]	Hourly Average Week/Weekend [g]	Standard Deviation	Standard Error	Total Average [g/day]	Total Hourly Average [g/day]
Weekday	11/10/2017	1502.65	**1628.2**	**67.84**	**733.19**	**177.82**	**1781.71**	**74.24**
	11/13/2017	2391.40						
	11/14/2017	2245.6						
	11/15/2017	913.80						
	11/16/2017	1910.6						
	11/17/2017	1105.5						
	11/20/2017	1528.1						
	11/21/2017	2517.25						
	11/22/2017	155.7						
	11/23/2017	2294.6						
	11/24/2017	1830.67						
	11/27/2017	2058.47						
	11/28/2017	321.25						
	11/29/2017	1303.3						
	11/30/2017	1394.25						
	12/1/2017	2735.55						
	12/4/2017	1471.45						
Weekend	11/11/2017	2646.33	**1935.1863**	**80.63276**	**560.82952**	**198.28318**		
	11/12/2017	1529.22						
	11/18/2017	1833.42						
	11/19/2017	1486.2						
	11/25/2017	2943.3						
	11/26/2017	1667.7						
	12/2/2017	1920.95						
	12/3/2017	1454.37						

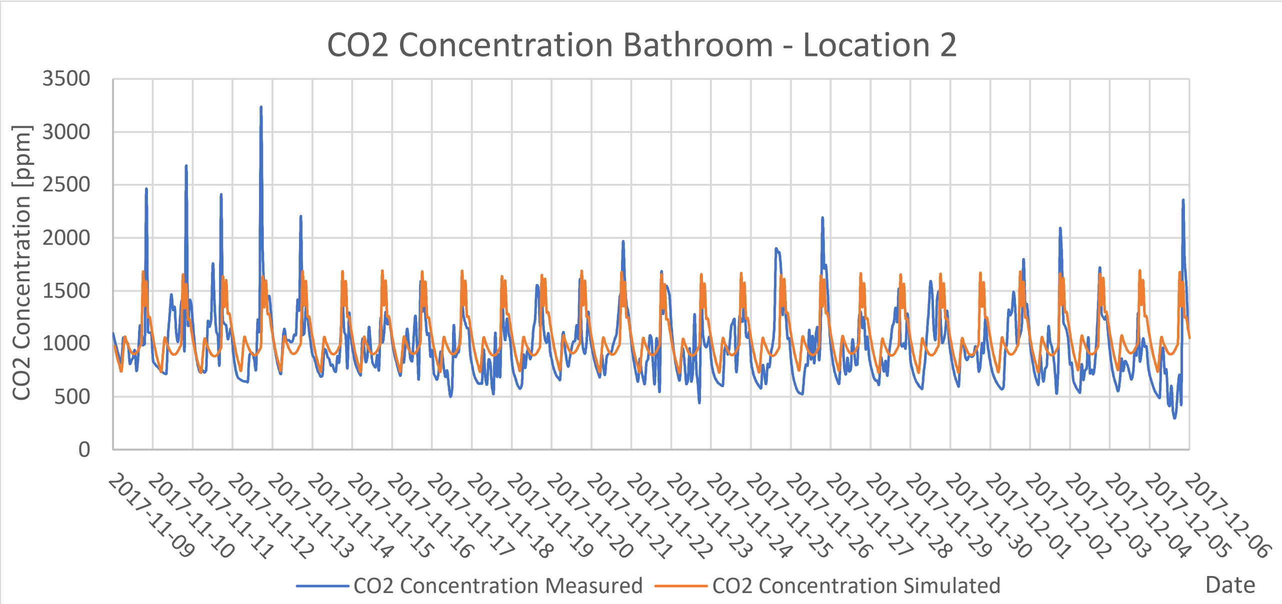
Standard Daily Profile - Bathroom			
Hours	Activity	Emissions [g]	Percentage [%]
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	Morning routine	159	26
7	Morning routine	159	26
8	Shower 1	622	100
9	0	0	0
10	0	0	0
11	0	0	0
12	Shower 2	311	50
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	Shower 3	311	50
22	Evening routine	155	25
23	Evening routine	155	25
Total		**932**	

Appendix D

D 1 - Location 2 – BSim model validation.







CO2 Concentration Bathroom - Location 2
CO2 Concentration [ppm]
3500
3000
2500
2000
1500
1000
500
0
2017-11-09
2017-11-10
2017-11-11
2017-11-12
2017-11-13
2017-11-14
2017-11-15
2017-11-16
2017-11-17
2017-11-18
2017-11-19
2017-11-20
2017-11-21
2017-11-22
2017-11-23
2017-11-24
2017-11-25
2017-11-26
2017-11-27
2017-11-28
2017-11-29
2017-11-30
2017-12-01
2017-12-02
2017-12-03
2017-12-04
2017-12-05
2017-12-06
CO2 Concentration Measured
CO2 Concentration Simulated
Date

D 2 - Brammersgade 12, data analysis for kitchen moisture generation profile.

Weekday 10/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
09:31	09:37	Breakfast	Water kettle	1	21
09:45	09:58	Breakfast	Water kettle, toasts	1	21
12:16	12:17	Washing hands		1	5
14:15		Washing hands		1	5
15:03	15:08	Washing dishes		1	47
15:14	15:23	Cooking	Frying Onions, Hood on 2	1	20
15:23	15:41	Cooking	Frying Meat, Hood on 2	1	74
15:23	15:39	Oven	Warming up tortillas, Hood on	1	42
20:55	21:00	Washing dishes		1	47
		Plants			24
				Total [g/day]	**306**

Weekday 14/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
01:05	01:10	Cooking	Warming up a glass of milk (stove)	1	10
06:51	06:55	Breakfast	Water kettle, toasts	1	21
07:49	07:53	Water kettle		1	21
08:11	08:16	Breakfast	Water kettle	1	21
08:45	08:47	Washing dishes		1	16
20:12	21:05	Cooking	Frying meat with vegetables, stuffed pancakes, Hood on 2	1	96
20:41	20:47	Washing dishes		1	47
		Plants			24
				Total [g/day]	**256**

Weekday 16/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
07:00	07:05	Breakfast	Water kettle, toasts	1	21
08:06	08:10	Breakfast	Water kettle	1	21
08:53		Washing dishes		1	16
12:50	13:03	Washing dishes		1	47
13:04	13:08	Water kettle		1	21
16:30	16:51	Cooking	Cooking rice, boiling eggs, Hood on	1	169
16:41	16:45	Water kettle		1	21
17:30	17:54	Cooking	Warming up pancakes (frying pan)	0	10
		Plants			24
				Total [g/day]	**350**

Weekday 22/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
04:58	05:02	Breakfast	Water kettle	1	21
09:30	09:36	Breakfast	Water kettle	1	21
09:57	09:59	Washing dishes		1	47
13:56	14:27	Cooking	Rice, Frying sausages with bacon	1	91
		Plants			24
				Total [g/day]	**204**

Weekday 23/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
06:31	06:38	Breakfast	Water kettle	1	21
07:03	07:05	Washing dishes		1	16
08:35	08:37	Breakfast	Water kettle, toasts	1	21
09:43	09:53	Washing dishes		1	16
10:23	10:25	Washing dishes		1	47
10:27	10:29	Cleaning	Washing floor	1	40
12:55	13:05	Cooking	Warming up luch (oven)	1	42
		Plants			24
				Total [g/day]	**227**

Weekday 24/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
08:00	08:05	Breakfast	Water kettle, toasts	1	21
08:35	08:42	Breakfast	Water kettle	1	21
09:06	09:07	Washing dishes		1	16
12:13	12:19	Cooking	Brewing hot chocoloate	1	10
14:11	14:19	Washing dishes		2	47
13:57	15:25	Cooking	Frying onions, boiling pasta, cooking soup, frying meatballs, Hood on 2	2	1057
		Plants			24
				Total [g/day]	**1196**

Weekday 27/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
06:34	06:42	Breakfast	Water kettle	1	21
07:05	07:07	Washing dishes		1	16
08:12	08:16	Breakfast	Water kettle, toasts	1	21
10:14	10:20	Cooking	Musli with milk (stove)	1	10
14:54	15:00	Water kettle		1	21
19:20	19:37	Oven	Cooking warm sandwiches	1	42
		Plants			24
				Total [g/day]	**155**

Weekday 29/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
08:51	09:10	Breakfast	Water kettle, boiling eggs, Hood on 2	2	173
09:29	09:30	Washing dishes		1	47
14:05	14:40	Cooking	Rice, Risotto, Hood on 3	2	113
19:07	19:12	Cooking	Warming up risotto (stove)	1	20
		Plants			24
				Total [g/day]	**377**

Weekday 01/12/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
09:15	09:23	Breakfast	Water kettle	1	21
09:48	09:51	Washing dishes		1	16
14:51	14:55	Washing dishes		1	47
15:55	16:14	Cooking	Boiling pasta, water kettle, Hood on 3	1	408
21:40	21:47	Cooking	Brewing hot chocoloate	1	10
		Plants			24
				Total [g/day]	**526**

Weekend 11/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
08:04	08:09	Breakfast	Water kettle, toasts	1	21
09:14	09:22	Washing dishes		1	16
09:20	09:24	Breakfast	Water kettle	2	21
11:11	11:33	Cleaning	Wiping dust with wet cloth	1	5
11:35	11:41	Cooking	Musli with milk (stove)	1	7
12:42		Washing hands		1	5
13:36	13:46	Oven	Warming up dinner	1	42
22:58	23:07	Oven	Warming up bread	1	10
		Plants			24
				Total [g/day]	**151**

Weekend 12/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
10:42	10:48	Washing dishes		2	16
10:48	11:04	Breakfast	Water kettle, scrambled eggs	2	42
15:13	15:20	Washing dishes		1	47
15:20	16:21	Cooking	Pancakes	1	30
16:21	16:35	Cooking	Frying meat and vegetables, Hood on 2	1	80
16:26	16:36	Oven	Warming up tortillas	1	10
18:11	18:15	Water kettle		1	21
22:11	22:32	Washing dishes		1	47
22:19	22:23	Water kettle		1	21
		Plants			24
				Total [g/day]	**338**

Weekend 18/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
07:28	07:33	Breakfast	Water kettle, toasts	1	21
10:27	10:30	Breakfast	Water kettle	1	21
10:55	10:56	Washing dishes		1	47
13:34	13:41	Washing dishes		1	47
14:09	14:32	Cooking	Rice, Frying meat, Hood on	1	91
14:39	16:00	Oven	Stuffed bell peppers, Hood on	0	42
14:57	15:04	Washing dishes		1	47
21:25	21:28	Water kettle		1	21
22:28	22:31	Water kettle		1	21
		Plants			24
				Total [g/day]	**382**

Weekend 19/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
07:20	07:24	Breakfast	Water kettle	1	21
09:05	09:32	Breakfast	Water kettle, Boiling eggs	1	174
09:55	09:58	Washing dishes		1	16
13:19	14:00	Washing dishes	Tests	1	47
13:47	14:34	Oven	Warming up dinner	0	42
13:58	14:02	Water kettle		1	21
16:40	16:54	Washing dishes	Tests	1	47
		Plants			24
				Total [g/day]	**392**

Weekend 25/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
07:05	07:10	Breakfast	Water kettle, toasts	1	21
10:43	10:50	Breakfast	Water kettle	1	21
11:20	11:22	Washing dishes		1	16
13:10	13:19	Washing dishes		1	47
13:45	13:55	Cooking	Warming up soup	2	140
14:42	14:46	Water kettle			21
15:15	15:35	Washing dishes	Tests		47
		Plants			24
				Total [g/day]	**337**

Weekend 02/12/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
05:57	06:00	Breakfast	Water kettle	1	21
09:37	09:44	Breakfast	Water kettle	1	21
10:02	10:05	Washing dishes		1	16
15:31	15:41	Washing dishes		1	47
15:51	16:09	Cooking	Rice, frying steaks, Hood on 2	1	91
		Plants			24
				Total [g/day]	**220**

D 3 - Brammersgade 12, data analysis for bathroom moisture generation profile.

Weekday 10/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
06:10	06:29	Morning routine	Using bathroom, shaving, etc.	1	10
07:01	07:08	Using bathroom		1	5
08:39	08:53	Morning routine	Using bathroom, washing face, etc.	1	10
13:15	13:16	Using bathroom		1	5
15:01	15:03	Using bathroom		1	5
17:27	17:28	Using bathroom		1	5
19:40	20:03	Using bathroom		1	5
20:03	20:20	Shower		1	500
23:14	23:15	Using bathroom		1	5
23:35	23:45	Shower		1	500
				Total [g/day]	**1050**

Weekday 14/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
01:03	01:05	Using bathroom		1	5
06:45	06:50	Morning routine		1	10
07:21	07:23	Using bathroom		1	5
07:26	07:46	Morning routine		1	10
07:59	08:06	Using bathroom		1	5
08:58	09:02	Using bathroom		1	5
10:05	10:07	Using bathroom		1	5
11:07	11:08	Using bathroom		1	5
13:24	13:25	Using bathroom		1	5
15:27	15:28	Using bathroom		1	5
17:39	18:00	Shower		1	500
20:08	20:10	Using bathroom		1	5
21:55	22:16	Shower		1	500
22:27	22:29	Using bathroom		1	5
				Total [g/day]	**1070**

Weekday 16/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
06:30	06:57	Morning routine		1	10
07:45	08:00	Morning routine		1	10
08:54	08:56	Using bathroom		1	5
10:40	10:41	Using bathroom		1	5
12:37	12:38	Using bathroom		1	5
13:13	13:16	Using bathroom		1	5
14:11	14:13	Using bathroom		1	5
17:16	17:56	Shower		1	500
17:20	17:23	Using bathroom		1	5
19:30	19:49	Using bathroom		1	5
22:23	22:25	Using bathroom		1	5
				Total [g/day]	**560**

Weekday 22/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
05:03	05:29	Morning routine		1	10
09:15	09:25	Morning routine		1	10
10:00	10:07	Using bathroom		1	5
11:30	11:55	Using bathroom		1	5
13:13	13:15	Using bathroom		1	5
15:10	15:13	Using bathroom		1	5
15:15	15:16	Using bathroom		1	5
17:53	18:06	Shower		1	500
20:33	20:52	Shower		1	500
22:25	22:36	Using bathroom		1	5
23:27	23:28	Using bathroom		1	5
23:32	23:22	Using bathroom		1	5
				Total [g/day]	**1060**

Weekday 23/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
06:10	06:26	Morning routine		1	10
07:06	07:12	Using bathroom		1	5
08:31	08:33	Using bathroom		1	5
09:37	09:41	Using bathroom		1	5
11:10	11:12	Washing shirt		1	90
11:12	11:14	Using bathroom		1	5
13:38	13:46	Hanging the shirt		1	
15:28	15:30	Using bathroom		1	5
18:10	18:30	Shower		1	500
22:28	22:36	Using bathroom		1	5
23:42	23:55	Shower		1	500
				Total [g/day]	**1130**

Weekday 24/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
08:06	08:08	Using bathroom		1	5
08:15	08:31	Morning routine		1	10
09:08	09:14	Using bathroom		1	5
11:35	11:36	Using bathroom		1	5
12:10	12:12	Using bathroom		1	5
12:46	12:48	Using bathroom		1	5
13:28	13:30	Using bathroom		1	5
13:50	13:52	Using bathroom		1	5
16:17	16:19	Using bathroom		1	5
16:26	16:27	Using bathroom		1	5
17:55	17:57	Using bathroom		1	5
20:02	20:13	Shower		1	500
22:56	23:01	Using bathroom		1	5
23:30	23:52	Shower		1	500
23:56	23:57	Using bathroom		1	5
				Total [g/day]	**1070**

Weekday 27/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
06:10	06:30	Morning routine		1	10
06:51	07:00	Using bathroom		1	5
07:07	07:10	Using bathroom		1	5
07:15	07:23	Using bathroom		1	5
08:00	08:08	Using bathroom		1	5
09:48	09:49	Morning routine		1	10
12:16	12:18	Using bathroom		1	5
15:34	15:36	Using bathroom		1	5
17:40	18:00	Shower		1	500
19:15	19:17	Using bathroom		1	5
19:20	19:21	Using bathroom		1	5
19:55	20:07	Using bathroom		1	5
22:24	22:38	Shower		1	500
23:02	23:03	Using bathroom		1	5
				Total [g/day]	**1070**

Weekday 29/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
08:30	08:37	Morning routine		1	10
08:38	08:50	Morning routine		1	10
09:30	09:36	Using bathroom		1	5
09:40	09:42	Using bathroom		1	5
10:10	10:13	Using bathroom		1	5
11:01	11:04	Using bathroom		1	5
12:10	12:24	Using bathroom		1	5
15:00	15:01	Using bathroom		1	5
15:54	15:56	Using bathroom		1	5
16:40	16:55	Using bathroom		1	5
17:40	17:58	Shower		1	500
19:05	19:06	Washing hands		1	5
21:20	21:22	Using bathroom		1	5
22:10	22:29	Shower		1	500
22:33	22:34	Using bathroom		1	5
				Total [g/day]	**1075**

Weekday 01/12/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
08:45	08:52	Morning routine		1	10
09:03	09:10	Morning routine		1	10
09:44	09:48	Using bathroom		1	5
10:35	10:39	Using bathroom		1	5
14:18	14:35	Using bathroom		1	5
14:37	14:39	Using bathroom		1	5
17:31		Drying sweaters		1	120
20:05	20:07	Using bathroom		1	5
20:11	20:27	Shower		1	500
20:30	20:42	Shower		1	500
22:11	22:15	Using bathroom		1	5
				Total [g/day]	**1170**

Weekend 11/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
05:48	05:50	Using bathroom		1	5
08:58	09:07	Morning routine		1	10
09:07	09:16	Morning routine		1	10
09:25	09:28	Using bathroom		1	5
09:46	09:51	Using bathroom		1	5
10:18	10:20	Using bathroom		1	5
10:50	10:52	Using bathroom		1	5
11:44	11:45	Using bathroom		1	5
12:20	12:36	Cleaning	Walls	1	20
12:43	12:45	Using bathroom		1	5
14:36	14:50	Using bathroom		1	5
16:53	17:08	Shower		1	500
20:22	20:24	Using bathroom		1	5
22:42	22:53	Shower		1	500
				Total [g/day]	**1085**

Weekend 12/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
10:20	10:34	Morning routine		1	10
10:36	10:44	Morning routine		1	10
11:31	11:36	Using bathroom		1	5
15:10	15:12	Using bathroom		1	5
15:37	15:39	Using bathroom		1	5
17:16	17:37	Shower		1	500
18:04	18:06	Using bathroom		1	5
18:06	18:22	Shower		1	500
20:00	20:02	Using bathroom		1	5
22:29	22:31	Using bathroom			5
23:22	23:28	Using bathroom			5
23:52	23:54	Using bathroom			5
				Total [g/day]	**1060**

Weekend 18/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
00:19	00:21	Using bathroom		1	5
05:00	05:31	Using bathroom		1	5
07:00	07:26	Morning routine		1	10
10:08	10:17	Morning routine		1	10
10:21	10:25	Using bathroom		1	5
10:58	11:01	Using bathroom		1	5
14:01	14:03	Using bathroom		1	5
14:37	14:38	Using bathroom		1	5
15:00	15:01	Using bathroom		1	5
15:59	16:00	Using bathroom		1	5
16:20	16:21	Using bathroom		1	5
18:17	18:36	Shower		1	500
21:11	21:13	Using bathroom		1	5
21:13	21:22	Shower		1	500
23:34	23:35	Using bathroom		1	5
				Total [g/day]	**1075**

Weekend 19/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
02:02	02:04	Using bathroom		1	5
06:50	07:18	Morning routine		1	10
08:45	08:57	Morning routine		1	10
09:34	09:36	Using bathroom		1	5
10:06	10:09	Using bathroom		1	5
11:55	11:56	Using bathroom		1	5
12:34	12:38	Using bathroom	Tests	1	5
14:02	14:03	Using bathroom		1	5
15:13	15:14	Using bathroom		1	5
15:15	15:30	Using bathroom		1	5
16:09	16:21	Using bathroom		1	5
16:55	17:00	Using bathroom		1	5
18:30	18:44	Shower		1	500
21:59	22:00	Using bathroom		1	5
22:35	22:37	Using bathroom		1	5
22:39	22:56	Shower		1	500
				Total [g/day]	**1080**

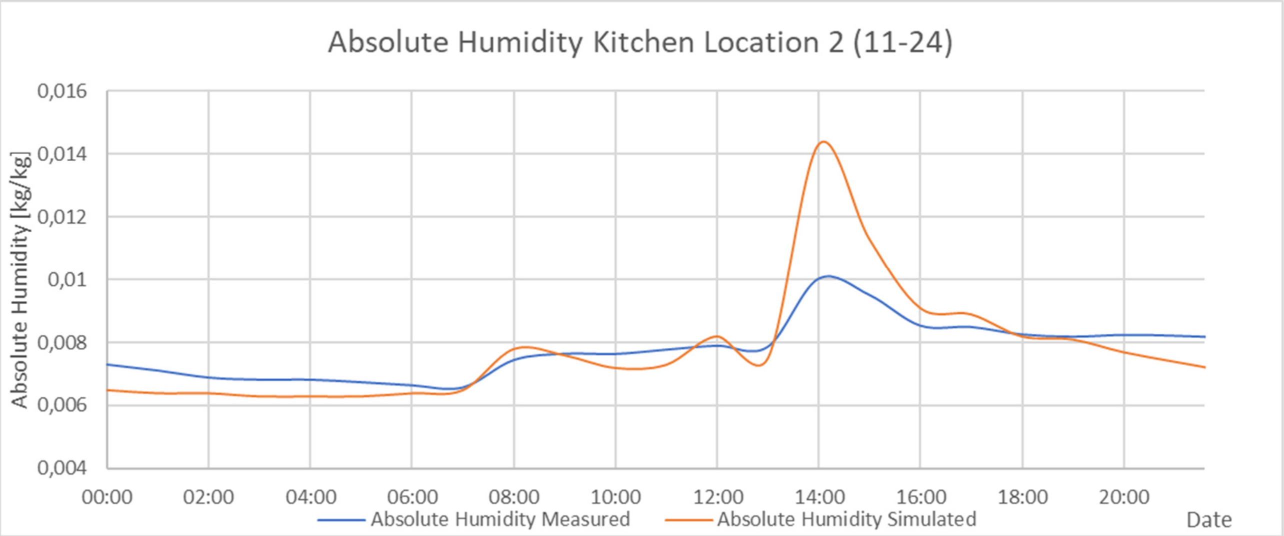
Weekend 25/11/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
06:56	07:02	Morning routine		1	10
10:22	10:38	Morning routine		1	10
11:22	11:26	Using bathroom		1	5
12:45	12:47	Using bathroom		1	5
13:59	14:00	Using bathroom		1	5
14:58	15:10	Using bathroom		1	5
15:37	15:39	Using bathroom		1	5
16:01	16:02	Using bathroom		1	5
16:29	16:31	Using bathroom		1	5
16:40	16:45	Using bathroom		1	5
16:58	16:59	Using bathroom		1	5
17:20	17:21	Using bathroom		1	5
17:46	17:47	Using bathroom		1	5
18:15	18:16	Using bathroom		1	5
20:31	20:45	Shower		1	500
22:54	22:55	Using bathroom		1	5
23:37	23:52	Shower		1	500
				Total [g/day]	**1085**

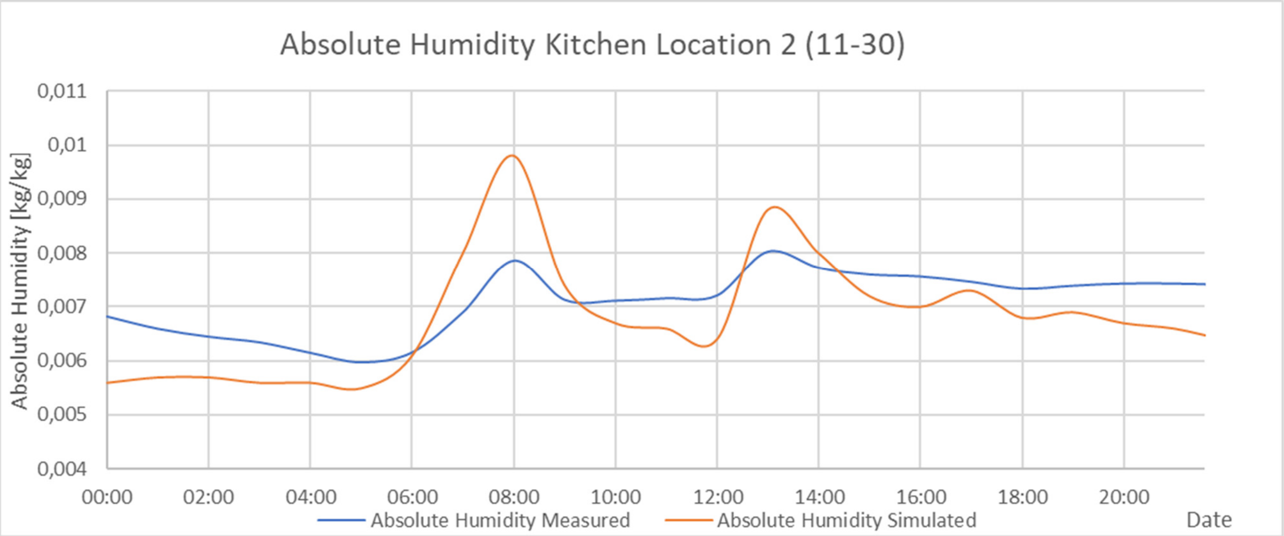
Weekend 02/12/2017					Moisture Emission [g]
Start	End	Activity	Extra Info	People	
06:00	06:25	Morning routine		1	10
09:20	09:31	Morning routine		1	10
10:14	10:18	Using bathroom		1	5
11:19	11:30	Using bathroom		1	5
13:32	13:35	Using bathroom		1	5
17:18	17:20	Using bathroom		1	5
17:25	17:27	Using bathroom		1	5
17:48	18:45	Shower		1	500
18:55	19:15	Shower		1	500
23:01	23:07	Using bathroom		1	5
				Total [g/day]	**1050**

D 4 - Correction factor moisture emissions from cooking

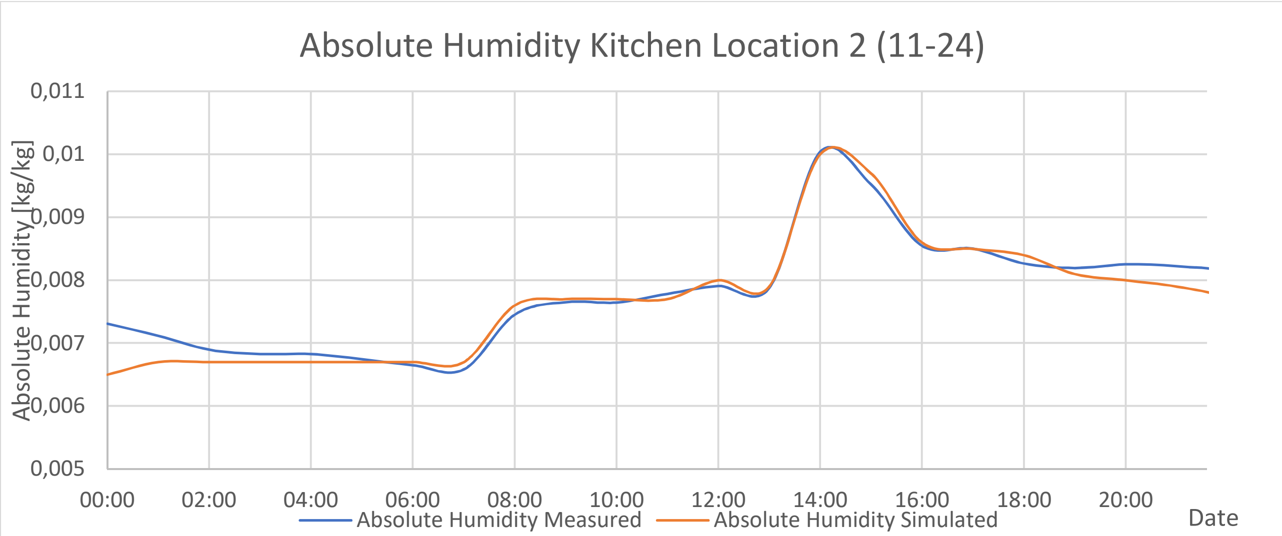
In the kitchen, cooking is one of the dominating moisture sources. However, when trying to replicate this action in the simulation, moisture emissions from the literature are not directly applicable. Often when cooking exhaust hood is used to extract steam directly. Therefore, only a part of actual moisture emission will increase indoor moisture content. In the software, airflow can be defined and simulated, but it will assume fully mixed indoor air and thus will not represent the actual case.

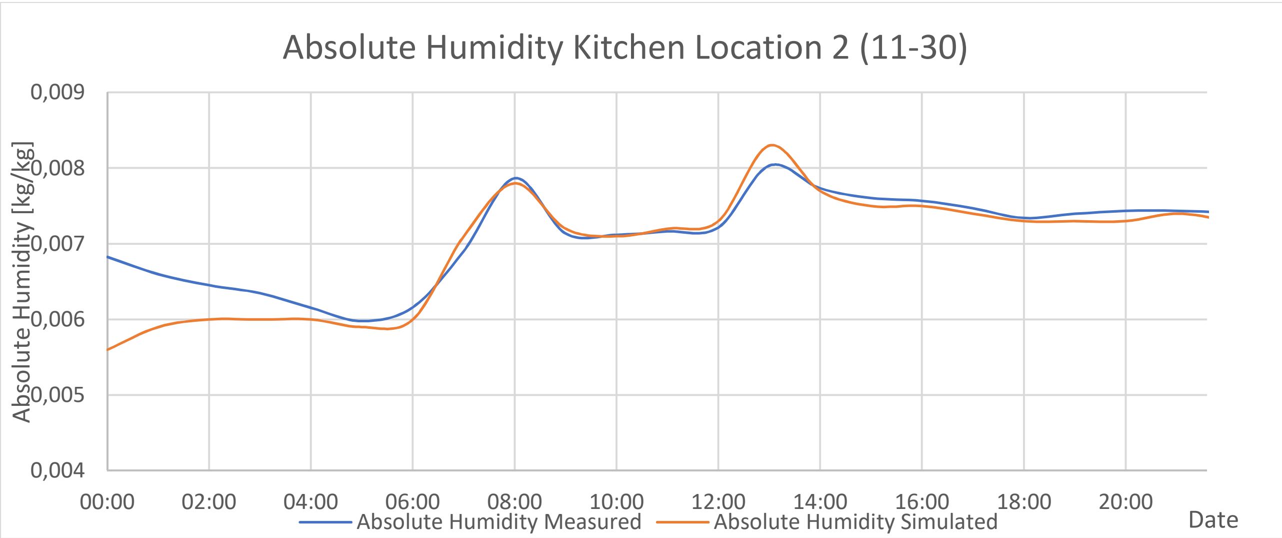
In order to use moisture emissions from literature with increased accuracy, test simulations have been performed to define a correction factor. A few well-documented cooking activities have been chosen and moisture emission values found in literature gradually reduced in the simulation until it finally matched measurements.





Simulation response with original values from literature and measurements can be seen in pictures above. At this point moiosture load values have been gradually lowered until result illustrated in the following graphs has been achieved.





Analysis of cooking activities:

Activity	*Measurement/literature value [g]*	*Simulated value [g]*	*Reduction factor [%]*
Cooking pasta, water kettle, washing dishes	455	154	66%
Soup, frying meatballs	710	385	46%
Boiling eggs	153	84	45%
Average			**52%**

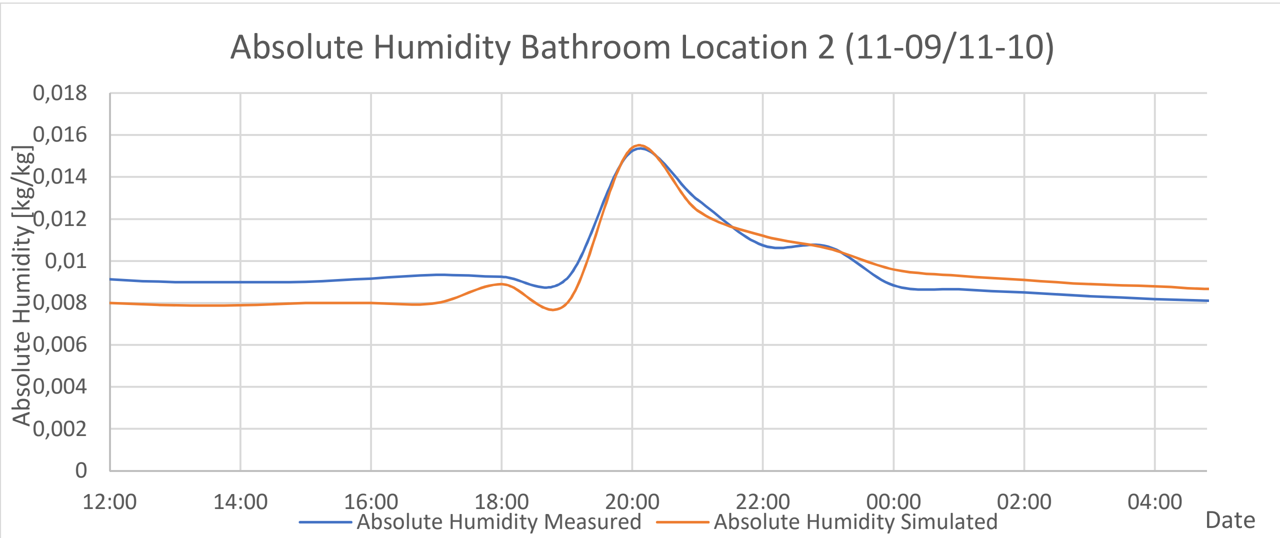
Based on these simulations moisture emissions from cooking with kitchen hood on should be reduced by approximately 50%.

D 5 - Evaporation of moisture and condensation from showering

In the first simulations, it has been observed that literature-based moisture emission values from showering (500-530g) cannot be used as an immediate moisture load. Otherwise absolute humidity peaks at a much higher value and falls much faster than measurements.
In order to match measurements, moisture load from showering has to be dispersed because only a particular part of it will affect indoor humidity levels immediately, rest of the moisture condensates on bathroom surfaces or is deposited on the floor and evaporates slowly in a few hours.

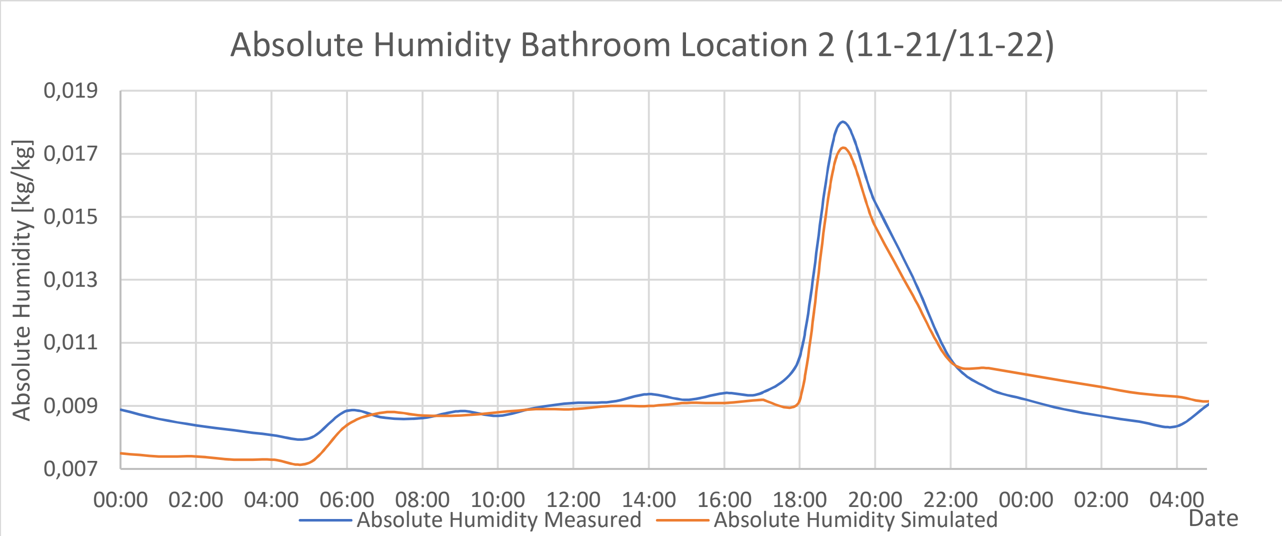
A few tests have been carried out by starting with a 500g moisture load per shower, then gradually dispersing it until peak value, and slope of the decay curve is matched.

Test 1



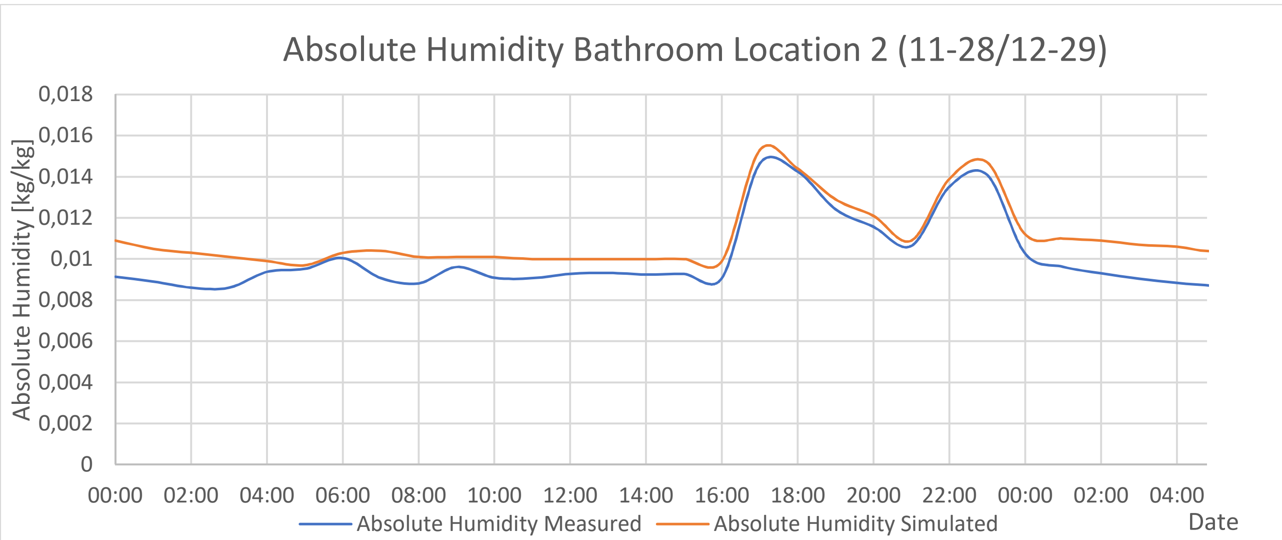
Hour	*Activity*	*Duration [min]*	*Simulated value [g]*
20	Shower	17	315
21	-	-	150
22	Using bathroom	2	50
23	Shower	10	50
24	-	-	0
Total			565

Test 2



Hour	*Activity*	*Duration [min]*	*Simulated value [g]*
17	Cleaning	-	15
18	Cleaning	-	15
19	Shower x2	35	500
20	Shower	6	250
21	-	-	150
22	-	-	75
23	-	-	0
Total			1005

Test 3

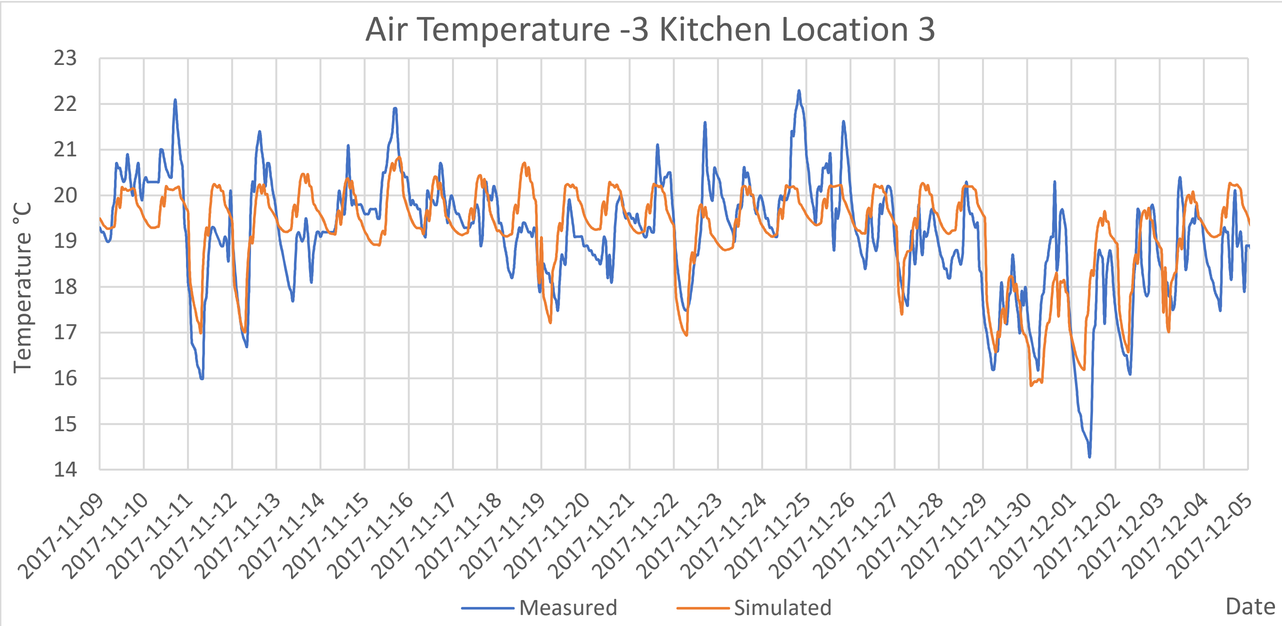


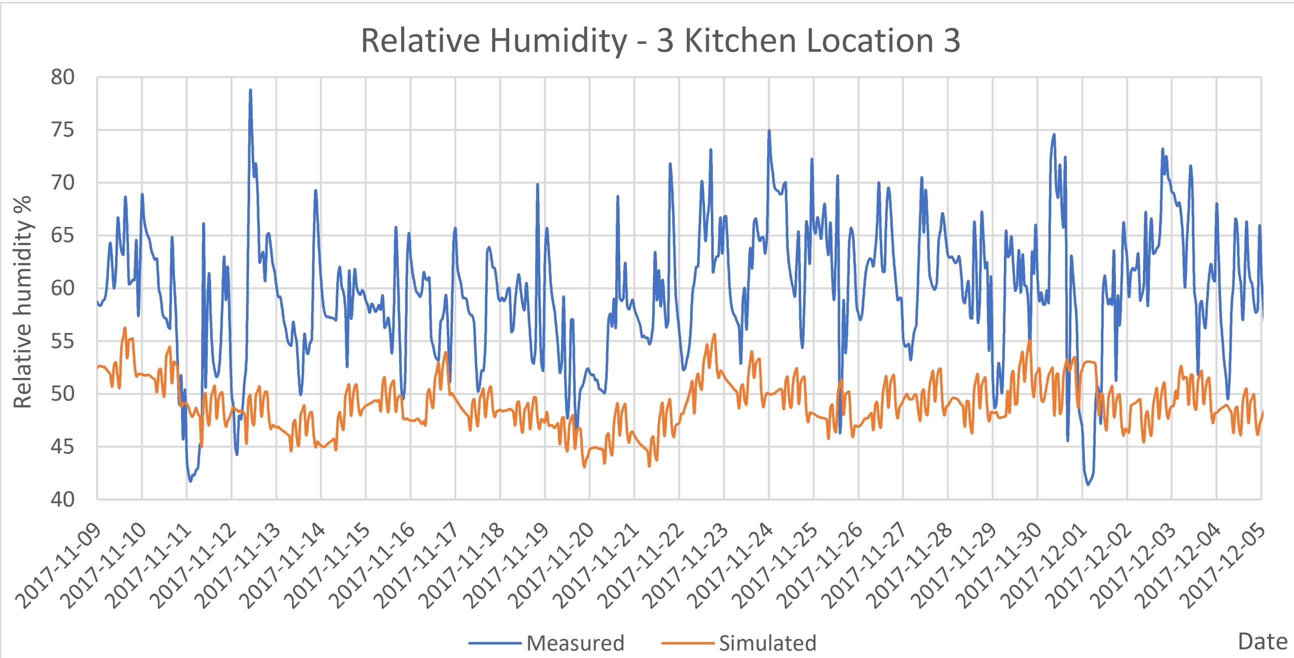
Hour	*Activity*	*Duration [min]*	*Simulated value [g]*
17	Shower	20	185
18	-	-	200
19	-	-	150
20	-	-	75
21	-	-	50
22	Shower	13	100
23	Using bathroom	5	150
00	-	-	0
Total			910

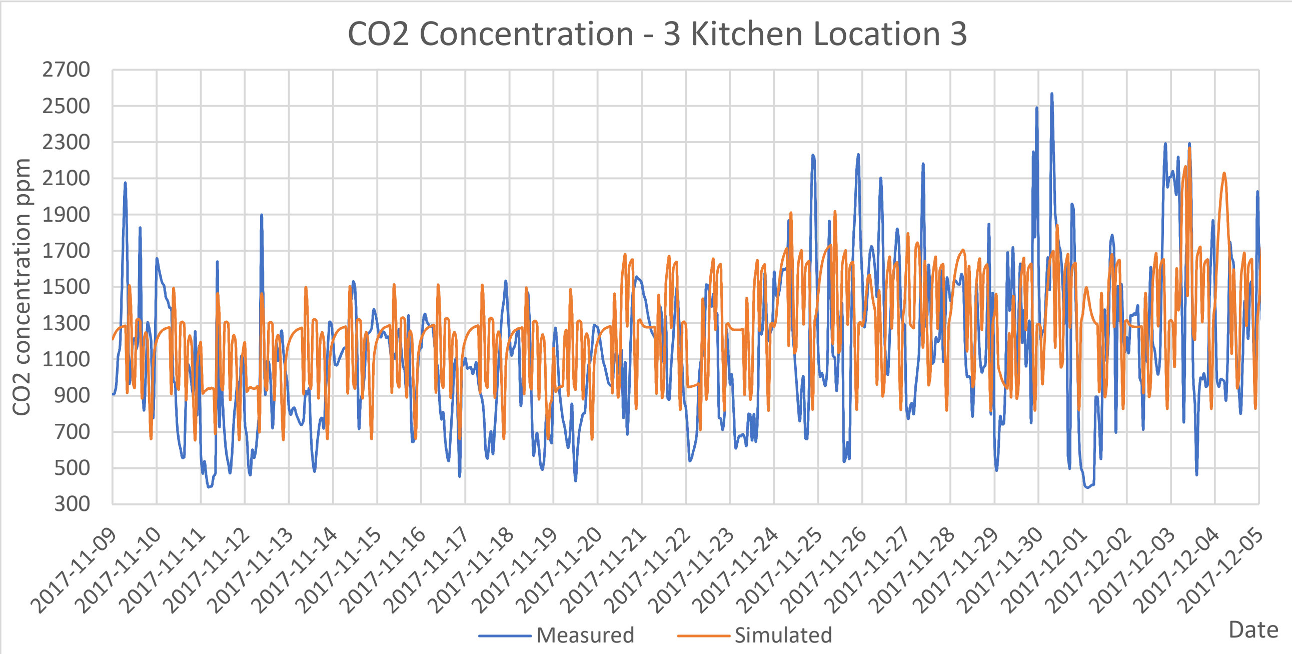
Based on performed tests it becomes evident that duration of the shower is also an essential factor to be taken into account (see Test 1). A value of 500 – 530 g is based on 18 min shower (Yik, Sat and Niu, 2004), therefore, if shower duration is known moisture emission value can be adjusted accordingly.

Appendix E

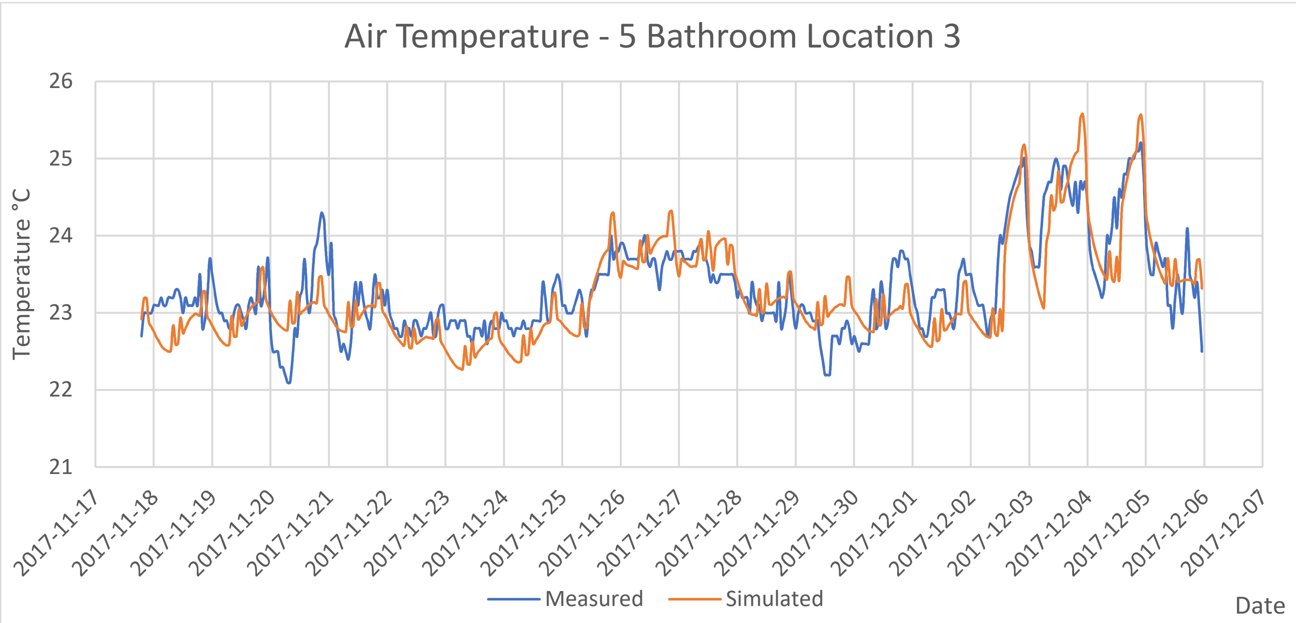
E 1 - Location 3 – BSim model validation.

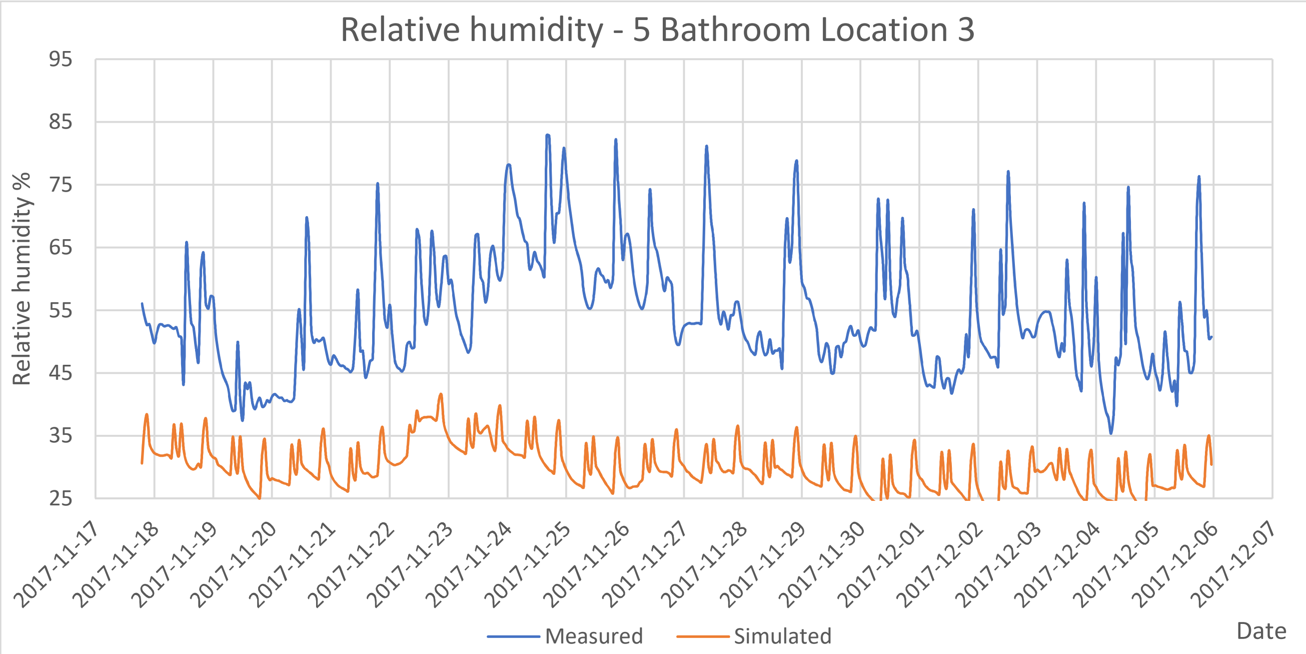


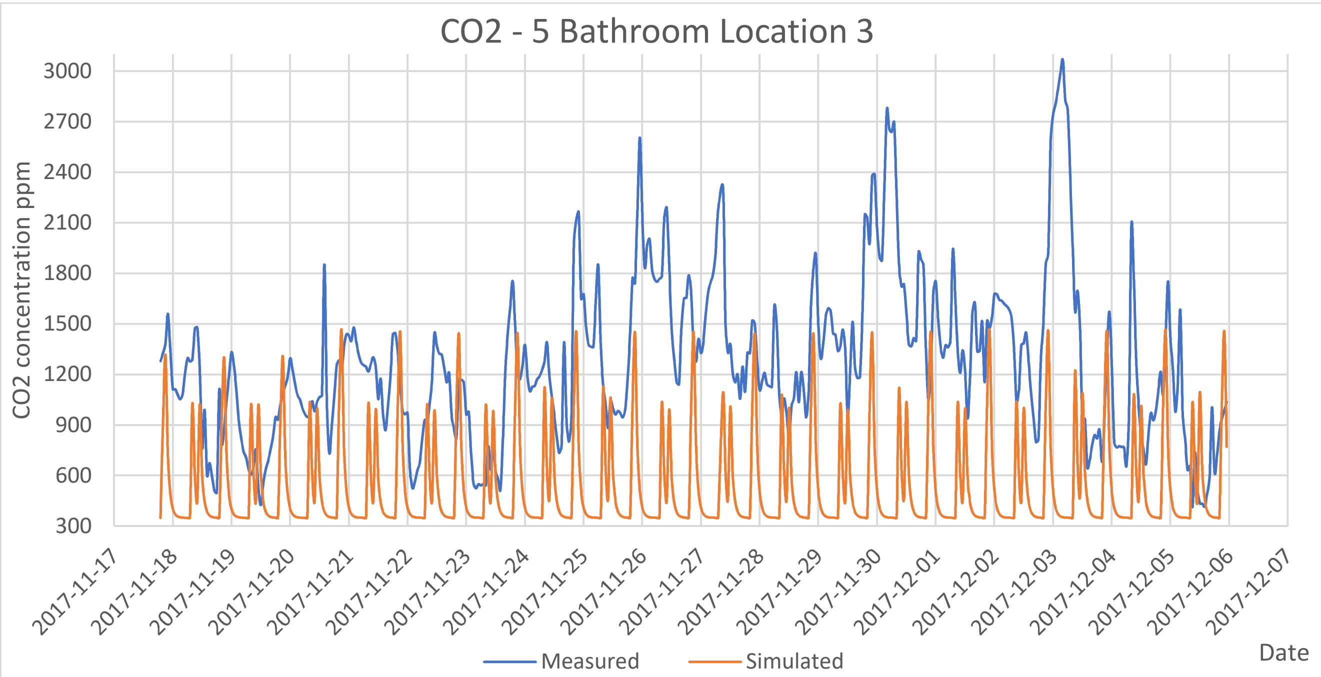




Room number 5 Bathroom




Relative humidity - 5 Bathroom Location 3
Relative humidity %
95
85
75
65
55
45
35
25
2017-11-17
2017-11-18
2017-11-19
2017-11-20
2017-11-21
2017-11-22
2017-11-23
2017-11-24
2017-11-25
2017-11-26
2017-11-27
2017-11-28
2017-11-29
2017-11-30
2017-12-01
2017-12-02
2017-12-03
2017-12-04
2017-12-05
2017-12-06
2017-12-07
Date
Measured
Simulated


CO2 - 5 Bathroom Location 3
CO2 concentration ppm
3000
2700
2400
2100
1800
1500
1200
900
600
300
2017-11-17
2017-11-18
2017-11-19
2017-11-20
2017-11-21
2017-11-22
2017-11-23
2017-11-24
2017-11-25
2017-11-26
2017-11-27
2017-11-28
2017-11-29
2017-11-30
2017-12-01
2017-12-02
2017-12-03
2017-12-04
2017-12-05
2017-12-06
2017-12-07
Date
Measured
Simulated

E 2 - Moisture Emission Tables

Vestre Ringgade 230, 5tv, Data analysis for kitchen moisture generation profile

E 2.1 - Kitchen Investigation

Weekday 13/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
10.42		Washing Hands		2	10,00			10,00
10.43	11.43	Cooking-Owen	(pizza&pate)	2	42,00	110,00		152,00
11.03		Washing Hands		2	10,00			10,00
11.03	11.15	Eating		2	79,00			79,00
15.30	15.46	Washing Dishes	(+eating)	1	50,00	7,33	6,00	56,00
15.52	16.00	Warming up Soup		1	10,00	3,67		13,67
16.00		Washing Hands		2	10,00			10,00
22.39		Washing Hands		1	5,00			5,00
22.40	22.43	Warming up Soup		1	42,00	13,75		55,75
							Total [g/day]	**391,42**

Weekday 14/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
09.28		Washing Hands		2	10,00			10,00
09.29	09.42	Breakfast		2	71,00	23,83		94,83
09.40	09.47	Washing Dishes		2	50,00	9,17	6,00	56,00
09.54	10.00	Coffe Filter		2	10,00			10,00
14.03		Washing Hands		1	5,00			5,00
14.04	15.01	Cooking	Stew+Boiling Patatoes	1	1026,00	52,25		1078,25
14.37	14.41	Washing Dishes		1	50,00		6,00	56,00
14.44		Washing Hands		2	10,00			10,00
14.45	15.25	Eating		2	158,00	73,33		231,33
15.25		Washing Hands		2	10,00			10,00
17.30	17.37	Washing Dishes		1	50,00	6,42	6,00	62,42
							Total [g/day]	**1623,83**

Weekday 15/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
09.30		Washing Hands		1	5,00			5,00
09.31	09.40	Boiling Water	(door close)	1	387,00	26,58		413,58
09.34	09.46	Frying eggs		1	20,73			20,73
09.45		Washing Hands		1	5,00			5,00
09.45	10.00	Eating		1	39,50			39,50
10.00		Washing Hands		1	5,00			5,00
11.48	11.52	Filter Coffee		1	10,00	3,67		13,67
13.03		Washing Hands		1	5,00			5,00
13.03	13.19	Oven	(pizza)	1	42,00	13,75		55,75
14.57	15.03	Washing Dishes		1	50,00	5,50	6,00	61,50
15.17		Washing Hands		1	5,00			5,00
15.17	16.47	Cooking	Stew+polenta	1	414,00	119,17		533,17
16.44	16.46	Washing Dishes		1	50,00		6,00	56,00
							Total [g/day]	**1218,90**

Weekday 16/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
10.05		Washing Hands		2	10,00			10,00
10.06	10.24	Cooking	Boiling Water	2	774,00	33,00		807,00
10.13	10.20	Washing Dishes		2	50,00		6,00	56,00
10.24		Washing Hands		2	10,00			10,00
10.24	10.39	Eating		2	79,00	13,75		92,75
16.16	16.19	Washing Dishes		1	50,00	2,75	6,00	58,75
16.23		Washing Hands		1	5,00			5,00
16.23	17.00	Boiling Water		0	1591,00			1591,00
							Total [g/day]	**2630,50**

Weekday 20/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
09.54	10.09	Washing Dishes		1	50,00	13,75	6,00	69,75
10.31	10.37	Coffee Filter		0	10,00			10,00
13.21		Washing Hands		1	5,00			5,00
13.21	13.41	Frying Eggs	toast (4g)	1	20,73	18,33	4,00	43,06
15.09		Washing Hands		1	5,00			5,00
15.09	16.15	Cooking-Owen		1	42,00	60,50		102,50
15.27	15.36	Washing Dishes		1	50,00	119,17	6,00	175,17
16.07		Washing Hands		1	5,00			5,00
16.07	16.22	Boiling Eggs		1	152,71	13,75		166,46
16.46	16.47	Washing Dishes		1	50,00	0,92	6,00	56,92
19.13	19.16	Washing Dishes		1	50,00	2,75	6,00	58,75
							Total [g/day]	**697,61**

Weekday 23/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
10.01		Washing Hands		1	5,00			5,00
10.01	10.15	Kettle + Eating	prepare breakfast+eating	1	97,43	12,83		110,26
13.30	13.38	Washing Dishes		1	50,00	7,33	6,00	63,33
13.47		Washing Hands		1	5,00			5,00
13.47	14.20	Frying	pasta souce	1	230,02	30,25		260,27
14.10	14.20	Boiling Water (pasta)		1	217,79			217,79
14.11	2min	Washing Dishes		1	50,00	13,75	6,00	69,75
15.57	16.17	Washing Dishes		1	50,00	0,92	6,00	56,92
							Total [g/day]	**788,32**

Weekday 24/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
09.20	09.23	Kettle		1	22,43	2,75		25,18
09.27	09.30	Washing Dishes		1	50,00	2,75	6,00	58,75
09.30		Washing Hands		2	10,00			10,00
09.30	09.47	Eating		2	79,00	31,17		110,17
09.46	09.47	Washing Dishes		2	5,00	1,83	6,00	12,83
15.34		Washing Hands		2	10,00			10,00
15.34	18.10	Boiling Water (soup)	2pots, 15min just one pot	2	1445,77	286,00		1731,77
16.25	16.28	Washing Dishes		2	50,00	5,50	6,00	61,50
17.12		Washing Hands		2	10,00			10,00
17.12	18.14	Cooking-Owen		0	42,00			42,00
17.49	17.52	Washing Dishes		1	50,00	2,75	6,00	58,75
18.02	18.03	Washing Dishes	1 cup	1	5,00	0,92	6,00	11,92
18.08	18.10	Washing Dishes		1	10,00	1,83	6,00	17,83
20.00		Washing Hands		1	5,00			5,00
20.00	20.19	Boiling Water		0	217,79			217,79
							Total [g/day]	**2383,49**

Weekday 27/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
08.39	08.44	Coffee Filter		1	10,00	4,58		14,58
10.01	10.05	Washing Dishes		1	50,00	3,67	6,00	59,67
12.21		Washing Hands		1	5,00			5,00
12.21	12.30	Cooking-Stove	x2	1	166,00	8,25		174,25
12.57	13.07	Washing Dishes		1	50,00	9,17	6,00	65,17
18.40		Washing Hands		2	10,00			10,00
18.40	19.12	Eating	sorting shoppings	2	158,00	58,67		216,67
19.41		Washing Hands		2	10,00			10,00
19.41	20.23	Cooking-Stove		1	166,00	38,50		204,50
20.27	20.31	Washing Dishes		1	50,00	2,75	6,00	58,75
21.48	21.50	Washing Dishes		1	5,00	1,83	6,00	12,83
							Total [g/day]	**831,42**

Weekend 12/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
09.47	09.53	Washing Dishes		2	50,00	11,00	6,00	67,00
09.49		Washing Hands		2	10,00			10,00
09.50	10.04	Cooking-Boiling	rice	2	16,96	25,67		42,63
09.55	10.41	Cooking-Owen		2	42,00	67,83		109,83
10.05		Washing Hands		2	10,00			10,00
10.06	10.40	Steam-Cooking		2	748,00			748,00
12.27		Washing Hands		1	5,00			5,00
12.28	15.13	Cooking-Stove	(washing a few dishes meanwhile 10min)	1	166,00	151,25		317,25
13.28	13.38	Washing Dishes		1	50,00		6,00	56,00
16.16	16.20	Washing Dishes		1	50,00	3,67	6,00	59,67
16.26	16.28	Washing Dishes		1	50,00	1,83	6,00	57,83
19.05		Washing Hands		1	5,00			5,00
19.06	19.36	Boiling Water (pasta)		0	217,79	27,50		245,29
							Total [g/day]	**1733,50**

Weekend 19/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
10.15		Washing Hands		1	5,00			5,00
10.16	10.28	Frying Eggs	door opened + toaster	1	20,73	20,17		40,90
10.17		Washing Hands		2	10,00			10,00
10.18	10.32	Eating		2	79,00	25,67		104,67
13.34		Washing Hands		2	10,00			10,00
13.35	15.13	Cooking-Owen		2	42,00	13,75		55,75
13.48	13.52	Washing Dishes		1	50,00	3,67	6,00	59,67
14.14	14.23	Cooking-Boiling		0	387,00			387,00
							Total [g/day]	**672,98**

Weekend 25/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
09.12		Washing Hands		1	5,00			5,00
09.13	09.23	Warming up Soup	stove	1	42,00	9,17		51,17
09.13	09.23	Washing Dishes		1	50,00		6,00	56,00
12.03	12.18	Washing Dishes		1	50,00	13,75	6,00	69,75
12.45		Washing Hands		1	5,00			5,00
12.45	13.07	Cooking		1	37,50	13,75		51,25
13.07	15.56	Cooking	stew on stove	1	166,00	154,92		320,92
18.44		Washing Hands		1	5,00			5,00
18.45	19.34	Cooking-Owen		1	42,00	44,92		86,92
19.03	19.08	Washing Dishes		1	50,00		6,00	56,00
19.10	19.54	Cooking-Stove		1	166,00	40,33		206,33
19.42		Washing Hands		1	5,00			5,00
19.43	20.00	Warming up food	stove	1	42,00	10,08		52,08
20.39	20.47	Washing Dishes		1	50,00	7,33	6,00	63,33
							Total [g/day]	**1033,8**

Weekend 02/12/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
08.39		Washing Hands		1	5,00			5,00
08.40	08.46	Washing dishes		1	50	5,50	6	61,50
08.55	09.05	Warming up food		1	42	9,17		51,17
10.51		Washing Hands		1	5,00			5,00
10.52	11.09	Boiling Water	pasta	1	217,79	15,58		233,37
11.00		Washing Hands		1	5,00			5,00
11.00	12.28	Cooking-Stove	stew	1	166	80,67		246,67
11.48	12.00	Washing Dishes		1	50		6	56,00
12.03	12.43	Boiling Water	potato	1	1720	36,67		1756,67
18.40	18.56	Washing Dishes		1	50	14,67	6	70,67
19.00		Washing Hands		1	5,00			5,00
19.00	19.28	Cooking-Stove	pasta-carbonara	1	447,81	25,67		473,48
19.34	19.42	Washing Dishes		2	50	7,33	6	63,33
20.25	20.29	Washing Dishes		2	50	3,67	6	59,67
							Total [g/day]	**3092,5**

E 2.2 -Kitchen overview of investigated days and results

Day/Date		Total Moisture Generation [g/day]	Average Daily Emission [g]	Hourly Average Week/Weekend [g]	Standard Deviation	Standard Error	Total Average [g/day]	Total Hourly Average [g/day]
Weekday	13/11/2017	391,42	**1320,69**	**55,03**	821,32	290,38	**1476,94**	**61,54**
	14/11/2017	1623,83						
	15/11/2017	1218,9						
	16/11/2017	2630,50						
	20/11/2017	697,6						
	23/11/2017	788,3						
	24/11/2017	2383,49						
	27/11/2017	831,42						
Weekend	12/11/2017	1733,5	**1633,19**	**68,05**	1067,87	533,93		
	19/11/2017	672,98						
	25/11/2017	1033,8						
	02/12/2017	3092,5						

E 2.3 - Bathroom Investigation

Weekday 09/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	Extra Info	People				
08.38	08.45	Morning Routine	(washing, brushing teeth)	2	98,00	12,83	4,00	114,83
10.37	10.44	Shower		1	205,80	6,42	79,00	291,22
20.57	21.04	Shower		1	205,80	6,42	79,00	291,22
22.18	22.24	Shower		1	176,40	5,50	79,00	260,90
22.25	22.30	Evening Routine		2	98,00	9,17	4,00	111,17
							Total [g/day]	**1069,33**

Weekday 20/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	Extra Info	People				
09.08	09.15	Morning Routine		2	98,00	12,83	4,00	114,83
10.42	10.47	Shower		1	530,00	4,58	79,00	613,58
14.20	14.40	Shower		1	530,00	18,33	79,00	627,33
22.40	00.00	Clothes/towels drying	Soften in water	0	403,00			403,00
22.00	22.08	Evening Routine		2	98,00	12,83	4,00	114,83
							Total [g/day]	**1873,58**

Weekday 21/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	Extra Info	People				
09.24	09.30	Morning Routine		1	49,00	5,50	4,00	58,50
10.52	11.00	Shower		1	235,20	7,33	79,00	321,53
11.08	11.13	Morning Routine		1	49,00	4,58	4,00	57,58
18.36	18.47	Shower		1	323,40	10,08	79,00	412,48
19.25	19.34	Shower		1	264,60	8,25	79,00	351,85
19.35	19.45	Cleaning		1	224,00	9,17		233,17
21.20	21.30	Evening Routine		2	98,00	18,33	4,00	120,33
							Total [g/day]	**1555,45**

Weekday 23/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
09.05	09.10	Morning Routine		1	49,00	4,58	4,00	57,58
10.25	10.33	Shower	(+toothbrushing)	1	284,20	7,33	79,00	370,53
23.28	23.33	Shower	(+toothbrushing)	1	196,00	13,75	79,00	288,75
23.40	23.47	Evening Routine		1	49,00	6,42	4,00	59,42
							Total [g/day]	**776,28**

Weekday 27/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
08.25	08.37	Morning Routine		2	98,00	22,00	4,00	124,00
08.40	08.52	Shower	(+toothbrushing)	1	401,80	11,00	79,00	491,80
09.40	09.52	Shower		1	352,80	11,00	79,00	442,80
17.19	17.34	Shower		1	441,00	13,75	79,00	533,75
18.40	18.50	Shower		1	294,00	9,17	79,00	382,17
21.22	21.33	Shower		1	323,40	10,08	79,00	412,48
22.20	22.35	Evening Routine		3	147,00	13,75	4,00	164,75
							Total [g/day]	**2427,75**

Weekday 30/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
07.00	07.11	Morning Routine		3	147,00	16,50	4,00	167,50
07.11	07.20	Shower		1	264,60	8,25	79,00	351,85
08.27	08.35	Shower		1	235,20	7,33	79,00	321,53
11.19	11.25	Shower		1	176,40	5,50	79,00	260,90
11.25	11.28	Brushing Teeth		1	49,00	2,75	4,00	55,75
16.45	17.00	Shower		1	441,00	30,25	79,00	550,25
23.00	23.11	Evening Routine		2	98,00	10,08	4,00	112,08
							Total [g/day]	**1652,37**

Weekend 18/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	Extra Info	People				
10.31	10.33	Morning Routine		1	49,00	1,83	4,00	54,83
12.06	12.08	Morning Routine		1	49,00	1,83	4,00	54,83
13.19	13.40	Shower		1	617,40	19,25	79,00	715,65
19.35	19.48	Shower		1	382,20	11,92	79,00	473,12
21.00	21.07	Evening Routine		2	98,00	12,83	4,00	114,83
							Total [g/day]	**1413,27**

Weekend 19/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	Extra Info	People				
09.18	09.21	Morning Routine		2	98,00	5,50	4,00	107,50
10.08	10.14	Shower		1	176,40	5,50	79,00	260,90
23.30	23.35	Evening Routine		2	98,00	9,17	4,00	111,17
							Total [g/day]	**479,57**

Weekend 25/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g/day]
hh:mm	hh:mm	Activity	Extra Info	People				
10.31	10.40	Morning Routine		2	98,00	16,50	4,00	118,50
10.49	10.56	Shower		1	205,80	6,42	79,00	291,22
19.50	20.05	Shower		1	441,00	13,75	79,00	533,75
23.42	23.45	Evening Routine		2	98,00	2,75	4,00	104,75
							Total [g/day]	**1048,2**

Weekend 26/11/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
09.15	09.20	Morning Routine		2	98,00	9,17	4,00	111,17
10.13	10.17	Shower		1	117,60	5,50	79,00	202,10
23.12	23.18	Evening Routine		2	98,00	11,00	4,00	113,00
							Total [g/day]	**426,3**

Weekend 03/12/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
09.15	09.30	Morning Routine	x4	4	196,00	22,00	4,00	222,00
12.12	12.40	Shower		1	823,20	25,67	79,00	927,87
19.10	19.24	Shower		1	411,60	12,83	79,00	503,43
23.21	23.27	Toothbrushing		1	49,00	13,75	79,00	141,75
23.50	00.00	Shower		1	294,00	9,17	79,00	382,17
00.02	00.15	Evening Routine		3	147,00	18,33	4,00	169,33
							Total [g/day]	**2124,55**

Weekend 04/12/2017					Moisture Emission [g]	Moisture People [g]	Extra Evaporation [g]	Total Moisture Emission [g]
hh:mm	hh:mm	Activity	Extra Info	People				
07.25	07.30	Morning Routine		1	49,00	4,58	4,00	57,58
09.09	09.13	Morning Routine		1	49,00	3,67	4,00	56,67
10.52	10.57	Shower		1	147,00	4,58	79,00	230,58
13.02	12.20	Shower		1	529,20	16,50	79,00	624,70
23.21	23.29	Evening Routine		2	98,00	7,33	4,00	109,33
							Total [g/day]	**1021,28**

E 2.4 - Bathroom overview of investigated days and results

Bathroom Day/Date		Total Moisture Generation [g/day]	Average Daily Emission [g]	Hourly Average Week/Weekend [g]	Standard Deviation	Standard Error	Total Average [g/day]	Total Hourly Average [g/day]
Weekday	09/11/2017	1069,33	**1559,1**	**64,96**	**585,63**	**239,08**	**1322,33**	**55,10**
	20/11/2017	1873,58						
	21/11/2017	1555,5						
	23/11/2017	776,28						
	27/11/2017	2427,8						
	30/11/2017	1652,4						
Weekend	18/11/2017	1413,3	**1085,5**	**45,23**	**631,56**	**257,83**		
	19/11/2017	479,57						
	25/11/2017	1048,2						
	26/11/2017	426,3						
	03/12/2017	2124,55						
	04/12/2017	1021,28						

E 2.5 - Standard Day profile Kitchen

Standard Daily Profile - Kitchen			
Hours	Activity	Emissions [g]	Percentage [%]
0	-	-	-
1	-	-	-
2	-	-	-
3	-	-	-
4	-	-	-
5	-	-	-
6	-	-	-
7	-	-	-
8	Washing Hands, Coffee, Kettle	42,68	21,65
9	Brakfast, Eating	194,04	98,41
10	Washing Dishes	59,73	30,29
11	-	-	-
12	-	-	-
13	Washing Hands, Cooking/2	197,17	100,00
14	Cooking/2	188,98	95,85
15	Eating, Washing Dishes	182,77	92,70
16	-	-	-
17	Washing Hands, Cooking/2	197,17	100,00
18	Cooking/2	188,98	95,85
19	Eating, Washing Dishes	182,77	92,70
20	-	-	-
21	-	-	-
22	-	-	-
23	-	-	-
	Total	**1434,29**	

E 2.6 - Standard Day profile Bathroom

Standard Daily Profile 5 - Bathroom			
Hours	Activity	Emissions [g]	Percentage [%]
0	-	-	-
1	-	-	-
2	-	-	-
3	-	-	-
4	-	-	-
5	-	-	-
6	-	-	-
7	-	-	-
8	-	-	-
9	Morning Routine	32,84	13,14
10			
11			
12			
13	Hygiene	32,84	13,14
14	Hygiene	32,84	13,14
15	-	-	-
16	Hygiene	38,15	15,26
17	Hygiene	38,15	15,26
18	-	-	-
19	-	-	-
20	-	-	-
21	Shower 1	250	100,00
22	Shower 2	174,08	69,63
23	Evening Routine	38,15	15,26
	Total	**637,05**	

E2.7 Infiltrations

The infiltration was determined based on the CO2 drop curve when nobody was present in the room. Two formulas were used, and their result was quite different, therefore, an average value between them was used.

First formula used:

$$\overline{Q} = V \frac{\ln \frac{C(t_1)}{C(t_2)}}{t_2 - t_1} \quad , \text{m}^3\text{h}^{-1}$$

where, V is the volume of the ventilated space in m^3, $C(t_1)$ and $C(t_2)$ are the percentage concentrations of the gas at time t_1 and t_2 in hours respectively, during the measurements.

Room Volume [m3]	Start Concentratio n in the room	Concentratio n in the supply air	Time 1	Time 2	Time Hours	Flow	Air Change
[V]	[Ct1]	[t2]	[h]	[h]	[t]	[q]	[n]
15,8	1573,7	1021,5	9	7	2	3,414	0,2160787

Second formula used:

$$c = \frac{q}{nV}(1 - e^{-n\tau}) + (c_0 - c_i)e^{-n\tau} + c_i$$

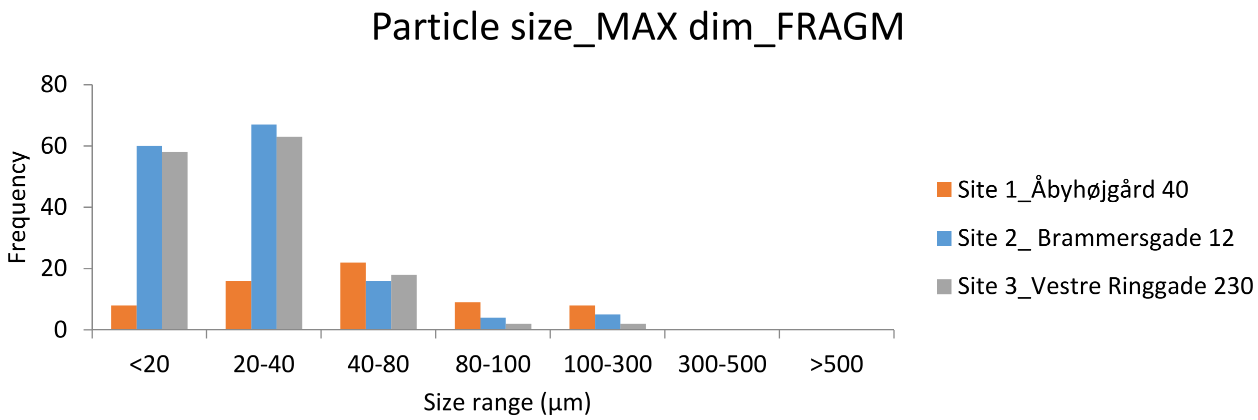
Where:

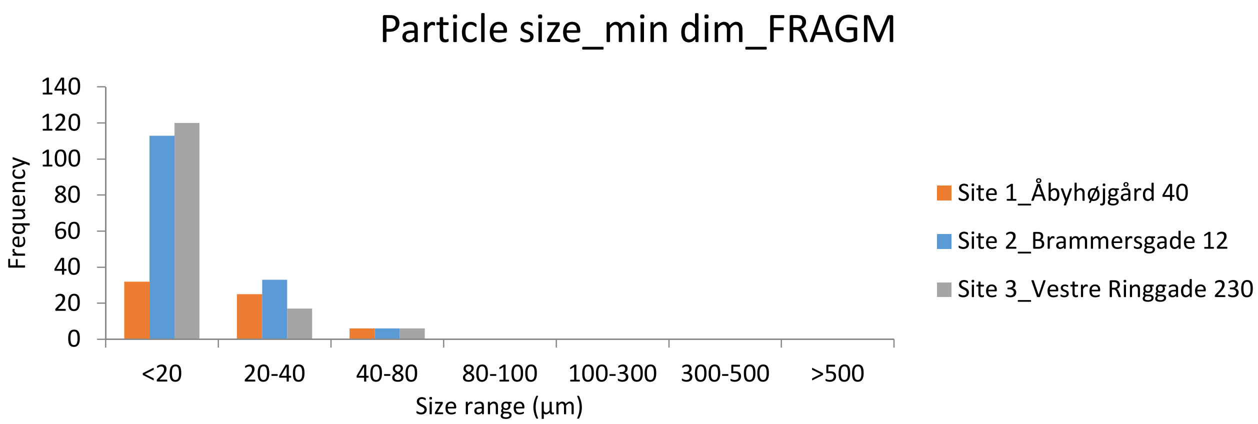
c	concentration of pollution in the room [m³/m³]
q	contamination source [m³/h]
n	Air change [h⁻¹]
V	Room volume [m³]
τ	Time [h]
c_o	Start concentration in the room [m³/m³]
c_i	Concentration in the supply air [m³/m³]

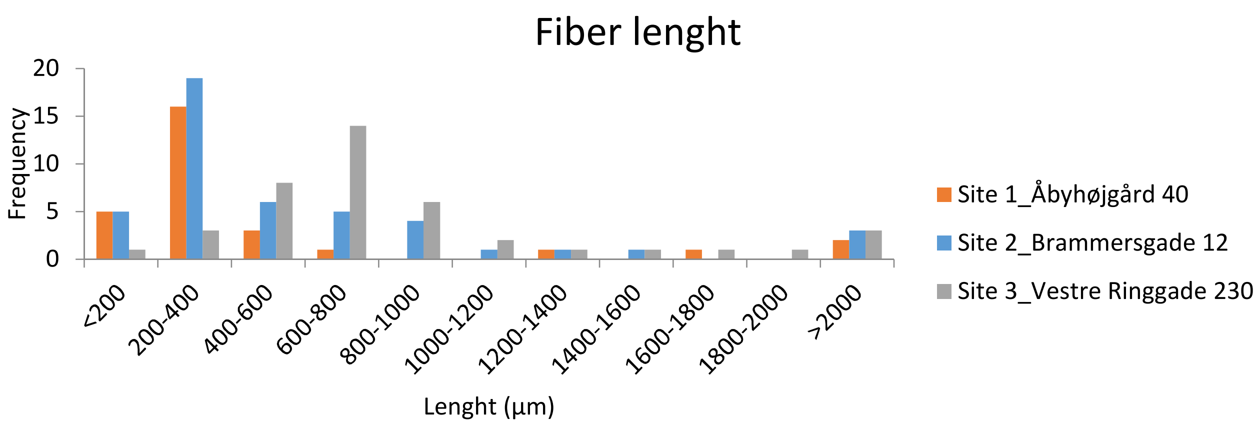
Concentration of pollution in the room	Start Concentration in the room	Concentration in the supply air	Constant	Air Change	Time Hours	Formula
[C]	[Co]	[Ci]	[e]	[n]	[t]	
1021,5	1573,7	350	2,71828	0,8738	2	1021,5

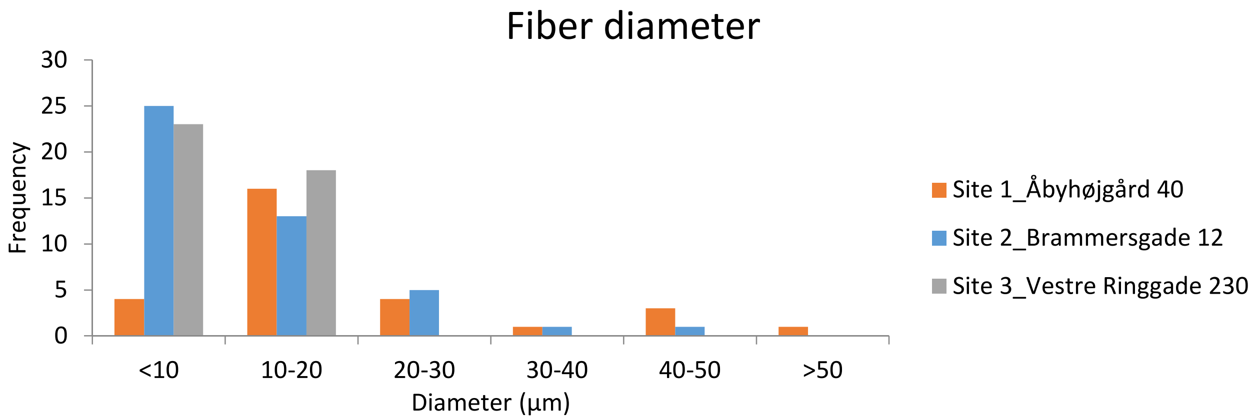
Appendix F

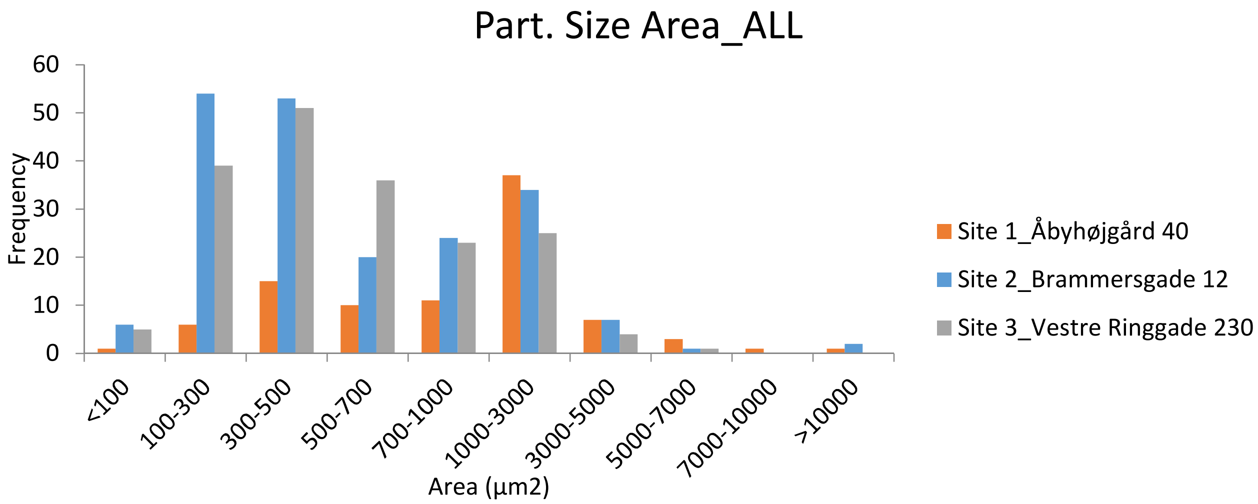
Graphical representation of airborne microplastic investigation results.

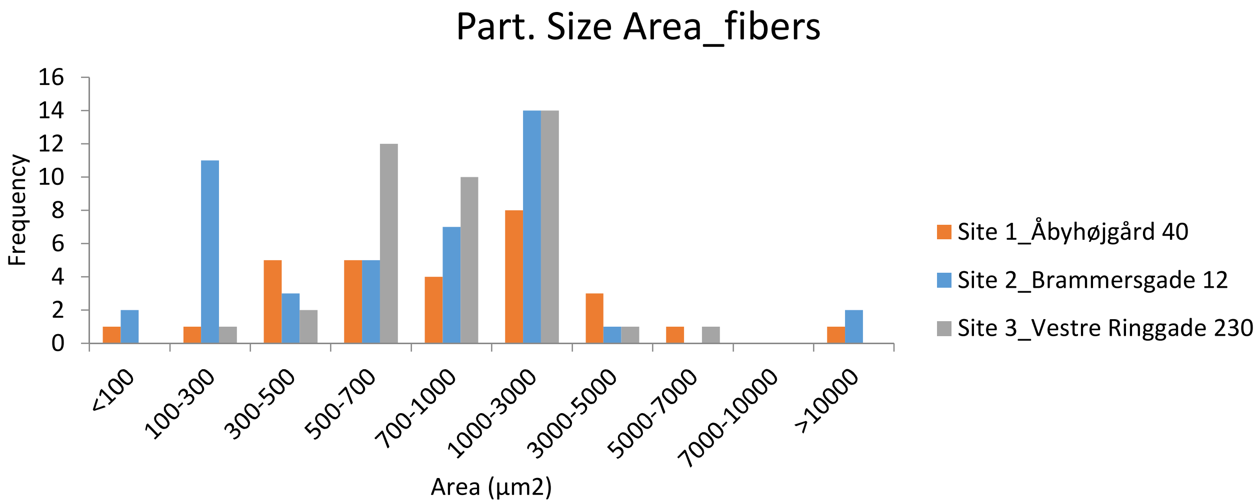


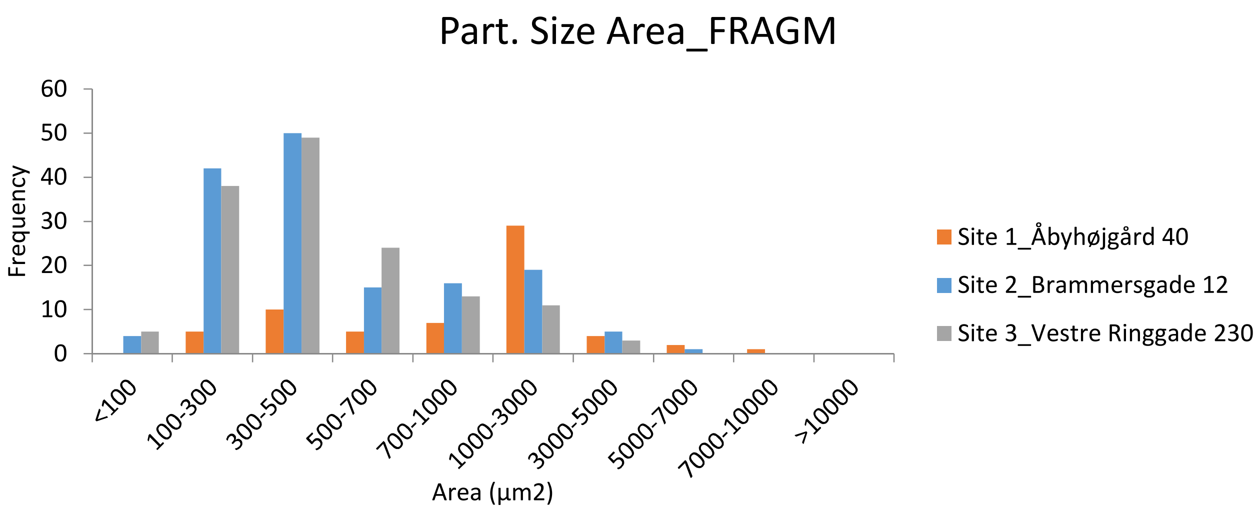





Fiber diameter
Frequency
30
25
20
15
10
5
0
<10
10-20
20-30
30-40
40-50
>50
Diameter (µm)
Site 1_Åbyhøjgård 40
Site 2_Brammersgade 12
Site 3_Vestre Ringgade 230


Part. Size Area_ALL
Frequency
60
50
40
30
20
10
0
<100
100-300
300-500
500-700
700-1000
1000-3000
3000-5000
5000-7000
7000-10000
>10000
Area (µm2)
Site 1_Åbyhøjgård 40
Site 2_Brammersgade 12
Site 3_Vestre Ringgade 230


Part. Size Area_fibers
Frequency
16
14
12
10
8
6
4
2
0
<100
100-300
300-500
500-700
700-1000
1000-3000
3000-5000
5000-7000
7000-10000
>10000
Area (µm2)
Site 1_Åbyhøjgård 40
Site 2_Brammersgade 12
Site 3_Vestre Ringgade 230



Acronyms

PE = Polyethylene

PP = Polypropylene

PEst = Polyester (Polyethylene terephthalate and other polyesters

PA (nylon) = Polyamide 66, Polyamide 6, Polyamide 12, etc.

PS = Polystyrene

PAcr = Generic Polyacrylates (Polymethyl methacrylate, polyethyl methacrylate, etc.)

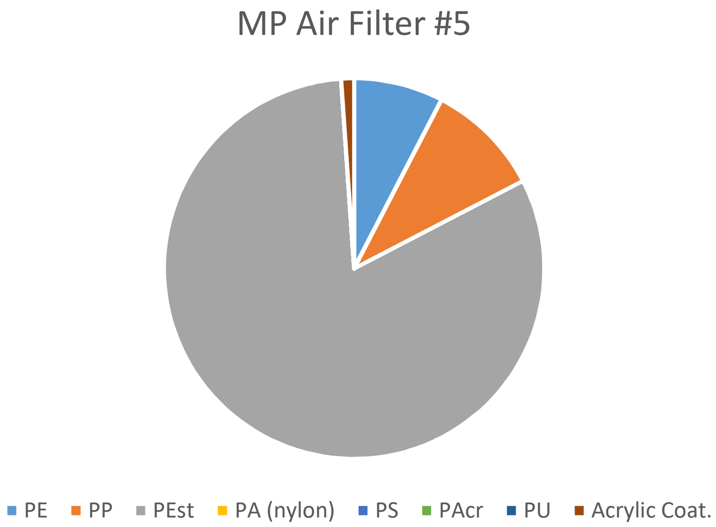
PU = Polyurethane (Polyurethane generic, polyurethane MDI/TDI, etc.)

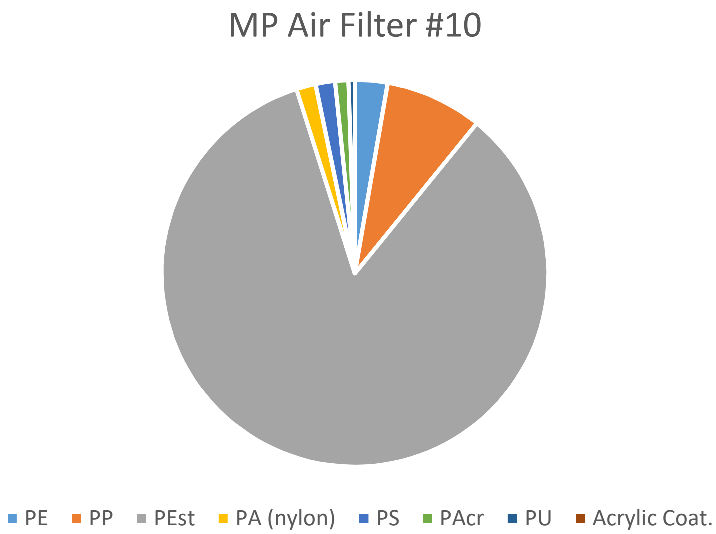
Acrylic coat = Acrylic coating (paint)

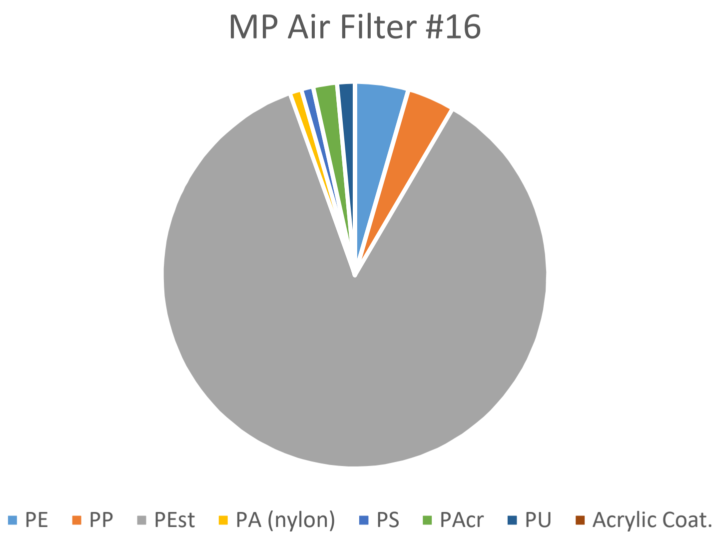
min dim = smaller axis

MAX dim = bigger axis

Polymers present in samples [%]







Particle Shape [%]