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MÁSTER UNIVERSITARIO EN INGENIERÍA INDUSTRIAL

PERSONAL PARTICULATE MATTER EXPOSURE AND ITS DEPENDENCY ON LIFESTYLE

TRABAJO FIN DE MÁSTER

Autor: Íñigo Bandeira Eguiraun

Director: Prof. Dusan Licina

Lausanne, Suiza

Junio de 2019

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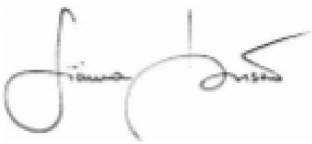

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Autor: **Bandeira Eguiraun, Íñigo.**

Director: Licina, Dusan.

Entidad Colaboradora: Hobel Laboratoy EPFL- École Polytechnique Fédérale de Lausanne.

RESUMEN DEL PROYECTO

Introducción

La calidad del aire es uno de los principales problemas en el mundo de hoy. Muchos efectos adversos para la salud pueden derivarse de la exposición a contaminantes del aire. Para evaluar con precisión la exposición a nivel individual a los contaminantes ambientales y, en última instancia, su impacto en la salud y el bienestar, es importante comprender mejor la exposición en diversos espacios interiores y exteriores a lo largo de los ciclos diarios de cada individuo. El objetivo de este proyecto es mejorar la comprensión de los niveles de exposición a partículas y su relación con el estilo de vida. Para lograr este objetivo, se realiza una evaluación de monitoreo personal analizando los resultados en términos de estilo de vida. El contaminante a investigar son las partículas (PM).

PM es una mezcla de partículas sólidas en el aire y gotas líquidas suspendidas en el aire, y es uno de los elementos principales de la contaminación del aire ambiente. Hay una gran variedad de fuentes de PM. Algunas de las principales fuentes externas son combustiones, industria, vehículos, niebla o incendios. Algunos otros ejemplos de fuentes interiores son cigarrillos, velas, aerosoles, polvo doméstico, cocina, resuspensión de polvo, productos de limpieza, humanos o PM transportados desde el exterior. Estas partículas quedan atrapadas dentro de los edificios, particularmente en las alfombras o mobiliario.

Tamaño, composición y concentración son las características necesarias para una definición adecuada de PM. El tamaño, generalmente medido en micrómetros, es el parámetro más importante para el comportamiento de la partícula. Cada partícula tiene una forma y tamaño diferentes. Sin embargo, para normalizar los estudios, se define un diámetro característico. Este diámetro es el diámetro equivalente de una partícula esférica con las mismas propiedades.

Debido al efecto sobre la salud, las partículas que generalmente se analizan son las que tienen 10 µm o menos como diámetro equivalente. Estas partículas se llaman partículas inhalables o PM10. Las partículas gruesas son las que se encuentran entre 2,5 µm y 10 µm. Si el diámetro es menor, entonces se consideran partículas finas (PM2,5) y partículas ultrafinas si el diámetro es menor que 0,1 µm (PM0,1). Si pensamos en la deposición de partículas en los pulmones humanos, podríamos llegar a la conclusión de que las partículas más pequeñas son las peores. Sin embargo, las partículas ultrafinas y las partículas con un diámetro entre 1 µm y 3 µm son las más peligrosas.

Las consecuencias de una mala calidad del aire son tremendamente costosas para la sociedad: vidas humanas, muertes prematuras, costos médicos, reducción de la producción de las empresas, etc. La contaminación del aire por PM fue el sexto riesgo más peligroso en el ranking *The Lancet*[1] en 2016 en términos de DAYLs. Alrededor del 7% de las muertes globales se le pueden atribuir a este factor. Se encuentra entre las 10 consecuencias principales entre 195 países diferentes como causa de muerte. La mala calidad del aire es peligrosa y costosa, y por ello debemos invertir más tiempo en investigación sobre este tema.

La exposición a contaminantes es una función de la concentración de los mismos y del tiempo de exposición. Esta concentración depende directamente del tipo de espacio donde se encuentra el usuario. Los diferentes microambientes (ME) a lo largo de los cuales un individuo se encuentra cada día, son determinantes para su exposición a contaminantes. Algunos de estos microambientes pueden ser más perjudiciales para su salud y pueden contribuir a una mayor exposición diaria a contaminantes. En promedio, las personas de los países desarrollados pasan alrededor del 90% de su tiempo en espacios interiores[2]. Este dato ha hecho que muchos investigadores conduzcas sus estudios en esta dirección.

La variedad de microambientes utilizados durante el día por una persona (transporte, hogar, trabajo y otros edificios) hace del espacio una variable principal de la exposición personal a contaminantes, como el tiempo. En el presente proyecto, se evalúan diferentes microambientes midiendo el tiempo pasado en cada uno de ellos y la exposición del usuario.

La exposición de cada persona es diferente debido a la alta variabilidad de los agentes. Es por eso que ningún estándar o directriz puede definir totalmente un umbral perfecto para cada usuario. Sin embargo, algunas organizaciones han definido diferentes pautas para ayudar a un mejor desarrollo de la población en términos de calidad del aire. Los que se utilizan en este proyecto como referencia, son las *Air Quality Guidelines* (AQGs)[3], de la Organización Mundial de la Salud (OMS) y la directriz de la EPA: *The American National Ambient Air Quality Standards* NAAQS[4]. Los umbrales de estas pautas se muestran en la siguiente tabla. Ambos se refieren a PM2.5 y a PM10. En el caso de la EPA, da diferentes categorías, la primaria para proteger la salud pública y la secundaria para proteger el bienestar público.

AQGs Guidelines	Annual mean	24-hour mean
PM2.5	*10 µg/m3*	*25 µg/m3*
PM10	*20 µg/m3*	*50 µg/m3*

EPA NAAQs Standards			
$PM_{2.5}$	primary	1 year	12.0 µg/m^3
	secondary	1 year	15.0 µg/m^3
	primary and secondary	24 hours	35 µg/m^3
PM_{10}	primary and secondary	24 hours	150 µg/m^3

Guidelines AQGs and EPA NAAQs

En general, los estándares o recomendaciones en temas de calidad de aire están establecidos, ya sea tomando datos de monitores fijos entre ciudades, o tomando información de literatura que ya tomó datos de monitores fijos en exteriores. Hay dos inconvenientes principales de estas normas o directrices. En primer lugar, están preparados para niveles de concentración ambiental que pueden no representar con precisión los niveles de concentración en interiores. En segundo lugar, estos valores de referencia se calculan depués de tomar muestras de diferentes ciudades con monitores fijos en emplazamientos específicos, como los techos de los edificios. Debido a esto, estos valores pueden no representar los valores necesarios para una regulación o guía de exposición individual correcta de una persona.

Esto nos lleva al punto principal de nuestro proyecto, la necesidad de una mejor comprensión y una mayor experimentación sobre la exposición personal a contaminantes. Para lograr este objetivo, se ha realizado un experimento de monitoreo personal. El experimento consiste en una evaluación de exposición personal a partículas, un experimento realmente complejo debido a la tremenda variabilidad del espacio, los hábitos de las personas y la dificultad de usar sensores comunes durante las actividades diarias.

Metodología

Este experimento tuvo como objetivo verificar cómo diferentes estilos de vida pueden afectar a la exposición personal a partículas. Además, pretendía demostrar la necesidad de un monitoreo personal para lograr información confiable de exposición real a contaminantes.

Un grupo de 4 usuarios fue monitoreado haciendo sus actividades diarias durante 4 días, 24 horas al día en Suiza. El objetivo de la prueba era recopilar datos de la exposición personal a partículas (PM) de cada uno de los usuarios y sus actividades diarias. Por razones de confidencialidad, cada participante recibió un número (P2, P3, P4 y P6). Al comienzo del experimento era 6 personas participantes. Sin embargo, y debido a algunos problemas técnicos, se redujo a solo 4 personas. Para comprender mejor cada una de las situaciones personales de los participantes, características de sus casa, hábitos y rutinas, se les pidió que llenaran tres cuestionarios diferentes. Uno antes de la realización del experimento, uno durante la prueba y uno al final de la misma. La primera consistía en un conjunto de preguntas para evaluar las características del edificio e identificar las posibles fuentes de contaminación. El segundo, también llamado TMAD (*Time-Microenvironment-Activity-Diary),* era un diario donde cada participante registraba las actividades diarias y los microambientes utilizados (como el hogar, la universidad, el transporte, el aire libre, etc.). El tercer cuestionario fue un cuestionario de exposición retrospectivo para revisar y discutir los datos recopilados con el resto de los cuestionarios.

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Graywolf Particle Counter 3500 and adapted backpack with the sensor. Source: left picture from Graywofl website. Right picture

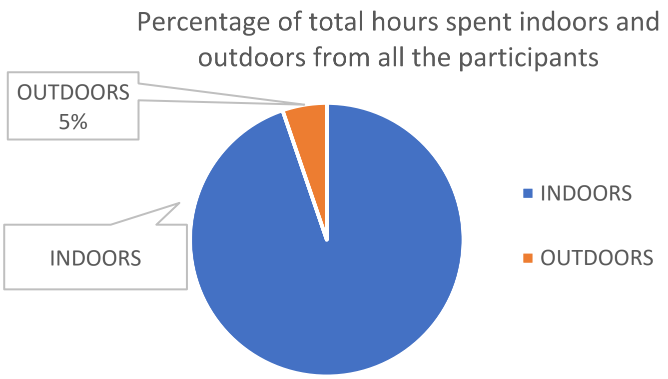
La exposición se midió con el uso de un Graywolf Particle Counter[5]. Cada participante llevaba el instrumento en una mochila y utilizaba un tubo conectado a la entrada del sensor, para extraer aire del área de respiración del usuario. La mochila se llevó durante cada uno de los desplazamientos del participante y, en caso de inactividad del usuario, se colocaba a menos de un metro de él.

Además, el participante número 6 tenía un segundo instrumento fijo, colocado en su casa para hacer una comparación entre monitoreo personal y fijo. Esta parte del experimento se realizó en paralelo con el resto de la prueba.

Resultados

El experimento se realizó con éxito para los participantes 3, 4 y 6. Debido a un problema técnico inesperado, todas las mediciones de exposición realizadas para el participante 2 se perdieron (su TMAD se completó con éxito y se utilizó para los resultados). Los resultados se analizan en el informe en dos pasos. En primer lugar, el TMAD y, en segundo lugar, los valores de exposición medidos por los sensores en función de la información del TMAD.

El primer resultado interesante logrado fue confirmar la tendencia general de pasar alrededor del 90% del tiempo en interiores. En el caso de los cuatro participantes, se alcanzó un 95% como se muestra en la figura. Además, otro hallazgo interesante fue verificar que todos los participantes pasaran la mayor parte de su tiempo en casa, lo que aumenta la importancia de una mejor calidad del aire en cada casa. Dormir, como se esperaba, era la actividad en la que los usuarios pasaban la mayor parte de su tiempo, seguida por trabajar o estudiar.



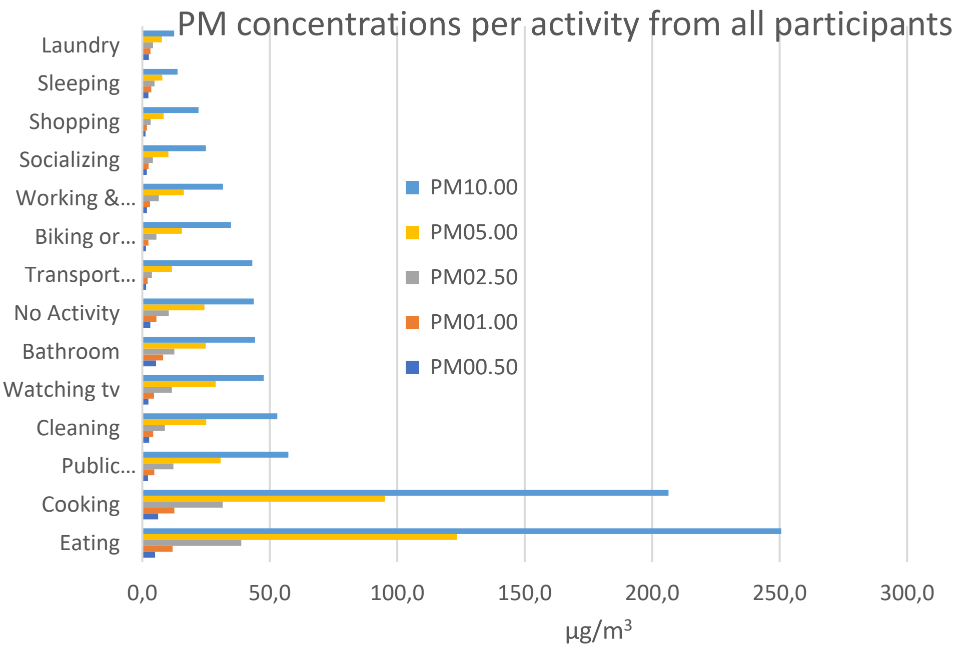
Percentage of total hours spent indoors and outdoors from all participants. TMAD

En la siguiente tabla se exponen los valores de PM medidos y el tiempo pasado en interiores o exteriores. Es interesante ver cómo casi todos los participantes tienen valores de concentración más altos en ambientes interiores que en ambientes exteriores.

I/O	PM00.50	PM01.00	PM02.50	PM05.00	PM10.00	% of total hours	Sum of hours
P3							
OUTDOORS	0,8	1,7	5,2	15,4	31,6	4,3%	4,3
INDOORS	3,1	6,9	20,9	61,2	117,3	95,7%	97,3
P4							
OUTDOORS	2,3	3,3	5,3	12,1	29,6	1,2%	1,4
INDOORS	3,0	4,3	5,7	9,5	17,0	98,9%	123,1
P6							
OUTDOORS	2,9	4,0	6,7	15,3	33,1	5,4%	5,1
INDOORS	1,5	2,8	6,6	19,8	45,2	94,6%	89,6

PM concentration indoors and outdoors per participant

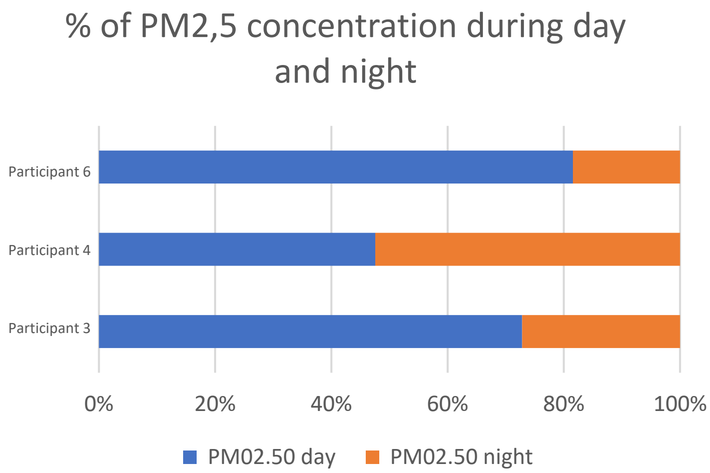
Otro aspecto importante al analizar la exposición a contaminantes y el estilo de vida son las actividades realizadas durante el día por cada participante. En la siguiente figura se puede observar los niveles de PM medidos durante cada actividad y el tiempo que se pasa en cada una de ellas. Cocinar y comer, fueron las actividades con los niveles más altos y con una parte representativa del tiempo dedicado a ello. Esto sucedió debido a la proximidad de la fuente del contaminante al individuo. Aumenta así, la importancia de la evaluación de la exposición personal en comparación con la evaluación de exposición de monitoreo fijo tradicional.



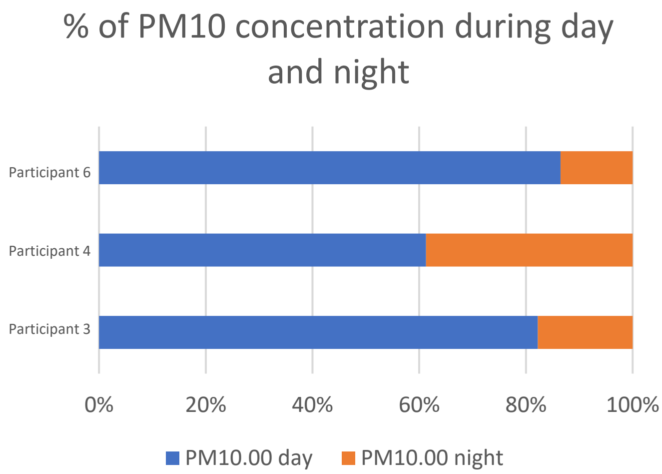
Activity	% of total hours per activity
Laundry	**0,09%**
Sleeping	**39,14%**
Shopping	**0,43%**
Socializing	**2,51%**
Working & Studying	**37,21%**
Biking or Walking	**2,62%**
Transport by car	**0,01%**
Bathroom	**0,49%**
Watching tv	**3,40%**
Cleaning	**1,56%**
Public transport	**1,36%**
Cooking	**3,45%**
Eating	**7,22%**

PM concentrations per activity from all participants and percentage of time spent in each activity

Otro hallazgo es la influencia del momento del día en la exposición personal. Se realizó un análisis entre el día y la noche. Los resultados fueron claros: durante el día, un individuo generalmente está expuesto a mayores concentraciones de PM. Las razones de



Percentage of PM2,5 concentration during night and day

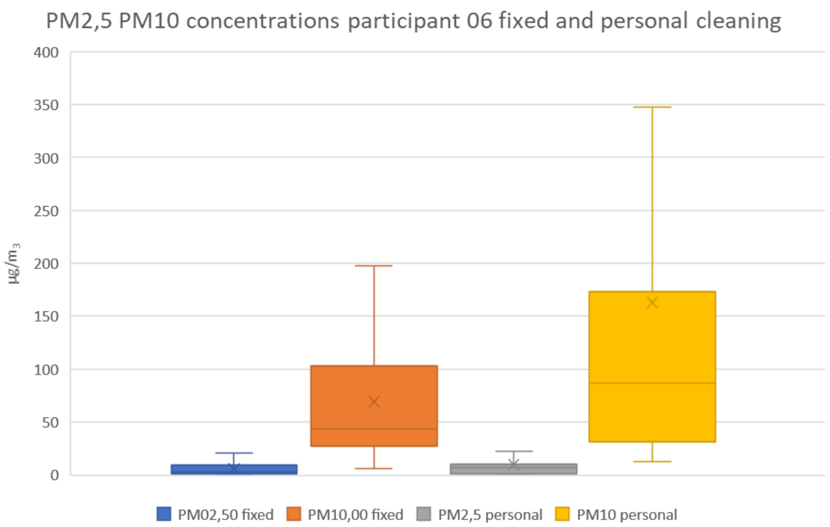


Percentage of PM concentration during night and day esto son la influencia de las fuentes, la existencia de sistemas de ventilación dentro de las habitaciones, la variabilidad de la actividad y los movimientos.

En el informe se pueden encontrar otros resultados finales. Buscan mostrar la influencia de diferentes variables en la exposición personal a PM. Estas variables generalmente definen el estilo de vida de la persona.

Otra parte de los resultados logrados es una comparación entre el monitoreo personal y fijo realizado por el participante 6. En este análisis se puede ver la importancia de la proximidad a la fuente y la nube personal. Para resumir estos resultados, se muestra el siguiente gráfico. Representa la concentración del participante 6 durante la limpieza, midiendo con los instrumentos de exposición personal (derecha) y con el sistema de monitoreo fijo (izquierda). La tendencia es la misma, pero se aprecia claramente que existe una diferencia entre las mediciones.

Al hacer una comparación entre los valores obtenidos y los valores de referencia presentados previamente, al cocinar y limpiar, la media de la evaluación de exposición personal siempre está por encima del umbral establecido por la EPA o AQG. La diferencia entre personal y fijo también se analizó calculando los factores de correlación entre los



PM 2,5 and PM10 concentrations for fixed and personal monitoring while cleaning. Concentration values in µg/m3

valores obtenidos por la evaluación personal y por el monitor fijo. Los factores mostraron una baja correlación al evaluar partículas de mayor diámetro (R^2 = 0,27 para PM10 durante la limpieza). Estos resultados explican la importancia de utilizar la evaluación de la exposición personal para lograr resultados más precisos.

Conclusiones

Con los resultados del experimento realizado queda demostrado cómo el estilo de vida puede afectar considerablemente a la exposición personal a partículas. La hora del día, el día de la semana, los diferentes microambientes utilizados, la proximidad a las fuentes o las actividades realizadas son algunas de las variables que se han analizado y se puede confirmar que afectan la exposición personal a partículas. Estas variables definen totalmente el estilo de vida de una persona, por lo tanto, su exposición a PM.

Tres participantes usaron un sensor de partículas adaptado durante 4 días, 24 horas al día para medir su exposición personal a PM. Se les pidió que llenaran de manera continua un diario de actividad que proporcionó a los investigadores suficiente información para confirmar la dependencia de la exposición a PM en el estilo de vida.

Algunas conclusiones alcanzadas al realizar este experimento son:

- La calidad del aire interior debe analizarse e investigarse mejor ya que las personas pasan la mayor parte del tiempo en espacios interiores (90% -95%). Además, los niveles de PM encontrados en microambientes interiores fueron generalmente más altos que los valores medidos en exteriores.
- Dormir y trabajar son las actividades en las que los participantes pasaron la mayor parte de su tiempo. Esto nos lleva a pensar que las casas y los espacios de trabajo deberían ser entornos altamente controlados en términos de calidad del aire.
- La alta variabilidad de las actividades y el entorno utilizado por cada persona hace que la evaluación de la exposición personal sea una tarea de alta complejidad. Esta variabilidad significa también una enorme complejidad para evaluar correctamente todos los diferentes niveles de exposición en cada EM. Además, una complejidad adicional es el laborioso uso de los sensores durante actividades cotidianas.
- La principal fuente de PM interior fue la actividad de cocinar, la limpieza también tuvo una importancia considerable en algunos casos. Comer también se relacionó con altos niveles de exposición. Esto muestra el efecto pasivo de cualquier una fuente de contaminantes como la cocina. Cocinar no solo contamina el área de la cocina sino también el resto de la casa.
- Por la noche, los niveles medidos de PM siempre fueron más bajos y menos variables que durante el día. Esto muestra la dependencia de PM en las actividades y el movimiento de los humanos.
- Al hacer el análisis entre los días laborales y los fines de semana, se demostró que, dependiendo de la rutina, la exposición puede variar mucho como lo hizo en los casos de los participantes 3 y 6.
- Se confirma una gran variabilidad de los resultados finales entre los diferentes participantes. Dando fuerte importancia a métodos de evaluación de la exposición individuales.

Se realizó un análisis final haciendo una comparación entre monitoreo personal y fijo para evaluar la exposición a PM. Uno de los participantes usó el sensor de PM personal durante los mismos dos días que se colocó un monitor de PM fijo en su casa. Los resultados fueron satisfactorios y, como se esperaba, demostró una diferencia existente entre ambos métodos, siendo más fiable y preciso el monitoreo personal. Las conclusiones alcanzadas con esta parte del experimento son:

- Varios factores afectan el monitoreo personal y fijo, lo que hace que la comparación sea una tarea compleja.
- Un mayor tamaño de partículas aumenta la diferencia entre los métodos de evaluación.
- Debido a la extrema proximidad de los sensores a la fuente (por ejemplo, durante tiempos de cocinado), algunos posibles valores atípicos podrían estar sesgando los resultados finales. Sin embargo, incluso al eliminar estos posibles valores atípicos, los resultados concluyen que las concentraciones de aire medidas por cada tipo de sistema de monitoreo son diferentes.
- Los resultados durante los tiempos de limpieza pueden ser concluyentes debido a la clara diferencia y la solidez de los datos utilizados. No hay posibles valores atípicos.

En resumen, este experimento permitió al equipo de investigadores probar la dependencia de la exposición personal a PM en el estilo de vida. Además, podrían confirmar la diferencia entre usar un sistema de monitor personal y uno fijo para evaluar la exposición personal.

Referencias

1. Lim, S. S. *et al.* A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* **380**, 2224–2260 (2012).

2. Pellizzari, E. D., Thomas, K. W., Clayton, C. A., Whitmore, R. W. & Shores, R. C. Particle total exposure assessment methodology (PTEAM): Riverside california pilot study. Volume 1. Final report. (1992).

3. Bruce, N. *et al.* WHO indoor air quality guidelines on household fuel combustion: Strategy implications of new evidence on interventions and exposure–risk functions. *Atmos. Environ.* **106**, 451–457 (2015).

4. Cortese, A. D. & Spengler, J. D. Ability of Fixed Monitoring Stations to Represent Personal Carbon Monoxide Exposure. *J. Air Pollut. Control Assoc.* **26**, 1144–1150 (1976).

5. Graywolf Particle Counter 3500. 3500

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RESUMEN DEL PROYECTO

Introduction

Air quality is one of the main issues on today's world. Many adverse health effects can derive from air pollutant exposure. In order to accurately assess individual level exposure to environmental pollutants, and ultimately its impact on health and well-being, it is important to better understand exposure in diverse indoor and outdoor spaces throughout human daily cycles. The objective of this project is to improve the understanding of exposure levels to particulate matter and its relation to lifestyle. To achieve this goal a personal monitoring assessment is done analysing the results in terms of lifestyle. The pollutant to be investigated is particulate matter (PM).

PM is a mixture of airborne solid particles and liquid droplets suspended in the air, and is one of the main elements of ambient air pollution. There is a wide variety of PM sources. Some of the primary outdoors sources are combustions, industry, vehicles, mist or fires. Some other examples of indoor sources are cigarettes, candles, aerosols sprays, home dust, cooking, dust resuspension, cleaning products, humans or PM transported from outdoors. These particles get trapped inside buildings, particularly in carpets.

Size, composition and concentration are the necessary characteristics for a proper PM definition. The size, usually measured in micrometres, is the most important parameter for the particle’s behaviour. Every particle has a different shape and size. However, to normalize studies, a characteristic diameter is defined. This diameter is the equivalent diameter of a spherical particle with the same properties.

Due to health effect, the particles that are usually analysed are the ones with 10µm or less as equivalent diameter. These particles are called inhalable particles or PM10. Coarse particles are the ones between 2,5 µm and 10 µm. If the diameter is smaller, then they are considered fine particles (PM2,5) and ultrafine particles if the diameter is smaller than

0,1 µm (PM0,1). If we think about deposition of particulate matter in human lungs, we might think that the smaller particles are, the worst. However, ultrafine particles and particles with a diameter between 1 µm and 3 µm are the most dangerous.

Bad air quality consequences are tremendously expensive for the society: human lives, of premature deaths, medical costs, reduction of companies' production as it reduces people's work efficiency, etc. PM air pollution was the sixth most dangerous risk in The Lancet[1] ranking in 2016 in terms of DAYLs. Around 7% of the global deaths can be attributed to it. It is in the top ten ranking of 195 different countries for being one of the main death causes. Bad air quality is dangerous and expensive, and that is why we need to investigate about it.

Air exposure is a function of concentration and time. The concentration is the quantity of pollutant present on the breathing area. And time, refers to the time to which the person is exposed to that concentration. This concentration depends directly on the type of space where the user is. The different microenvironments along the ones an individual comes across each day, is determinant to his exposure to pollutants. Some of these microenvironments can be more prejudicial for his health and can contribute to a higher daily exposure to pollutants. On average, people from developed countries spend around 90% of their time indoors[2], which takes a lot of researchers to drive their studies to this topic.

The variety of microenvironments used during the day by a person (transport, home, work and other buildings) makes the space a main variable of personal exposure, as time. In the present project, different microenvironments are assessed by measuring the time spent in each of them and the exposure of the user.

Each people exposure is different due to the high variability of agents. That is why none standard or guideline can totally define a perfect threshold for every user. However, some organizations have defined different guidelines to help a better population development in terms of air quality. The ones used in this project as references are the *air quality guidelines (AQGs)*[3], from the World Health Organization (WHO) and the EPA guideline: *The American National Ambient Air Quality Standards NAAQS*[4]. The thresholds of these guidelines are shown in the following table. They both refer to PM2.5 and to PM10. In case of the EPA, it gives different categories, the primary to protect public health and the secondary to protect the public welfare.

AQGs Guidelines	Annual mean	24-hour mean
PM2.5	*10 µg/m3*	*25 µg/m3*
PM10	*20 µg/m3*	*50 µg/m3*

EPA NAAQs Standards			
$PM_{2.5}$	primary	1 year	12.0 $\mu g/m^3$
	secondary	1 year	15.0 $\mu g/m^3$
	primary and secondary	24 hours	35 $\mu g/m^3$
PM_{10}	primary and secondary	24 hours	150 $\mu g/m^3$

Guidelines AQGs and EPA NAAQs

Generally, all these kinds of standards or guidelines are written, either taking data from fixed monitors between cities, either taking information from literature which already took data from fixed outdoors monitors. There are two main drawbacks of these standards or guidelines. Firstly, they are prepared for ambient concentrations levels which may not accurately represent the indoor concentration levels. Secondly, these references values are calculated after taking samples from different cities with fixed monitors in specific emplacements such as building’s roofs. Because of this, these values may not represent the needed values for a correct individual exposure regulation or guideline.

This takes us to the main point of our project, the necessity of a better understanding and a larger experimentation on personal exposure to pollutants. To achieve this goal, an experiment is done. The experiment consists on a personal exposure assessment to particulate matter, an experiment really complex due to the tremendous variability of space, people habits and difficulty of using common sensors during daily activities.

Methodology

This experiment aimed to check how different lifestyles can affect personal exposure. In addition, it aimed to prove the necessity of personal monitoring to achieve reliable information of real exposure to pollutants.

A group of 4 users was monitored doing their daily activities during 4 days, 24 hours a day in Switzerland. The aim of the test was to collect data from the personal exposure to particulate matter (PM) of each of the users and their daily activities. For confidentiality reasons each participant was given a number (P2, P3, P4 and P6). At the beginning of the experiment it was supposed to be done by 6 people. However, and due to some technical issues, it was reduced to only 4 individuals. To understand better each of the participants personal situations, building characteristics, habits and routines they were asked to fill three different questionnaires. One before doing the test, one during the test and one at the end of the test. The first one was a set of questions to evaluate the building characteristics and to identify the possible sources of pollution. The second one, also called TMAD (*Time-Microenvironment-Activity-Diary*), was a diary where each participant recorded the daily activities and the microenvironments used (such as home, university, transport, outdoors, etc). The third questionnaire was a retrospective exposure questionnaire to review and discuss the gathered data with the rest of the questionnaires.

The exposure was measured with the using a Graywolf Particle Counter[5]. The instrument was carried by each participant in a backpack and using a pipe to extract air from the user's breathing area.

Graywolf Particle Counter 3500 and adapted backpack with the sensor. Source: left picture from Graywofl website. Right picture from own elaboration.

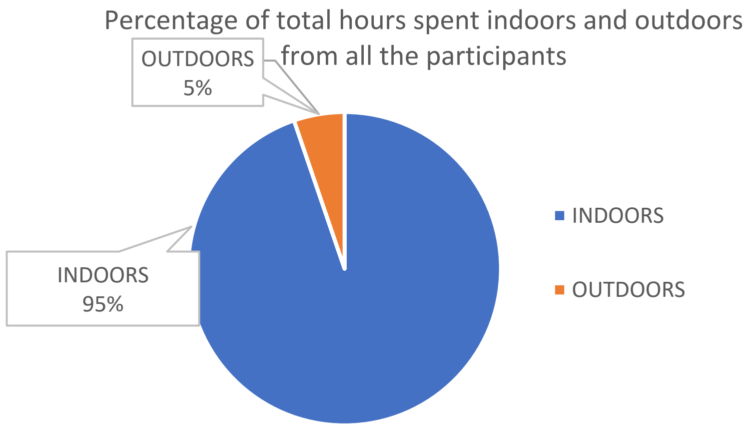
The backpack was carried during each of the participant's displacements and in case of user inactivity, the backpack was placed closer than one meter from him

In addition, participant number 6 had a secondary instrument placed at his house to do a comparison between personal and fixed monitoring. This part of the experiment was done in parallel with the rest of the test.

Results

The experiment was successfully done for participants 3, 4 and 6. Due to an unexpected technical problem all the exposure measurements done for participant 2 were lost (his TMAD was successfully completed and used for the results). The results are analysed in the report in in two steps. Firstly, the TMAD and secondly, the exposure values measured by the sensors depending on the TMAD information.

The first interesting result achieved was to confirm the general tendency of spending around 90% of the time indoors. In case of the four participants a 95% was reached as show in the figure. In addition, another interesting finding was to check that all participants spent most of their time at home, enhancing the importance of a better air quality in each house. Sleeping, as expected, was the activity in which the users spent most of their time.



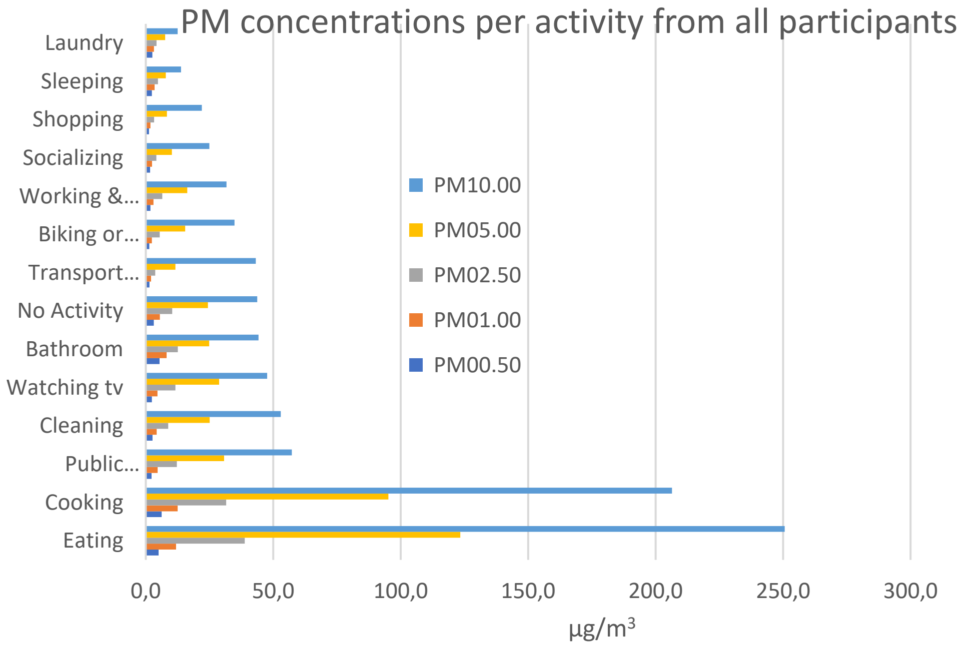
Percentage of total hours spent indoors and outdoors from all participants. TMAD

In the following table the values of PM measured and the time spent indoors or outdoors is exposed. It is interesting to see how almost all participants have higher concentration values in indoor environments than in outdoors environments.

I/O	PM00.50	PM01.00	PM02.50	PM05.00	PM10.00	% of total hours	Sum of hours
P3							
OUTDOORS	0,8	1,7	5,2	15,4	31,6	4,3%	4,3
INDOORS	3,1	6,9	20,9	61,2	117,3	95,7%	97,3
P4							
OUTDOORS	2,3	3,3	5,3	12,1	29,6	1,2%	1,4
INDOORS	3,0	4,3	5,7	9,5	17,0	98,9%	123,1
P6							
OUTDOORS	2,9	4,0	6,7	15,3	33,1	5,4%	5,1
INDOORS	1,5	2,8	6,6	19,8	45,2	94,6%	89,6

PM concentration indoors and outdoors per participant

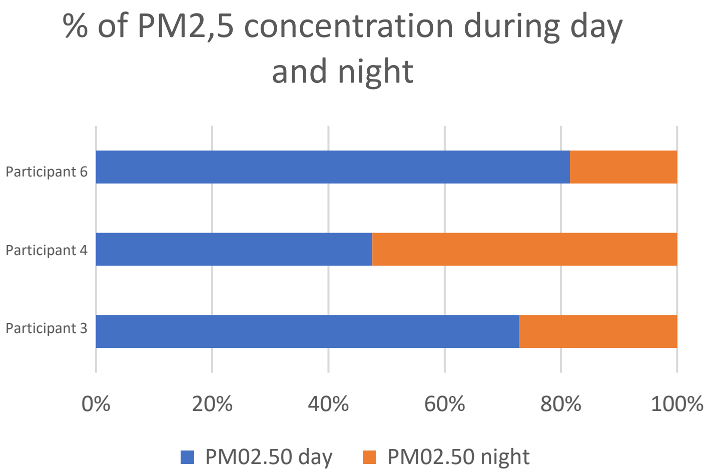
Another important aspect when analysing the exposure to pollutants and the lifestyle is the activities done during the day by each participant. In the following figure it can be observed the levels of PM measured during each activity and the time spent in each of them. Cooking and eating were the activities with the highest levels and with a representative portion of time spent on it. This happened due to the proximity of the pollutant's source to the individual and enhances the importance of personal exposure assessment versus the traditional fixed monitoring exposure assessment.



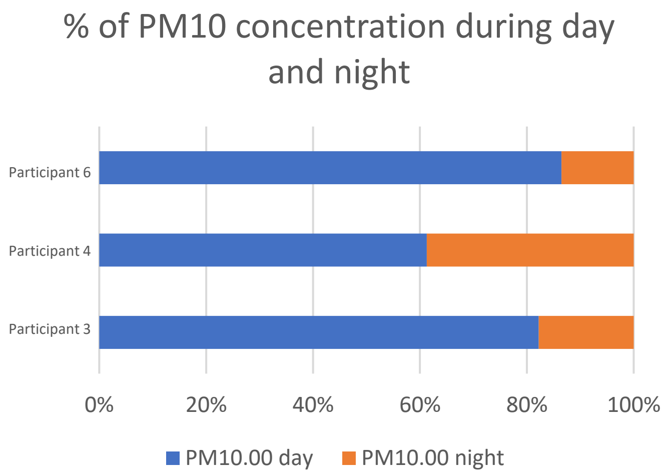
Activity	% of total hours per activity
Laundry	**0,09%**
Sleeping	**39,14%**
Shopping	**0,43%**
Socializing	**2,51%**
Working & Studying	**37,21%**
Biking or Walking	**2,62%**
Transport by car	**0,01%**
Bathroom	**0,49%**
Watching tv	**3,40%**
Cleaning	**1,56%**
Public transport	**1,36%**
Cooking	**3,45%**
Eating	**7,22%**

PM concentrations per activity from all participants and percentage of time spent in each activity

Another finding is the influence of the time of the day in the personal exposure. An analysis between day and night was done. The results were clear: during the day, an

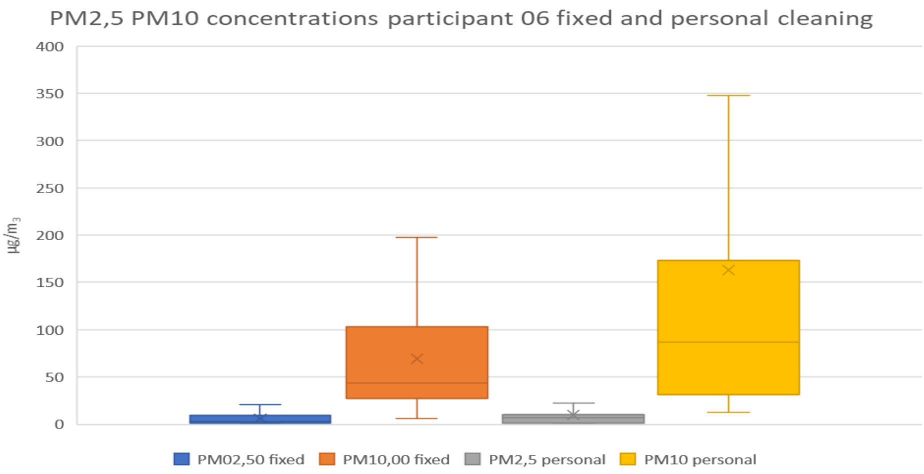


Percentage of PM2,5 concentration during night and day



Percentage of PM concentration during night and day individual is generally exposed to higher PM concentrations. The reasons of this are the influence of sources, existence of ventilation systems inside the bedrooms, activity variability and movements. In the report other final results can be found. They seek to show the influence of different variables in personal exposure to PM. These variables usually define the person's lifestyle.

Another part of the achieved results is a comparison between personal and fixed monitoring done by participant 6. In this analysis it can be seen the importance of the proximity to the source and the personal cloud. To summarize these results the following graph is shown. It represents the concentration from participant 6 while cleaning, measuring with the personal exposure instruments (right) and with the fixed monitor system (left). The tendency is the same but is clearly appreciated that there is an existing different between measurements. When doing a comparison between the obtained values and the reference values of the guidelines, when cooking and cleaning, the mean from the personal exposure assessment is always above the threshold established by the EPA or AQGs. The difference between personal and fixed was also analysed by calculating the correlation factors between the values obtained by the personal assessment and by the fixed monitor. The factors showed a low correlation when assessing higher diameter particles (R^2=0,27 for PM10 while cleaning). These results explain the importance of using personal exposure assessment to achieve more accurate results.



PM 2,5 and PM10 concentrations for fixed and personal monitoring while cleaning. Concentration values in µg/m3

Conclusions

It has been confirmed that the lifestyle can affect considerably the personal exposure to particulate matter. Time of the day, day of the week, the different microenvironments used, proximity to sources or activities are some of the variables that has been analysed and it can be confirmed that they affect the personal exposure to particulate matter. These variables totally define the lifestyle of a person, thus their exposure to PM.

Three participants wore an adapted particle counter during 4 days, 24 hours a day to measure their personal exposure to PM. They were asked to fill continuously a time activity diary which gave the researchers enough information to confirm the PM exposure dependency on lifestyle.

Some conclusions achieved by performing this experiment are:

- Indoor air quality should be better analysed and investigated as people spent most of their time in indoor spaces (90%-95%). In addition, the PM levels found at indoor microenvironments were usually higher than the measured values outdoors.
- Sleeping and working are the activities in which the participants spent most of their time. This takes us to think that personal houses and working spaces should be high controlled environments in terms of air quality.
- The high variability of activities and environment used by each person makes personal exposure assessment a high complexity task. This variability means an also enormous complexity to correctly asses all the different levels of exposure in each ME. In addition, an extra complexity added is the usability of the sensors in daily life.
- The main source of indoor PM was the activity of cooking, cleaning had a considerable importance in some cases too. Eating was also linked to high levels of exposure. This shows the passive effect of cooking as a source of pollutants. Cooking not only pollutes the kitchen area but also the rest of the apartment.
- At night-times the measured levels of PM were always lower and less variable than during the day. This shows the dependency of PM on humans' activities and movement.
- Doing the analysis between labour days and weekends it was proved that, depending on the routine, the exposure can highly variate as it did in cases of participant 3 and 6.

A final analysis was done doing a comparison between personal and fixed monitoring to asses PM exposure. One of the participants wore a personal PM sensor during the same two days that a fixed PM monitor was placed in his house. The results were satisfactory and, as expected, it proved an existing difference between both methods, being more reliable and accurate the personal monitoring. The conclusions achieved with this part of the experiment are:

- Several factors affect personal and fixed monitoring, making the comparison a complex task.
- Higher size of particles makes bigger the difference between methods of assessment.
- Due to the extreme proximity of the sensors to the source (for example while cooking) some possible outliers could be biasing the final results. However, even when deleting these possible outliers, the results conclude that the air concentrations measured by each type of monitoring system are different.
- The results during the cleaning times can be conclusive due to the clear difference and the strength of the used data. There are no possible outliers.

To sum up, this experiment allowed the team of researchers to prove the dependency of the personal exposure to PM on lifestyle. In addition, they could confirm the difference between using a personal and a fixed monitor system to assess personal exposure.

References

1. Lim, S. S. *et al.* A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* **380**, 2224–2260 (2012).
2. Pellizzari, E. D., Thomas, K. W., Clayton, C. A., Whitmore, R. W. & Shores, R. C. Particle total exposure assessment methodology (PTEAM): Riverside california pilot study. Volume 1. Final report. (1992).
3. Bruce, N. *et al.* WHO indoor air quality guidelines on household fuel combustion: Strategy implications of new evidence on interventions and exposure–risk functions. *Atmos. Environ.* **106**, 451–457 (2015).
4. Cortese, A. D. & Spengler, J. D. Ability of Fixed Monitoring Stations to Represent Personal Carbon Monoxide Exposure. *J. Air Pollut. Control Assoc.* **26**, 1144–1150 (1976).
5. Graywolf Particle Counter 3500. 3500

FIGURES

TABLES

Content

1. INTRODUCTION

Air quality is the main environmental risk for human health[1]. In 2012 almost 3 million people lost their lives due to ambient air pollution (outdoors)[2]. According to WHO (World Health Organization), in 2017 this number increased to 4,2 million and 3,8 million lives were ended due to indoor air pollution. The number of premature deaths only because of particulate matter is expected to reach 3,6 million a year by 2050[3]. Western Pacific and South East Asia are the areas most affected with the worst indicators of ambience exposure. In urban areas air pollution continues to increase having its effects not only in the life quality, but also in the economy. Bad air quality costs human lives, increases medical costs to treat unhealthy population, it reduces companies' production as it reduces people's work efficiency. Historical and cultural monuments can be damaged by a lack of good air quality and a needed reparation increases the unexpected costs. Also, bad air quality can affect food, water and other livings which can be translated in additional costs. Pulmonary diseases, heart diseases, lung cancer, stroke, irritation of the eyes, cardiovascular and reproductive diseases are the main health issues that a human can experience due to bad air quality. To sum up, there is a social problem that needs to be approached and it is crucial to quantify the impact on the individual.

In order to know how is an individual affected by any pollutant, is needed to know his personal exposure. As a person is always interacting with time and space, lots of variables affect the exposure levels (Building characteristics, environmental situation, activity performed, transport used, proximity to pollutant sources, etc.). Many international organisms have established different criteria for level exposure. However, these levels are not accurate to the real exposure of the individual as they are based on information gathered with fixed monitors or mathematical models. The goal of this project is to have a better understanding on how is the individual's real personal exposure to pollutants and how can this be affected by his lifestyle.

To achieve this goal, an experiment is done. The personal exposure of PM of 3 participants is measured during four entire days. At the same time, each of the participants is asked to fill a time-microenvironment-activity diary (TMAD), which will be useful to the researches to better understand the different exposure levels.

The repost is divided in 5 main sections: introduction, state of the art, methodology, results and conclusion. During this first section, a brief introduction to the topic of pollution, indoor air quality and exposure is done. Later on, in the section of state of the art a deep analysis of the existing studies and experiments is elaborated. Analysis that is used to correctly design the proposed experiment, better explained in the methodology section. In the section of results, the gathered data by the TMAD and the sensors are discussed. Finally, the report ends with a chapter of conclusions.

1.1. Terminology to understand

The big risks related to bad air quality, the complexity of a good characterization of the problem and the necessity of a good and clear quantification of the consequences, take us to dedicate the first section of the report to define an accurate nomenclature. Population exposure to air pollution and personal exposure can be misunderstood if the exact words are not used. A general awareness about air quality is arising in our society and some articles are confusing due to the misuse of some technical words. To clearly define the most important words of the inhalation process an explication from outside to inside is going to be done as presented in Figure 1.

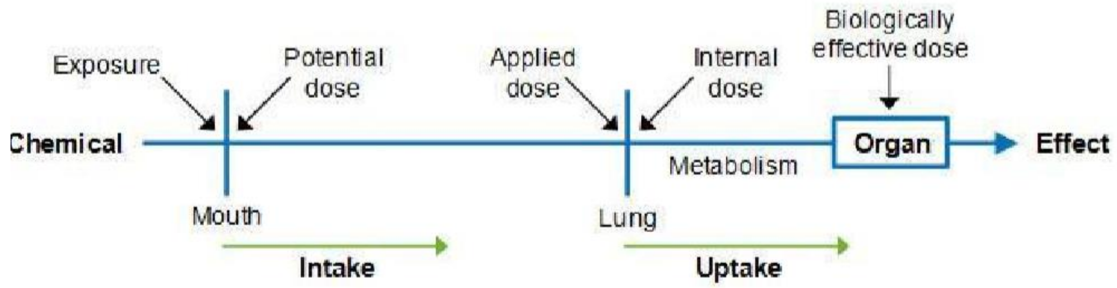


Figure 1 Nomenclature Schema

Source: EPFL - IAQ course slides

Exposure and concentration are usually used in a similar way. However, their meanings target different ideas. Concentration responds to the amount of a pollutant per unit of volume. Exposure is a product between the constant concentration of a pollutant and the time over which the person is subjected to the it. Exposure can be also defined as the breathing zone concentration over time.

The next term is inhalation, which is the intake of the individual. It is the product of pollutant concentration on air, the time over which the individual is exposed and the personal breathing rate. It defines the quantity of pollutant that achieves to enter inside the body. Internal dose is the quantity of the inhaled air pollutant that actually has a contact with the metabolism. Finally, from that quantity of pollutant which is in contact with the metabolism not everything achieves to get inside. That part is called *dose*. Our report will me mainly focused on the first steps: concentration, exposure and intake.

1.2. Particulate matter and possible effects

(For a better reading during the report, particulate matter will be referred as PM). PM is a mixture of airborne solid particles and liquid droplets suspended in the air, and is one of the main elements of ambient air pollution. There is a wide variety of PM sources. Some of the primary outdoors sources are combustions, industry, vehicles, mist or fires. Some other examples of indoor sources are cigarettes, candles, aerosols sprays, home dust, cooking, dust resuspension, cleaning products, humans or PM transported from outdoors. These particles get trapped inside buildings, particularly in carpets.

Size, composition and concentration are the necessary characteristics for a proper PM definition. The size, usually measured in micrometres, is the most important parameter for the particle's behaviour. Every particle has a different shape and size. However, to normalize studies, a characteristic diameter is defined. This diameter is the equivalent diameter of a spherical particle with the same properties.

Due to health effect, the particles that are usually analysed are the ones with 10µm or less as equivalent diameter. These particles are called inhalable particles or PM10. Coarse particles are the ones between 2,5 µm and 10 µm. If the diameter is smaller, then they are considered fine particles (PM2,5) and ultrafine particles if the diameter is smaller than 0,1 µm (PM0,1). If we think about deposition of particulate matter in human lungs, we might think that the smaller particles are, the worst. However, ultrafine particles and particles with a diameter between 1 µm and 3 µm are the most dangerous. We can define three steps in the respiratory process. The first part is the nasopharyngeal or head airways area which is the closest to the inhalation area. Then the air reaches the tracheobronchial zone while being introduced inside the lung trough

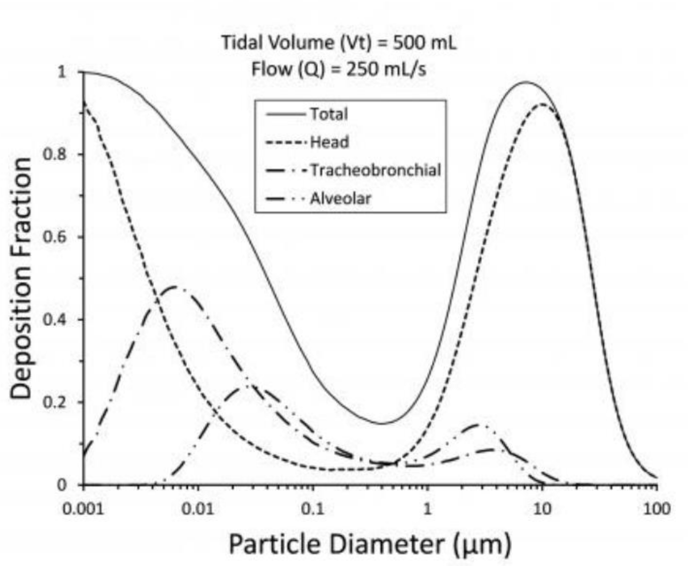


Figure 2 Estimation ratio of particle deposition in different parts of the lung depending on the size of the particle. Source: EPA United States Environmental Protection Agency.

the trachea and the bronchus. Finally, the alveolar zone where the respiratory bronchioles are found. Depending on the size particle each of these areas, the deposition rate changes.

In Figure 2 this effect is summarized. Impaction, sedimentation and diffusion are the main deposition mechanism of PM. Depending on the size of the particles one mechanism is more effective than others. For bigger particles, impaction and sedimentation can be more determinant for their inertia and size. Diffusion occurs with small particles that are not ruled by gravitational forces, but by Brownian motion.

The fact that particulate matter can enter into the lungs makes it tremendously dangerous for human health. Lung cancer, sinus, respiratory infections or asthma are some of health the respiratory issues related to particulate matter. In addition, it can be the cause of cardiovascular problems as irregular heartbeat, or even heart-attacks. PM air pollution was the sixth most dangerous risk in *The Lancet*[4] ranking in 2016 in terms of DAYLs. Around 7%[4] of the global deaths can be attributed to it. It is in the top ten ranking of 195 different countries for being one of the main death causes.

Bad air quality costs human lives, increases medical costs to treat unhealthy population, it reduces companies' production as it reduces people's work efficiency. Historical and cultural monuments can be damaged by a lack of good air quality and a needed reparation increases the unexpected costs. Also, bad air quality can affect food, water and other livings which can be translated in additional costs. Pulmonary diseases, heart diseases, lung cancer, stroke, irritation of the eyes, cardiovascular and reproductive diseases are the main health issues that a human can experience due to bad air quality.

Health End Point	Health Valuation: Premature Death[1-3] ($ Billions/yr)	Medical Cost[2-4] ($ Billions/yr)	Lost Productivity Cost[3,5] ($ Billions/yr)	Total Cost ($ Billions/yr)
CO: poisoning	0.15	<0.001	NA	0.15
VOCs: cancer	0.73	0.011	NA	0.74
ETS: lung cancer	2.4	0.025	NA	2.4
ETS: heart disease	23	0.055	NA	23
ETS: asthma episodes	NA	0.020[5]	NA	0.020
ETS: low birth weight	NA	0.19	NA	0.19
ETS: otitis media	NA	0.019[5]	NA	0.019
Radon: lung cancer	9.5	0.097	NA	9.6
Mold and moisture: asthma and allergies	0.031	0.19[5]	NA	0.22
Sick building syndrome	NA	NA	8.5	8.5
TOTAL[6]	36	0.6	8.5	45

Table 1 Cost of pollution health effects. Source: California indoor air quality

In the report: *Indoor Air Pollution in California*[5]*,* a group of researches summarizes the economic effects of all this problems created by a lack of an appropriate indoor air quality in the state of California (USA). The results are presented in Table 1. They estimated a total of 45 billion dollars per year. They took into account not only the cost of premature deaths and medical costs but also the cost of losing productivity. It is known that the loss of productivity has a big potential to be one of the main costs. However, there is a limited amount of available information about it. To sum up, there is a social problem that needs to be approached and it is crucial to quantify the impact on the individual.

1.3. Exposure

1.3.1. What is exposure?

The Cambridge English Dictionary defines exposure as "*the fact of experiencing something or being affected by it because of being in a particular situation or place*" [6]. If we adapt this definition to our topic, exposure is a substance concentration to which an individual is subjected to, during an amount of time. This means that mathematically it can be calculated as the integral of the pollutant concentration times time (I). The concentration units, as already mentioned in this report, can be number of concentrations, as units per volume (molecules/m^3), mass concentration units (µg/m^3) or molar concentration (ppm).

$$E = \int_0^t C(t) \cdot dt \qquad \text{(I)}$$

The total exposure to which an individual is subjected during a period of time is the sum of the exposures in each of the individual microenvironments (II) (house, office, transport, public spaces, stores, etc). It has, obviously, a direct dependency on the individual's activity pattern.

$$E_{total} = \sum_{i=1}^{n} \int_0^{t_i} C_i(t) \cdot dt \qquad \text{(II)}$$

When analysing the exposure, it is necessary to determine the source, the pathway and the quantity as well as where and when it happens. In case we want to compare two different environments exposure, it is possible to use a relative inhalation exposure ratio as determined in the following equation (III).

$$E_{relative\ i-j} = \frac{C_i}{C_j} \cdot \frac{\Delta \boldsymbol{t_i}}{\Delta t_j} \qquad \text{(III)}$$

When assessing exposure, two types are defined: long- and short-term exposure. Long-term exposure is usually related to carcinogenic pollutants. The second type of exposure is short-term exposure, usually related to dangerous pollutants in elevated concentrations.

1.3.2. Inhalation and exposure

It is necessary to clearly identify the difference between exposure and inhalation. Inhalation is the real quantity of pollutant that crosses a body boundary. Because of this, we add a new factor on our equation (II), which is de breathing rate (Q_b) at a given time t (IV).

$$I_{total} = \sum_{i=1}^{n} \int_{0}^{t_i} C_i(t) \cdot Q_b(t) \cdot dt \qquad \text{(IV)}$$

In the following picture Figure 3 Example of *CO2 concentration* it is shown a real example of CO_2 levels in a bedroom. The inhabitant's exposure of this bedroom can be taken from the integral of the graph during time. In other words, the highlighted area. If we would like to know the inhalation of this individual, we should have the information about his real personal exposure (the levels shown are from the well mixed air of the room) and his breathing rate. The first factor is going to be the main topic of our report and will be described in further sections. The second factor has to be determined either in an empirical way or with some statistical methods. Some examples of empirical methods are showed in the section: Exposure, inhalation and breathing rate from the STATE OF THE ART chapter

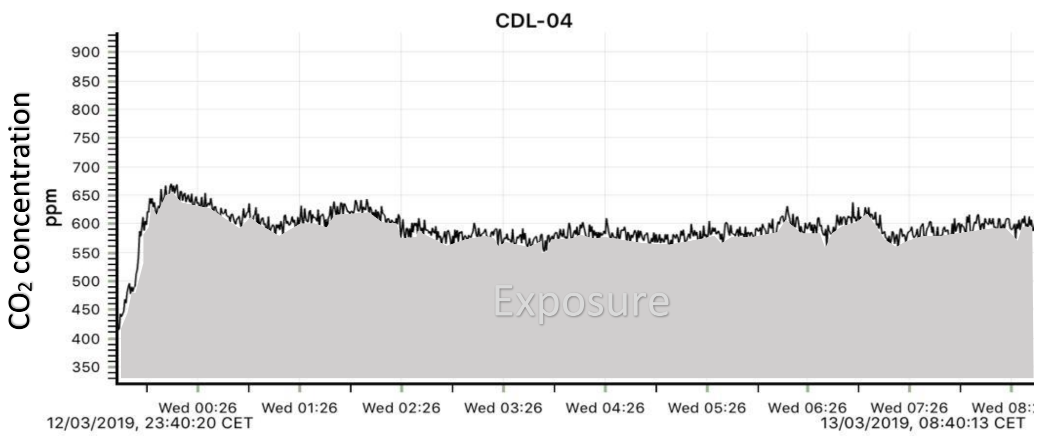


Figure 3 Example of CO2 concentration and exposure

1.4. Environmental mixtures, types, and importance

Usually when thinking about exposure we relate it to air. However, a human being is exposed by other different routes such as water, food, soil or noise. Lungs, skin, ears and intestine are the main parts of the body affected by it as the pollutant can be inhaled, ingested or can contact the skin. Serious harmful effects on populations' health can occur due to excessive exposure to multiple environmental agents (as explained in the section of Particulate matter and possible effects). In order to go deeper into the scope of exposure, the article *Assessing Cumulative Health Risks from Exposure to Environmental Mixtures—Three Fundamental Questions*[7] is going to be summarised. The main goal of this article was to define the correct exposure factors and cumulative risk assessment. Biological, physical, chemical and psychosocial agents can create a risk of vulnerability to any human being. Some examples these agents can be a bacteria, heat or noise, ozone and unemployment respectively. An environmental mixture is a combination of any of these agents. In the article, three main ideas from environmental mixtures are analysed: the most important environmental mixture for public health, the nature and magnitude of cumulative exposures and the mechanism and consequences on population. In this part of our report, we are interested in the environmental mixture or also called microenvironment definition.

To start with the first point, three categories of environmental mixtures are proposed in the article: similar, defined and coincidental mixtures. These categories depend on the target of the research, analysis, experiment or test to be done. Similar mixtures refer to combination of agents that has similar properties. Usually the agents of these mixtures have a common source or have been created with the same commercial use. However, they have some differences such as geographic location of the source, time since they were emitted or different composition ratios. As the chemical or physical structure is comparable, the effect can be characterized by a unique dose. This makes this category the most commonly assessed.

The second type are defined environmental mixtures. They are a combination of agents with different properties but enough well-known composition between them to still have a meaningful and manageable assessment. Some examples of this category are tobacco smoke or coke oven emissions.

The last category are the coincidental mixtures. Any mixture done by any hazardous combination from different agents is included into this group. The mixture can occur constantly, rarely with a similar agent's composition or totally different. It basically defines any real-world situation such as urban air.

There is a practical reason on defining these three categories. The first group allows us to do a manageable analysis of a specific agent or combination of similar ones. This simplifies the scope of the problem focusing on how to assess the mixture. The second group, called defined mixtures, is source-oriented. This allows the researches to, again, simplify the problem and to get focus on the analysis of the mixture. Thirdly, if the goal is to do an analysis of the receptor, we will use the last category, called coincidental mixtures. This is the most complex situation as it includes any possible agent at the analysed scenario. In order to do a correct assessment of the situation is necessary to know all the relevant agents during the entire day. This means a continuous follow-up of the population. To do so, some techniques are developed. We will cover some of these techniques in the section Monitoring or Exposure Assessment.

As in our day-to-day life we are exposed to infinite coincidental mixture exposures it is important to establish priorities between them and concerning the population interest. Each of the mixtures can have its risk in different factors. It can be risky because of the scope of the exposure (number of people exposed), because of the nature of the exposure (frequency, duration, magnitude), because of the harshness of the effects or because of the probability of interaction between agents.

Based on these argumentations we took, as researchers, the decision of focusing our attention in personal exposure to pollutants with a special emphasis on indoor air environmental mixtures. In average people can spend around 90% of a day inside a building[8]. The exposure time makes the indoor air quality an important mixture environment to be analysed.

In order to know the magnitude of the effect of the exposure on a population, it is important to know the cumulative exposure. Cumulative exposure assessment is a complex assessment due to the lack of historical information about the individuals. Some studies are helping to cover this problem[7]. Some governments are establishing environmental health tracking systems of hazardous pollutants in their population. These systems collect the data, analyse it, interpret it and storage it creating big databases with useful information about the cumulative exposure. Also, the innovative IoT sensors provide big quantities of data related to this topic. Another important analysis is the short-term exposure. With this type of analysis, high concentration levels of hazardous pollutants can be quantified. In order to do so, a personal assessment has to be done.

Some studies analyse the changes of microenvironments and its relation with human exposure to pollutants. One example is described in the paper *Personal exposure monitoring of PM2.5 in indoor and outdoor microenvironments*[9]. One of their conclusions is the acknowledge of the difficulty to measure these changes. That is why we believe that there is still a lot to explore in this topic.

1.5. Time spent outdoor and indoor

It is a fact that on average people from developed countries spend most of their time indoors. The time spent at home, at work, using any transport or inside any other building, reaches the 90%[10] of the daily time of an average individual. This value has been demonstrated by several studies during the past decades. Taking the report *Indoor Air Pollution in California*[5], from the California Environmental Protection Agency as a reference, we found some interesting information to understand the time spent in each ME. They estimated that, on average, children (< 12 years old) spend almost 80% of their time at home, and a total of 90% indoors. For adults this estimation was 62% at home and 94% totally indoors. These values are presented in the Figure 4.

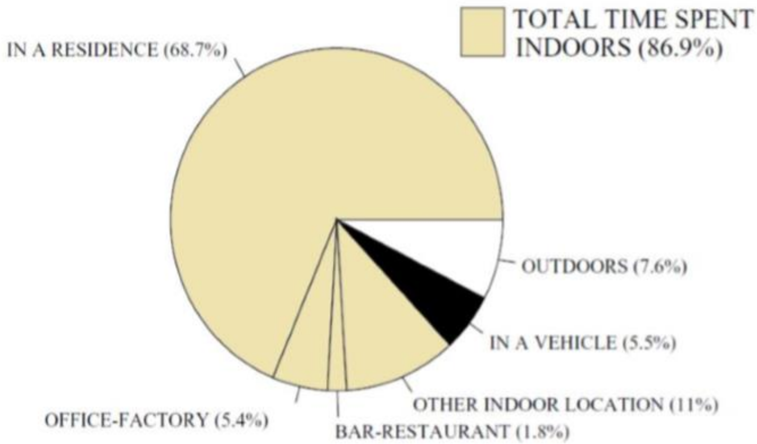


Figure 4 Total time spent indoors and in other ME. Source: Klepeis et al., 2001 J Exp Anal Environ. Epidem.

This takes us to the importance of evaluating indoor air quality and more specifically the air quality at home. The different microenvironments (ME) along the ones an individual comes across each day, can be determinant to his exposure to pollutants. Some of these ME can be more prejudicial for his health and can contribute to a higher daily exposure to pollutants. Usually, there are less pollutants sources inside buildings than outside. However, the effect on the indoor ME pollutants concentration can be higher as the spaces are closed and the pollutant cannot easily get diluted. The building envelope is one of the main factors that contributes to this effect. In the 1970 and due to the energy crisis, a necessity of reducing the energy consumption in HVAC appeared. Buildings started to be better insulated in order not to loss energy and they started to have a higher air tightness. This gain in energetic efficiency, had the drawback of reducing the air exchange with the exterior, which means poorer indoor air quality. Another important factor is the proximity of the individuals to indoor sources. An easy example to understand this is the action of cooking. The stoves combustion can be an important source of carbon monoxide and other gases, and the cooker stays during a period of time at nearly 40 cm close from the stove. This proximity makes the exposure to the emitted gas greater and thus higher risk.

The quantity of time spent inside buildings, the building insulation and the proximity to sources makes indoor air pollutants dangerous and risky to any individual and calls to the necessity of being correctly assessed.

1.6. Guidelines and standards for air quality

Due to each individual variability, none standard or guideline can totally define a perfect threshold for every user. However, some organizations have defined different guidelines to a better population development in terms of air quality.

In 2005 the WHO stablished their air quality guidelines (AQGs)[11] in the area of air pollutants. These guidelines aim to help all the populations around the world to achieve a good air condition. Is necessary to know that WHO provides just some guidelines that each country can follow or not. However, is the responsibility of each national government to establish a specific standard to protect their public health. Every national standard is influenced by different factors such as technical feasibility, social conditions, political situation or health risks considerations.

Three important facts took the WHO to write the AQGs:

1. The population had already started to have a better knowledge about the air pollution problem as well as the limitations of its control
2. Some findings had become known reporting new healthy risks related to Ozone (O3) and PM in developed countries where the urban air quality is supposed to be the most controlled.
3. Also, it had been discovered that new adverse effects were linked with air quality.

The levels proposed by the AQCs are not equally accessible to every single country and that is why the WHO proposed interim targets for each pollutant. These interim targets allow to each nation to follow different targets depending on their possibilities, but always improving their situation by lowering risks.

Particulate matter, ozone, nitrogen dioxide and sulfur dioxide are the gases covered by the AQS from WHO. In our case we are particularly interested on PM. WHO's guidelines are based on PM2,5 even though PM10 is the most studied and better reported. However, the values from these guidelines for the PM2.5 can be transferred to PM10 using a factor of 0,5 in developing urban areas[11]. This ratio goes from 0,5 to 0,8 depending on local conditions.

In the Table 2 the values for these guidelines are shown. As we can see there is a differentiation between short term and long-term exposure levels.

AQGs Guidelines	Annual mean	24-hour mean
PM2.5	*10 µg/m3*	*25 µg/m3*
PM10	*20 µg/m3*	*50 µg/m3*

Table 2 AQGs. WHO's guidelines for particulate matter. Source: World Health Organization, WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide

To stablish these values some literature was reviewed and the PM2,5 concentration limit values from it. The *Six-Cities Study*[12] claims a PM2,5 mean of 18 µg/m$^{3.}$ *The American Cancer Society Study (ACS Study)*[13] does it at 20 µg/m^3. However, and due to statistical uncertainty, this level should be closer to 13 µg/m3. From the report: *An Association Between Air Pollution And Mortality In Six U.S. Cities*[14] it can be extracted that the lowest risks in the tested cities are obtained with levels between 11 µg/m^3 and 12,5 µg/m^3. Using this scientific literature, WHO established in 10 µg/m^3 the limit for an annual exposure of PM2,5 as it is below any of the considered values.

The interim values for long-term exposure are presented in the following Table 3. Three levels are defined: IT-1, IT-2 and IT-3, being IT-1 the riskiest level and IT-3 the lowest. The IT-3 has 15% higher risk of mortality due to long-term exposure, IT-2 has a 6% less risk than the first level and finally, IT-3 has the another 6% less than IT-2. The lowest levels of exposure are certified following the 10 µg/m^3 guidelines for PM2.5.

	PM_{10} ($\mu g/m^3$)	**$PM_{2.5}$ ($\mu g/m^3$)**	**Basis for the selected level**
Iinterim target-1 (IT-1)	70	35	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level.
Interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [2–11%] relative to theIT-1 level.
Interim target-3 (IT-3)	30	15	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% [2-11%] relative to the -IT-2 level.
Air quality guideline (AQG)	**20**	**10**	These are the lowest levels at which total, cardiopul-monary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to $PM_{2.5}$.

Table 3 WHO quality guidelines and interim targets for PM: annual mean concentrations. Source: World Health Organization, WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide

In the Figure 5 a world map is represented highlighting the different interim levels for annual average air quality.

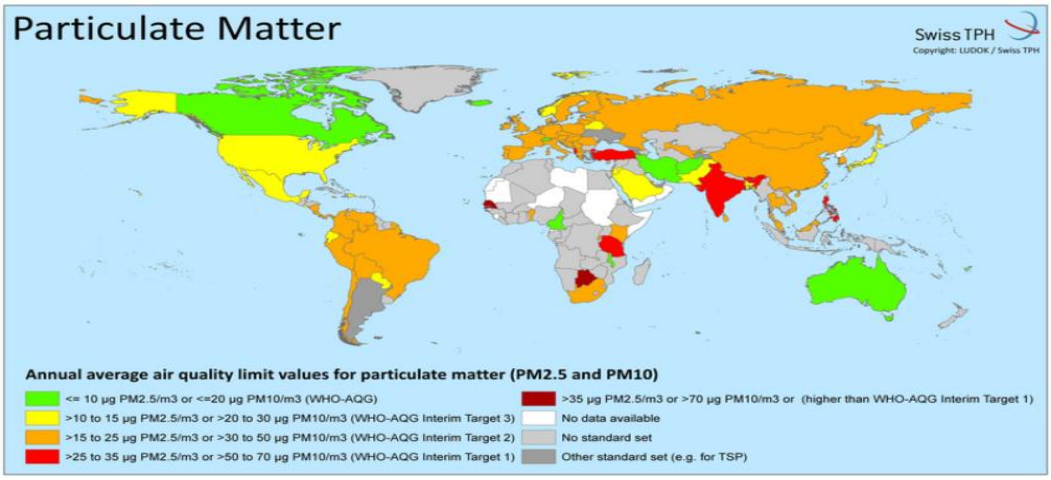


Figure 5 Figure 5 Annual average air quality limit values for PM (2,5 & 10) per countries. Source: Swiss Tropical and Public Health Institute

Short-term exposure is highly dependent on the source and the pollutant. WHO established a guideline of 25 µg/m^3 PM2,5 as a maximum average for a 24h period. They also proposed three levels situations to follow three different goals. They based each of the thresholds on a multi-city studies of risk assessment in developed and developing countries[11]. The results from this multi-cities study, shown that, in short-term exposure, an increase of 10 µg/m^3 in daily concentration leads to an increase of 0,5% in mortality. Knowing this and other results extracted from those studies, they established the interim target-1 on 150 µg/m^3 with a 5% increase on mortality risk over the short-term AQG. The interim target-2 has a 100 µg/m^3 threshold with an associated 2,5% increase over the AQG. Finally, the last level establishes the interim target-3 in 75 µg/m^3 with a risk increase of 1,2% over the AQG.

	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	**Basis for the selected level**
Interim target-1 (IT-1)	150	75	Based on published risk coefficients from multi-centre studies and meta-analyses (about 5% increase of short-term mortality over the AQG value).
Interim target-2 (IT-2)	100	50	Based on published risk coefficients from multi-centre studies and meta-analyses (about 2.5% increase of short-term mortality over the AQG value).
Interim target-3 (IT-3)*	75	37.5	Based on published risk coefficients from multi-centre studies and meta-analyses (about 1.2% increase in short-term mortality over the AQG value).
Air quality guideline (AQG)	**50**	**25**	Based on relationship between 24-hour and annual PM levels.

Figure 6 WHO quality guidelines and interim targets for PM: 24-h mean concentrations. Source: World Health Organization, WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide

The EPA sets the American National Ambient Air Quality Standards NAAQS[15]. In this document, thresholds for six different pollutants are presented. They differentiate between primary and secondary standards, being primary the ones which protect the public health and secondary the ones protecting the public welfare. Carbon monoxide, lead, nitrogen dioxide, ozone, PM and sulfur dioxide are covered in this standard. Our interest is focused on PM levels which are provided by short-term and long-term exposure in the NAAQS.

Final rule	Indicator	Averaging time	Level	Forı
1997—62 FR 38652 July 18, 1997.	$PM_{2.5}$	24-hour	65 µg/m³	98th percentile, averaged
		Annual	15.0 µg/m³	Annual arithmetic mea years.[c d]
	PM_{10}	24-hour	150 µg/m³	Initially promulgated 99tl over 3 years; when 19 were vacated, the form mained in place (not than once per year on period).
		Annual	50 µg/m³	Annual arithmetic mean, a
2006—71 FR 61144 October 17, 2006.	$PM_{2.5}$	24-hour	35 µg/m³	98th percentile, averaged
		Annual	15.0 µg/m³	Annual arithmetic mea years.[c e]
	PM_{10}	24-hour	150 µg/m³	Not to be exceeded more average over a 3-year ı

Table 4 EPA NAAQs standard for PM, historical overview. Source: https://www.govinfo.gov/content/pkg/FR-2013-01-15/pdf/2012-30946.pdf

Guidelines and standards change through time depending on historical factors. As an example, we present some different versions of the same standard presented by the EPA. It can be observed how the threshold levels changed during time. The first version for the NAAQS dated 1971, established on 75 µg/m³ the maximum threshold for a yearly concentration as a primary standard, 60 µg/m³ for secondary for TSP. In short-term, the levels were established on 260 µg/m³ as a primary standard and 150 µg/m³ as secondary standard for TSP. As shown in the Table 4 the yearly PM2,5 level was lowered down to 15 µg/m³ on 1997 and to 65 µg/m³ per day. For PM10 it was placed on 150 µg/m³. The EPA version of 2006 established on 15 µg/m³ the maximum threshold for a yearly concentration as a primary standard, 50 µg/m³ for secondary. In short-term, the levels were established on 35 µg/m³ for PM2,5 and 150 µg/m³ for PM10.

Finally, the actual version of the NAAQS for PM provided by the EPA establishes in 2012 a PM2,5 concentration level maximum of 12 µg/m³ as a primary yearly standard, and 15 µg/m³ as secondary. For short-term a concentration level of 35 µg/m³ for PM2,5 is established as maximum and 150 µg/m³ for PM10. The Table 5 these standards are exposed.

EPA NAAQs Standards			
$PM_{2.5}$	primary	1 year	12.0 µg/m^3
	secondary	1 year	15.0 µg/m^3
	primary and secondary	24 hours	35 µg/m^3
PM_{10}	primary and secondary	24 hours	150 µg/m^3

Table 5 PM2,5 and PM10 standards from EPA NAAQs

Generally, all these kinds of standards or guidelines are written, either taking data from fixed monitors between cities, either taking information from literature which already took data from fixed outdoors monitors. There are two main drawbacks of these standards or guidelines. Firstly, they are prepared for ambient concentrations levels which may not accurately represent the indoor concentration levels. Secondly, these references values are calculated after taking samples from different cities with fixed monitors in specific emplacements such as building's roofs. Because of this, these values may not represent the needed values for a correct individual exposure regulation or guideline.

This takes us to the main point of our project, the necessity of a better understanding and a larger experimentation on personal exposure to pollutants. In the following sections a summary of the already done studies about monitoring and personal exposure is done.

2. STATE OF THE ART

In the previous section, an introduction on the topic of air quality was done. Types of pollutants, health and social-economic effects of them, exposure, people's tendency to spend most of their time indoors and guidelines and standards for pollution are some of the covered topics. Pollution is a major problem for our society and needs to be correctly assessed. The current guidelines and standards are based on information which may not accurately represent the real personal exposure. For this reason, there is an existing necessity on achieving better knowledge of personal exposure.

In this section, a review of papers and about relevant topics for a better design of our experiment is done. These topics are: exposure, environmental mixtures, monitoring or exposure assessment, variables influencing exposure and relevant questionnaires for a good assessment.

2.1. Exposure, inhalation and breathing rate

In the introduction section a brief discussion explaining the difference between inhalation and exposure was done. Breathing rate, concentration and time of exposure are the three factors to know the personal inhalation. As mentioned before, the breathing rate can be either calculated with statistical method, either calculated in an empirical way. In this section, a set of experiments and studies are analysed to have an idea of the quantity of air that a person breathes and therefor the inhalation rate.

In the chapter 6 of the Exposure Factors Handbook[16] from the EPA (United States Environmental Protection Agency) some information related with human inhalation is exposed by reviewing some existing literature[16]. In the Report of the Task Group on Reference Man[17] the International Commission on Radiological Protection (ICRP) estimated an inhalation rate of 0.70 m^3/day for babies aged less than a year, 3.76 m^3/day for one year old babies, 14.8 m^3/day for children, 21.1 m^3/day for female adults and 22.8m^3/day for male adults[16]. They based their calculation on an assumption about the daily activities of a person. They assumed that an adult individual spends 8 hours resting and 16 hours doing activities, the kids ratio is 10h-14h and the new-born's ratio 23h-1h[16].

Another interesting and very detailed study about human inhalation was done by the *Département de santé environnementale et santé au travail*[18], from the Université de Montreal. They calculated the Physiological Daily Inhalation Rates (PDIRs) using the doubly labelled water method (DLW). This method consists on giving an oral dose of labelled water (^2H_2O and $H_2{}^{18}O$) and measuring the losing rate in urine. This dose of water contains stable isotopes of deuterium

^2H and heavy oxygen-18. The difference between the disappearance rates of these two elements is connected with CO_2 production. For a complete analysis they used calorimetry and nutritional measurements. The CO_2 production permits the calculation of the total daily energy expenditures (TDEEs) using some respiratory information and diet composition of the test participants. Finally, the PDIR is calculated using the TDEEs, the Energy Cost of Growth (ECG, given by the DWL method), a factor containing the uptake factor and an equivalent ventilatory ratio. The results obtained with this model are presented in the Table 6. In this study the researchers took into account the body mass index (BMI) of 2,210 individuals, as well as other factors as gender or body weight. In the previous article male adults were estimated to have a rate of 22,8 m^3/day[17]. The study from Montreal's University presents a value around 18 m^3/day and 20 m^3/day for male adults between 30 and 65 years old placed in the 75th percentile[18]. For female adults from the same age and percentile, the levels are between 13 m^3/day and 15 m^3/day. It can be observed that the results are more complex than the previous commented study. However, some of the values are similar and give us a clear idea of the daily inhalation rates. It also shows the difficulty of assessing a good value the inhalation rate. These values are all presented in m^3/day, but in the ventilation industry they are usually presented in m^3/h.

Table 6-4. Distribution Percentiles of Physiological Daily Inhalation Rates (PDIRs) (m^3/day) for Free-Living Normal-Weight Males and Females Aged 2.6 Months to 96 Years

Age Group (years)	N	Body Weight[a] (kg) Mean ± SD	Physiological Daily Inhalation Rates[b] (m^3/day) Mean ± SD	Percentile[c] 5th	10th	25th	50th	75th	90th	95th	99th
Males											
0.22 to <0.5	32	6.7 ± 1.0	3.38 ± 0.72	2.19	2.46	2.89	3.38	3.87	4.30	4.57	5.06
0.5 to <1	40	8.8 ± 1.1	4.22 ± 0.79	2.92	3.21	3.69	4.22	4.75	5.23	5.51	6.05
1 to <2	35	10.6 ± 1.1	5.12 ± 0.88	3.68	3.99	4.53	5.12	5.71	6.25	6.56	7.16
2 to <5	25	15.3 ± 3.4	7.60 ± 1.28	5.49	5.95	6.73	7.60	8.47	9.25	9.71	10.59
5 to <7	96	19.8 ± 2.1	8.64 ± 1.23	6.61	7.06	7.81	8.64	9.47	10.21	10.66	11.50
7 to <11	38	28.9 ± 5.6	10.59 ± 1.99	7.32	8.04	9.25	10.59	11.94	13.14	13.87	15.22
11 to <23	30	58.6 ± 13.9	17.23 ± 3.67	11.19	12.53	14.75	17.23	19.70	21.93	23.26	25.76
23 to <30	34	70.9 ± 6.5	17.48 ± 2.81	12.86	13.88	15.59	17.48	19.38	21.08	22.11	24.02
30 to <40	41	71.5 ± 6.8	16.88 ± 2.50	12.77	13.68	15.20	16.88	18.57	20.09	21.00	22.70
40 to <65	33	71.1 ± 7.2	16.24 ± 2.67	11.84	12.81	14.44	16.24	18.04	19.67	20.64	22.46
65 to ≤96	50	68.9 ± 6.7	12.96 ± 2.48	8.89	9.79	11.29	12.96	14.63	16.13	17.03	18.72
Females											
0.22 to <0.5	53	6.5 ± 0.9	3.26 ± 0.66	2.17	2.41	2.81	3.26	3.71	4.11	4.36	4.81
0.5 to <1	63	8.5 ± 1.0	3.96 ± 0.72	2.78	3.05	3.48	3.96	4.45	4.88	5.14	5.63
1 to <2	66	10.6 ± 1.3	4.78 ± 0.96	3.20	3.55	4.13	4.78	5.43	6.01	6.36	7.02
2 to <5	36	14.4 ± 3.0	7.06 ± 1.16	5.15	5.57	6.28	7.06	7.84	8.54	8.97	9.76
5 to <7	102	19.7 ± 2.3	8.22 ± 1.31	6.06	6.54	7.34	8.22	9.11	9.90	10.38	11.27
7 to <11	161	28.3 ± 4.4	9.84 ± 1.69	7.07	7.68	8.70	9.84	10.98	12.00	12.61	13.76
11 to <23	87	50.0 ± 8.9	13.28 ± 2.60	9.00	9.94	11.52	13.28	15.03	16.61	17.56	19.33
23 to <30	68	59.2 ± 6.6	13.67 ± 2.28	9.91	10.74	12.13	13.67	15.21	16.59	17.42	18.98
30 to <40	59	58.7 ± 5.9	13.68 ± 1.76	10.78	11.42	12.49	13.68	14.87	15.94	16.58	17.78
40 to <65	58	58.8 ± 5.1	12.31 ± 2.07	8.91	9.66	10.92	12.31	13.70	14.96	15.71	17.12
65 to ≤96	45	57.2 ± 7.3	9.80 ± 2.17	6.24	7.02	8.34	9.80	11.27	12.58	13.37	14.85

[a] Measured body weight. Normal-weight individuals defined according to the BMI cut-offs.

[b] Physiological daily inhalation rates were calculated using the following equation: $(TDEE + ECG) \times H \times (V_E/VO_2) \times 10^{-3}$, where H = 0.21 L of O_2/Kcal, V_E/VO_2 = 27 (Layton, 1993) and ECG = stored daily energy cost for growth (kcal/day).

[c] Percentiles based on a normal distribution assumption for age groups.

N = Number of individuals.

SD = Standard deviation.

Source: Brochu et al. (2006b).

Table 6 Table 1 Distribution percentiles of PDIRs by age and BMI. Source: Exposure Factors Handbook

Another interesting study from *Stifelman (2007)*[16], was done also using the DWL method. In this case the goal was to show the inhalation daily rate depending not only on the age and gender but also on how active the person is. Using the recommended energy expenditure data from the IOM and the DWL data, an equivalent inhalation rate was calculated and is shown in the Table 7. Similar conclusions can be taken from these results, an adult equivalent inhalation rate is around 18 m^3/day and is less if the person is less active, around 14 m^3/day[16].

Table 6-13. Mean Inhalation Rate Values (m^3/day) for Males, Females, and Males and Females Combined[a]			
Age Group[b,c] (years)	Males[d]	Females[d]	Combined[d]
Birth to <1	3.4	3.4	3.4
1 to <2	4.9	4.9	4.9
2 to <3	5.9	5.5	5.7
3 to <6	9.5	9.1	9.3
6 to <11	11.8	11.2	11.5
11 to <16	16.1	14.0	15.0
16 to <21	19.3	14.6	17.0
21 to <31	18.4	14.3	16.3
31 to <41	17.6	13.7	15.6
41 to <51	17.6	13.7	15.6
51 to <61	16.5	12.9	14.7
61 to <71	16.5	12.9	14.7

[a] Inhalation rates are for IOM Physical Activity Level (PAL) category "active"; the total number of subjects for all PAL categories was 3,007. Sample sizes were not reported.
[b] Age groups from Table 6-12 were regrouped to fit into the U.S. EPA age groupings.
[c] See Table 6-25 for concordance with U.S. EPA age groupings.
[d] Weighted (where possible) average of reported study means.

Source: Stifelman (2007).

Table 7 Mean Inhalation Rate Values. Source: Stifelman 2007

As we can see all these studies made estimations of all ages and genders. We can also find lots of studies focused only on the most vulnerable groups of people. For example, kids. *Arcus-Arth and Blaisdell (2007)* with the article *Statistical Distributions of Daily Breathing Rates for Narrow Age*[19] *Groups of Infants and Children,* did an estimation of the inhaling rates only for children. Proximity to indoor sources, behavioural conducts, indoor spent time, under-developed immune systems and lung size are the main reasons why children are a vulnerable group in terms of indoor air quality. As we already discussed, deposition factors make the floor and carpets important sources of indoor PM pollution. It is common to see a baby crawling on the floor, which means increasing the resuspension of particles and also means being closer to the pollution source. It is proved that kids have a big tendency to put their fingers inside of their mouth as well as other objects that main contain some pollutants. This increases the possibility of inhaling hazardous elements. In addition, the ratio between the amount of inhaled air by kids and their body size is much higher that the ratio for an adult person. This means a relative higher amount of pollutants inhaled than the inhaled by adults. For all these reasons we can find a big amount of studies focusing only on kids.

2.2. Monitoring or Exposure Assessment

Any individual in his day a day life is exposed to multiple different environment with different concentration levels of pollutants. In some microenvironments it is well known the present environmental mixtures. We know the pollutants present in these microenvironments and the goal while analysing them is to characterize a specific source. For example, while cooking. It is known that while cooking some specific particulate matter and gases are generated. If a study is done around cooking as an activity, it will be done in order to characterize how hazardous the subjected stoves can be -for example-. Other microenvironments are totally composed by coincidental mixtures and if analysed, the goal can be, for example, analyse the individual exposure.

The main challenges when measuring the concentration levels to which an individual is exposed are the temporal and spatial variability. There is a constant dynamic in our life that evolves several different variables that affect the person's exposure to pollutants. Getting to assess the exact exposure of a person is almost impossible. However, some techniques are developed to do so. Some of them are more precise than others and a large amount of studies have addressed this problem. In this section of the report different types of assessments, a description of the actual situation and an analysis of different past studies is done.

When doing a qualitative assessment two factors are needed to be taken into account: the different environmental situations and the lifetime risk of the population. Identifying the source, defining characteristic factors from the pollutant and building a model are the three main points of the exposure assessment. There are several existing methods to assess the exposure: direct assessment, indirect assessment, use of low-cost monitors, use of an exposure reconstruction or use a mathematical model for the mass balance and exposure.

2.2.1. Low cost monitoring and IoT

Today's technology permits the creation of innumerable instruments to collect data from several situations. Microsensors are used all around the world due to their low cost and high-speed performance. An example of this can be found in the paper *An Indoor Monitoring System for Ambient Assisted Living Based on Internet of Things Architecture*[20]*,* a wireless device is presented. This device harvest data from different variables to assess indoor air quality and show them to the user in real life with a phone app. The information generated thanks to these sensors are usually not high-quality data. However, they create a high-density amount of data which provides information in short periods of times and depending on the purpose can be tremendously useful.

2.2.2. Exposure reconstruction

This assessment method targets internal body biomarkers to estimate the dose of pollutants or the inhaled air. Biomarkers such as saliva, urine, tissues can be used to do so. The results that can be taken from this type of assessment is the inhaled quantity of an element, not its source or pathway. An example of this type of test is the already presented *Stifelman* (2007)[16] study. In this study they used the DWL method, analysing the urine, they made an estimation of the equivalent inhalation rate for humans.

2.2.3. Indirect exposure assessment

Also called scenario evaluation, this method of assessment estimates the concentration of pollutants and the time exposed to it by using different mathematical models. These models take activity pattern data, facts, locations, assumptions about the sources, the pathways and individual's information to create the estimation. The results obtained with these kinds of models can be validated with direct measurements.

An example of indirect assessment is the study *Pollutant Exposures from Natural Gas Cooking Burners: A Simulation-Based Assessment for Southern California*[21] done in the Lawrence Berkeley National Laboratory with collaboration of Stanford University. The goal of these researchers was to assess the effect of gas stoves in CO, NO2 and formaldehyde (HCHO) exposure levels in Californian homes. In our report we discuss the topic and results of this paper more deeply in the section Studies focused on cooking and types of stoves. However, in terms of methodology is a great example of scenario evaluation. The use of several assumptions increases the indirect exposure assessment uncertainty.

They used a mass-balance model to reach their goal. As an input to their equation they estimated concentration levels using representative samples taken from previous studies. In addition, they took into account other factors as the building characteristics, using times of the stoves, proximity of the user to the stoves, characteristics of the fume extractor and information about outdoors levels. With all this information they used a mass-balance model for a single-zone simulating: deposition (only determinant in NO2), indoors emissions, filtration, ventilation and penetration (penetration factor used was 1 for all pollutants). With this model they did some simulations which gave them outputs as the concentration levels of CO, NO2 and HCHO for indoor spaces in summer and winter in Western California. Their results are commented in the section: Studies focused on cooking and types of stoves

2.2.4. Direct exposure assessment

Direct exposure targets the personal exposure and it is the only way of knowing the real exposure levels of the individual. Even though that it is the most accurate method, it has several drawbacks. This method tends to be costly as the instruments are expensive and are used only for one person. In addition, it has an associated high complexity as it needs to be adapted each of the users and it has the risk of having biased data by the user. Another negative aspect of this method is the difficulty of selecting a representative population. Not only in terms of quantity but also in terms of characteristics of the individuals. So, it requires an exhaust analysis and a careful design to expand the taken data to larger population results. Another important consideration when doing a direct assessment is the implementation. The researcher needs to know how to implement the several needed sensors to the individual in order to do the correct measurements.

For most pollutants is not possible to drive a direct assessment due to the expensive cost, extreme complexity and to technical infeasibilities. As these methods require not only personal measurements but also personal data, it has to meet some ethical guidelines.

Our experiment will use a direct exposure method explained later on the section EXPERIMENT METHODOLOGY. The following paragraphs present example of past experiments with similar purposes. First some articles about direct exposure are presented. Later is analysed the type of variables that these same articles or others try to analyse.

2.2.4.1. Examples direct monitoring

In the paper *A Comparison of Particulate Matter from Biomass-Burning Rural and Non-Biomass-Burning Urban Households in North-eastern China*[22], a direct exposure assessment is described. As the name says, they goal of the researchers was to assess the difference between biomass and non-biomass fuels effects on PM emissions from kitchens in China. In our report a brief discussion of the results in done in the section Studies focused on cooking and types of stoves **¡Error! No se encuentra el origen de la referencia.**. However, the methodology used is a good example of direct assessment. They chose the city of Liaoning (China) as urban area to test and the rural areas of Shenyang. They did the measurements from May to August 2006. These months were chosen because is the only moment of the year when biomass is only used for cooking and not for heating. This reminds us the seasonally effect on the pollutant's concentrations during the year. For a correct exposure analysis, they installed stationary PM10 monitors indoors and outdoors, they used personal PM2,5 monitors and a time activity diary (TAD) for each participant. A total of 10 different locations were used to place the fixed monitors. Inside households, the sensors were placed approximately 1 meter away from the stoves. This information will be interesting to use in our experiment. The fixed monitoring outdoors devices were placed between 50 and 80 meters away to the closest house and all of them at a height around 0,6 meter from the ground level. The personal monitoring devices were attached to the belt of the 10 participants involved in the experiment. These personal measurements lasted 3 days for each participant and were consecutive and 15 hours per day. If the individual could not carry the device, the instrument should be placed close to the individual. The monitors had a pipe connected to the inlet of each device in order to better reach the breathing area. Something different from other studies is that this study TAD was done by an external observer to avoid any possible data biasing[22].

In 1990, the study *Particle Total Exposure Assessment Methodology (PTEAM)*[23] was done in California to assess aerosol concentrations distribution in personal, indoor and outdoors[24]. They monitored 178 individuals taking personal samples of PM10 during 12h, and fixed monitoring samples of PM10 and PM2.5. In that moment the standard for outdoors PM levels was stablished at 150 µg/m^3. Approximately a 25%[24] of the tested population was estimated to be at this level. One of the conclusions extracted from this study is the influence of several indoor activities such as house cleaning, cooking or smoking.

Contribution of various microenvironments to the daily personal exposure to ultrafine particles: Personal monitoring coupled with GPS tracking[25] is a study done in Copenhagen in 2013. In this study 59 individuals' exposure was real-time assessed during 48h. One of the variables to analyse was the different microenvironments. For a better analysis a GPS tracker was carried by each of the users. They used a device called NanoTracer PNT1000 to measure PM between 10nm and 300 nm. After the experiment all the sensors were compared to calculate a correction factor.

Each participant carried a backpack with the device on it, and a special sampling tube attached to the inlet of the sensors probe. As in every personal monitoring experiment, they were asked to carry the backpack during all day and place it close to them if at some moment it was not possible to carry it. One of the main risks is the lack of battery, that is why every participant was asked to charge the sensor at any moment they could.

2.3. Outdoors, indoors, microenvironments and time–activity patterns.

Lots of studies have been done regarding personal monitoring or air quality assessment. Each of them with a different purpose. In our study we want to check how does lifestyle affects the exposure levels of an individual. The variables to take into account in our experiment are: microenvironments variability and time activity patterns or time variability. Some studies have already done different experiments to test how these variables affect the exposure levels. In the following sections an analysis of past studies covering all these variables is done. Assessing the ME changes, entails a great difficulty and complexity. The first big distinction of types of ME can be done between indoors and outdoors exposure. Then the typical ME defined are home, work, transport and other building. MEs are highly related with time activity pattern which is also discussed in this section.

In the article: *The National Human Activity Pattern Survey (NHAPS), a Resource for Assessing Exposure to Environmental Pollutants*[8]*,* the researchers show the results of a two-year probability-based telephone survey about human activities and exposure to pollutants in the USA between 1992 and 1994. A 24 hours a retrospective questionnaire through a telephone call was done to obtain the activity diaries from the participants. The information that was given consisted on start time and end time of an action plus the microenvironment where it happened. The first indicative information that they came across among all the participants was a total 86% of time spent indoors and 6% inside a vehicle. The obtained information about the time spent with smokers. 43% of the time spent with a smoker, was in residences.

In the already mentioned article about urban and rural kitchens in China: *A Comparison of Particulate Matter from Biomass-Burning Rural and Non-Biomass-Burning Urban Households in North-eastern China*[22]*,* a comparison between indoors and outdoors levels is also done. One of the analysis they did was to check the correlation between outdoors levels and indoor levels in cooking times and in no cooking times. The result was that during cooking times no existing correlation appeared. Which means that indoor and outdoor levels were totally independent and affected by different factors. However, in non-cooking periods the correlation between them was high enough to be determinant. These interesting values appeared in the rural home

	Correlation coefficients between rural kitchen and rural outdoor PM_{10} levels (*p*-value)		
Home designation	Entire study period	Cooking times	Noncooking times
Rural home 1	0.397 (0.004)	0.121 (0.633)	0.900 (< 0.001)
Rural home 2	–0.043 (0.760)	–0.018 (0.936)	0.157 (0.407)
Rural home 3	–0.057 (0.658)	–0.270 (0.183)	0.845 (< 0.001)

Table 8 Relationship between rural kitchen and rural outdoors PM10 levels. Source: A Comparison of Particulate Matter from Biomass-Burning Rural and Non-Biomass-Burning Urban Households in North-eastern China

1 and in the rural home 3 with a p value close to 0,9 as shown in Table 8.

A comparison between indoor and outdoor concentrations of particulate matter was also done in the article: *Indoor/outdoor relationship and chemical composition of fine and coarse particles in the southern California deserts*[26]. They based their experiment and study in Coachella Valley during the winter and spring of 2000, when the penetration from outdoor particles is the highest. They tested the indoor air in 13 different houses. One of their findings was a higher contribution of fine particles indoor rather than outdoors. From the total PM indoor concentration, 74% was fine particles while checking the outdoor PM10 concentration, 61% was fine particles. Not only the ratio of fine particles was higher outdoors but also the mass concentration with an indoor-to-outdoor ratio of 1,03.

This ratio was also measured in the experiment summarized in the report: *Characterization of the indoor particles and their sources in an Antarctic research station*[27]. They came to the result of an I/O ratio from the Antarctic research station larger than the I/O ratio in urban buildings. The highest ratio was obtained with particles between 2,5 µm and 10 µm due to human activity.

The report: *Air Pollution Exposure in European Cities : the EXPOLIS Study*[28] asses the exposure of different European cities, determining the main personal and environmental relations with exposure. One of the factors analysed by these researchers was the importance of the microenvironment, and to do so they used a time-microenvironmental-activity data (TMAD). The TMAD was done during the 48 hours of 2 consecutive working days. This test was also useful to determine the participants activities and its relation with exposure.

In their TMAD results some interesting findings can be observed. In average, the participants spent 2 hours per day in any type of transport in the cities of Grenoble Helsinki, Milan, Athens, or Prague. They also present the detailed information of minutes in each type of transport: taxi, personal car, bus, metro, etc. The minimum time spent at home on average was 13,6 hours per day in Milan, and the maximum 15,8 hours per day in Athens. The time spent at work has the opposite tendency. Athens had the lowest time: 4,4 hours per day, and Milan the highest: 6,6 hours per day. They estimated around an hour per day staying outdoors. They defined another interesting ME called ETS: environmental tobacco smoke in indoors spaces away from home. The tested population spent between 0,5 hours and 3 hours in this type of ME. The city with the lowest ETS ratio was Oxford and the highest was Grenoble. In average, in all the cities spent 2,16 hours in ETS environment rather than home or work.

These exposure times helped them to achieve a better analysis of the daily personal exposure to pollutants. Night-time exposure had a large dependency on the reported traffic form close highly transited streets, as well as the type of environment where the house was located (industrial, countryside, etc). The personal exposure and also the home indoor levels were similar between Grenoble, Basel, Prague and Athens. Helsinki had the lowest levels of PM2,5 (in average 4 $\mu g/m^3$ less than the others), being the city with the lowest concentrations from all the tested cities.

In the paper *Personal exposure monitoring of PM2.5 in indoor and outdoor microenvironments*[9] the spatial variable to pollutants exposure, was assessed. They used a low-cost particulate counter as instrument to investigate short-term PM2,5 exposure depending on the different environment. A total of 17 volunteers did the experiment, each of them using a GPS tracker to better know their geographic position. In total they gathered data related to 35 different profiles. The obtained results shown the big difficulty of assessing the impact of each microenvironment to the total exposure, due to the large variability of factors. In the Table 9 a summary from the 35 different profiles results in different microenvironments can be found. The environments tested were home, private residential buildings, public building, transport, work and outdoors environments. In our results a similar approach will be done to have a better understand of the measured levels.

Microenvironment	n	$PM_{2.5}$ ($\mu g\ m^{-3}$)	
ME		Mean	sd
Home	59,539	8.4	17.3
Outdoor other	2157	6.2	6.9
Private residential building	2237	10.2	15.2
Public building	7468	6.3	8.4
Transport	7224	7.0	6.0
Work	14,868	3.0	2.2

Table 9 Summary of the results from a microenvironment exposure. Source: Personal exposure monitoring of PM2.5 in indoor and outdoor microenvironments

Another study that assessed the time and space variability on the pollutants concentrations and exposure is: *Contribution of various microenvironments to the daily personal exposure to ultrafine particles: Personal monitoring coupled with GPS tracking*[25]*.* This study was done in Copenhagen and they conclude that around 50% of the UFP exposure during the day occurs at home. Another 40% inside other buildings rather than home. 5% was related the use of transports and the last 5% to outdoors environments[25]. They present in *Figure 7* the estimated daily exposure for five different types of lifestyle scenarios, all of them hypothetical.

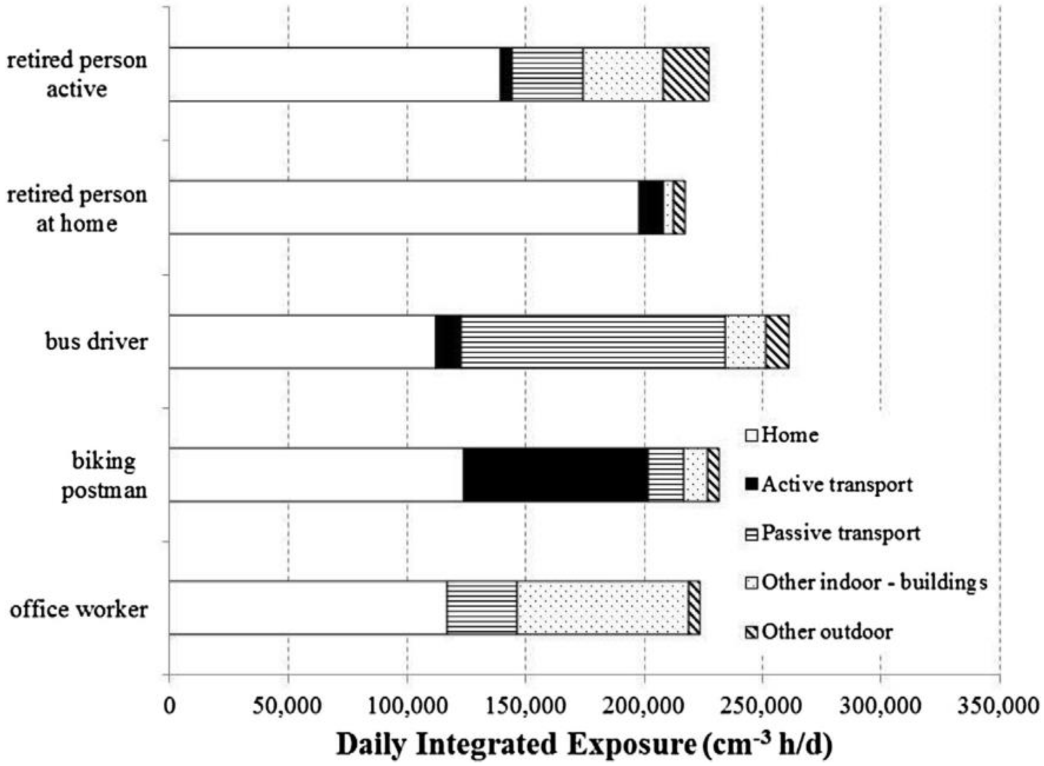


Figure 7 Daily Integrated Exposure for 5 lifestyle scenarios. Source: Contribution of various microenvironments to the daily personal exposure to ultrafine particles: Personal monitoring coupled with GPS tracking

The five types of lifestyle are: retired active person, retired person staying at home, bus driver, biking postman and office worker. It is interesting to see how the lifestyle affects the personal exposure.

Another interesting result provided by this paper is the average indoor UFP concentrations for all the microenvironments. These results are presented in Table 10. The highest mean appears to be in indoor buildings as expected.

Variable	Mean (SD)	Geometric mean	Median	95th percentile	Max
Total time with available UFP and GPS data (h)	39.2 (10.5)	36.5	42.1	50.2	51.0
At home					
Average for each person	11.8 (10.1)	9.0	9.0	32.1	61.5
95th%-ile for each person	46.3 (63.8)	27.8	35.9	133	424
Active transport					
Average for each person	11.1 (5.2)	9.9	10.4	22.3	26.5
95th%-ile for each person	25.3 (16.3)	20.6	21.0	59.1	72.9
Passive transport					
Average for each person	16.9 (9.9)	14.3	14.9	38.5	44.8
95th%-ile for each person	47.8 (43.6)	34.9	33.9	134	240
Other indoor – buildings					
Average for each person	22.7 (57.2)	10.6	8.5	126	359
95th%-ile for each person	124 (438)	29.5	124	980	2517
Other outdoor					
Average for each person	17.3 (37.6)	10.6	9.6	42.7	268
95th%-ile for each person	80.5 (314)	26.1	24.0	167	2150

Table 10 UFP concentrations for determined ME. Source: Personal monitoring coupled with GPS tracking

It can be seen that, assessing the effect of different ME on personal exposure, is extremely related with activity patterns. The different activities that an individual does during his day, affects to his personal exposure. Researchers have tried different methods to link activity patterns to, in this case, personal exposure. Diaries, recall questionnaires or even observers have been used to collect information about the activity pattern.

A large set of studies focused their attention on transport. Cars' ventilation air is inducted from the exterior, which is usually an urban road. This air is exposed to other vehicles contamination and the concentration levels of determinant gases or PM tend to be high. For these reasons, some studies target these environments. In the last-mentioned articles, they conclude that the exposure levels on transports depends on a lot of variables. The route, the weather, type and number of vehicles and even street configuration. The article: *Ultrafine particle exposures while walking, cycling, and driving along an urban residential roadway*[29], tried to analyse the transport phenome in terms of air quality. They did a comparison between four transportation modes: by car with windows open, by car with window close, by bike and walking. They achieved some interesting results. For example, they found that UFP levels were lower while using a car with the windows closed than open. UFP exposure was seven times higher while walking or biking rather than using the car. They conclude their report with the influence of the wind as a way of particle transport. The levels variated during the test days depending on the direction of the wind.

2.3.1. Studies focused on cooking and types of stoves

Several studies aim to assess cooking as an indoor source. In India a test was done taking information from 418 different households. The name of this test is*: Exposure from cooking with biofuels: pollution monitoring and analysis for rural Tamil Nadu, India*[30]. The two main findings shown in the paper, are the '*passive cooking effect'* and the importance of a good kitchen design. The first one was discovered by taking measurements not only with a personal monitoring on the cooker, but also with a fixed monitoring placed two meters away from the stoves. The recorded levels were around 200 and 500 $\mu g/m^3$ in both cases. These are interesting values to later on have a reference for our results. The second point of this study is the importance of a good kitchen design. A good kitchen fume extractor is an important factor, and it is also important the type of stoves in use. Gas stoves are more harmful in terms of air quality than electric stoves as many studies expose.

Pollutant Exposures from Natural Gas Cooking Burners: A Simulation-Based Assessment for Southern California[21] is the name of a study done to check this effect in the Lawrence Berkeley

National Laboratory with collaboration of Stanford University. It is a study which methodology has already been discussed in the section Indirect exposure assessment as a good example of it. Now, in this section the results are analysed to have a good reference when checking our own results. This group of researchers developed a mass-model taking previously data from homes and occupants' activities. They came up to the conclusion that gas stoves increase around 30% the concentration of NO2 during summer and even more, close to 40%, in winter. Similar numbers for CO, 25%[31], and lower percentage for HCHO. These values change depending on the deposition rate used, usually between 1,05/hr and 0,5/hr. When using 1,05/hr the concentration increase was bigger than the simulation when using 0,5/hr.

One of their final conclusions was the fact that, due to gas stoves, 12 million Californians are weekly exposed to NO2 levels above ambient air standards and 1,7 million to CO levels too. In addition, the model suggested a big importance of using a proper ventilation hood. Placing in 55%-70%[21] the percentage of Californian houses that, using gas stoves and decent ventilation hoods, are below ambient guidelines thresholds.

Another experiment to check the difference between gas and electric stoves was done in Edinburgh in the department of Environmental and Occupational Medicine at the University of Napier. The name of the study is: *Ultrafine particles and nitrogen oxides generated by gas and electric cooking*[32]. The study was done using two sources of pollutants in a controlled, closed and non-ventilated environment. These two sources were an electric and a gas set of stoves. Each one with four rings. This experiment was focused on UFP and NOx. They tried to cook different types of food. From vegetables to bacon. This last one was the food that more UFP released. They succeed on experiencing a difference between gas stoves and electrical stoves. Placing the second ones as a better option for air quality[32].

In China another study was done to check the influence in exposure levels of biomass and non-biomass fuels while cooking in rural and urban kitchens[22]. We have already covered this study for its methodology as an example of direct assessment and for the desire of testing between indoors and outdoors. In this case the interesting part is the cooking results. Now the results are discussed in order to have a better understanding and reference of our own future results. For a better analysis, statistical methods were applied to the obtained data. In the paper is possible to find different comparisons: PM10 levels between urban and rural kitchens, PM10 levels between kitchens and living rooms, between indoor and outdoor PM10 levels, PM2,5 levels between participants and activities and between biomass, non-biomass and electric stoves.

One conclusion from this paper is the strong relation between kitchen levels and living room areas in the same house. It is not the first referenced paper that talks about this fact. In this case they conclude this using a regression analysis at 95% confidence interval. As we see in the Table 11, taken from their article, there is a big existing correlation.

Home designation	Correlation coefficient (*p*-value)
Urban home 1	0.77 (0.051)
	0.77 (< 0.001)[a]
Urban home 2	0.86 (< 0.001)
Urban home 3	0.93 (< 0.001)

Table 11 Correlation factor between living rooms and kitchen PM concentrations. Source: A Comparison of Particulate Matter from Biomass-Burning Rural and Non-Biomass-Burning Urban Households in North-eastern China.

In Table 12 it can be found the mean levels of PM10 in cooking and non-cooking periods. A mean of 67 $\mu g/m^3$ is obtained in cooking times in urban areas, and almost 4 times higher in rural houses. As mentioned in the paper, this difference can be explained with the differences between rural and urban buildings as well as for the use of biomass fuel or electric stoves. In urban areas more of this second type are found.

	Total study period		Cooking times		Noncooking times	
Household type	No. of hours	PM_{10} (mean ± SD)	No. of hours	PM_{10} (mean ± SD)	No. of hours	PM_{10} (mean ± SD)
Rural	190	100.6 ± 203.1	76	202.1 ± 293.6	114	33.01 ± 15.31
Urban	144	61.34 ± 111.8	29	67.00 ± 32.58	115	59.40 ± 123.8
	143[a]	52.77 ± 44.08[a]			114[a]	48.62 ± 44.83[a]

[a]Excludes outlier value from indoor construction for urban kitchen 1.

Table 12 PM10 levels for urban and rural kitchens, by cooking and non-cooking periods in µg/m3. Source: A Comparison of Particulate Matter from Biomass-Burning Rural and Non-Biomass-Burning Urban Households in North-eastern China.

2.4. Fixed vs personal

Some articles related with personal versus fixed monitoring are reviewed in this section. Articles presenting experiments that aim to have a more accurate information about personal exposure or that aim to check how reliable can be the data taken with fixed monitoring devices. This is the case of the first report: *Ability of Fixed Monitoring Stations to Represent Personal Carbon Monoxide Exposure*[33]. This group of researchers wanted to check if the information provided by fixed location ambient air quality monitoring stations was accurate enough to represent personal exposure to carbon monoxide. This experiment was done in Boston, and they provided personal monitors to 66 participants and took information from different fixed monitoring stations of the city. The volunteers were asked to carry the samplers in a backpack, to place them in the seat of a car in case of driving, and on the desk if working. They found some miscorrelations between sampling with factors of 1,3 to 2,1 in 1 hour mean in six of the fixed monitors. In addition, they estimated a double average concentration of CO in cars than in train. They conclude the report asking for an improvement in the traffic flow by reducing car volumes.

The Estimation of Personal Exposures to Air Pollutants for a Community-Based Study of Health Effects in Asthmatics—Design and Results of Air Monitoring[34]*,* is an article that summarizes an experiment done in Houston with the goal of obtaining the necessary information to provide an accurate estimation of individual exposure. To achieve so, the researchers made use of three different monitors: fixed ambient monitors, indoor and outdoor monitors for the participants' home, and personal monitoring devices.

The first type of monitors where placed in middle points between participants (maximum 4 km radius from each participant). These instruments were prepared to sample O3, NOx, NO2, CO, SO2, TSP and pollen. The monitor for measuring the residential levels outdoors and indoors was a mobile van. This vehicle was provided with measurement instruments and went from house to house of each participant to do one-week samplings. It was able to measure the same pollutants as the ambient monitors but TSP. This was possible to do it only for 12 different houses. In addition, 30 of the 51 participants were provided with personal instrument for measuring ozone and particles with a maximum size of 2,5µm. The participants were asked to fill twice a day a diary with their activities and different microenvironments. The results gave the researchers a nice set of information to correctly asses the personal data. In addition, one of their conclusions was the necessity of considering the changes of concentrations between microenvironments, and their effect on the personal daily exposure. The traditional ways of assessing personal exposure are by doing estimations with ambient air monitors and do not consider these changes on microenvironments.

Another interesting study that covers the topic of personal and fixed monitoring is: *Applications of GPS-tracked personal and fixed location PM2.5 continuous exposure monitoring*[35]. In the

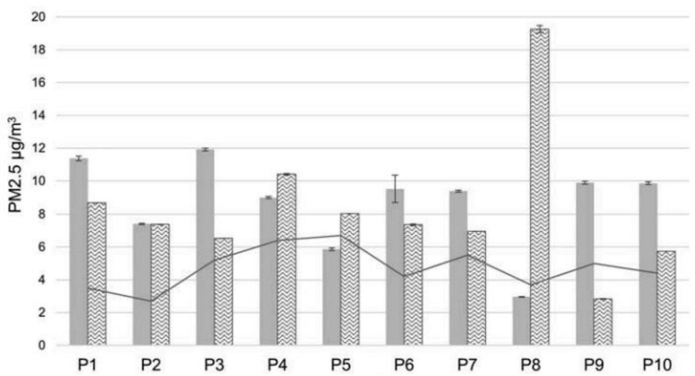


Figure 8 Comparison of daily particulate matter exposure methods. Source: Applications of GPS-tracked personal and fixed location PM2.5 continuous exposure monitoring

experiment exposed in this paper, a group of researchers measured the PM2,5 concentration at the breathing zone of 10 different participants and tracked their position with using GPS systems during 24h. The sampling instruments were worn in a vest and the participants were asked to fill an activity diary each 15 minutes to avoid biasing for recall. In addition, they used information from fixed stations to compare with the personal data. With the GPS positioning data, they managed to do a concentration map and estimation of the total exposure more reliable than just fixed monitors. The high variability of microenvironments during the participants day, showed a wide dispersion of the obtained data with the personal monitors. This reinforces the potential of personal monitors against fixed stations. Generally, the particulate matter concentration levels measured with the personal monitors were higher than the concentrations measured by the fixed monitors. In the Figure 8 the total results are presented. Another of the finding was that using the GPS data to obtain information of different microclimate, PM2,5 fixed monitors were more accurate than using just the stationary outdoor monitor. To conclude they encourage the government to use personal monitoring techniques to better understand the different microenvironment exposure of people who might need it for healthy issues.

2.5. Conclusion of state of the art

From all these analysed experiments we can subtract some interesting conclusions before facing the experiment:

- Important of different ME: transport, home, work and other buildings and the impact of tobacco.
- Reference values for TMAD test
- Reference values for concentration levels in different ME and activities such as cooking.
- Importance of day and night assessment to check the existing variability
- Importance and difference between outdoors and indoors concentration levels.
- Complexity of direct exposure and personal assessment.

3. METHODOLOGY

3.1. Master Thesis methodology Scope & goals of the project

This project is linked to Viviana Gonzalez's PHD. She is a doctorate student at EPFL working with professor Dusan Licina. A biweekly meeting plus a constant interaction between all the parties was the way of working in terms of logistics. The laboratory is placed in the city of Fribourg (Switzerland) and the meetings were, mostly all of them, in EPFL, Lausanne. In order to achieve the goals of the project, an experiment was be done. The experiment methodology is explained in the following section. A planning for a successfully performance of the project is showed in the following chronogram in the *Figure 9*. During the first weeks, the project scope and goals were defined, followed by a continuous investigation which lasted the whole project.

ACTIVITY	INIT	DURATION	REAL INIT	REAL DURATION	COMPLETED
Goals project definition	1	5	1	5	100%
Research and readings	2	12	1	14	100%
Sensors	6	2	6	2	100%
Define test goals	7	2	7	2	100%
Planify test	9	2	9	3	100%
Test	11	2	11	3	100%
Test results	12	3	12	4	100%
Analyse results	13	3	14	3	100%
Conclusions	13	3	15	2	100%
TOTAL PROJECT	1	15	1	16	100%

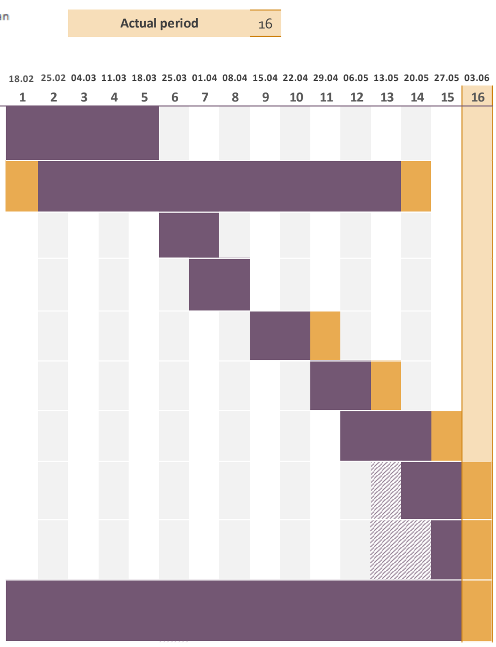


Figure 9 Project Planning. Source: Own Elaboration

After, there was a period of introduction to the sensors to be used to get familiarized with them. Define the test goals took two weeks to correctly focalise the aim of the experiment. Preparing the experiment was supposed to take 2 weeks. However, and due to some last-minute technical reasons, it took one week more than expected, causing delays in the rest of the tasks. This preparation time included the technical design, plus all the needed bureaucracy necessary to be done. This bureaucracy is related to the ethical procedure needed to be done as we have done an experiment with human participants. This form was performed with Viviana Gonzalez (PhD student at EPFL). The test started on time but lasted one week than expected. After taking all the samples, the gathered data was organized during some weeks. The next step was to analyse this data and start taking conclusions.

Each of the users had a different personal profile. To know better the personal characteristics that could influence the test some questionnaires were done. In the section of results, we can find the results to this form, as well as in the

APPENDIX section.

3.2. Structure of the report

The report has 5 main sections: Introduction, State of the art, Methodology, Results and Conclusion. The first part covers a brief introduction to the problem of pollution and exposure stablishing the main goal of the project: a better understanding of personal exposure. The section of state of the art summarizes the main experiments that have been done in the past year related to personal exposure or direct assessment and experiments that can be useful for a better design of ours. The methodology section explains the project logistics, experiment design and material used in the experiment. Results and discussion section, shows the gathered data from the experiment and shows a deep analysis of it. Finally, the report is closed with a final conclusion highlighting the main findings of the project.

3.3. EXPERIMENT METHODOLOGY

The aim of this report is to better understand personal exposure to pollutants. To do so, the experiment defined had the goal of assessing individual level exposure to particulate matter. This experiment aimed to check how different lifestyles can affect personal exposure. An additional second goal was to prove the necessity of personal monitoring to achieve reliable information of real exposure to pollutants.

3.4. Definition of the experiment

Six different participants were supposed to take part on this experiment. For confidentiality reason their names cannot be shared on this document. Their designated numbers were: P1, P2, P3, P4, P5 and P6. However, due to technical problem the experiment was reduced to 4 participants: P2, P3, P4 and P6.

This group of people was monitored doing their daily activities during 4 days, 24 hours a day in Switzerland. The aim of the test was to collect data from the personal exposure to pollutants of each of the users and their daily activities. More precisely the levels of particulate matter concentration. To understand better each of the participants personal situations, building characteristics, habits and routines they were asked to fill three different questionnaires. One before doing the test, one during the test and one at the end of the test.

The exposure was measured with the using one Graywolf Particle Counter 3500 per participant. The instrument was carried in a backpack adapted to the sensor in order to do all the measurements as close as possible to the user’s breathing zone. An example of this set up can be find in Figure 10. To better achieve this, and additional tubing system was placed at the inner probe of the sensor. This tubbing system requires a correction factor for the taken results. This correction factor is better explained in the first chapter of the results section.

The backpack was carried during each of the participant's displacements and in case of user inactivity, the backpack was placed closer than one meter from him. This last constraint was to be sure that the gathered data came from personal exposure measures. The user had no need of manipulating the instrument at any time as the measurements were continuous. The only thing the user was asked to do, was to charge the battery each night to assure a good functionality. At the beginning of each experiment the users received a training session where the research team explains the test and the use of the instrument.

In addition, participant number 6 had a secondary instrument placed at his house to do a comparison between personal and fixed monitoring. This part of the experiment was done in parallel with the rest of the test.

3.4.1. Questionnaires

For a better understanding of the collected data by the sensors, three different questionnaires were done:

3.4.1.1. Short Screening Questionnaire

Before starting the personal monitoring, each participant answered a questionnaire to get important information about the situation in which the experiment was done. This questionnaire included questions about participants, building characteristics, basic habits of occupants and neighbourhood characteristics. The results from these questionnaires are presented in the RESULTS & DISCUSSION section, and the original response are attached in the

3.4.1.2. Time-Microenvironment-Activity-Diary (TMAD)

During the experiment, each of the participants was asked to fill a second questionnaire each two hours or each time that they changed of activity. The questionnaire's purpose was to record all the daily activities as well as to create an idea of the momentaneous microenvironment. This information was extremely important for the research team to do a correct match between the exposure levels and the momentaneous activity. Also, it was helpful to have a correct lifestyle profile of each of the participants.

The microenvironments described as closed questions were: home, work, transport, outdoors and other buildings. The activities: working and studying, biking, walking, driving, using the public transport, eating, cooking, cleaning, sleeping or cleaning. In both cases a last option was added as an open response. The user had to insert a start and finish time of each of the actions and a personal number that was randomly assigned by the researchers as already explained.

3.4.1.3. Retrospective Exposure Questionnaire

A follow-up informal interview was done with each participant once finished the experiment. In this meeting the gathered information was discussed looking for any mismatch with the TMAD.

The participants needed to be over 18 years old to be part of the experiment, be able to read and speak English and they cannot be smokers. Before starting the experiment, they were asked to sign a consent form where the research team present the methodology of the experiment, risks and the data use.

All the participants were volunteers and they accepted freely to carry out the experiment. One of the requirements was the possession of a university degree. This was mandatory as it is demonstrated that the participants of experiments with higher studies get better involved.

3.5. Ethics

As the experiment includes human participants it was necessary to have the approval of the EPFL Research Ethics Committee (HREC No.). To have that approval some constraints about confidentiality, data usage and personal information needed to be accomplished. For example, each of the participants had a randomly assigned a number to fill all the questionnaires instead of using their names. This number is used during all the results analysis and conclusions to talk about each of the participants.

Due to the CH Federal law on data protection ("*Loi fédérale sur la protection des données*" – RS 235.1) the data has to be anonymous and will be accessed only by the main investigator. In addition, it will be safely storage and used only with research purposes.

3.6. Material

The needed material to be used were backpacks, the sensor and a device with internet access. More precisely the sensor was Graywolf Particle Counter 3500. It counts particle mass concentration in real-time with 6 different channels, the number of particles in the range of 0,3-10,0 micrometers[36]. The sensor was provided by the HOBEL laboratory. Each of the users' backpack was adapted to carry the sensor as shown in the following picture.

Figure 10 Graywolf Particle Counter 3500 and adapted backpack with the sensor. Source: left picture from Graywofl website. Right picture from own elaboration.

3.7. Data treatment

Once collected all the data, an exercise of organizing and analysis was done. For the TMAD, the platform Google Forms was used and then the file was downloaded to an excel version. Some participants mistakes needed to be corrected and everything was needed to be placed in a normalized form to do a correct use of it. The data gathered by the Graywolf sensor was treated in an excel file. Both sets of data, TMAD and concentrations, needed to be merged in a unique file for a better comprehension. This task had the main barrier of having different time ranges between the TMAD and the concentration data from the sensor. This problem was finally solved by coding a Macro for Excel with Visual Basic (program presented in APPENDIX B Visual Basic code) Once all the data was merged in a file, the final results were taken from it to analyse the main variables that affect personal exposure in terms of lifestyle. A comparison between different microenvironments and activities is done between participants. Also, a comparison checking other factors as day time and night-time and a final comparison between fixed and personal monitoring.

4. RESULTS & DISCUSSION

4.1. Structure of the results and conclusions

In this section the results of the experiment are shown. The experiment was successfully done for participants 3, 4 and 6. Due to an unexpected technical problem all the measurements done for participant 2 were lost. However, his TMAD was successfully completed and will be discussed with the rest of the participants results as it can add richness to the conclusions.

Firstly, the results of the pre-test questionnaires are shown. A brief description of the four participants is done based on the answers. Secondly, the results from the TMAD test are given, showing interesting information of time spent in different microenvironments and activities. Finally, the gathered information by each sensor is presented and linked with the TMAD information. A general overview of the concentration levels is done in first instance. Then, more detailed results are provided with an analysis between the different variables that can affect personal exposure related with the lifestyle. Some of this analysis are depending on microenvironments, activities and timing. The chapter of results from the sensors ends with a comparison between personal and fixed monitoring to asses exposure from participant 6.

4.2. Pre-test Results

A pre-test questionnaire was done to each of the participants. The goal of this form was to acquire valuable information to understand the concentration levels. Some questions were done to the participants about the building characteristics and its inhabitants' habits. The questions about the building characteristics aimed to identify the possible sources of pollution. Either from indoors, like the materials used in the apartment construction, or from outdoors, as the presence of industries close to the building. Some of these questions were: location of the building, size of the apartment, type of ventilation, construction materials, presence of plants or pets, types of stove and type of heating system. The questions about the inhabitants' habits aimed to analyse the possible factors that could affect to the future measurements. Ventilation, presence of smokers or cooking and cleaning frequency were some of the questions done about each of the participants' flatmates. It is important to know all this information as it is not covered by the TAD. The TAD just gathered information, during the experiment, from the participant's routine, and not from his or her flatmates or building.

All the responses to these questionnaires are presented at the APPENDIX section of the report.

4.2.1. Participant 2

Participant 2 is a 24 years old male university student, living in the city of Renens (Switzerland). As a volunteer, he accepted to fill the first questionnaire done in our experiment. Participant 2 uses the public transport and the bike as means of transport. He lives in an apartment with two other students aged 21 and 22. Is a 2nd floored apartment with rooms of 17m2 size, one room per person. The apartment uses radiant floor as heating system and has carpet and cork inside the bedrooms and in the hallway. The floor in the rest of the rooms is composed of tiles. The walls of every room but the bathroom, are painted. The bathroom walls are covered with tiles. One of the flatmates of our participant 2 is a smoker and uses the balcony to smoke. They have no plants and neither pets inside the apartment. Each of the inhabitants cooks two or three times per week using electric stoves. They clean the floor a total of 2 or 3 times per week using detergents and they have a dehumidifier inside the apartment. They use natural ventilation and they keep the windows opened more than an hour per night. The building in in a suburban are of the city, it is not close to any highly transited street and there are existing industries or fabrics in the neighbourhood.

4.2.2. Participant 3

Participant 3 is 26 years old living with another person aged 28 in an 80 m2 apartment. In the city of Fribourg (Switzerland). The apartment is in an 8th floor of a building ubicated in a suburban area of the city. This building is close to a highly transited street and the neighbourhood has some industries or fabrics. The apartment of participant 3 has radiant floor and this floor is built on wood in the bedrooms. The kitchen's, the bathrooms' and the hallways' floor are covered by tiles. All the walls from the apartment are painted but the ones from the bathroom which are composed by tiles. None of the inhabitants is a smoker. They have between 1 and 5 plants inside the apartment and no pets. They cook everyday using electric stoves. The floor is cleaned once a week using a vacuum cleaner. At night they usually open the windows between 2 and 5 minutes. The apartment has natural ventilation. Participant 3 usually goes walking and does not use the public transport and cars neither.

4.2.3. Participant 4

Participant 4 is a 32 years old female with a university degree, who lives with other 3 people in an a 90m2 apartment. This apartment is in a 5th floor of a building ubicated in the city centre of Fribourg (Switzerland), close to a highly transited city and with some industries or fabrics in the neighbourhood. She uses the public transport as a mean of transport 2 or 3 times a week. Her apartment is heated by radiators, the bedrooms' floor is made on wood, as the hallway. The kitchen's and the bathrooms' floor are covered by tiles. The walls from the apartment are all painted but the ones from the bathroom, which are composed by tiles. There are smokers in the apartment and they smoke inside the kitchen. They have between 6 and 10 houseplants and no pets. They usually cook 2 or 3 times per week each person and clean the floor every two weeks using detergents and a vacuum cleaner. Sometimes they leave the windows open at night-time during 30 or 60 minutes. The apartment is naturally ventilated.

4.2.4. Participant 6

Participant 6 is a 24 years old male university student, who lives with other 3 students in an 80 m2 apartment. This apartment is in a second floor of a building ubicated in the city centre of Lausanne (Switzerland). This building is close to a highly transited street and close to industries and fabrics too. The apartment has radiant floor to heat the house and the material used on the floor is PVC. All the walls from the apartment are painted but the ones from the bathroom which are composed by tiles. There are no plants, no pets and no smokers in the apartment. They cook every day using electric stoves. They clean the floor once per week using a vacuum cleaner. They often keep the window opened at night during more than an hour. The apartment is provided with a mechanical ventilation system in the kitchen and in each of the bedrooms. Participant 6 uses public transport as means of transport every day.

4.3. TAD Results General and per participant

During the experiment, each of the participants was asked to fill a second questionnaire. The responses were usually taken after 2 hours, when changing activity or microenvironment. The questionnaire's goal was to have a good knowledge of each of the participants routine. Form this questionnaire, we extracted the following information: activity done, place or microenvironment where the activity took place and if it was indoors or outdoors. A fourth question was added to check which participant was answering by inserting his or her personal number, which was previously randomly assigned to maintain his or her anonymity.

The microenvironments options were: home, work, transport, outdoors or other buildings. The activities were: transport by car, laundry, shopping, bathroom, painting, using public transport, cleaning, socializing, biking or walking, watching TV, cooking eating, working or studying and sleeping. In addition, and as already mentioned in the METHODOLOGY, an open question was added in case the participant could not identify his or her activity or microenvironment with the provided ones.

All the participants were provided with a link and a QR code to access the platform where they answered the questions. With this TAD really interesting information was gathered with a total duration of 391 hours. Which means approximately 16 days of questionnaire (4 days per participant). A total of 257 different responses were obtained. All these answers were normalized into a same format and time length with the help of Microsoft Excel tools, using macros and Visual Basic algorithms.

In this section, an analysis of the time spent indoors or outdoors, in different microenvironments and doing different activities is done.

4.3.1. Time spent Indoors and Outdoors

As already mentioned in last sections, the population from developed countries tend to spend around 90% of their time indoors (on average). Our results confirm this fact. The following figure shows the percentage of the amount of time spend indoors and outdoors from our four

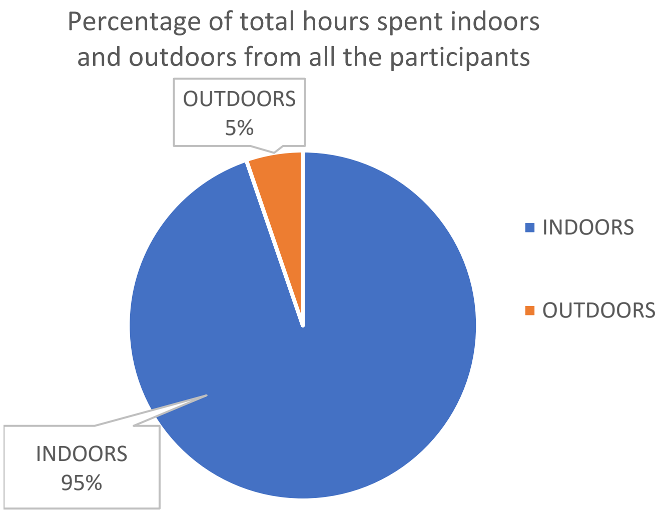


Figure 11 Percentage of total hours spent indoors and outdoors from all participants. TMAD

participants.

	% of hours of each ME	sum of hours in each ME
INDOORS	94,76%	371,2
OUTDOORS	5,24%	20,5
Total	**100,00%**	**391,7**

Table 13 Percentage and number of hours spent indoors and outdoors from all participants. TMAD

Only 5% of the participants' time during the TAD test was spent outdoors. This explains the importance of indoor air quality assessment. This value variates depending on the participant,

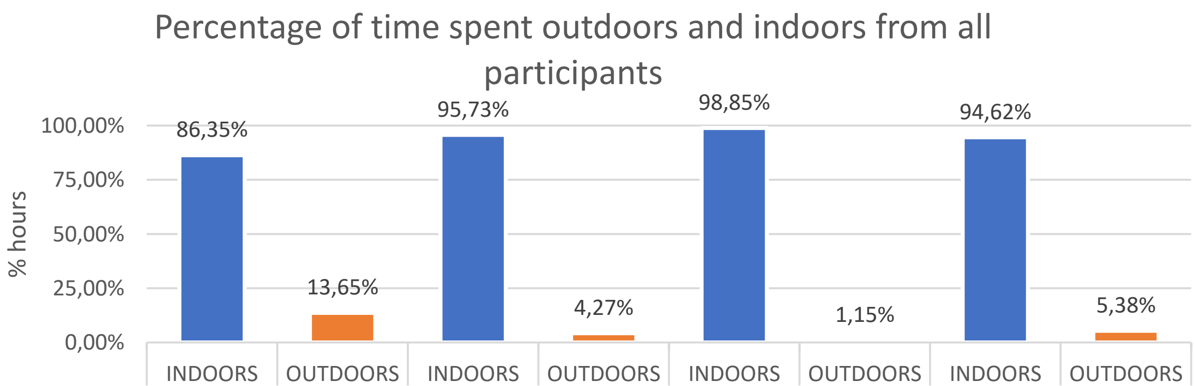


Figure 12 Percentage of time spent outdoors and indoors per participant. TMAD. From left to right: P2, P3, P4 and P6.

but the proportion between outdoors and indoors remains similar. Each of the individuals has a different lifestyle. Participant number 2 is the one who spent the least time indoors with an 86,3% of his total time. Participant number 4 is the one who spent the most of her time indoors with a 98,8% of her total TAD time

4.3.2. Microenvironment

Going further, we analyse the time spent in different ME. The general results of the TAD for this analysis are presented in the following table:

	% of hours at each ME	**sum of hours in each ME**
Home	73,18%	286,6
Work	15,69%	61,4
Outdoors	5,16%	20,2
Other buildings	2,60%	10,2
Transport	1,80%	7,1
Library	1,57%	6,2
Total	**100,00%**	**391,7**

Table 14 Percentage and number of hours per ME. TMAD

The microenvironments (ME) where the participants spent most of their time, were at home with a 73% of their total hours. Then at work with a 15% of the total hours. Work environment considers office or university's rooms as some of the participants were students. In the report: *Indoor Air Pollution in California*[235], the group of researchers estimated a value of 94% of time spent indoor for adults and 62% at home. Our participants time spent at home seems to be slightly higher. However, we have to take into account that all the participants did the TAD test during two days of weekend and two labour days. During the weekends the normal tendency is to stay at home a larger amount of the time, which is what it happened in this case.

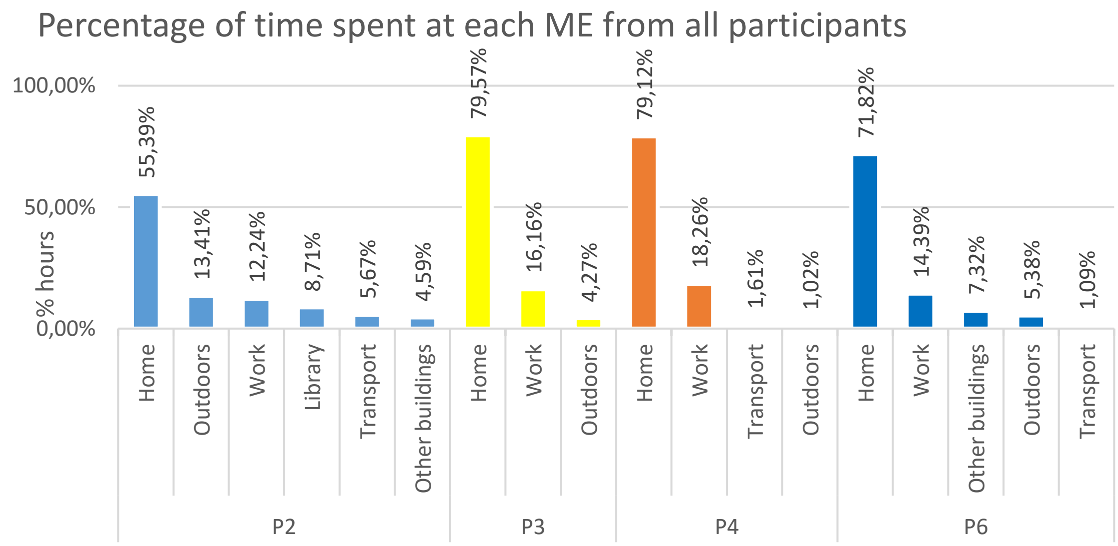


Figure 13 Percentage of hours spent per ME per participant. TAMD

Even tough that the different microenvironments used during the day are more or less common trough all participants, there is an existing variability on the amount of time in each of them. Participant number 2 spent only a 55% of his time at home, while participant number 3 and 4 spent 79%.

4.3.3. Activity pattern

Checking the amount of time spent doing each activity we arrive to the following results. The participants spent 39% of their time sleeping and a similar amount of time working or studying. The next activities in terms of amount of spent time on them, were eating and cooking.

	% of total hour per activity	Sum of hour per activity
Sleeping	39,14%	153,28
Working & Studying	37,21%	145,75
Eating	7,22%	28,27
Cooking	3,45%	13,52
Watching tv	3,40%	13,33
Biking or Walking	2,62%	10,25
Socializing	2,51%	9,85
Cleaning	1,56%	6,10
Public transport	1,36%	5,33
Painting	0,51%	2,00
Bathroom	0,49%	1,93
Shopping	0,43%	1,67
Laundry	0,09%	0,33
Transport by car	0,01%	0,05
Total	**100,00%**	**391,7**

Table 15 Percentage and number of hours spent per activity from all participants. TMAD

Sleeping, working and study are the activities in which all participants spent most of their time. Following Pareto's principle, around 80% of the total time, was spent in two activities: sleeping and working or studying. After this two all the percentages go down to a value close to 4-7% in activities like eating, cooking or socializing. Around 3% of the time of participant 2 is spent in public transport, 1,5% from participant 3, and 1% from participant 6. Participant 3 did not use

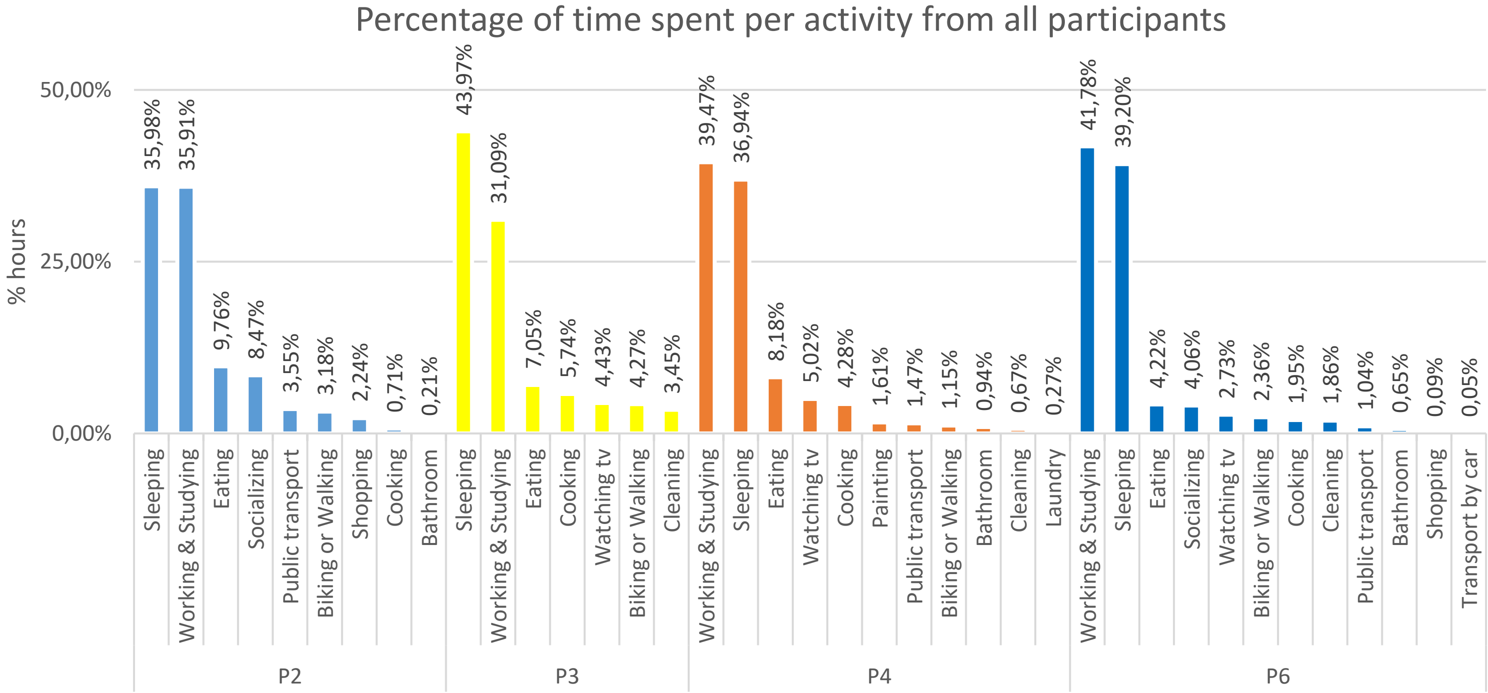


Figure 14 Percentage of hours spent per activity and per participant. TMAD

the public transport as said in the pre-test questionnaire.

4.3.4. Conclusions from microenvironment and activity responses

Without being conclusive, these results give us a good idea of the microenvironment and activity patterns for all the participants. From this brief analysis of the TAD data and pre-test questionnaire we can extract some conclusion that will be useful in the next analysis:

- The existing difference between participants habits and buildings.
- All of our participants spent around 95% of their time indoors. This show us the importance of assessing indoor air quality.
- The variability of activities between participants and therefore the complexity of assessing them.
- This first analysis gives the reader an idea of the amount of time spent in each ME and doing each activity, which will help to have a better comprehension of further results.

4.4. Measurements General and per participant

In this section, the PM concentration data is analysed. The final goal of this analysis is to check the time and activity dependency of personal exposure. During the analysis different variables will be discussed. The structure of this analysis starts with a general overview of the results. Then, it covers a personal review for each participant, with a comparison between them. In addition, the study covers a deeper breakdown of the results depending on each of the ME, activities or other interesting variables for a better personal exposure assessment. The last topic covered is a comparison between personal and fixed monitoring exposure from participant 6. The presented data presents the concentration levels of personal exposure during 4 different days for each participant (participant 3, participant 4 and participant 6). The data was taken during 24 hours.

As the personal monitoring system was provided with a pipe to take samples from the breathing zone and at the same time carry the sensors inside a backpack, a correction factor needs to be applied. When using a tubing system, the air and particle flow properties variates. With the help of the HOBEL laboratory and the chapter 6 of the article: *Aerosol Measurement: Principles, Techniques, and Applications*[37], the following correction factors were calculated:

	PM00.50	PM01.00	PM02.50	PM05.00	PM10.00
Measured/Real value	1	0,99	0,97	0,89	0,6

Table 16 Correction factor between value measured and real value to apply to each size of particle. Source: HOBEL laboratory and Aerosol Measurement: Principles, Techniques, and Applications

Without going into deeper details, these values were calculated taking into account the particle deposition into the tubing walls caused by particle diffusion and gravity-driven deposition. However, these values need to be applied to each of the sizes of particles. Which means that we cannot use them as we do only have the mass concentration of particles with a diameter size equal or lower that the provided. To be clearer, our measurement of PM10 tell us the mass concentration of every single particle with a diameter size equal or smaller than 10 µm and the

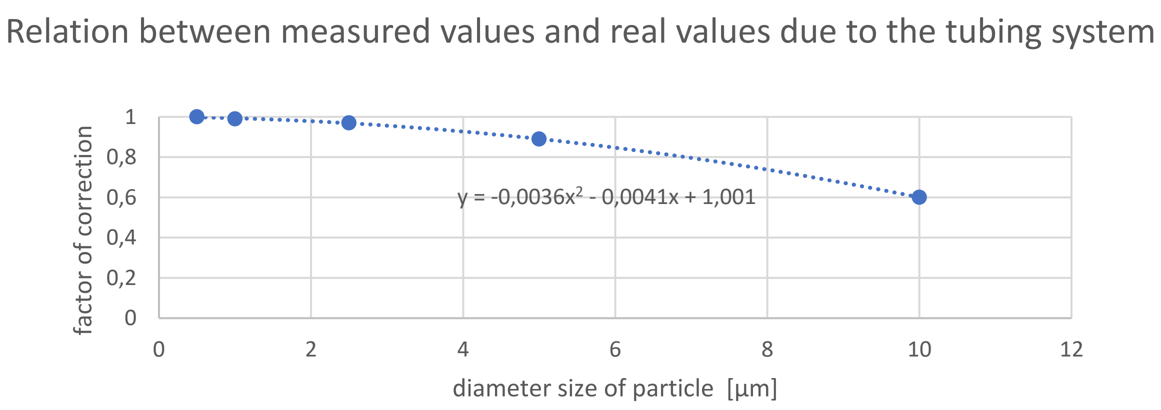


Figure 15 Relation between measured values and real values due to the tubing system. Source: Own elaboration

given correction factors are specifically for 0,5 µm, 1 µm, 2,5 µm, 5 µm and 10 µm. The following table shows the relation between diameter size and factor of correction.

Estimating an average diameter size per each channel: 7,5 µm for the 10 µm channel, 3,75 for the 5 µm channel and so on, we came up with these final correction factors:

	PM00.50	**PM01.00**	**PM02.50**	**PM05.00**	**PM10.00**
Measured/Real value	1	0,9959	0,9828	0,935	0,76775

Table 17 Correction factor between value measured and real value for using pipes and to apply to each channel. Source: Own elaboration

This is not the most accurate solution but takes us closer to an optimal. All the presented results from personal monitoring are converted using the last correction factor.

4.4.1. General Overview

Total	PM00.50	PM01.00	PM02.50	PM05.00	PM10.00
Mean	2,58	4,50	9,74	25,93	51,67
Median	1,50	2,27	3,86	8,19	15,90
Standard deviation	3,68	8,48	30,60	121,87	297,86
Range	84,43	173,84	951,31	4766,94	14120,79
Minimum	0,00	0,00	0,00	0,00	0,00
Maximum	84,43	173,84	951,31	4766,94	14120,79
N	15565	15565	15565	15565	15565

Table 18 Statistics general results of PM concentration for all participants. Concentration values in µg/m^3

This table summarises the total obtained data. A total of 15565 samples were taken during 12 different days, for 3 different participants. These levels come from the breathing zone of each of the participants and represents the personal exposure of our three participants. In total they were exposed to an average of 50 µm/m3 for PM10 and almost 10 µm/m3 for PM2,5, which is below any guideline or standard threshold, but not too far (PM10 average is actually at the same value as WHO guideline). More representative is the median which is established in a value of 16 µm/m3 and 14 µm/m3, respectively. Below these values, are the 50% of the concentration values. This confirm us that generally the measured concentrations are below limits. The standard deviation tells us how dispersed the data is. We will compare this value with future results to check the variability of the measures. A maximum value of 14120 µm/m3 was measured. Later on, the report we will analyse how representative this value can be or if it can be considered as an outlier. This value is too high to be exposed. However, it might have been reached during cooking periods being too close to the PM source. In Figure 16 we can see the same information presented with a boxplot. This type of representation will be use during the entire report due to its graphical facility to analyse data. The average value is represented by a

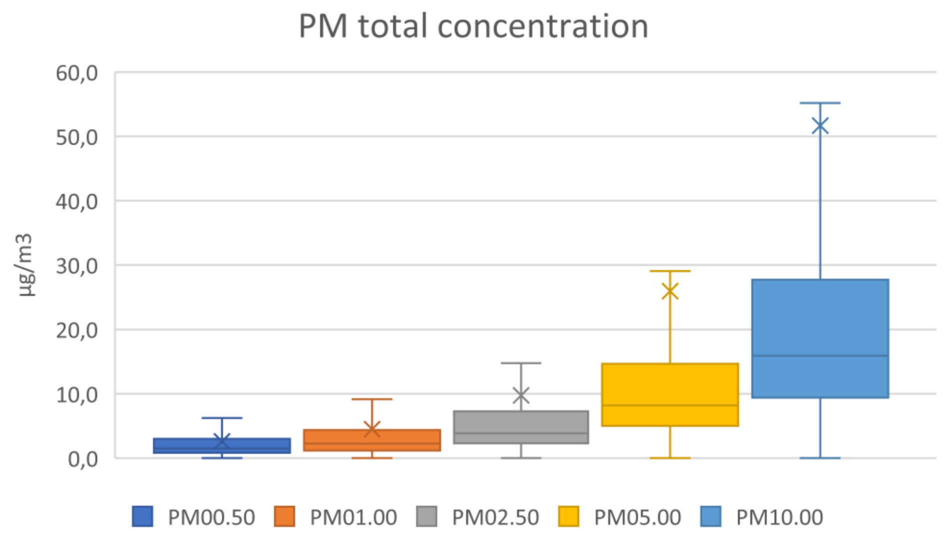


Figure 16 PM total concentration from all participants

cross. The central mark represents the median, the edges of the box percentile 25th and 75th of the gathered data. The whiskers include the rest of the data which is not consider outlier.

Average PM concentrations	PM00.50	PM01.00	PM02.50	PM05.00	PM10.00
P3	**3,0**	**6,6**	**20,5**	**60,1**	**114,2**
P4	**3,2**	**4,6**	**6,5**	**13,0**	**24,7**
P6	**1,6**	**2,9**	**6,5**	**19,0**	**43,3**
Total	**2,6**	**4,5**	**9,7**	**25,9**	**51,7**

Table 19 Average PM concentrations per participant. Concentration values in µg/m³

In this Table 19 the average concentration values for each participant are presented. Each value represents the mean for the four days of measurements. As we can see there is a substantial difference between participants. Participant 3 has a higher average and it is close to 115 µm/m3 for PM10 and 20,5 µm/m3 for PM2,5. The PM10 value is above the WHO guidelines but still below the EPA standard. This variability between participants might be explained with the activity analysis which will be done in the following's sections.

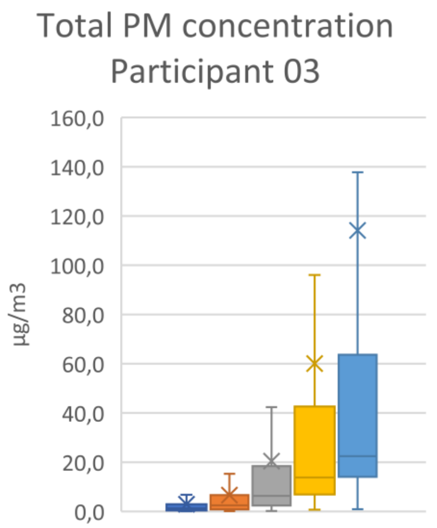


Figure 17 Total PM concentration Participant 03

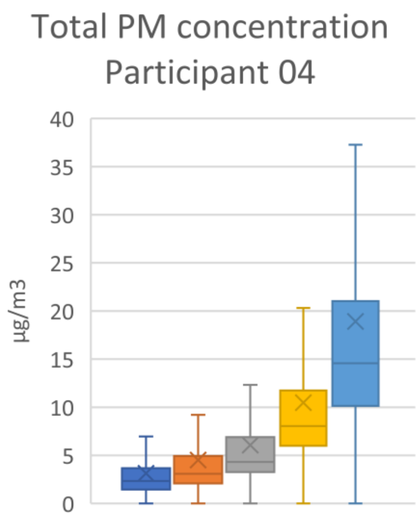


Figure 19 Total PM concentration Participant 04

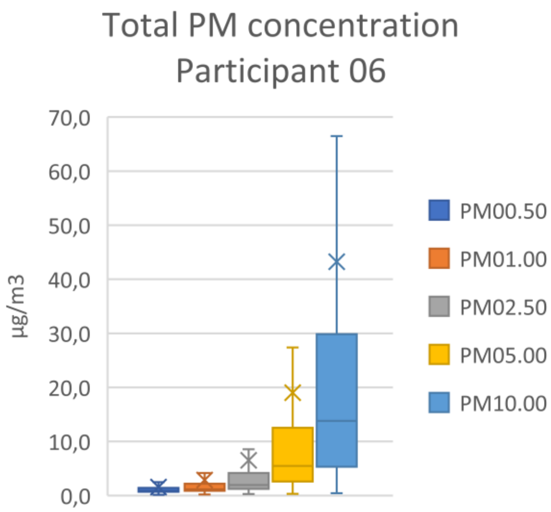


Figure 18 Total PM concentration Participant 06

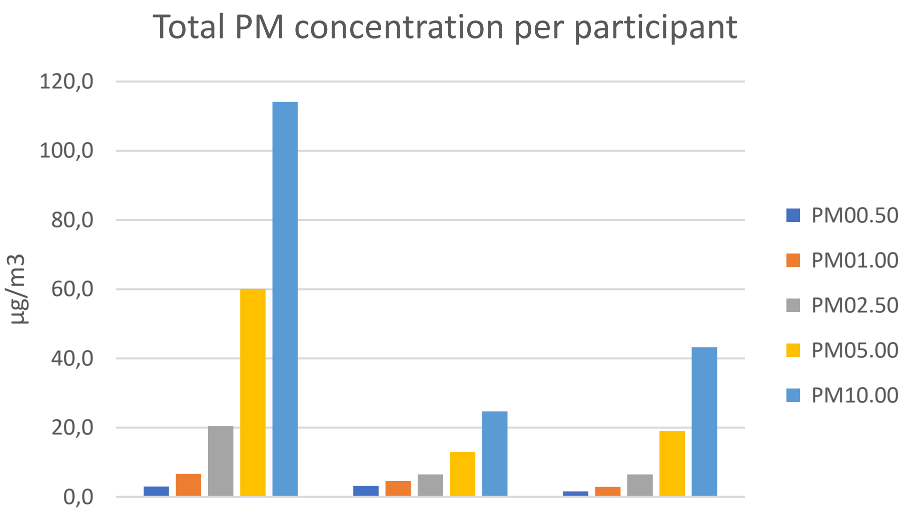


Figure 20 Total PM concentrations per participant

4.4.2. Analysis per day with time activity and microenvironment diary

In this part of the results the time line concentration exposure of each participant is presented. These next figures represent the average per hour. They are useful to create a visual image of the time line of each participant. The goal of this figure is not to show specific values but to detect the most critic events and to show a general view of the entire personal exposure. The TMAD and the concentrations levels are mixed to have a better comprehension. For a clearer view the time axe has been replaced by the events. In each graph we discuss two different days.

4.4.2.1. Participant 3

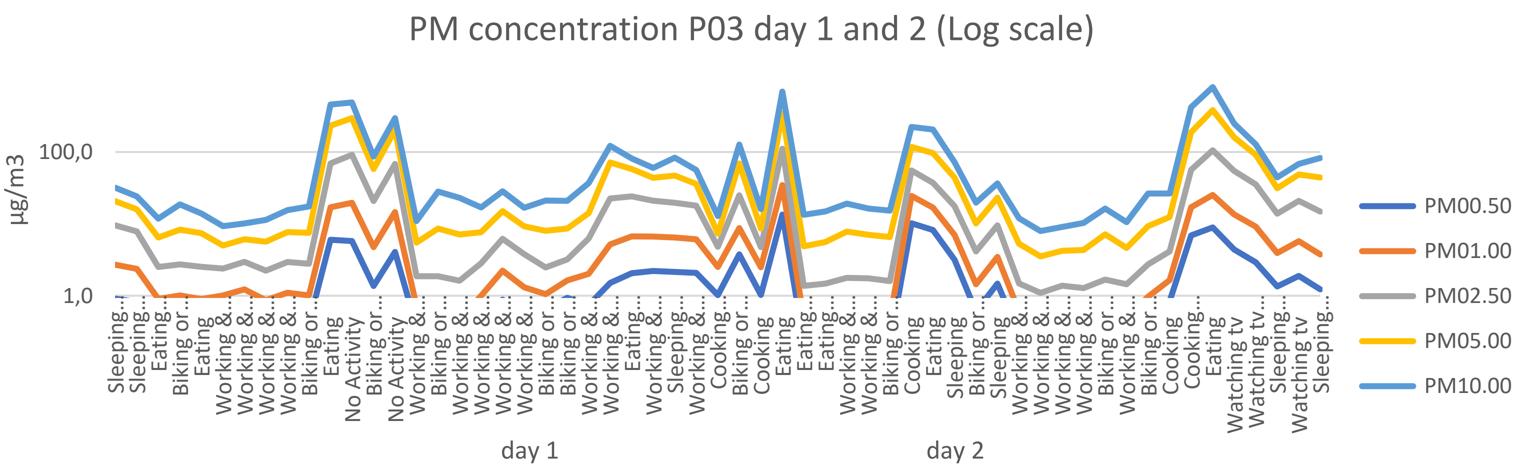


Figure 21 PM concentration P03 day 1 and 2 (Log scale) p3

Starting with participant 3, a time line overview of his personal exposure during the 4 days of test is plotted. The vertical axe is plotted with a log scale for a better appreciation of the results. As we can appreciate, the highest peaks are always related with cooking or eating activities. During the first day the main peaks happens at noon, reaching levels of 500 µg/m^3 for PM10 as hourly average. At the second day in the morning, a level of 700 µg/m^3 is reached during a short period of time at noon, while cooking. The level of PM10 concentration reaches 240 µg/m^3. Finally, at the end of day 3 the highest average point is reached with a value of 800 µg/m^3.

One interesting finding is that each time that the participant goes biking (or walking) a small peak happens. This will be more discussed later doing a comparison between indoors and outdoors exposure.

During days 3 and 4 we find similar results being happening the greatest exposure peaks during cooking times. These peaks reach values as 1200 µg/m^3 or even 5000 µg/m^3 for PM10 as hourly average. Later it will be discussed if these values are representative or not. An interesting finding and important for further results, is that usually the action of eating happens just after cooking. This increases the probability of having higher concentration levels during eating times even if the stoves are already off.

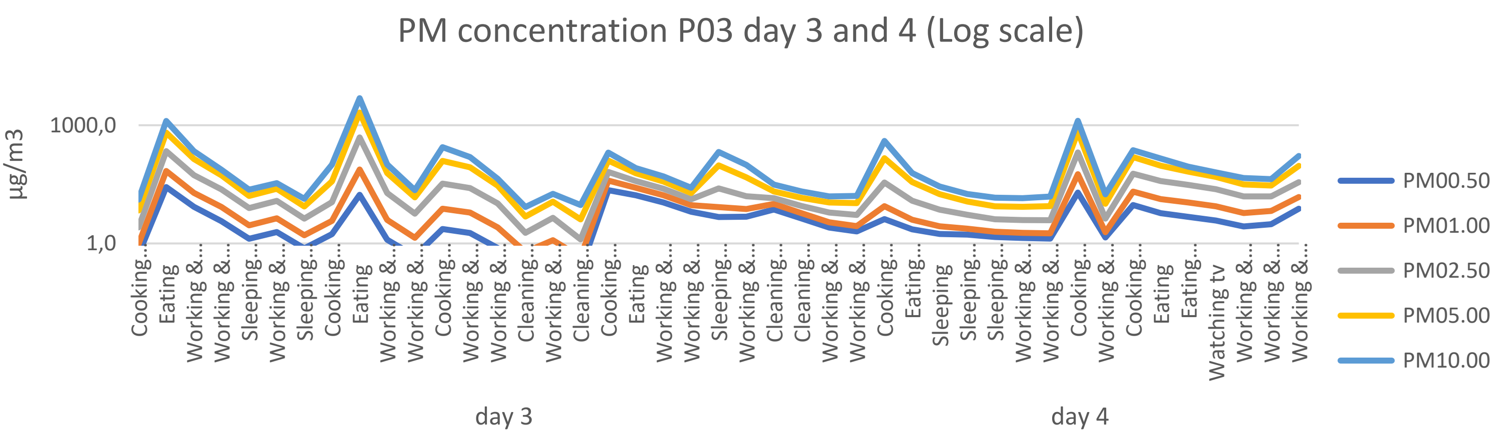


Figure 22 PM concentration P03 day 3 and 4 (Log scale)

p3

4.4.2.2. Participant 4

For participant 4 the same graphs are plotted. We can see the main peaks for her first two days. Generally, her exposure values are lower and more controlled than the previous participant. During day 1, there is an interesting increase on exposure levels when the participant changes from sleeping to walking or cycling (arrow 1). This tells us that the exposure outdoors was higher than at home. Same situation happens later, before the end of day 2 when she changes from working & studying to biking or walking (arrow 2). Generally, we can appreciate a relation between changing of action and variance of exposure levels. This can be caused for changing microenvironments or can also be related with movement and resuspension. Some peaks can

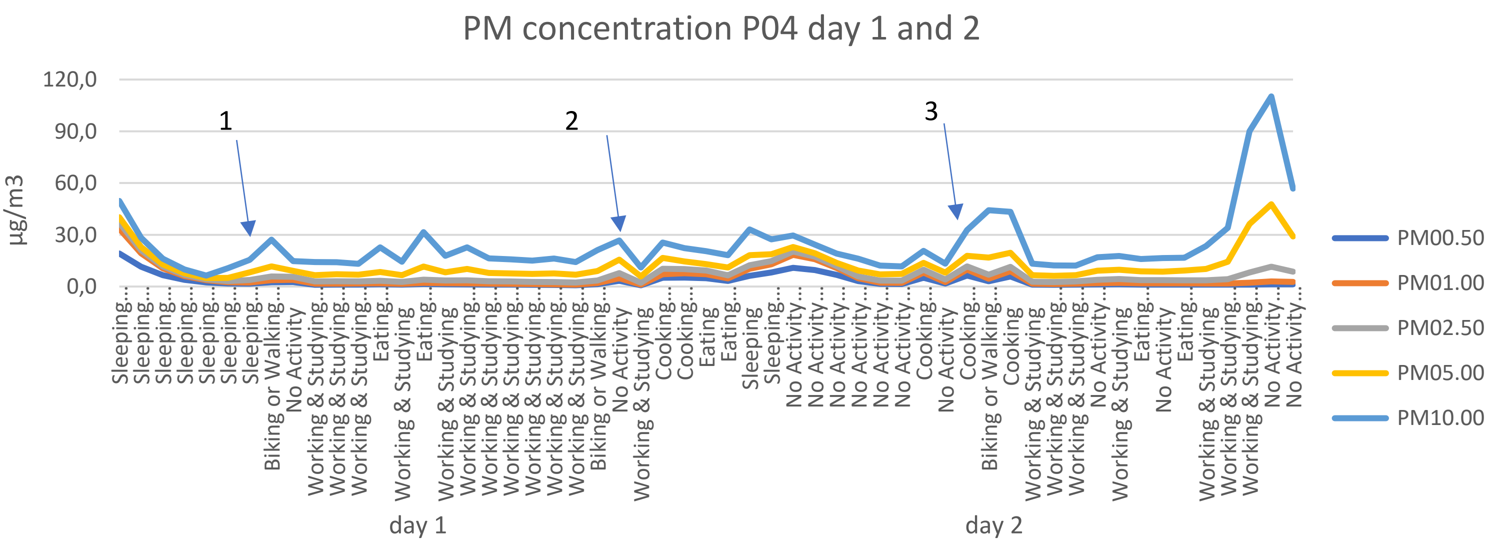


Figure 23 PM concentration participant 4, day 1 and 2

be related to cooking activities too (arrow 3).

During days 3 and 4 the main peaks are surprisingly related to bathroom times. A possible answer to this is either a wrong ventilation of the room or an existence of vapour particles (arrows 1 and 2). Again, we can observe that the main changes of concentration levels happen when changing activity.

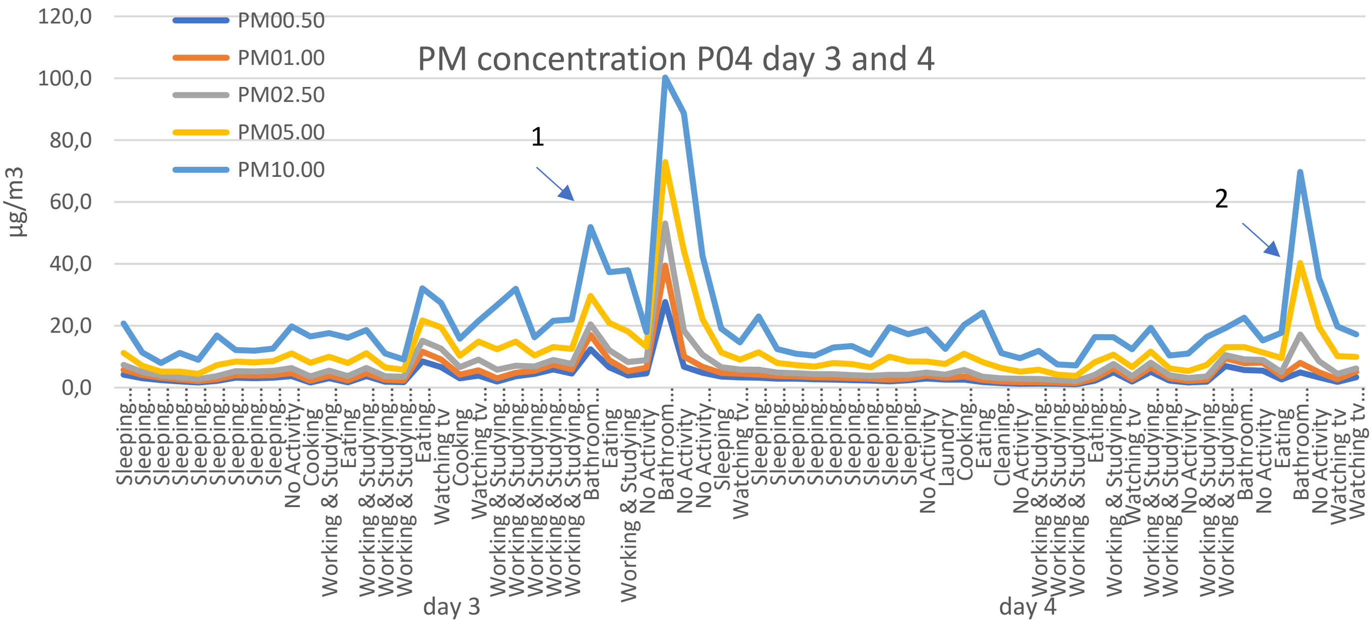


Figure 24 PM concentration participant 4, day 3 and 4

4.4.2.3. Participant 6

During the four days from participant 6 we can observe a similar tendency to have the greatest peaks during cooking times (arrows 1,2 and 3). The highest peaks happen during day one (arrow 1) while cooking and eating. Something noticeable is the low level and continuous tendency of concentration measured while sleeping. During sleeping hours, the activity is null and so the movement, which implies less probability of activating sources or resuspension. At the end of day 2, there is a peak when the participant claims to be cleaning.

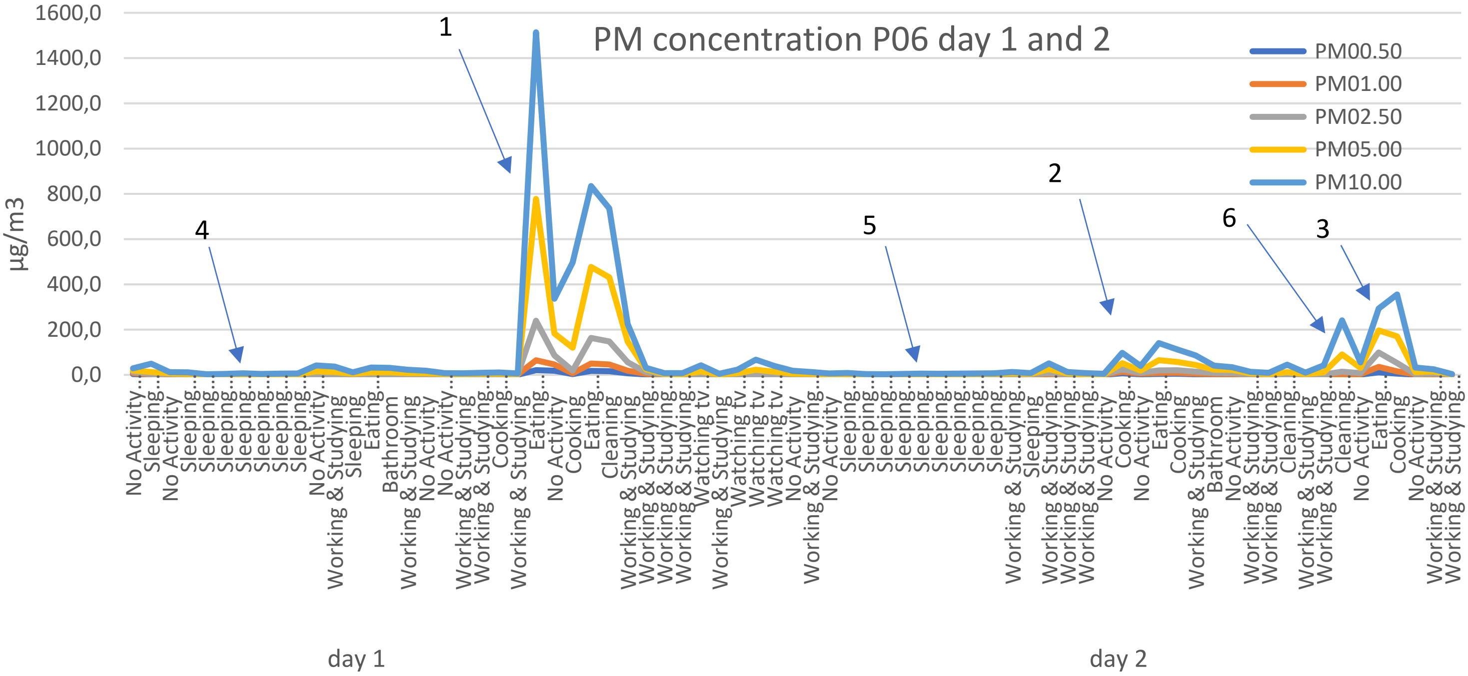


Figure 25 PM concentration participant 6 day 1 and 2

During day 3 the results are shown with lower scale and the variations can better appreciated. There are no cooking times. The highest peak happens while studying at the university cafeteria (as the participant shows in the TMAD) (arrow 1) and during university class (arrow 2). The levels reached during this second day are lower than the ones reached in the last days. The main reason is the lack of cooking times.

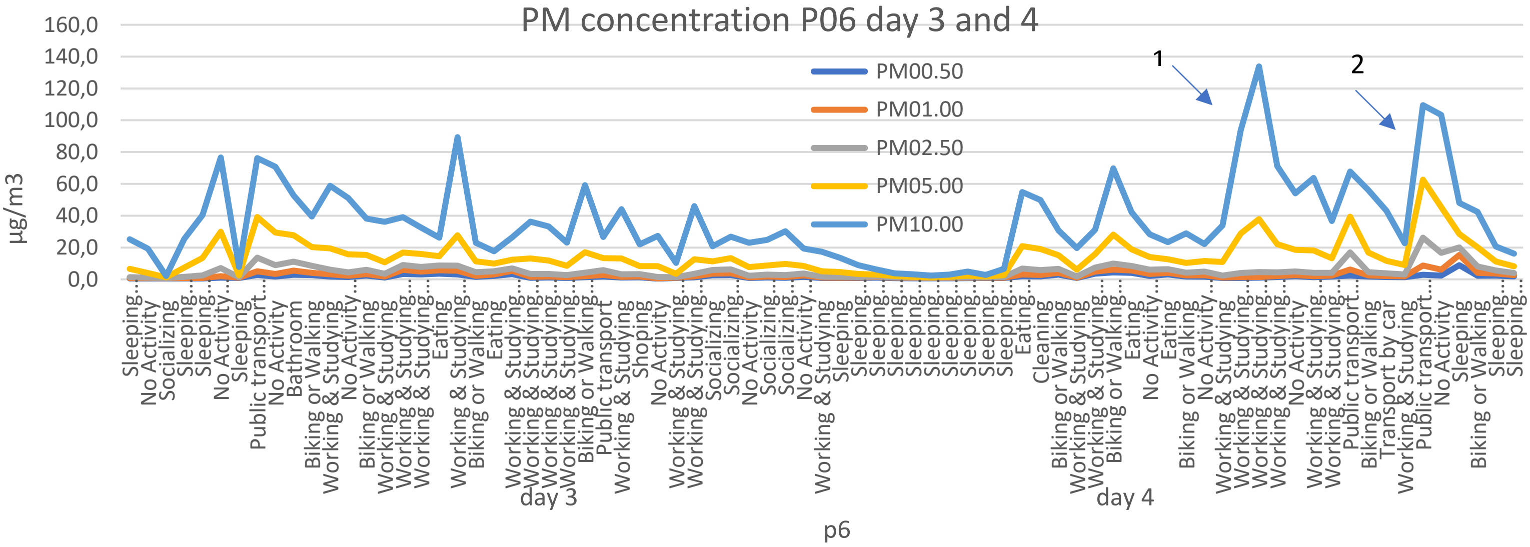


Figure 26 PM concentration participant 6 day 3 and 4

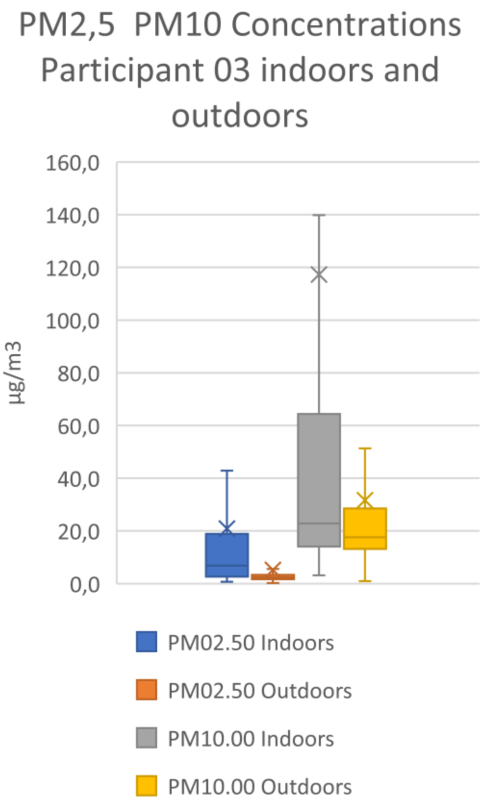
4.4.3. Microenvironments

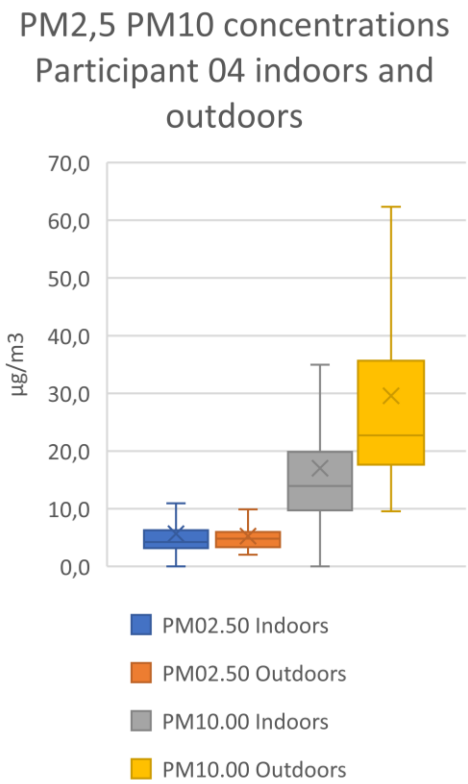
As explained in the introduction and in the methodology one of the main variables to check is the influence of the microenvironment (ME). In this section this analysis is done. The first thing to do is a comparison between indoor and outdoor personal exposure. To do so, the following table is presented.

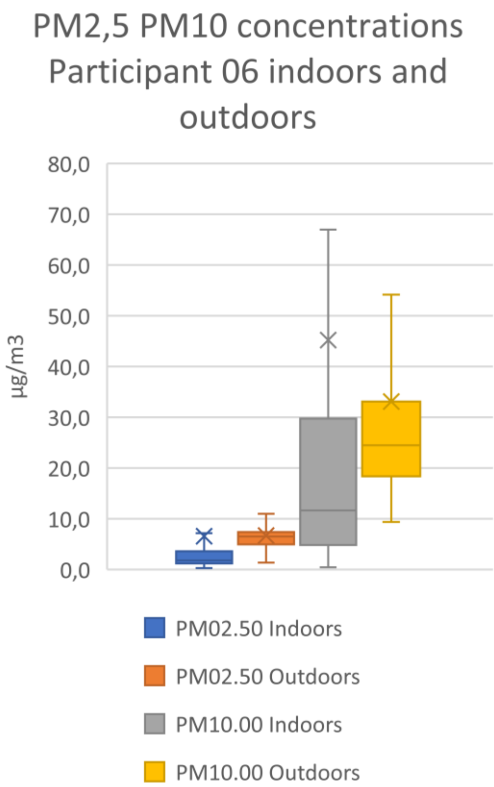
I/O	PM00.50	PM01.00	PM02.50	PM05.00	PM10.00	% of total hours	Sum of hours
P3							
OUTDOORS	0,8	1,7	5,2	15,4	31,6	4,3%	4,3
INDOORS	3,1	6,9	20,9	61,2	117,3	95,7%	97,3
P4							
OUTDOORS	2,3	3,3	5,3	12,1	29,6	1,2%	1,4
INDOORS	3,0	4,3	5,7	9,5	17,0	98,9%	123,1
P6							
OUTDOORS	2,9	4,0	6,7	15,3	33,1	5,4%	5,1
INDOORS	1,5	2,8	6,6	19,8	45,2	94,6%	89,6

Table 20 PM concentrations per participant indoors and outdoors, and a comparion with number and percentage of hours. Concentration values in µg/m³

Table 20 presents the average concentration levels of PM for each participant and the spent hours indoors or outdoors. All the participants spent most of their time indoor. Participant 3 and 6 have higher concentrations of PM10 indoors than outdoors. Participant 4 has lower PM10







concentration levels indoor.In terms of PM2,5 all participants have higher concentrations indoors but participant 6 that has a slighty lower value which might not be representative.

Participant 3 has a PM10 indoor-outdoor ratio (I/O) of 3.7 and a PM2,5 I/O ratio of 4. Participant 4 presents a PM10 I/O ratio of 0.57 and 1.07 for PM2,5. Finally participant 6 has a PM10 I/O ratio of 1.35 and 0.98 for PM2,5. In the following figures the PM2,5 and PM10 concentrations for the three participants are presented differenciating between indoors and outdoors environments. Something interesting to observe is the difference in variability between indoors and outdoors. The variability or presence of more dispersed values, can be seen in the difference between the average value and the mean.

If we do the same analysis for the rest of microenvironments, we can find some interesting results. In the Table 21 we find summarized all the main ME used by the participants, their average PM concentrations in each of them and the number of hours spent in each ME.

ME	PM00.50	PM01.00	PM02.50	PM05.00	PM10.00	% of hours in each ME	Sum of hours in each ME
P3							
Home	4,08	9,03	27,50	80,64	153,81	80%	80,80
Outdoors	0,78	1,71	5,22	15,41	31,63	4%	4,30
Work	0,36	0,83	2,31	6,57	14,33	16%	16,40
P4							
Outdoors	2,26	3,33	5,26	12,05	29,58	1%	1,30
Work	1,09	1,68	3,39	9,64	21,11	18%	22,70
Home	3,45	4,86	6,17	9,44	16,10	79%	98,50
P6							
Transport	2,19	4,48	11,58	29,29	56,27	1%	1,00
Work	1,62	2,58	4,66	17,19	51,70	14%	13,60
Home	1,44	2,79	6,86	20,19	44,02	72%	68,00
Outdoors	2,87	4,03	6,69	15,28	33,08	5%	5,10
Other buildings	3,26	4,97	7,63	14,35	28,03	7%	6,90

Table 21PM concentration per ME and per participant and hours spent in each ME. Concentration values in µg/m³

From participant 3 it can be seen that he spent most of his indoor time at the ME with the highest PM concentration in his case: home. In this ME participant 3 was exposed to an average PM10 of 153 µg/m^3 , which is 3 times higher than the WHO[38] guidelines threshold and it is at the same level as EPA NAAQs[15] limits. PM2,5 average concentration was 27 µg/m^3 which is a few points higher that the WHO guidelines and lower than the 35 µg/m^3 WPA's limit for PM2,5 24h.

Participant's 4 highest average concentration happened outdoors which is the ME where she spent the least of her time, only 1%. The average concentration outdoors for participant 4 was 29 μg/m^3. More than 5 times lower than participant's 3 highest concentration average level of PM10. PM2,5 highest average concentration was also outdoors with 5 μg/m^3. Participant 4 spent 79% of her time at home where her average values were in safe ranges with 16 μg/m^3 average of PM10 and only 6 μg/m^3 of PM2,5.

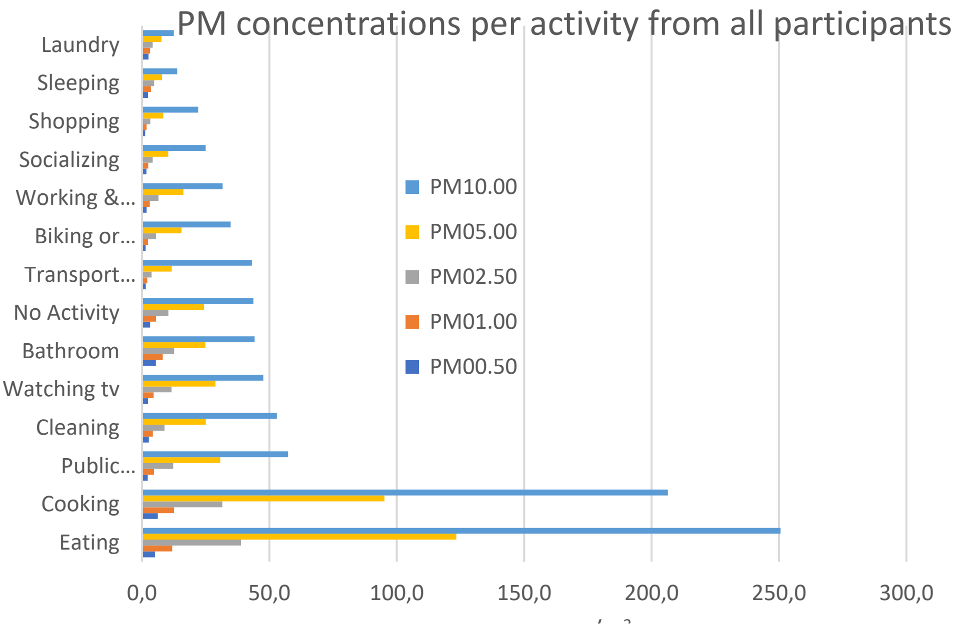
Participant 6 had his highest average concentrations levels inside public transport with 56 μg/m^3 average of PM10 and 11 μg/m^3 average for PM2,5. Values that are below the EPA's limits, but above WHO's guidelines (PM10). However, he spent only 1% of his time in this ME, which makes it not deterministic. In terms of PM10 the second place with the highest average was at work with a value on the WHO's limit. The place where he spent most of his time was at home (72%) where he had a 44 μg/m^3 average concentration of PM10 and 7 μg/m^3 of PM2,5.

With this comparison it can be already checked how, different routines and home characteristics, can affect to our personal exposure. For the moment participant 3 had the biggest average exposure in the place where he spent the most of his time, home. Another interesting fact is the average concentration levels measured by each participant outdoors. The values are almost the same: around 31 μg/m^3. Checking the historical daily PM10 values for the city of Lausanne[39], during the days of the experiment them measured mean was around 10 μg/m^3. If we compare these values with participant's 6 outdoors level for those days, the difference is big. This mismatch might be due to the specific location of participant 6.

Another important conclusion from these results is the high variability between different ME. In participant's 3 results, the highest average value is 10 times higher than the ME with the lowest concentration average. And this lowest average is half of the outdoors levels (in terms of PM10). Participant 4 is the one with the most regular values, but there is still a 15 μg/m^3 difference between home and outdoors. In case of participant number 3, the difference between the lowest and the highest goes up to 30 μg/m^3.

4.4.4. Activities

The activity pattern is deterministic in the personal exposure to pollutants. In this graph the measured average levels per activity are shown. The activities are sorted by PM10 concentration average in ascendant order. The activity with the highest PM10 average was eating followed by cooking with 250 µg/m^3 and 206 µg/m^{3}respectively. These two activities were far from the rest of the averages. The following most polluted activity was using the public transport with almost 60 µg/m^3. At the right of the Table 27 it can be found a summarizing table with the total percentage of time spent doing each activity. It is interesting to highlight that eating and cooking cover the 10% of the total spent time of our participants. After sleeping and working or studying, the highest budget of time.



Activity	% of total hours per activity
Laundry	**0,09%**
Sleeping	**39,14%**
Shopping	**0,43%**
Socializing	**2,51%**
Working & Studying	**37,21%**
Biking or Walking	**2,62%**
Transport by car	**0,01%**
Bathroom	**0,49%**
Watching tv	**3,40%**
Cleaning	**1,56%**
Public transport	**1,36%**
Cooking	**3,45%**
Eating	**7,22%**

Figure 27 PM concentrations per activity from all participants and percentage of time spent in each activity

The next interesting thing to check is the activity pattern and their PM concentrations depending on each participant. Table 22 presents the PM concentrations and hours spent doing each activity. This comparison shows the importance of each activity in the total result.

Starting with participant 3 it can be checked that the highest PM10 average value was while eating with an average of 480 µg/m^3 and 7% of his time spent on it. For that same action the PM2,5 had an average value of 60 µg/m^3. Both values are very far for the guidelines or standards from WHO and EPA. The second highest action was cooking with similar levels: 310 µg/m^3 for PM10 and 50 µg/m^3 for PM2,5. Also, too far from any stablished limit. The next highest value was watching TV with 103 µg/m^3 for PM10 and 30 for PM2,5. These values are better but still high. They are inside the EPA's limits for outbounds of WHO's guidelines. He spent 4,4% of his time watching TV. The relation between cooking eating and watching TV is clear. Cooking is the main cause of these high levels for the three activities. If we take a look at participant's 3 TMAD time-line presented in the previous section, Figure 21, it can be seen that the action of eating was always preceded by cooking. This means that all the PM generated while cooking stays in the kitchen/room for a time. If just after cooking participant 3 started eating at the same place or close to it, the exposure levels might have been the same as while cooking. In addition, TMAD responses might not be accurate in the finish time of cooking and beginning of eating.

Activities	PM00.50	PM01.00	PM02.50	PM05.00	PM10.00	% of total hours per activity	Sum of hour per activity
P3							
Eating	6,0	15,8	60,1	205,3	428,0	7,1%	7,17
Cooking	8,0	17,8	50,4	154,2	310,6	5,7%	5,83
Watching tv	2,9	8,2	29,5	73,3	103,1	4,4%	4,50
Working & Studying	1,9	3,8	9,8	23,9	39,4	31,1%	31,58
Sleeping	1,3	2,8	8,4	20,1	33,2	44,0%	44,67
Biking or Walking	0,8	1,7	5,2	15,4	31,6	4,3%	4,33
Cleaning	3,3	4,6	7,0	11,7	18,4	3,5%	3,50
P4							
Bathroom	8,8	12,5	16,7	27,1	45,5	0,9%	1,17
Biking or Walking	2,3	3,3	5,3	12,1	29,6	1,2%	1,43
Cooking	4,5	6,6	8,9	14,2	24,4	4,3%	5,33
Eating	3,1	4,3	6,1	11,4	21,9	8,2%	10,18
Working & Studying	2,1	2,9	4,5	9,5	19,1	39,5%	49,15
Watching tv	3,2	4,6	6,5	10,9	17,7	5,0%	6,25
Sleeping	3,4	4,9	6,0	8,6	14,2	36,9%	46,00
Laundry	2,6	3,2	4,2	7,6	12,5	0,3%	0,33
Cleaning	1,4	2,0	3,0	6,3	11,2	0,7%	0,83
P6							
Cooking	4,8	10,3	26,6	101,4	299,8	2,0%	1,85
Eating	6,3	16,3	49,9	142,6	269,1	4,2%	4,00
Cleaning	1,9	4,6	15,8	63,7	149,4	1,9%	1,77
Public transport	2,2	4,7	12,2	30,7	57,3	1,0%	0,98
Watching tv	0,3	0,6	2,1	15,1	44,6	2,7%	2,58
Transport by car	1,5	2,1	3,7	11,6	43,1	0,1%	0,05
Biking or Walking	2,4	3,5	6,1	16,8	43,0	2,4%	2,23
Bathroom	1,9	3,6	8,2	22,5	42,9	0,7%	0,62
Working & Studying	1,4	2,4	5,3	16,0	37,5	41,8%	39,58
Socializing	1,7	2,5	4,2	10,3	25,0	4,1%	3,85
Shopping	1,3	1,8	3,3	8,3	22,0	0,1%	0,08
Sleeping	1,0	1,5	2,1	4,1	8,9	39,2%	37,13

Table 22 PM concentrations per activity and per participant, including the time spent in each. Concentration values in µg/m^3

Watching TV, as shown in the TMAD responses, happened always after cooking and eating. Supposing that this action happened in the same apartment as where the action of cooking and eating, a passive effect might had happened. As shown in the report *A Comparison of Particulate*

Matter from Biomass-Burning Rural and Non-Biomass-Burning Urban Households in North-eastern China[22]*,* kitchens and living room's concentration of PM are strongly correlated for a passive action received by the living rooms. For participant 3, the activities of cleaning, biking or walking, sleeping and working or studying were on average always below any standard or guideline's limit.

Participant 4 had her highest average value at the bathroom where she spent almost 1% of the time. This value is not significant as the time spent is too low and the levels of PM are not high enough to be dangerous. Something interesting from participant 4 is the low concentration values for cooking and eating. 40 µg/m^{3}and 33 µg/m^3 respectively for PM10 average. Values that compared to the other participant are too low. This might be due to what the participant considered as cooking. It is clear that frying chicken nuggets cannot have the same effect on PM than preparing a César salad. She spent almost 40% of her time working or studying, during those moments she had levels of 19 µg/m^{3}for PM10 and 4,5 µg/m^3 for PM2,5. Values out of any

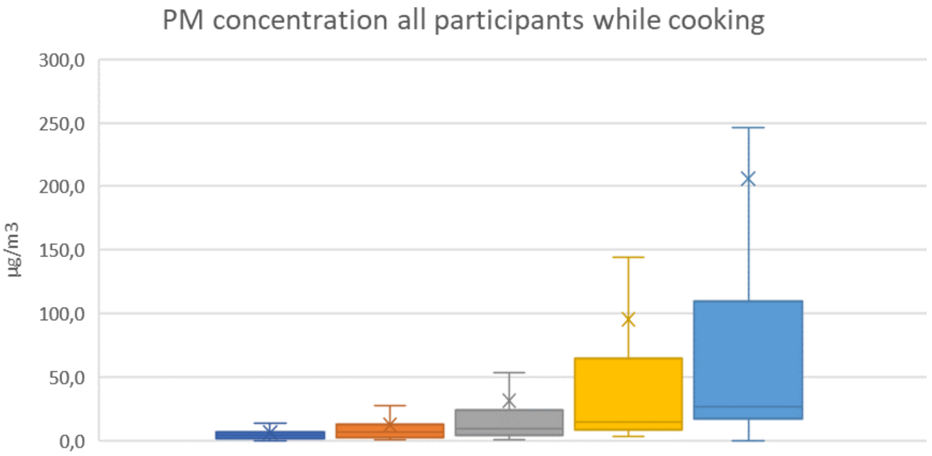


Figure 28 PM concentration while cooking from all participants.

danger zone and below any limits.

Participant 6 had his greatest concentration levels while cooking with a PM10 average of 300 µg/m^3 and 26 µg/m^3 for PM2,5. PM2,5 value for cooking is acceptable but PM10 average while cooking is too far from any value. Is two time the EPA limit for 24 hours. He spent 2 % of his time cooking and 4% eating. The eating concentration averages were also high: 270 µg/m^3 and 50 µg/m^3. Both higher that EPA's standards and WHO guideline. The high levels for the activity of eating might be caused by a passive effect of cooking as already explained. It is curious that PM10 levels are higher while cooking, but the other PM values are lower while cooking rather than eating. The third action with the highest average concentration is while cleaning with a PM10 value of 150 µg/m^3. He spent 2% of his time exposed to these levels. The last activity that overpasses the EPA's 24-h standard (50 µg/m^3) was using public transport with an average of 57 µg/m^3. The activities with the highest amount of time were working or studying and sleeping. Both activities have concentrations values below any guideline or standard.

It is interesting to compare some activities between participants. Participant 6 has the lowest level of PM (by far) while sleeping. This might be due to the difference between ventilation systems. Participant 6 had mechanical ventilation while the other participants did not (as shown in the pre-test questionnaire results). Another interesting difference, already commented, is the cooking times. Participant 6 and 3 had similarly high values which participant 4 did not. The working place from participant 4 is the cleanest in terms of PM10 with a difference of μg/m^3.

From this section we have achieved some interesting finding as the passive effect of cooking in eating times, and the high levels of PM in both activities. Also, we have checked the effectiveness of mechanical ventilation. Participant 6, the only with this type of ventilation had by far the lowest concentrations during sleeping times when all of them spent almost 40% of their time.

Some other results, which were not expected, are the low levels for cleaning measured for participant 3 and 4. Far from the 150 μg/m^3 PM10 concentration measured in participant 6, participant's 3 and 4 cleaning activities do not even reach 20 μg/m^3 in the worst case. Cleaning is usually a main source of indoor pollutants. However, a too narrow definition of what cleaning is, might be the reason why the levels are too low.

4.4.5. Time analysis

4.4.5.1. Night times and day times

Time variability is one of the main factors that affects personal exposure to pollutants. Is directly related to human activity. At night people stay sleeping at home, which means less activity, less movement, less traffic, etc. In our experiment we wanted to check if that really happened. The results match with the expectations. In the following table the PM averages during night and day are presented. These same results are plotted in the next figures showing the contribution of daily and nightly exposure to the total by participants.

Day (8h-23:59h)	*PM00.50*	*PM01.00*	*PM02.50*	*PM05.00*	*PM10.00*
P3	3,0	6,8	20,9	61,7	117,5
P4	2,7	3,8	5,8	12,0	23,1
P6	1,9	3,6	8,4	25,4	57,6

Night (0h-7:59h)	***PM00.50***	***PM01.00***	***PM02.50***	***PM05.00***	***PM10.00***
P3	**0,8**	**2,4**	**7,8**	**16,4**	**25,4**
P4	**3,6**	**5,3**	**6,4**	**9,0**	**14,6**
P6	**0,8**	**1,2**	**1,9**	**3,9**	**9,0**
Total general	***2,7***	***3,9***	***5,0***	***7,6***	***13,1***

Table 24 Night PM concentrations in μg/m^3

In case of participant 3, the average PM10 at night was 25 μg/m^3 while the daily was 117 μg/m^3. The ratio between and night and day (N/D) is 0,2. This ratio for PM2,5 is slightly higher, 0,37. Participant 4 had also lower PM10 at night with an average of 14,6 μg/m^3. During the day was 23,1 μg/m^3. This makes a ratio (N/D) of 0,6. However, for PM2,5 the average is almost the same during day and night, being the night average higher. The N/D ratio is 1,1. This ratio was not expected, but the reason why might be the low concentrations measured for participant 4. Finally, participant 6 had a nightly PM10 average of 9 μg/m^3 while the average during the day was 57 μg/m^3. The ratio for PM10 is 0,15 while for PM2,5 is 0,22. The total nightly average for PM10 was 13 μg/m^3 and 66 μg/m^3 during the day. The general N/D ratio is 0,19 for PM10 and 0,42 for PM2,5.

Generally, the PM concentrations during night is lower than the concentration during day. Our results totally agree with the expectations. Another important finding is the difference of concentrations during night times between participants. Participant 6 had the lowest with 9 μg/m³ average while participant 4 had 15 μg/m³ and participant 3, 25 μg/m³. Building characteristics such as ventilation or materials of the bedroom might be the reason for this difference. To conclude, the main idea that we take from this analysis is high effect that activity variability has on personal exposure.

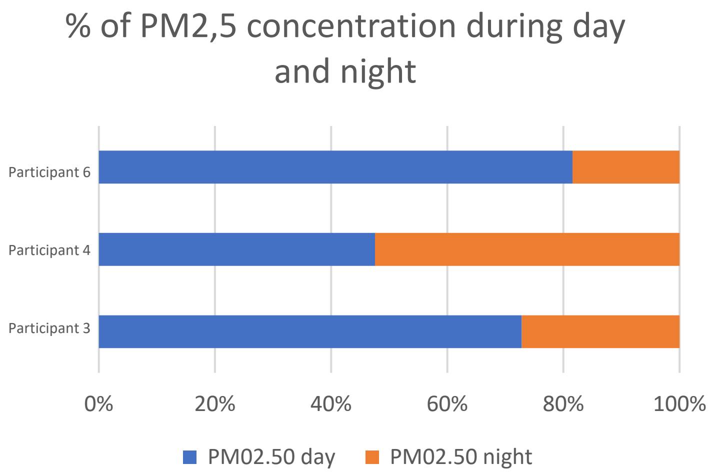


Figure 30 Percentage of PM2,5 concentration during night and day

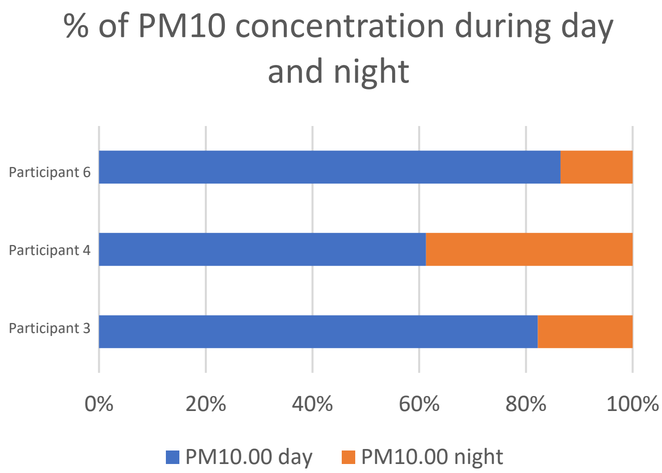


Figure 30 Percentage of PM concentration during night and day

4.4.5.2. Weekend and labour days

Usually people have different routines during weekends. How can this be related to personal exposure? In this section we do a brief analysis between concentration exposure at weekends and labour days. Each participant did the personal exposure test during two weekend days and two labour days.

Labour days	PM00.50	PM01.00	PM02.50	PM05.00	PM10.00
P3	1,7	4,5	16,0	47,7	88,7
P4	1,9	3,0	5,2	12,9	26,6
P6	2,0	3,1	5,3	14,8	38,6
Total general	1,8	3,5	8,8	25,1	51,3

Table 25 Labour days PM concentrations in μg/m³

Participants 3 and 6 were clearly affected by the change of routine. Both mean values of concentration exposure increased notoriously. In case of participant 3 the PM10 mean changed from 88 μg/m³ to 146 μg/m³ (65% higher). In PM2,5 this increase went from 16 μg/m³ to 26 μg/m³. Participant 6 had also a high increase from 38 μg/m³ to 75 μg/m³ in PM10 which means an increase of 98%. For PM2,5 the change was from 5 μg/m³ to 11 μg/m³, doubling the register. Participant's 4 measurements were actually slightly higher during the weekend. There is an existing 6 µg/m^3 difference between labour days and weekends for PM10, and 1 µg/m^3 for PM2,5, which is a minimum difference.

Generally, we have checked that the tendency during weekends is to have higher PM concentrations than during labour days. If we take a look at hour participants TMAD, most of their time during weekends was spent at home. Home as a ME was one of the most polluted ME as it can be checked back in the table Table 21.

WE days	PM00.50	PM01.00	PM02.50	PM05.00	PM10.00
P3	4,4	9,1	26,0	76,1	146,8
P4	3,3	4,5	6,3	11,2	20,2
P6	1,8	4,0	11,4	35,2	75,1
Total general	3,2	5,9	14,5	40,8	80,7

Table 26 Weekend days PM concentration levels in µg/m^3

4.5. Personal and fixed monitoring

As already mentioned in previous chapters of the report, the guidelines or standards are all based in outdoors information using fixed monitors. This may not accurately represent the personal exposure to which an individual is exposed during his day. The amount of time spent indoors, the different ME to which the individual is exposed and the proximity of the person to the source are the reasons why a personal monitoring assessment is needed.

One of our participants, participant number 6, used a second device to assess the particulate matter concentration of his house. The objective of the use of this second device was to do a comparison between fixed monitoring and personal exposure monitoring. This fixed monitor was placed in an area of his bedroom and kitchen where it was possible to do a good assessment of the air quality. This means, a place not too close to the any source, in a at a height between 0.6 and 1 meter and not too close to a ventilation hood. These locations are shown in Figure 31.

Figure 31 Position of fixed monitoring devices inside the bedroom and in the kitchen. Participant 6

During the following paragraphs is expected to have higher values in the personal monitor measurements than in the fixed monitor. Personal cloud and proximity to sources are the main two factors that can cause this difference. These assumptions are checked by analysing actions from the participant which implied being close to the source such as cooking and cleaning. Another important hypothesis to consider, which is actually related to the last affirmation, is the fact that the levels of pollutants measure during static periods tend to have a lower risk to have different results between devices. In dynamic moments, where each second implies a new condition, the results between personal and fixed might be more variable. Dynamism implies movement, which implies resuspension, hence, extra PM in the air.

In order to have a complete analysis of this part of the experiment and confirm these last hypothesis two different parts are presented:

- General comparison using statistical techniques during the two days
- Analysis per activity: cooking and cleaning

4.5.1. General comparison

In the following table the averages for PM2,5 and PM10 from both days are presented.

	PM02,50 fixed	PM2,5 personal	PM10,00 fixed	PM10 personal
Day 1	11,5	9,6	50,1	91,4
Day 2	7,6	5,6	27,8	33,3
Total general	9,4	7,4	38,2	60,3

Table 27 PM concentration personal and fixed monitoring. Concentration values in µg/m3

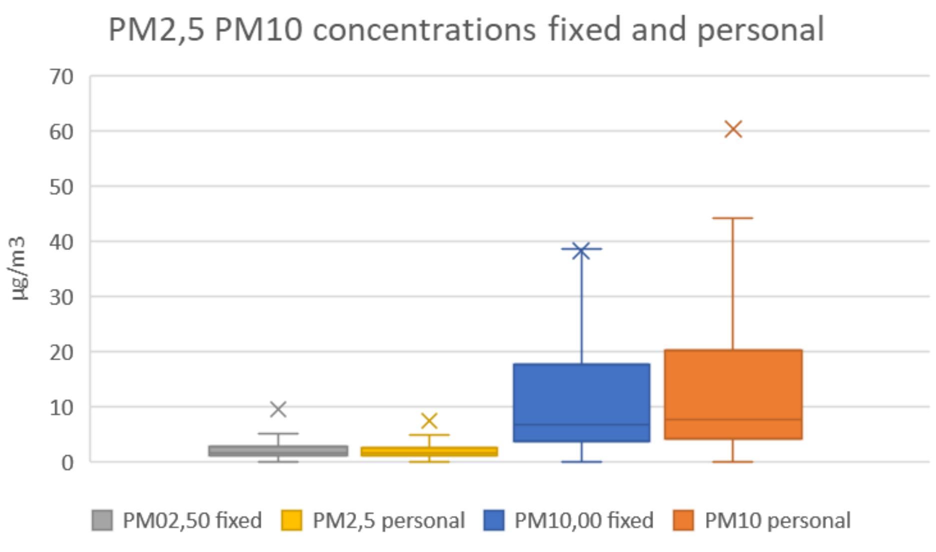


Figure 32 PM2,5 and PM10 concentrations for fixed and personal.

The PM10 concentration measures seems to be higher in the personal monitor than in the fixed monitoring. The values from PM2,5 are really similar, the fixed monitor registered a higher

average for a few more points. The medians in both types of monitoring are similar. There is only a slightly difference, being higher the median concentration for personal monitoring. This difference can be seen in the Figure 32 and it might be more representative than the mean. In the next

Table 28 the percentiles for each channel are presented for the entire two days. It can be observed that the values between devices are quite similar. It is difficult to take any conclusion from it. However, this shows a general behaviour. The stationary moments have higher time

PM00,50 fixed	PM 0,5 personal	PM01,00 fixed	PM 1,0 personal	PM02,50 fixed	PM2,5 personal	PM05,00 fixed	PM5,0 personal	PM10,00 fixed	PM10 personal	
0,60	0,62	0,82	0,84	1,10	1,05	1,69	1,59	2,99	2,98	Percentile 25
0,79	0,77	1,38	1,21	2,44	1,94	4,13	3,55	5,51	6,93	Percentile 50
1,61	1,43	3,57	3,20	8,53	7,69	18,04	17,11	26,08	29,62	Percentile 75
6,98	4,82	20,13	13,21	52,56	34,22	91,40	63,50	102,86	110,23	Percentile 95

budget which means higher weight in this kind of statistics. In addition, a minimal difference in the any of the factors that affect the measures, can be the cause of this small non-expected difference between fixed and personal concentrations. In the activity moments where the individual is moving, cooking or cleaning, the results might be more conclusive.

Table 28 Percentiles for PM concentration for personal and fixed monitoring. Concentration values in µg/m^3

	PM10,00 fixed	***PM10 personal***	***Difference***
Mean	38,2	60,3	37%
Median	6,7	7,6	11%
Standard deviation	208,2	717,2	71%

Table 29 Difference between PM10 fixed and personal values. Concentration values in µg/m3

In terms of PM10, there is a big difference between personal and fixed monitoring. Almost a 40% in the average, and an 11% in the median which might be more representative. The standard deviation of the personal measurements is higher than in fixed monitoring, due to the existence of higher peaks.

In the following table an R analysis is done to check the correlation between variables. The table has three parts to mention. The two corners (at the right and the upper side), and the part inside the orange box. The information of both corners might not be interesting to our analysis as it shows the relation between channels from the same device, and obviously: the more similar the diameter size is, the higher the correlation is. However, it is curious to see how between the channels from the personal device there is lower correlation than between the channels from the fixed monitoring. The area inside the orange box is the most interesting part of the table and shows the correlation between the channels from the fixed and the personal monitor.

	PM00,50 fixed	*PM01,00 fixed*	*PM02,50 fixed*	*PM05,00 fixed*	*PM10,00 fixed*	*PM 0,5 personal*	*PM 1,0 personal*	*PM2,5 personal*	*PM5,0 personal*	*PM10 personal*
PM00,50 fixed	1,00									
PM01,00 fixed	0,94	1,00								
PM02,50 fixed	0,84	0,97	1,00							
PM05,00 fixed	0,83	0,93	0,98	1,00						
PM10,00 fixed	0,80	0,88	0,92	0,98	1,00					
PM 0,5 personal	0,77	0,70	0,61	0,61	0,59	1,00				
PM 1,0 personal	0,81	0,75	0,66	0,68	0,67	0,97	1,00			
PM2,5 personal	0,76	0,72	0,64	0,68	0,70	0,83	0,93	1,00		
PM5,0 personal	0,55	0,51	0,46	0,51	0,53	0,60	0,70	0,87	1,00	
PM10 personal	0,21	0,20	0,18	0,20	0,21	0,24	0,30	0,48	0,82	1

Table 30 Correlation factor R between fixed and personal monitoring.

Generally, both sensors seem to be correlated. The smaller the particles are, the higher the relation is. PM10 from the personal device seems not to have almost any relation with the measurements from the fixed device. A possible answer to this fact is the behaviour of the particles. Firstly, the particles close to any source are all more compact among them, and in further areas they stay more dispersed -as in the location of the fixed monitor- using all the room’s available space. Secondly, the bigger the particle is, the greater the effect of gravity and deposition is. This means that the emitted particles could have not reached the area of the fixed monitor.

4.5.2. Cleaning

Cleaning	PM10,00 fixed	PM10 personal	Difference
Mean	69,2	163,0	58%
Median	43,6	86,7	50%
Standard deviation	63,3	209,9	70%
Maximum	318,0	1017,4	69%

Table 31 Difference between fixed and personal monitoring for PM10. Concentration values in µg/m3

During the second day of measurement participant 6 spent around 2 hours cleaning his apartment. He used detergent and chemical products to clean the bathroom and a vacuum cleaner for the rest of the apartment. The concentration level average, during the use of the chemical products, raised to around 50 µg/m^3 in the personal monitor (PM10). When using the vacuum machine, the average reached 240 µg/m^3, having peaks of more than 1000 µg/m^3. Considering all type of cleaning as the same action, the average of the activity was 163 µg/m^3 in the personal monitor, and 69 µg/m^3 in the fixed monitor. A difference of 50% between medians shows the influence of measuring close to the source. This medians difference, might be one of the most conclusive results taken from all the experiment and is shown in Figure 33. A maximum value of 1000 µg/m^3 was measured with the personal monitor, 70% higher than the measured peak with the fixed monitor. These results are representative as there is no existence of any possible outlier as it could happen in the case of cooking. Table 32 shows the correlation factor (R) between fixed and personal monitoring while cleaning and summarizes the lack of correlation.

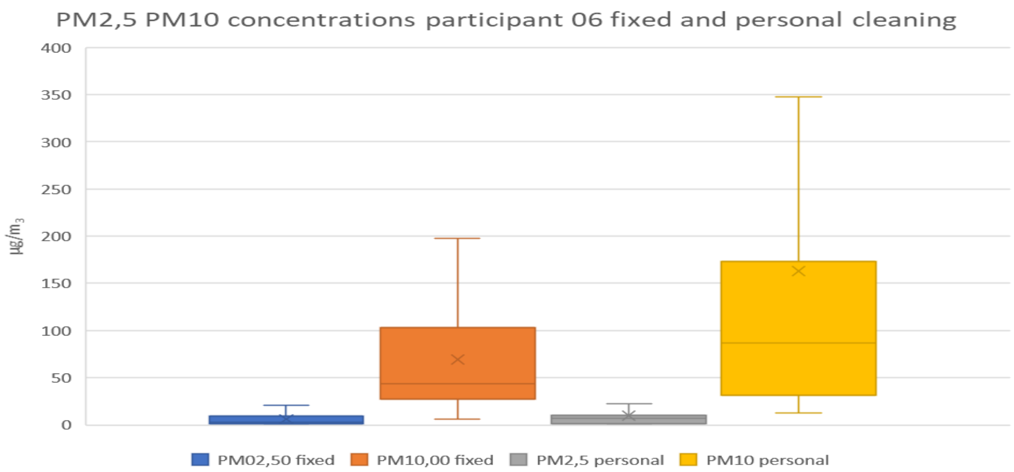


Figure 33 PM 2,5 and PM10 concentrations for fixed and personal monitoring while cleaning. Concentration values in µg/m3

Cleaning R value	*PM00,50 fixed*	*PM01,00 fixed*	*PM02,50 fixed*	*PM05,00 fixed*	*PM10,00 fixed*
PM 0,5 personal	0,44	0,39	0,38	0,40	0,34
PM 1,0 personal	0,38	0,35	0,35	0,36	0,30
PM2,5 personal	0,38	0,34	0,34	0,37	0,32
PM5,0 personal	0,38	0,30	0,30	0,35	0,35
PM10 personal	0,26	0,15	0,14	0,20	0,27

Table 32 Correlation factor R between fixed and personal monitoring while cleaning

Table 33 Correlation factor R between fixed and personal monitoring while cooking

4.5.3. Cooking personal vs fixed

R-Value cooking	***PM00,50 fixed***	***PM01,00 fixed***	***PM02,50 fixed***	***PM05,00 fixed***	***PM10,00 fixed***
PM 0,5 personal	0,70	0,70	0,64	0,59	0,54
PM 1,0 personal	0,76	0,79	0,74	0,70	0,66
PM2,5 personal	0,73	0,77	0,74	0,71	0,70
PM5,0 personal	0,46	0,50	0,49	0,48	0,49
PM10 personal	0,11	0,13	0,14	0,14	0,15

The correlation table (Table 33) shows the independency between variables. Personal PM10 is not explained by fixed PM10. The mean is 50% higher in the case of the personal assessment and the median 6% higher. Again, the values in the personal measurements were more dispersed.

Cooking	*PM10,00 fixed*	*PM10 personal*	*Difference*
Mean	365,7	727,3	50%
Median	101,39	108,329534	6%
Standard deviation	730,8	3040,2	76%

Table 34 Difference between fixed and personal monitoring while cleaning

It is interesting to also check the percentile for each size of particles. In almost every case, every percentile is higher in the personal measurements than in the fixed. In case of PM5 an PM2,5 the values are almost the same between devices.

In the Figure 36, the values from personal monitoring and from fixed monitoring are represented, as well as the tendency line and the R^2 value between them. Even though the fact that the R^2 value between PM10 from personal and fixed monitoring is too low to be considered correlated, the disposition of the points shows us a different idea. There is a possibility that these low values of correlation between PM10 and the rest of measurements, are caused by the existence of non-representative outliers. Values too high that can be biasing the final results.

To check it, the highest peaks are eliminated. The results are presented in Figure 34. At the left the concentration levels with all the cooking data. At the right the same data without the possible outliers. The average from the personal measurements gets closer to the fixed device.

PM00,50 fixed	PM 0,5 personal	PM01,00 fixed	PM 1,0 personal	PM02,50 fixed	PM2,5 personal	PM05,00 fixed	PM5,0 personal	PM10,00 fixed	PM10 personal	
2,9	**3,6**	**6,3**	**7,5**	**18,2**	**17,8**	**40,6**	**36,1**	**58,6**	**64,1**	Percentile 25
6,2	**6,4**	**12,2**	**12,5**	**25,2**	**23,3**	**60,0**	**56,4**	**101,4**	**108,3**	Percentile 50
16,1	**14,7**	**43,5**	**40,0**	**137,3**	**132,2**	**329,0**	**385,9**	**441,0**	**642,1**	Percentile 75
32,2	**24,2**	**88,6**	**74,5**	**272,9**	**249,6**	**707,3**	**830,8**	**1030,7**	**1446,7**	Percentile 95

Table 35 Percentiles for PM concentration for personal and fixed monitoring while cooking. Concentration values in µg/m3

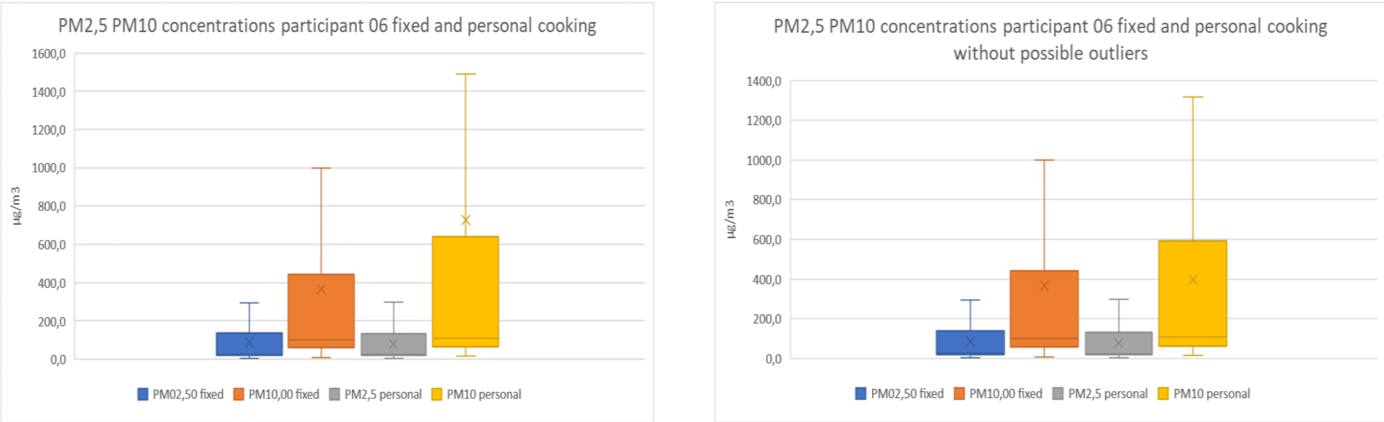


Figure 34 PM2,5 and PM10 concentrations from personal and fixed monitoring. Left figure with all the existing data, right figure without the outliers

Probably this information is nor more reliable. However, it is still showing an existing difference between personal and fixed monitoring. The question now is: ¿are these values real outliers? Or, ¿should them be taken into account? To answer this question, it might be necessary to do a deeper analysis on how do the sensors work. ¿Which physical mechanism do the sensor uses to measure the size of each particle? ¿can this mechanism be biased by vapor giving wrong results?

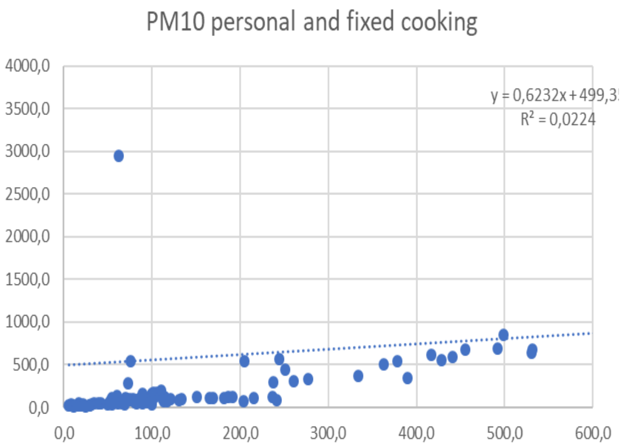


Figure 36 PM10 personal and fixed concentration while cooking

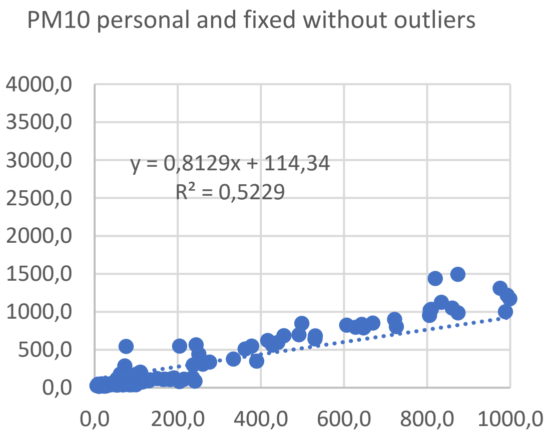


Figure 36 PM10 personal and fixed concentrations without outliers

One way or the other, we came to the following conclusions during this analysis:

- Personal and fixed monitoring are affected by several factors which are not easy to control.

- Generally, there is a difference between measurements and this difference is bigger with bigger sizes of particles.
- There are possible outliers that might be biasing the final results. However, even when getting rid of these possible outliers, the results conclude that the air concentrations measured by each type of monitoring system are different.
- The results during the cleaning times can be conclusive due to the clear difference and the strength of the used data. There are no possible outliers.
- Proximity to the source and personal cloud are the main factors that affect this difference of measurements. Being the first factor clearly demonstrated in our experiment.

5. CONCLUSIONS

It has been confirmed that the lifestyle can affect considerably the personal exposure to particulate matter. Space and time variability are two main factors to take into account when assessing this issue. During the experiment these two variables have been checked by analysing the time activity pattern of the participants. Three participants wore an adapted particle counter during 4 days, 24 hours a day to measure their personal exposure to PM. They were asked to fill continuously a time activity diary which gave the researchers enough information to confirm the PM exposure dependency on lifestyle.

The first interesting result was to confirm the high percentage of time that the participants spent indoor, and more precisely at their house. In general, they spent a 95% of their time indoors. Which proves the necessity to focus more attention in indoors' air quality. Sleeping and working (or studying) were the activities in which the participants spent the most of their time. They spent around 40% of their time in each of these two activities. Activity pattern and microenvironment use are totally connected. When analysing the TMAD test, one important conclusion to highlight is the high variability of different spaces that the participants faced during their days. This variability means an also enormous complexity to correctly asses all the different levels of exposure in each ME. The PM levels at indoor microenvironments were usually higher than the measured values outdoors. The main source of indoor PM was the activity of cooking, having the activity of cleaning a considerable importance in some cases too. Eating was also linked to high levels of exposure. This shows the passive effect of cooking as a source of pollutants. Cooking not only pollutes the kitchen area but also the rest of the apartment. At night-times the measured levels of PM were always lower and less variable than during the day. This shows the dependency of PM on humans' activities and movement. Doing the analysis between labour days and weekends it was proved that, depending on the routine, the exposure can highly variate as it did in cases of participant 3 and 6.

A final analysis was done doing a comparison between personal and fixed monitoring to asses PM exposure. One of the participants wore a personal PM sensor during the same two days that a fixed PM monitor was placed in his house. The results were satisfactory and, as expected, it proved an existing difference between both methods, being more reliable and accurate the personal monitoring. A lot of different factors, which are not easy to control, affected both types of measurements. Ventilation, occupancy, weather, proximity to sources, particle size or personal cloud are some of these influencing factors. Proximity to source effect was clearly proved with the analysis between personal and fixed monitors while cooking and cleaning. While cooking, the results shown a low correlation between both measurements. This low correlation could be explained by the existence of too high values that could possibly be considered as outliers. When doing so, and excluding these values, the correlation became higher. The question to answer after this experiment is if these values should be considered as outliers or if these values are totally related to real cooking exposure to PM. While cleaning the results were conclusive due to the clear difference between personal and fixed measurements and the strength of the used data.

To sum up, this experiment allowed the team of researchers to prove the dependency of the personal exposure to PM on lifestyle. In addition, they could confirm the difference between using a personal and a fixed monitor system to assess personal exposure.

5.1. Limitations of the study and future improvements

The experiment had some limitations. Firstly, a probable biased data taken from the TMAD from the users was used. Some of the responses were incoherent or not accurate enough to give conclusive results. Three participants were able to complete the experiment. This number of participants might not be big enough to achieve general conclusions to greater groups of population. In addition, the data taken was limited to periods of only 4 days. A drawback during the experiment was the noise that the used devices generated constantly. Some of the participants had concerns about it. The team of researches tried, as much as they could, to make the particle counter device the most friendly-user to the participants. However, the noise created by the devices was still too annoying for the user. Another important limitation was the use of a non-appropriate tubing system in the inner of the sensor. Even though that a calculated correction factor was used, the data gathered might not be totally precise. In terms of the data analysis, the generated data was too big to have a fluent manageable use of it using Microsoft Excel. For future experiments it is recommendable to use more modern and advanced big data techniques. In order to achieve further conclusions, it would be interesting to take a larger population and more subgroups of types of people. This would add interesting information to the study. In addition, it would be interesting to analyse more different types of pollutants rather than only particulate matter. For doing so, more sensor would be necessary. This experiment was limited to particulate matter measurements as the group of researchers has only access to this pollutant sensor device.

6. REFERENCES

1. Ambient (outdoor) air quality and health. Available at: https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health. (Accessed: 29th March 2019)

2. *World Health Organization (WHO). Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease; World Health Organization (WHO): Geneva, Switzerland, 2016; ISBN 9789241511353.*

3. Health and Environment Chapter of the OECD Environmental Outlook to 2050: The Consequences of Inaction - OECD. Available at: https://www.oecd.org/env/indicators-modelling-outlooks/healthenvchapter-environmentaloutlookto2050.htm. (Accessed: 30th March 2019)

4. GBD 2016 Risk Factors Collaborators, E. *et al.* Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet (London, England)* **390**, 1345–1422 (2017).

5. Shimer, D., Phillips, T. & Jenkins, P. Report to the California Legislature INDOOR: INDOOR AIR POLLUTION IN CALIFORNIA. *Purs. to Heal. Saf. Code 39930* **39930**, 1–363 (2005).

6. EXPOSURE | meaning in the Cambridge English Dictionary. Available at: https://dictionary.cambridge.org/dictionary/english/exposure. (Accessed: 2nd May 2019)

7. Sexton, K. & Hattis, D. Assessing cumulative health risks from exposure to environmental mixtures - three fundamental questions. *Environ. Health Perspect.* **115**, 825–32 (2007).

8. Klepeis, N. E. *et al. The National Human Activity Pattern Survey (NHAPS) A Resource for Assessing Exposure to Environmental Pollutants*.

9. Steinle, S. *et al.* Personal exposure monitoring of PM2.5 in indoor and outdoor microenvironments. *Sci. Total Environ.* **508**, 383–394 (2015).

10. Schweizer, C. *et al.* Indoor time-microenvironment-activity patterns in seven regions of Europe. *J. Expo. Sci. Environ. Epidemiol.* **17**, 170–181 (2007).

11. WHO. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. *World Heal. Organ.* **WHO/SDE/PH**, 5–18 (2005).

12. Health Effects Institute. Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of particulate air pollution and mortality. *A Spec. Rep. Institute's Part. Epidemiol. Reanalysis* 97 (2000).

13. Krewski, D. *et al.* Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. *Res. Rep. Health. Eff. Inst.* 5-114; discussion 115–36 (2009).

14. Dockery DW et al. *An association between air pollution and mortality in six U.S. cities*. (1993).

15. CFTC. National Ambient Air Quality Standards for Particulate Matter EPA. Rules and regulations. **78**, 1–57 (2013).

16. Wang, B., Wang, Z., Wei, Y., Wang, F. & Duan, X. Highlights of the Exposure Factors Handbook. 15–21 (2011). doi:10.1016/b978-0-12-803125-4.00012-2

17. Mann, W. B. *Report of the task group on reference man*. *The International Journal of Applied Radiation and Isotopes* **28**, (2002).

18. Brochu, P., Bouchard, M. & Haddad, S. Physiological Daily Inhalation Rates for Health Risk Assessment in Overweight/Obese Children, Adults, and Elderly. *Risk Anal.* **34**, 567–582 (2014).

19. Arcus-Arth, A. & Blaisdell, R. J. Statistical Distributions of Daily Breathing Rates for Narrow Age Groups of Infants and Children. *Risk Anal.* **27**, 97–110 (2007).

20. Marques, G., Pitarma, R., Marques, G. & Pitarma, R. An Indoor Monitoring System for Ambient Assisted Living Based on Internet of Things Architecture. *Int. J. Environ. Res. Public Health* **13**, 1152 (2016).

21. Logue, J. M., Klepeis, N. E., Lobscheid, A. B. & Singer, B. C. Pollutant Exposures from Natural Gas Cooking Burners: A Simulation-Based Assessment for Southern California. *Environ. Health Perspect.* **122**, 43–50 (2014).

22. Jiang, R. & Bell, M. L. A Comparison of Particulate Matter from Biomass-Burning Rural and Non-Biomass-Burning Urban Households in Northeastern China. *Environ. Health Perspect.* **116**, 907–914 (2008).

23. Pellizzari, E. D., Thomas, K. W., Clayton, C. A., Whitmore, R. W. & Shores, R. C. Particle total exposure assessment methodology (PTEAM): Riverside california pilot study. Volume 1. Final report. (1992).

24. Clayton, C. A. *et al.* Particle Total Exposure Assessment Methodology (PTEAM) study: distributions of aerosol and elemental concentrations in personal, indoor, and outdoor air samples in a southern California community. *J. Expo. Anal. Environ. Epidemiol.* **3**, 227–50 (1993).

25. Schipperijn, J. *et al.* Contribution of various microenvironments to the daily personal exposure to ultrafine particles: Personal monitoring coupled with GPS tracking. *Atmos. Environ.* **110**, 122–129 (2015).

26. Geller, M. D., Chang, M., Sioutas, C., Ostro, B. D. & Lipsett, M. J. Indoor/outdoor relationship and chemical composition of fine and coarse particles in the southern

California deserts. *Atmos. Environ.* **36**, 1099–1110 (2002).

27. Pagel, É. C. *et al.* Characterization of the indoor particles and their sources in an Antarctic research station. *Environ. Monit. Assess.* **188**, 167 (2016).

28. Jantunen, M. J. *et al.* Air Pollution in European Cities: the EXPOLIS Study, Final Report. **EU contrac**, (1999).

29. Quiros, D. C., Lee, E. S., Wang, R. & Zhu, Y. Ultrafine particle exposures while walking, cycling, and driving along an urban residential roadway. *Atmos. Environ.* **73**, 185–194 (2013).

30. Parikh, J., Balakrishnan, K., Laxmi, V. & Biswas, H. Exposure from cooking with biofuels: pollution monitoring and analysis for rural Tamil Nadu, India. *Energy* **26**, 949–962 (2001).

31. Nicole, W. Cooking Up Indoor Air Pollution: Emissions from Natural Gas Stoves. *Environ. Health Perspect.* **122**, (2014).

32. Dennekamp, M. *et al.* Ultrafine particles and nitrogen oxides generated by gas and electric cooking. doi:10.1136/oem.58.8.511

33. Cortese, A. D. & Spengler, J. D. Ability of Fixed Monitoring Stations to Represent Personal Carbon Monoxide Exposure. *J. Air Pollut. Control Assoc.* **26**, 1144–1150 (1976).

34. Stock, T. H. *et al.* The Estimation of Personal Exposures to Air Pollutants for a Community-Based Study of Health Effects in Asthmatics-Design and Results of Air Monitoring. *J. Air Pollut. Control Assoc.* **35**, 1266–1273 (1985).

35. Sloan, C. D. *et al.* Applications of GPS-tracked personal and fixed-location PM 2.5 continuous exposure monitoring. *J. Air Waste Manage. Assoc.* **66**, 53–65 (2016).

36. Graywolf Particle Counter 3500. 3500

37. Rawson, P. PART II. Techniques. *Ceramics* (2014). doi:10.9783/9780812207347.23

38. Bruce, N. *et al.* WHO indoor air quality guidelines on household fuel combustion: Strategy implications of new evidence on interventions and exposure–risk functions. *Atmos. Environ.* **106**, 451–457 (2015).

39. Data of the previous 30 days NABEL: Particulate matter (PM10). Available at: https://www.bafu.admin.ch/bafu/en/home/topics/air/state/data/historical-data/nabel--daily-values-of-the-previous-30-days/werte-der-letzten-30-tage-nabel--feinstaub--pm10-.html. (Accessed: 5th June 2019)

7. APPENDIX

7.1. APPENDIX A

7.1.1. Participant 2 Pre-test

I. BASIC INFORMATION ABOUT PARTICIPANTS

How old are you? ________24

What is your gender? Male☐X Female☐

What is your education level? University degree☐X high school☐ other ____

How many people live in the apartment? ________3 _______

a. Age of others: _____________21 and 22 _

Floor area of your apartment: ________ m17 2

On which floor do you live? ________2nd

How long have you been living in this apartment? ________years1

II. BUILDING CHARACTERISTICS

What type of heating system do you have?

Radiators ☐

Radiant walls ☐

Radiant floor/ceiling ☐X

Flooring materials in your apartment:

Rooms: PVC☐ wooden floor☐ carpet☐X cork☐X other______

Kitchen: PVC☐ wooden floor☐ tiles☐X cork☐ other______

Bathroom: PVC☐ wooden floor☐ tiles☐X cork☐ other______

Hallway: PVC☐ wooden floor☐ tiles☐ cork☐ other______Carpet

Types of surface layers on your walls:

Rooms: wallpaper☐ paint☐X tiles☐ other __________

Kitchen: wallpaper☐ paint☐X tiles☐ other __________

Bathroom: wallpaper☐ paint☐ tiles☐X other __________

Hallway: wallpaper☐ paint☐X tiles☐ other __________

III. BASIC HABITS OF OCCUPANTS

- Smoking

Do you have any smokers in your apartment? Yes▢X No▢

If yes, where does he/she smoke?

On balcony▢X In kitchen▢ In bathroom▢ In rooms▢ Outside▢

- Houseplants

  Do you have any houseplant in your apartment? Yes▢ No▢X
  How many plants do you have in your apartment? 1 - 5▢ 6 - 10▢ More than 10▢

- Cooking

How often do you cook?

Never▢ 2x – 3x per week▢X Every day▢ Other__________

Which type of stove do you use? Gas ▢ Electric▢X

- Pets

Do you have any pets in your apartment? Yes▢ No▢X

If yes, which type of pets do you have? Cat▢ Dog▢ Bird▢ Other__________

- Cleaning

How often do you clean up the floor in your apartment?

Every day▢ 1x/week▢ 2x – 3x/week▢X Other_________

Do you use cleaning detergents? Yes▢X No▢

Do you use the following devices in your apartment? If yes, please tick which one.x

Vacuum cleaner▢ Humidifier▢ Dehumidifier▢ Air cleaners▢ Fans▢

- Window opening

Do you keep opened the windows in your bedroom at night? Never▢ Sometimes ▢X Often▢

How long do you usually keep the windows opened at night?

▢Less than 2 minutes/day ▢2 - 5 minutes/day ▢ 5 - 10 minutes/day

▢10 - 30 minutes/day ▢30 – 60 minutes/day ▢X more than one hour

- Transportation

What type of transportation mode do you regularly use?

Walking ▢X Car ▢

Bicycle ▢X Public transportation ▢X

How often do you use it?

Every day ▢X 1x/week ▢ 2x – 3x/week ▢ Other_________

VI. NEIGHBOURHOOD CHARACTERISTICS

Where is your residence located?

In the city center ▢

In suburban areas ▢X

Other__________________

Is your residence near to a highly transited street?

Yes ▢

No ▢X

Are there industries/fabrics in your neighbourhood?

Yes ▢X

No ▢

7.1.2. Participant 3 Pre-test

BASIC INFORMATION ABOUT PARTICIPANTS

1. How old are you? _______26
2. What is your gender? Male/ Female
3. What is your education level? University degree/ high school other ____
4. How many people live in the apartment? _______2 ______
5. a. Age of others: ___________28 _
6. Floor area of your apartment: _______ m80 2

   On which floor do you live? _______8

How long have you been living in this apartment? _______years1/2

BUILDING CHARACTERISTICS

What type of heating system do you have?

Radiators

Radiant walls

Radiant floor/ceiling ☐/

Flooring materials in your apartment:

Rooms: PVC☐ wooden floor☐/ carpet☐ cork☐ other______

Kitchen: PVC☐ wooden floor☐ tiles☐/ cork☐ other______

Bathroom: PVC☐ wooden floor☐ tiles☐/ cork☐ other______

Hallway: PVC☐ wooden floor☐ tiles☐/ cork☐ other______

Types of surface layers on your walls:

Rooms: wallpaper☐ paint☐/ tiles☐ other __________

Kitchen: wallpaper☐ paint☐/ tiles☐ other __________

Bathroom: wallpaper☐ paint☐ tiles☐/ other __________

Hallway: wallpaper☐ paint☐/ tiles☐ other __________

BASIC HABITS OF OCCUPANTS

Smoking

11. Do you have any smokers in your apartment? Yes☐ No☐/ 12. If yes, where does he/she smoke?

13. On balcony☐ In kitchen☐ In bathroom☐ In rooms☐ Outside☐

- Houseplants

Do you have any houseplant in your apartment? Yes☐/ No☐

How many plants do you have in your apartment? 1 - 5☐/ 6 - 10☐ More than 10☐

Cooking

How often do you cook?

Never☐ 2x – 3x per week☐ Every day☐/ Other__________

Which type of stove do you use? Gas ☐ Electric☐/

Pets

Do you have any pets in your apartment? Yes☐ No☐/

If yes, which type of pets do you have? Cat☐ Dog☐ Bird☐ Other__________

Cleaning

How often do you clean up the floor in your apartment?

Every day☐ 1x/week☐/ 2x – 3x/week☐ Other_________

Do you use cleaning detergents?Yes☐ No☐/

Do you use the following devices in your apartment? If yes, please tick which one. Vacuum cleaner☐/ Humidifier☐ Dehumidifier☐ Air cleaners☐ Fans☐

Window opening

Do you keep opened the windows in your bedroom at night? Never☐ Sometimes ☐/ Often☐

How long do you usually keep the windows opened at night?

☐Less than 2 minutes/day ☐/ 2 - 5 minutes/day ☐ 5 - 10 minutes/day

☐10 - 30 minutes/day ☐30 – 60 minutes/day ☐more than one hour

Transportation

What type of transportation mode do you regularly use?

Walking ☐/Car ☐

Bicycle ☐ Public transportation ☐

How often do you use it?

Every day ☐/ 1x/week ☐ 2x – 3x/week ☐ Other_________

VI. NEIGHBOURHOOD CHARACTERISTICS

Where is your residence located?

In the city center ☐

In suburban areas ☐/

Other__________________

Is your residence near to a highly transited street?

Yes ☐/

No ☐

Are there industries/fabrics in your neighbourhood?

Yes ☐/

No ☐

7.1.3. Participant 4 Pre-test

I. BASIC INFORMATION ABOUT PARTICIPANTS

How old are you? _______32

What is your gender? Male Femalex

What is your education level? University degreex high school other ____

How many people live in the apartment? _______3 ______

a. Age of others: ___________25 _

Floor area of your apartment: _______ m90 2

On which floor do you live? _______5th

How long have you been living in this apartment? _______years6 months

II. BUILDING CHARACTERISTICS

What type of heating system do you have?

Radiators x

Radiant walls

Radiant floor/ceiling

Flooring materials in your apartment:

Rooms: PVC wooden floorx carpet cork other______

Kitchen: PVC wooden floor tilesx cork other______

Bathroom: PVC wooden floor tilesx cork other______

Hallway: PVC wooden floorx tiles cork other______

Types of surface layers on your walls:

Rooms: wallpaper paintx tiles other __________

Kitchen: wallpaper paintx tilesx other __________

Bathroom: wallpaper paint tilesx other __________

Hallway: wallpaper paintx tiles other __________

III. BASIC HABITS OF OCCUPANTS

- Smoking

Do you have any smokers in your apartment? Yesx No

If yes, where does he/she smoke?

On balcony In kitchenx In bathroom In rooms Outsidex

- Houseplants

Do you have any houseplant in your apartment? Yes☐x No☐

How many plants do you have in your apartment? 1 - 5☐ 6 - 10☐x More than 10☐

- Cooking

How often do you cook?

Never☐ 2x – 3x per week☐x Every day☐ Other__________

Which type of stove do you use? Gas ☐ Electric☐x

- Pets

Do you have any pets in your apartment? Yes☐ No☐x

If yes, which type of pets do you have? Cat☐ Dog☐ Bird☐ Other__________

- Cleaning

How often do you clean up the floor in your apartment?

Every day☐ 1x/week☐ 2x – 3x/week☐ Other_________every 2 weeks

Do you use cleaning detergents? Yes☐x No☐

Do you use the following devices in your apartment? If yes, please tick which one.

Vacuum cleaner☐x Humidifier☐ Dehumidifier☐ Air cleaners☐ Fans☐

- Window opening

Do you keep opened the windows in your bedroom at night? Never☐ Sometimes ☐x Often☐

How long do you usually keep the windows opened at night?

☐Less than 2 minutes/day ☐2 - 5 minutes/day ☐ 5 - 10 minutes/day

☐10 - 30 minutes/day ☐x 30 – 60 minutes/day ☐more than one hour

- Transportation

What type of transportation mode do you regularly use?

Walking ☐ Car ☐

Bicycle ☐ Public transportation ☐x

How often do you use it?

Every day ☐ 1x/week ☐ 2x – 3x/week ☐x Other_________

VI. NEIGHBOURHOOD CHARACTERISTICS

Where is your residence located?

In the city center ☐x

In suburban areas ☐

Other__________________

Is your residence near to a highly transited street?

Yes ☐x

No ☐

Are there industries/fabrics in your neighbourhood?

Yes ☐x

No ☐

7.1.4. Participant 6 Pre-test

I. BASIC INFORMATION ABOUT PARTICIPANTS

How old are you? ____24__

What is your gender? Male☐ Female☐

What is your education level? University degree☐ high school☐ other ____

How many people live in the apartment? _____________

a. Age of others: ____________

Floor area of your apartment: _______ m2

On which floor do you live? _______

How long have you been living in this apartment? _______years

II. BUILDING CHARACTERISTICS

What type of heating system do you have?

Radiators ☐

Radiant walls ☐

Radiant floor/ceiling ☐

Flooring materials in your apartment:

Rooms: PVC☐ wooden floor☐ carpet☐ cork☐ other______

Kitchen: PVC☐ wooden floor☐ tiles☐ cork☐ other______

Bathroom: PVC☐ wooden floor☐ tiles☐ cork☐ other______

Hallway: PVC☐ wooden floor☐ tiles☐ cork☐ other______

Types of surface layers on your walls:

Rooms: wallpaper☐ paint☐ tiles☐ other __________

Kitchen: wallpaper☐ paint☐ tiles☐ other __________

Bathroom: wallpaper☐ paint☐ tiles☐ other __________

Hallway: wallpaper☐ paint☐ tiles☐ other __________

III. BASIC HABITS OF OCCUPANTS

- Smoking

Do you have any smokers in your apartment? Yes☐ No☐

If yes, where does he/she smoke?

On balcony☐ In kitchen☐ In bathroom☐ In rooms☐ Outside☐

- Houseplants

14. Do you have any houseplant in your apartment? Yes☐ No☐

15. How many plants do you have in your apartment? 1 - 5☐ 6 - 10☐ More than 10☐

- Cooking

How often do you cook?

Never☐ 2x – 3x per week☐ Every day☐ Other__________

Which type of stove do you use? Gas ☐ Electric☐

- Pets

Do you have any pets in your apartment? Yes☐ No☐

If yes, which type of pets do you have? Cat☐ Dog☐ Bird☐ Other__________

- Cleaning

How often do you clean up the floor in your apartment?

Every day☐ 1x/week☐ 2x – 3x/week☐ Other_________

Do you use cleaning detergents? Yes☐ No☐

Do you use the following devices in your apartment? If yes, please tick which one.

Vacuum cleaner☐ Humidifier☐ Dehumidifier☐ Air cleaners☐ Fans☐

- Window opening

Do you keep opened the windows in your bedroom at night? Never☐ Sometimes ☐ Often☐

How long do you usually keep the windows opened at night?

☐Less than 2 minutes/day ☐2 - 5 minutes/day ☐ 5 - 10 minutes/day

☐10 - 30 minutes/day ☐30 – 60 minutes/day ☐more than one hour

- Transportation

What type of transportation mode do you regularly use?

Walking ☐ Car ☐

Bicycle ☐ Public transportation ☐

How often do you use it?

Every day ☐ 1x/week ☐ 2x – 3x/week ☐ Other_________

VI. NEIGHBOURHOOD CHARACTERISTICS

Where is your residence located?

In the city center ☐

In suburban areas ☐

Other__________________

Is your residence near to a highly transited street?

Yes ☐

No ☐

Are there industries/fabrics in your neighbourhood?

Yes ☐

No ☐

7.2. APPENDIX B Visual Basic code

```
Function buscar_actividad(fecha, hora, persona)

    Worksheets("tabla 2").Activate

    For i = 1 To 257

        fecha_aux = ThisWorkbook.Sheets("tabla 2").Cells(i, 5).Value
        persona_aux = ThisWorkbook.Sheets("tabla 2").Cells(i, 13).Value
        init = ThisWorkbook.Sheets("tabla 2").Cells(i, 6).Value
        fin = ThisWorkbook.Sheets("tabla 2").Cells(i, 7).Value

        If (fecha = fecha_aux) And (persona = persona_aux) And (hora > init And hora < fin) Then
            buscar_actividad = ThisWorkbook.Sheets("tabla 2").Cells(i, 4).Value
              Exit For


        ElseIf (fecha = fecha_aux) And (persona = persona_aux) And (hora > init And hora > fin And
init > fin) Then
            buscar_actividad = ThisWorkbook.Sheets("tabla 2").Cells(i, 4).Value
              Exit For


        ElseIf (fecha = fecha_aux) And (persona = persona_aux) And (hora < init And hora < fin And
init > fin) Then
            buscar_actividad = ThisWorkbook.Sheets("tabla 2").Cells(i, 4).Value
              Exit For

        Else
            buscar_actividad = "No Activity"

        End If
    Next i
End Function
Function buscar_IO(fecha, hora, persona)

    Worksheets("tabla 2").Activate

    For i = 1 To 257

        fecha_aux = ThisWorkbook.Sheets("tabla 2").Cells(i, 5).Value
        persona_aux = ThisWorkbook.Sheets("tabla 2").Cells(i, 13).Value
        init = ThisWorkbook.Sheets("tabla 2").Cells(i, 6).Value
        fin = ThisWorkbook.Sheets("tabla 2").Cells(i, 7).Value

        If (fecha = fecha_aux) And (persona = persona_aux) And (hora > init And hora < fin) Then
            buscar_IO = ThisWorkbook.Sheets("tabla 2").Cells(i, 2).Value
              Exit For


        ElseIf (fecha = fecha_aux) And (persona = persona_aux) And (hora > init And hora > fin And
init > fin) Then
            buscar_IO = ThisWorkbook.Sheets("tabla 2").Cells(i, 2).Value
              Exit For


        ElseIf (fecha = fecha_aux) And (persona = persona_aux) And (hora < init And hora < fin And
init > fin) Then
            buscar_IO = ThisWorkbook.Sheets("tabla 2").Cells(i, 2).Value
              Exit For
        Else
            buscar_IO = "No IO"

        End If

    Next i
```

```
End Function
Function buscar_ME(fecha, hora, persona)

    Worksheets("tabla 2").Activate

    For i = 1 To 257

        fecha_aux = ThisWorkbook.Sheets("tabla 2").Cells(i, 5).Value
        persona_aux = ThisWorkbook.Sheets("tabla 2").Cells(i, 13).Value
        init = ThisWorkbook.Sheets("tabla 2").Cells(i, 6).Value
        fin = ThisWorkbook.Sheets("tabla 2").Cells(i, 7).Value

        If (fecha = fecha_aux) And (persona = persona_aux) And (hora > init And hora < fin) Then
            buscar_ME = ThisWorkbook.Sheets("tabla 2").Cells(i, 3).Value
              Exit For


        ElseIf (fecha = fecha_aux) And (persona = persona_aux) And (hora > init And hora > fin And
init > fin) Then
            buscar_ME = ThisWorkbook.Sheets("tabla 2").Cells(i, 3).Value
              Exit For


        ElseIf (fecha = fecha_aux) And (persona = persona_aux) And (hora < init And hora < fin And
init > fin) Then
            buscar_ME = ThisWorkbook.Sheets("tabla 2").Cells(i, 3).Value
              Exit For

        Else
            buscar_ME = "Other"

        End If


       Next i

End Function
```