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MÁSTER UNIVERSITARIO EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER

# INDOOR AIR QUALITY AND THERMAL COMFORT ASSESSMENT AT UNIVERSITY CAMPUS BUILDING

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Madrid

Agosto de 2019

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Fdo.: Pablo Santolaya Escanuela Fecha: 13/ 08/ 2019

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MÁSTER UNIVERSITARIO EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER

# INDOOR AIR QUALITY AND THERMAL COMFORT ASSESSMENT AT UNIVERSITY CAMPUS BUILDING

Autor: Pablo Santolaya Escañuela

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Madrid

Agosto de 2019

# EVALUACIÓN DE LA CALIDAD DEL AIRE INTERIOR Y DEL CONFORT TÉRMICO EN EDIFICIOS UNIVERSITARIOS

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ICAI – Universidad Pontificia de Comillas

EPFL – École Polytechnique Fédérale de Lausanne.

## RESUMEN DEL PROYECTO:

### 1. INTRODUCCIÓN

La calidad ambiental en interiores generalmente se caracteriza por cuatro factores principales, como son el confort térmico, la calidad del aire interior, el confort acústico y el confort visual. Debido a que la mayoría de las personas pasan hasta el 90% de su tiempo en interiores (Hui et al. 2006; Godwin y Batterman, 2007), se ha considerado que los efectos de la calidad del aire y el confort térmico tienen un impacto significativo en la salud y el rendimiento de las personas en el aprendizaje en las instalaciones académicas y su lugar de trabajo. Con una creciente preocupación por el uso de energía de combustibles fósiles, y una tendencia creciente a mudarse a edificios de bajo consumo, ha aparecido una tendencia a moverse hacia sistemas de HVAC más eficientes y menos costosos. A pesar de la reducción de las emisiones y el ahorro de costes que podrían beneficiar al medio ambiente y a los propietarios de los edificios, se ha demostrado que el confort térmico y la calidad del aire interior tienen un impacto significativo en el rendimiento cognitivo de los ocupantes.

Se ha demostrado que el confort térmico tiene un impacto significativo en el rendimiento del estudio y el rendimiento en exámenes. Además de esto, el aire dentro de las oficinas, edificios escolares y residencias está normalmente contaminado por una gran variedad de contaminantes tóxicos, especialmente edificios más antiguos que se construyeron con regulaciones menos estrictas. Por lo tanto, la ventilación se ha convertido en un factor clave para garantizar el control del comfort humano y la mejora de la calidad del aire interior. La falta de esta incluso puede ser perjudicial para los ocupantes no solo en términos de rendimiento al estudiar o trabajar, sino que también agrava las alergias o favorece los "Sick Building Byndroms" (SBS). Esto puede conducir a signos de reacciones corporales negativas, como dolores de cabeza, ojos / garganta irritados y nariz congestionada [1] y resultando en dificultad para concentrarse en el trabajo. La alta temperatura en habitaciones densamente ocupadas junto con los bio efluentes humanos se consideraron como las principales razones por las cuales los ocupantes se sienten incómodos, lo que normalmente ocurre en un espacio con mala ventilación. Este documentado que la temperatura y la humedad relativamente bajas pueden ayudar a reducir los síntomas de SBS y mejorar el rendimiento del trabajo de oficina [2]. Wargocki y col. también descubrió que el rendimiento del trabajo de oficina típico (como mecanografía, cálculos aritméticos y corrección de pruebas) se puede mejorar eliminando las fuentes de contaminación y aumentando la tasa de ventilación [3–5]

Recientemente, la calidad del aire interior en las escuelas y universidades se ha convertido en un tema de interés (Daisey, Angell y Apte, 2003). Por lo general, estos tipos de edificios se caracterizan por ser entornos altamente contaminados, como aulas u oficinas. Esto se debe a la gran concentración de alumnos en las clases, los descansos cortos, la falta de ventilación, la falta de sistemas de ventilación mecánica y la falta de espacio para asignar oficinas personales a los estudiantes y miembros de la facultad, lo que resulta en un aumento del número de ocupantes por habitación, y, por lo tanto, las fuentes de emisiones en interiores, mientras que se mantienen los mismos niveles de ventilación.

**Estado del arte**

Si bien no hubo muchas investigaciones sobre la ventilación dentro de las escuelas durante el siglo XX, últimamente este tema está empezando a ser más relevante. El Estándar 62.1 de ASHRAE recomienda un mínimo de 7.5 l / s por persona y 0.6 l / s por metro cuadrado para las aulas dentro de las escuelas. Las tasas de ventilación promedio, según la literatura y analizado por (Daisey et al. 2003) en la literatura europea y americana, se exponen en la figura 1 de dicho estudio.

En 1993, Turk et al. informó después de un estudio en dos escuelas de Nuevo México, sobre la tasa de ventilación de varias habitaciones antes y después de la mitigación del radón, con la mayoría de los resultados insatisfactorios y por debajo de 3 l / s por persona, muy por debajo del mínimo requerido. Nielsen (1984), informó, después de un estudio de 11 escuelas en Dinamarca, tasas de ventilación en el rango de 1.8 a 15.4 l / s por persona, siendo el promedio algo inferior a los requisitos mínimos para las escuelas.

Smedje y col. (2000) mostraron en un estudio en 39 escuelas en Suecia que el 77% de las escuelas no cumplían con la regulación de los códigos de construcción, mientras que Seppanen y Fist (2002) encontraron que hubo un aumento en la prevalencia del SBS entre 30% y 200% en los edificios con aire acondicionado en comparación con la ventilación natural.

Se han realizado múltiples estudios sobre el confort térmico y la calidad del aire interior. Dias L. et al (2014) realizaron un estudio en escuelas secundarias portuguesas para evaluar la calidad el aire en interiores (IAQ). Para ello se analizan IAQ y TC mediante mediciones de la temperatura interior, humedad relativa y concentración de CO2. Las condiciones promedio del aula en términos de las medidas mencionadas anteriormente se compararon con los valores de referencia marcados por los estándares de IAQ y se usaron para compararlas con la satisfacción de los ocupantes de dicha sala mediante encuestas. Estas encuestas se centraron en el confort térmico y la calidad del aire interior de los estudiantes, sus pensamientos sobre el entorno térmico y sus preferencias con respecto a dicho tema, con respuestas en escala de 7 puntos. Todos estos datos se estudiaron para evaluar los índices de confort térmico de Fanger, el valor medio percibido (PMV) y el porcentaje de personas insatisfechas (PPD).

En una investigación similar, Alves c: et al (2013) realizó un estudio en dos instalaciones deportivas universitarias. En él, los parámetros de confort (temperatura, humedad relativa y CO2), CO y TVOC fueron monitoreados continuamente. Además, las concentraciones de NO2 y partículas también se analizaron para evaluar el IAQ de ambos edificios. Para realizar el estudio, se analizaron las tasas de ventilación. La concentración de contaminantes del aire interior se analizó estadísticamente y se comparó con otras investigaciones y estándares internacionales para evaluar el impacto en la salud que podría tener en los usuarios de las instalaciones.

### Objetivo del proyecto

El objetivo principal de este documento es estudiar las condiciones térmicas y de calidad del aire interior dentro de los edificios de EPFL, como son las oficinas de estudiantes, la biblioteca Rolex y la residencia de estudiantes de Atrium. Se prestará especial atención a las concentraciones de CO2 para medir la ventilación de cada espacio, así como la concentración de partículas en los diferentes recintos. La concentración de gases como el dióxido de nitrógeno, el dióxido de azufre, el monóxido de carbono y el ozono también se considerará cuando los datos estén disponibles. Todos los resultados se compararán con los estándares establecidos por ASHRAE y la OMS y algunos de los resultados se compararán con encuestas realizadas entre el cuerpo estudiantil para comparar el cumplimiento con el estándar internacional de los diferentes edificios, así como observar la calidad del aire y confort térmico percibidos dentro de las instalaciones de EPFL.

## 2. METODOLOGIA

### Instrumentos

Para el desarrollo del proyecto y la recopilación de datos, los instrumentos utilizados para llevar a cabo las mediciones de la concentración de contaminantes fueron:

- Un medidor de gas (Graywolf DirectSense-II) capaz de registrar la concentración en tiempo real de TVOC, CO2, CO, ozono (O3), NO2 y SO2, así como la temperatura y la humedad relativa.
- Un contador de partículas ópticas para medir las partículas de materia llamado Graywolf Particle Counter 3500.
- Un CO2 HOBO MX para medir la temperatura de humedad relativa y la concentración de CO2.

Estos se usaron para medir TVOC, CO2, CO, ozono (O3), NO2 y SO2, temperatura y humedad relativa.

### Ubicación

Para el estudio, se eligieron múltiples ubicaciones en EPFL donde los estudiantes generalmente pasan la mayor parte de su tiempo. Estos lugares eran la biblioteca Rolex, la residencia Atrium donde se diferencia entre la habitación privada y la sala de estar y una oficina en el edificio GR.

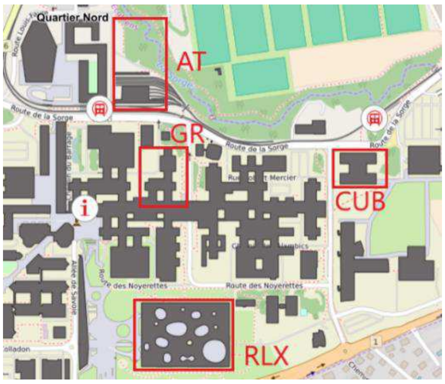


*Figure 1 Ubicaciones del estudio en la EPFL*

En todas las habitaciones, los instrumentos mencionados anteriormente se distribuyeron entre las habitaciones, manteniendo una cierta distancia con las principales fuentes de contaminación para poder obtener datos valiosos de estado estacionario y no ser manipulados por valores instantáneos.

### Métodos

Para lograr los objetivos del proyecto, se realizaron múltiples pruebas para evaluar la calidad del aire y el confort térmico de los estudiantes dentro de los espacios mencionados. El análisis se puede dividir en tres secciones diferentes. La primera parte comprendió del análisis de la concentración de CO2 para medir la tasa de ventilación en la habitación utilizando ecuaciones de Fangers para luego comparar los resultados con los estándares establecidos por ASHRAE 62.1, EN13799 y EN 15251. En una segunda parte se analizan el resto de los contaminantes y se comparan con los estándares para determinar el cumplimiento de la regulación existente dentro de los edificios. Y, por último, una prueba más subjetiva donde la calidad del aire y el confort térmico se analizan a los ojos de los estudiantes con la ayuda de encuestas y luego se comparan con el índice de porcentaje de personas insatisfechas (PPD) y los índices de voto medio pronosticado (PMV), calculados utilizando un herramienta de confort térmico del Centro para el Entorno Construido en Berkeley (CBE), para ver la validez del modelo y la comodidad real que sienten los ocupantes, independientemente de lo que digan las normas.

*Cálculo de la tasa de ventilación*

Para calcular la tasa de ventilación se utilizó la ecuación de Fanger. La sala se llenó de CO2 debido a la presencia de ocupantes. Al analizar los datos totales del período de acumulación y el descenso de la concentración, se midió la tasa aproximada de ventilación. Dependiendo de la habitación y de la facilidad con la que se obtuvieron dichos datos, se utilizaron dos ecuaciones diferentes. Una primera aproximación al analizar el proceso de descomposición y al aproximarse con dos puntos cuando fuese posible, ya que resultó ser más preciso. Esta ecuación proviene de la ecuación de balance de masa y después de algún ajuste se reduce a:

$$\lambda = \frac{1}{t} \cdot \ln \frac{c_0 - c_{out}}{c - c_{out}}$$

Donde λ corresponde a la tasa de intercambio de aire, t a la diferencia en el tiempo y $c_0$ es la concentración máxima y $c_{out}$ es la concentración de CO2 en el exterior.

Cuando esto no era posible, el método acumulado era usado, donde la habitación estaba vacía al principio y luego se llenaba con estudiantes para generar CO2 hasta un punto de estabilidad. Para este método se usó la misma ecuación, pero otras aproximaciones para estimar la concentración en estado estacionario fueron necesarias, ya que en muchos casos se desconoce.

*Normativas*

Para este trabajo, se analizaron múltiples estándares para comparar los resultados obtenidos con las pautas nacionales e internacionales, haciendo especial énfasis en tres temas diferentes: concentración permitida de CO2, tasa de ventilación mínima y límites permitidos de concentración de gas que se resumen en las siguientes tablas. La Tabla 1 es el resultado de la aplicación de los requisitos mínimos de ventilación de ASHRAE 62.1 en cada habitación teniendo en cuenta el área de superficie y la ocupación esperada.

*Table 1. Minimum ventialtion rate*

| Ubicación | nº personas | Area ($m^2$) | Ventilación (l/s) |
|---|---|---|---|
| Oficina | 3 | 20 | 13,5 |
| Dormitorio | 1 | 15,5 | 7,15 |
| Zona común | 2 | 23,5 | 12,05 |

En el caso de la Tabla 2, se presenta una recopilación de las concentraciones máximas permitidas para diferentes contaminantes gaseosos y partículas (PM). Los límites de concentración se promedian durante cierto período de tiempo y pueden referirse a diferentes estándares, ya que no todos cubren todos los temas.

*Table 2 Máxima concentración permitida para gases*

| Parameter | Exposure time | Guidelines | Source |
|---|---|---|---|
| $SO_2[\mu g/m^3]$ | 10-minute mean | 500 | WHO, 2005 |
| | 24-hour mean | 20 | |
| $O_3[\mu g/m^3]$ | 1-hour mean | 200 | |
| | 8-hour mean | 100 | |
| | annual mean | 40 | |
| $NO_2[\mu g/m^3]$ | 1-hour mean | 200 | |
| | annual-mean | 40 | |
| $PM_{2.5}[\mu g/m^3]$ | 24-hour mean | 25 | |
| | annual mean | 10 | |
| $PM_{10}[\mu g/m^3]$ | 24-hour mean | 50 | |
| | annual mean | 20 | |
| CO $[mg/m^3]$ | 15-minute mean | 100 | WHO, 2010 |
| | 1-hour mean | 35 | |
| | 8-hour mean | 10 | |
| | 24-hour mean | 7 | |
| $CO_2$[ppm] | 15-minute mean | 5000 | ASHRAE Standard 62.1-2016 |
| | 8-hour mean | 3000 | |
| TVOC $[\mu g/m^3]$ | 8-hour mean | 500 | WELL, 2017 |

*Encuestas*

Finalmente, se desarrollaron encuestas para analizar el confort térmico y la percepción de la calidad del aire interior de los estudiantes. Las preguntas más relevantes que se hicieron fueron las siguientes para la biblioteca Rolex:

a) ¿Como calificarías la temperatura en el interior del Rolex?
b) ¿Como de satisfecho estas con la temperatura en el Rolex?
c) ¿Como de satisfecho estas con la calidad del aire en el Rolex?
d) ¿Como calificarías los siguientes problemas?

Y lo siguiente para la residencia en Atrium:

a) ¿Como calificarías la temperatura en la zona común?
b) ¿Como calificarías la temperatura en el cuarto?
c) ¿Como de satisfecho estas con la calidad del aire dentro del apartamento?
d) ¿Como de satisfecho estas con la calidad del aire dentro del cuarto?
e) ¿Como calificarías los siguientes problemas?

## RESULTS

### Tasa de ventilación y $CO_2$

*Oficina*

Las mediciones de la concentración de CO2 se realizaron las 24 horas del día durante casi dos semanas. Durante este tiempo, la concentración promedio de CO2 fue de 695 ppm. La concentración mínima se observó al comienzo del día a 399 ppm, con la concentración más alta siendo 1539 a primera hora de la tarde del 1 de abril de 2019. En general, el 18.4% del tiempo de ocupación, la concentración estuvo por encima del límite de 1000 ppm establecido por ASHRAE como se puede ver en la Tabla 4. Al evaluar la evolución de la concentración de CO2 en la habitación, se descubrió que la tasa de ventilación era 3,62 l/s, muy por debajo del requerimiento mínimo como se puede ver en la Tabla 3.

*Sala común de atrium*

En este caso, las mediciones se tomaron en un período de tiempo pequeño, por lo que no fue posible obtener el promedio de tiempo de varios días. Durante el período de medición, la concentración

*Table 3 Compilation of highest lowest and average values of ventilation data*

| Parametros | Valores minimos | | | | Valores maximos | | | | Media | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | OF | BD | LR | RX | OF | BD | LR | RX | OF | BD | LR | RX | |
| T(ºC) | 18.4 | 19.5 | 19.2 | 23.52 | 26.3 | 24.3 | 21.8 | 25.11 | 22.4 | 21.5 | 20.9 | 24.03 | 20-24 |
| RH (%) | 16.3 | 31.3 | 36.9 | 27.01 | 68.3 | 40.4 | 58.8 | 37.7 | 30.1 | 36.25 | 43.5 | 30.77 | 30-70 |
| $CO_2$ (ppm) | 399 | 373 | 314 | 686 | 1539 | 1412 | 1096 | 1071 | 695 | 892 | 507 | 861 | <1000 |

máxima de CO2 fue de 1096 ppm y la concentración mínima fue de 314 ppm. Durante los dos días, el límite de 1000 ppm solo se superó durante el 1,4% del tiempo y la concentración media de CO2 fue de 507 ppm. Del mismo modo, antes en este caso, la tasa de ventilación también está por debajo del mínimo.

*Dormitorio de Atrium*

Durante el tiempo de análisis y con la ventana de la habitación cerrada, la concentración de CO2 alcanzó un valor máximo de 1412, siendo el mínimo de 373 ppm correspondiente al comienzo del período de medición. La media general de la concentración de CO2 fue de 892 ppm, superando el límite de 1000 ppm en el 43.7% del tiempo. Al calcular la tasa de ventilación, todavía se puede ver un claro déficit en la ventilación natural en la habitación.

*Table 4 Ventilation rate vs minimum requirement*

| Location | Ventilation rate | Ventilation rate (l/s) (req) |
|---|---|---|
| Office | 3.,62 | 13,5 |
| Bedroom | 4,05 | 7,15 |
| Living room | 4,65 | 12,05 |

## Concentración de gases

*Oficina*

The result of comparison between guidelines and measured values in the target office is summarized below (Table 5). It is shown that $SO_2$ is the only pollutant whose concentration exceeds the chosen guideline values (regulated by the World Health Organization) while other pollutants all respect their guidelines respectively.

$O_3$ concentration is obviously stable with a mode of 19.6 $\mu g/m^3$ accounting for about 80% of the whole measurement duration and with a low mean value (19.0$\mu g/m^3$).CO level is also far below the regulatory values with an overall mean of 0.6 $mg/m^3$ during the whole period. Meanwhile, there is no $NO_2$ in the office at most of the time series with only two non-zero measured data (56.4 and 37.6 $\mu g/m^3$ respectively). When it comes to the TVOC level, it can be noticed that TVOC concentration varies between 80 (92) and 390 (331) $\mu g/m^3$ on 5-minute (8-hour) average.

On the other hand, particulate matters staying in the objective office show a satisfactory level with respect to the regulatory values. $PM_{2,5}$ contains a maximal mean value of 5.88$\mu g/m^3$ (compared to 25$\mu g/m^3$) for 24-hour exposure while $PM_{10}$ with a maximal mean of 20.75$\mu g/m^3$ (50µg/m3as a regulatory threshold).It is also suggested that $PM_{2,5}$ and $PM_{10}$ levels are relatively stable and do not fluctuate much.

*Sala común Atrium*

Para la sala de estar, la concentración de O3 es casi inexistente con una concentración de 0 µg / m3 durante el 96.3% del tiempo y un pico de 39.2 µg / m3 en solo cuatro mediciones durante todo el proceso. El nivel de CO también está muy por debajo de los valores reglamentarios, con concentraciones más altas durante el primer día durante los períodos de cocina, pero alcanzando un máximo de 0.8 mg / m3. Mientras tanto, el NO2 no está presente en el aire en esta situación, siendo su promedio durante todo el período medido de 0 µg / m3. Cuando se trata del nivel de TVOC, de manera similar al CO, podemos ver un aumento en la concentración de aire debido a la actividad realizada durante el primer día y los platos cocinados. El segundo día, con una mejor ventilación, el TVOC se reduce casi a la mitad, con un pico el 6 de abril a alrededor de 1350 µg / m3 y un pico mucho más pequeño a alrededor de 800 µg / m3 el 7 de abril (conversión desde ppb a µg / m3, asumiendo un peso molecular promedio de 100). Como se puede observar, la media promedio de 8 horas para TVOC en la cocina es el doble de la concentración permitida por los estándares. Esto puede explicarse debido al cierre intencional de las ventanas durante los tiempos de cocción, hábito que generalmente no ocurre pero que denota y confirma una falta de ventilación que ya se observó en la sección anterior.

**Encuesta**

*Rolex*

El cuestionario en Rolex se realizó al final del primer día de mediciones el 7 de mayo de 2019. El cuestionario se explicó a los estudiantes y se completó a través de su teléfono móvil a través de una aplicación. En ese momento, los estudiantes habían estado en el edificio durante aproximadamente 2 horas y estaban a punto de tomar un descanso alrededor de las 17:00. Durante el tiempo que los estudiantes estuvieron presentes en el edificio, como se puede ver en la Tabla 4, las condiciones fueron: Ta = 24ºC, HR = 30.77% y CO2 = 894 en promedio.

En términos de confort térmico, el 41.7% de las personas se sintió "algo insatisfecho" y el 16.7% respondió "muy insatisfecho" con la temperatura interior, lo que hace que la percepción general del TC en el edificio Rolex no sea satisfactoria. Algunos incluso señalaron que esto a veces los hace perder la concentración o tomar descansos con más frecuencia.

Con respecto a la calidad del aire interior, los resultados denotaron una mejor apreciación de la IAQ, ya que solo el 16,7% de las personas están "algo insatisfechas" con la calidad del aire en elRolex, el 8,7% están "muy insatisfechas" y el 75% de las personas se sienten ya sea neutral al respecto o con una respuesta satisfactoria.

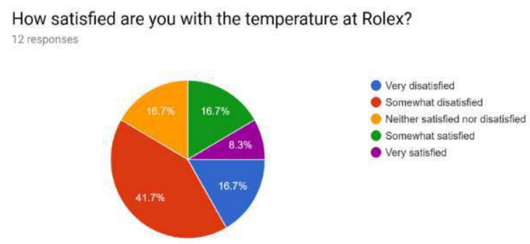


*Figure 2 Survey: satisfaction of temperature in rolex*

Al apreciar la calidad del aire en el edificio Rolex, los estudiantes encuentran que el aire es de buena calidad. Al calificar múltiples problemas que generalmente ocurren en interiores, solo se informó que el aire con olor a aire era un problema importante en solo el 16.6% del tiempo y el 58.3% considerando que no era un problema o uno muy menor. La limpieza del aire fue

| Parameter | Exposure time | Office | Kitchen | Guidelines |
|---|---|---|---|---|
| $SO_2$[μg/m$^3$] | 10-minutes mean | 1074 | 175 | 500 |
| | 24-hour mean | 264 | 110 | 20 |
| $O_3$[μg/m$^3$] | 1-hour mean | 46 | 6.87 | 200 |
| | 8-hour mean | 39 | 2.75 | 100 |
| $NO_2$ [μg/m$^3$] | 1-hour mean | 7.9 | 0 | 200 |
| $PM_{2,5}$ [μg/m$^3$] | 24-hour mean | 6.41 | 6.16 | 25 |
| $PM_{10}$ [μg/m$^3$] | 24-hour mean | 26.9 | 28.9 | 50 |
| CO [mg/m$^3$] | 15-minutes mean | 1.72 | 0.76 | 100 |
| | 1-hour mean | 1.48 | 0.73 | 35 |
| | 8-hour mean | 1.18 | 0.56 | 10 |
| | 24-hour mean | 0.94 | 0.21 | 7 |
| TVOC[μg/m$^3$] | 8-hour mean | 650 | 1030 | 500 |

muy positiva: el 50% de los estudiantes lo consideraron un problema y solo uno lo consideró un problema importante. Finalmente, el mayor problema notado por los estudiantes fue el mal olor (olor corporal) alrededor de las áreas de estudio, con solo un 25% que considera que no es un problema y un 25% que lo considera un problema importante, pero en general tiene resultados satisfactorios.

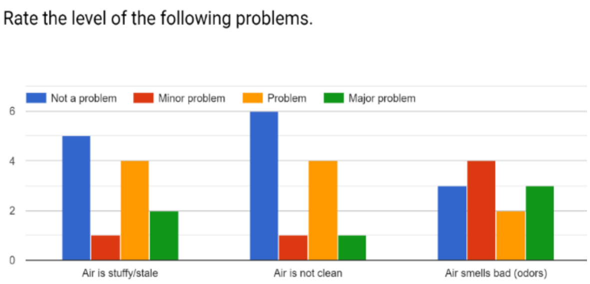


*Figure 3 Survey: Air quality issues rating at Rolex*

*Residencia Atrium*

Las personas que respondieron el cuestionario sobre la residencia en Atrium tenían entre 20 y 23 años de edad. Debido a que resultó difícil hacer que las personas respondiesen el cuestionario, solo 7 estudiantes participaron en el estudio, con un 71.4% de hombres y un 28.6% de mujeres. En este caso, el promedio de clo era difícil de evaluar ya que la mayoría de los estudiantes varían en la forma en que se visten durante el día mientras están en casa.

En la respuesta a la primera pregunta "¿Cómo calificaría normalmente la temperatura en lo común?", El 57.1% de los estudiantes encuentra que la temperatura dentro de los apartamentos es satisfactoria, con solo el 28.6% encuentrandola "algo fría" y el 14.3% que la encuentra "Algo caliente". Cuando la misma pregunta fue respuesta con respecto a la comodidad térmica del dormitorio, el 71.4% de los estudiantes respondió: "Ni caliente ni frío", y solo el 28.6% de ellos encontró que la temperatura era "Algo caliente".

Con respecto a la calidad del aire interior dentro del apartamento, los resultados destacan un IAQ deficiente, con un 42,9% de las respuestas "Algo insatisfecho" y un 14,3% de ellas "Muy insatisfecho". Por lo tanto, esto hace que más del 50% de los participantes en la encuesta no estén contentos con el aire que respiran diariamente en su apartamento. Cuando se hizo la misma pregunta sobre el IAQ de las habitaciones individuales, las respuestas fueron muy diferentes, con solo el 28,6% de los participantes insatisfechos, aunque ninguno respondió con una respuesta positiva tampoco.

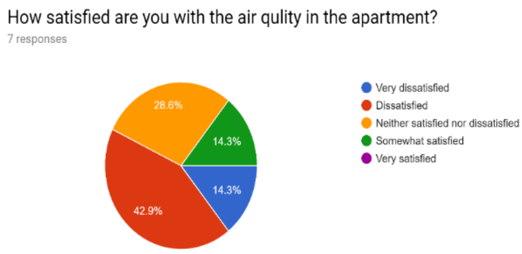


*Figure 4 Evaluation of atrium living room IAQ*

Cuando se les pidió que calificaran la magnitud de ciertos problemas con respecto al IAQ, de los 7 participantes, 4 de ellos encontraron que el aire estaba tapado / añejado como un "problema" o "problema mayor". Con respecto a la limpieza del aire, solo 3 de los 7 participantes lo consideran "problema" o "problema mayor". El problema más observado por los estudiantes fue el mal olor en el interior, ya que era un "problema mayor" en 4 de las 7 respuestas y un "problema" en 2 de las 7 respuestas, lo que lo convierte en el mayor problema dentro de la residencia.

## PMV and PPD indices

Para evaluar estos valores, se utilizó una herramienta del Centro de Medio Ambiente Construido en Berkeley. Los parámetros introducidos para la condición ambiental fueron los valores medios, mínimos y máximos para los parámetros medidos, la velocidad del aire se consideró como 0.1 (m / s) como una aproximación para los espacios interiores normales ya que no había mediciones disponibles. La tasa metabólica considerada es la de una persona sentada haciendo un trabajo rudimentario, como leer o escribir, ya que es la actividad más común de los estudiantes dentro de los espacios estudiados. Finalmente, se consideró que el aislamiento de la ropa era de 0.74 clo apartamento (pantalones de chándal y una camisa de manga larga) para el interior y 0.96 (chaqueta, pantalón y camisa de manga larga) en la biblioteca Rolex después de discutir con los participantes del estudio sus hábitos y por observación. Para comparar los resultados de los cuestionarios con los valores de PMV y PPD, los resultados de los índices de Fanger se pueden encontrar en la Tabla 6.

### PD based on $CO_2$ concentration

En habitaciones donde la concentración de CO2 se debe principalmente a los ocupantes, se recomienda determinar el porcentaje de personas insatisfechas en función de la concentración de CO2.

*Table 5 PD in different environments*

| | Living room | Bedroom | Rolex library | Office |
|---|---|---|---|---|
| $CO_2$ (ppm) | 507 | 892 | 861 | 695 |
| C (ppm) | 157 | 542 | 511 | 345 |
| PD (%) | 5.5% | 17.1% | 16.32% | 10.85% |

## Discussion

*Atrium living room*

Al otro lado del resultado obtenido en esta sala, la tasa de ventilación obtenida mediante el uso del método de descomposición de dos puntos es demasiado baja como lo establece la norma ASHRAE 62.1. En términos de contaminantes gaseosos, los niveles parecen mantenerse bajo control durante todo el período de medición, siendo el único valor atípico del SO2 en algunas situaciones puntuales.

Al comparar los resultados de las evaluaciones de confort térmico, el modelo de Fanger muestra las peores calificaciones que la encuesta. Estos resultados reflejan que las condiciones generales en esta sala son bastante buenas y están dentro de los estándares, sin embargo, debido a que los valores de ocupación no se registran bien y, por lo tanto, no se usan, la temperatura promedio y otros parámetros promedios pueden ser más bajos que durante la exposición real a El ambiente interior que sugiere la encuesta.

En términos de calidad del aire, se observa una mayor insatisfacción con más del 50%, mientras que el valor obtenido al usar la concentración de PD sugiere solo un 5,5% de las personas insatisfechas. Se considera que esta discrepancia se debe a la presencia esporádica de personas en la sala de estar y, por lo tanto, a la baja concentración de CO2 producida por los ocupantes, pero a grandes cantidades de otros gases y partículas, como el bote de basura y los alimentos, pero eso no se considera en la ecuación utilizada . Este razonamiento se ve reforzado por la respuesta de los ocupantes que identifican el mal olor del aire como un problema importante, mientras que el aire no se considera particularmente sucio.

*Atrium bedroom*

A partir de los resultados obtenidos durante el proyecto, se observan promedios más altos en temperatura y concentración de $CO_2$ en esta sala. Esto puede explicarse por la baja tasa de

*Table 6 PPD adn PMV with max min and average values*

| Parameters | Atrium living room | | | Atrium bedroom | | | Rolex library | | | Office | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max |
| T (ºC) | 19.2 | 20.9 | 21.8 | 19.5 | 21.5 | 24.3 | 23.52 | 24.08 | 25.11 | 18.4 | 22.4 | 26.3 |
| RH (%) | 36.9 | 43.5 | 58.5 | 31.3 | 36.25 | 40.48 | 27.01 | 30.77 | 37.7 | 16.3 | 68.3 | 30.1 |
| M (met) | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| $I_{clo}$ (clo) | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 |
| V (m/s) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| PMV | -1.4 | -0.89 | -0.55 | -1.35 | -0.77 | 0.03 | 0.06 | 0.22 | 0.52 | -1.21 | 0.06 | 0.75 |
| PPD | 46% | 22% | 11% | 43% | 17% | 5% | 5% | 6% | 11% | 36% | 5% | 17% |

ventilación en esta sala de solo 4.65 l / s por debajo del requisito mínimo.

La comparación del confort térmico entre la encuesta realizada, los valores de PPD y PMV en este caso muestran una ligera diferencia en la temperatura percibida del método analítico y el estándar. Con un 71% de las respuestas de la encuesta siendo neutral y un PMV que denota solo el 17% de PPD. En general, no obstante, las condiciones son satisfactorias.

Con respecto al IAQ, la encuesta muestra una ligera insatisfacción de los ocupantes de Atrium con el 29% de los participantes ligeramente insatisfechos, mientras que el resto respondió con una respuesta neutral. Los resultados del uso de la concentración de DP muestran que un 17,1% de las personas no están satisfechas. En general, ambas valoraciones son similares, principalmente debido a la emisión de menos olores por objetos extraños a los ocupantes, como fue el caso de la cocina.

*Librería Rolex*

La biblioteca Rolex registró la temperatura promedio más alta de las habitaciones analizadas, con 24,03 ºC y superando el límite para un edificio de categoría II. Su humedad relativa está activada en el límite inferior del rango de confort, y la concentración promedio de $CO_2$, incluso si no es superior a 1000 ppm, es algo alta situándose en 861 ppm. Parte de este valor se debe a la falta de ventanas operables, así como a la alta exposición al sol a través de las paredes de vidrio.

En términos de confort térmico, la encuesta muestra una alta tasa de insatisfacción, con un 41,7% de personas que están algo insatisfechas y más del 50% tienen una respuesta negativa y en general consideran que la temperatura es alta o muy alta. En comparación con el valor de PMV, se puede ver una gran diferencia. Con un valor de 0.22 y solo un 6% de PPD según el estándar EN15251, se debe lograr el confort térmico, pero la mayoría de las personas informaron bajas tasas de satisfacción. Cuando se les preguntó sobre el tema, los participantes consideraron que la diferencia entre la temperatura exterior e interior era significativa, especialmente debido a la ropa usada.

Con respecto a IAQ, la encuesta muestra respuestas en rangos de -2 a 2 en una pregunta de escala de cinco puntos, pero la mayoría de las respuestas son positivas y solo el 25% de las personas no están contentas con la calidad del aire.

Comparando esto con la PD calculada con la concentración de CO2, cuyo resultado es un valor de 16.32 por ciento insatisfecho, se llega a la conclusión de que el IAQ general dentro del edificio Rolex es satisfactorio, siendo así el único problema en dicho edificio el confort térmico.

*Oficina*

En términos de confort térmico, al analizar los índices de Fanger, se encuentra un gran rango de valores en el PMV, esto se debe principalmente a la baja temperatura durante la noche que enfría la habitación cuando los ocupantes llegan por la mañana, y las altas temperaturas en el tarde con exposición directa al sol que calienta la habitación a través de las ventanas. Con valores promedio de los parámetros de comodidad que resultan en un PMV de 0.06, los resultados son bastante satisfactorios, pero el rango de valores observados podría dificultar la comodidad del ocupante ya que dentro de una oficina es más difícil adaptarse en términos de ropa.

Con respecto a IAQ, dado que no se realizó ninguna encuesta para este espacio, solo está disponible el PD basado en la concentración de CO2. Con un resultado de 10.85% de personas insatisfechas, y al comparar los valores de la Tabla 6 con los estándares, el IAQ de la habitación se considera bastante satisfactorio para los ocupantes ya que no se observa una gran concentración de contaminantes, excepto SO2, pero esto debido a fuentes externas, no es probable que afecte el IAQ en un día promedio durante todo el año.

## CONCLUSION

En este estudio se ha estudiado el TC y el IAQ de múltiples ubicaciones de la EPFL. Los parámetros ambientales que influyen en TC e IAQ y en comparación con la concentración de otros gases y la evaluación subjetiva de los ocupantes.

El estudio muestra que la ventilación en todos los lugares estaba por debajo de la tasa de ventilación mínima requerida según la norma ASHRAE 62.1. Esto provoca, en algunos espacios, como la sala común de Atrium, bajos valores de confort percibidos en términos de IAQ. La concentración de CO2, aunque no particularmente alta, demostró elevarse por encima del límite en múltiples ocasiones, haciendo que las habitaciones a veces se sientan tapadas o permitiendo malos olores de los efluentes biológicos del cuerpo o de otras fuentes.

El confort térmico resultó ser a veces inadecuado para los ocupantes. Los rangos de PMV son bastante grandes, lo que hace que los entornos sean muy dinámicos, con grandes cambios entre la mañana y la tarde con una mayor exposición al sol, alcanzando temperaturas superiores a los 25 ºC.

En general, las condiciones en los edificios en EPFL parecen proporcionar condiciones satisfactorias de IAQ y TC, sin embargo, se deben estudiar más sistemas de ventilación controlados o regulados para obtener mejores resultados. Algunos de los sistemas propuestos para ser explorados serían: ventilación basada en la concentración y temperatura de CO2, o incluso explorar la ventilación personal en algunos casos, como el dormitorio individual donde la concentración de CO2 alcanza altos niveles si las ventanas se mantienen cerradas por la noche o en la librería Rolex, donde, debido a la alta concentración de personas, los malos olores y las molestias son comunes entre los estudiantes.

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# INDOOR AIR QUALITY AND THERMAL COMFORT ASSESSMENT AT UNIVERSITY CAMPUS BUILDING

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Collaborating entities:

ICAI – Universidad Pontificia de Comillas

EPFL – École Polytechnique Fédérale de Lausanne.

## PROJECT SUMMARY:

### 1. INTRODUCTION

Indoor environmental quality is usually characterized by four major factors, such as Thermal Comfort, Indoor Air Quality, Acoustic Comfort and Visual Comfort. As most individuals spend up to 90% of their time indoors (Hui et al. 2006; Godwin and Batterman, 2007) the effects of air quality and thermal comfort have been considered to have a significant impact on the health and performance of people in learning facilities and their workplace. With increase concern on the use of fossil fuel energy, and an increasing trend to move to low consumption buildings, a trend for more efficient and less expensive HVAC systems has appeared. Despite the reduced emission and cost saving that might benefit the environment and building owners, thermal comfort and indoor air quality has been proven to have a significant impact on occupant's cognitive performance.

Thermal Comfort has been proven to have a significant impact on studying and test performance. Added to this, air inside offices, school buildings and residences is normally contaminated by a large variety of toxic contaminants, especially older buildings which were built with less strict regulations. Thus, ventilation has become a key factor to ensure control for human comfort and to improve indoor air quality. A lack of it can even be harmful to occupants not only in terms of performance when studying or working but also aggravating allergies or favoring Sick Building Syndromes (SBS). This may lead to signs of negative body reactions such as headaches, irritated eyes/throats and congested noses [1] and find it difficult to concentrate on their work. High temperature in a densely occupied room together with human bio effluents were regarded as main reasons why occupants feel uncomfortable, which normally take place in a space with bad ventilation. It is reported that relatively low temperature and humidity can help reduce SBS symptoms and improve the performance of the office work [2]. Wargocki et al. also found that the performance of typical office work (such as typing, arithmetical calculations and proof-reading) can be improved by removing pollution sources and increasing ventilation rate [3–5]

Recently, the indoor air quality at schools and universities has become a topic of interest (Daisey, Angell, & Apte, 2003). Usually these types of buildings are characterized by potentially high polluted environments such as classrooms or offices. This is due to crowded classes, short breaks, poor ventilation, a lack of mechanical ventilation systems and the lack of space to assign personal offices to students and faculty members, which results in an increase the number of occupants per room and the sources of emission indoors while maintaining the same levels of ventilation.

## State of the art

While there were not many researches on ventilation rates inside of schools during the 20th century, it's starting to become more relevant as of late. The ASHRAE Standard 62.1 recommends a minimum of 7.5 l/s per person and 0.6 l/s per square meter for classrooms inside of schools. Average ventilation rates, as reported by literature and analyzed by (Daisey et al. 2003) in European and American literature, are exposed in Fig.1 of said study.

In 1993, Turk et al. reported after a study in two school in New Mexico, the ventilation rate of multiple rooms pre and post mitigation of radon with most of the results being unsatisfactory and below 3 l/s-person, well below the minimum required. Nielsen (1984), reported, after a study of 11 schools in Denmark ventilation rates in the range of 1.8 to 15.4 l/s-person, with the average being somewhat inferior to the minimum requirements for schools.

Smedje et al. (2000) showed in a study in 39 schools in Sweden that 77% of schools did not meet building codes regulation, while Seppanen and Fist (2002) found that there was an increase in prevalence of sick building syndrome between 30% to 200% in the buildings with air-conditioning when compared to natural ventilation.

Multiple studies have been performed about thermal comfort and indoor air quality. Dias L. et al (2014) conducted a study in Portuguese secondary schools to assess IAQ. For this IAQ and TC are analyzed by means of measurements of the indoor temperature, relative humidity and CO2 concentration. The average conditions of the classroom in terms of the measurements previously mentioned were compared to the reference values marked by the IAQ standards and used to compare with the satisfaction of the occupants of said room by mean of surveys. These surveys focused on the thermal comfort and indoor air quality of the students, their thoughts on the thermal environment, and their preferences in regard to said subject with 7-point scale answers. All this data was studied in order to evaluate Fanger's thermal comfort indices, the perceived mean value (PMV) and percent of people dissatisfied (PPD).

In a similar research Alves c: et al (2013) did a study in two university sport facilities. In it, comfort parameters (temperature, relative humidity and CO2), CO and TVOC were continuously monitored. In addition, NO2 and particulate matter concentrations were also analyzed to assess the IAQ of both buildings. To perform the study, the ventilation rates were analyzed. The concentration of indoor air pollutants was statistically analyzed and compared to other research and international standards to evaluate the health impact it could have on the users of the facilities.

## Goal of this project

The main purpose of this paper is to study the thermal and indoor air quality conditions inside of the EPFL buildings such as student offices, the Rolex library and the student residence of Atrium. A special focus will be made to the concentrations of CO2 to measure the ventilation of each space as well as the concentration of particulate matter in the different spaces. The concentration of gases such as Nitrogen Dioxide, Sulfur Dioxide, Carbon Monoxide and Ozone will also be considered when the data is available. All the results will be compared to the standards set by

ASHRAE and the WHO and some of the results will be compared to surveys realized among the student body to compare the compliance with the international standard of the different buildings as well as note the perceived air quality and thermal comfort inside of the EPFL facilities.

## 2. METHODOLOGY

### Instruments

For the development of the project and the collection of data, the instruments used to carry on the measurements of pollutants concentration were:

- A gas meter (Graywolf DirectSense-II) capable of recording the real time concentration of TVOC, CO2, CO, Ozone (O3), NO2 and SO2, as well as temperature and relative humidity.
- An optical particle counter to measure particulate matter called Graywolf Particle Counter 3500.
- A HOBO MX $CO_2$ to measure relative humidity temperature and $CO_2$ concentration.

These were used to measure TVOC, $CO_2$, CO, Ozone ($O_3$), $NO_2$ and $SO_2$, temperature and relative humidity.

### Location

For the study, multiple locations at EPFL where students usually spend most of their time were chosen. These locations were the Rolex library, the Atrium residency differentiating between the private room and the living room and an office in the GR building.

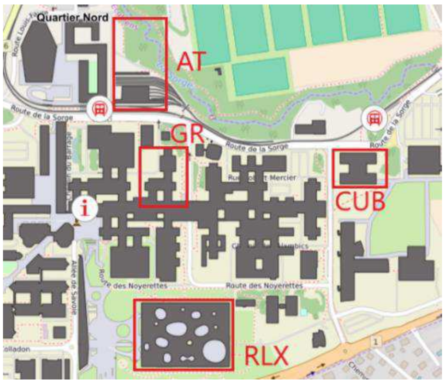


*Figure 1 Locations of study at EPFL*

In all of the rooms the instruments mentioned above were distributed across the rooms, keeping a certain distance with the main sources of pollution to be able to get valuable steady state data and not be tampered with by instantaneous values.

### Methods

To accomplish the goals of the project multiple test were performed to assess the air quality and thermal comfort of the students inside of the mentioned spaces. The analysis can be divided into three different section. The first part comprised the analysis of the $CO_2$ concentration to measure the ventilation rate in the room using Fangers equations to later compare the results with the standards set by ASHRAE 62.1, EN13799 and EN 15251. A second part where the rest of the pollutants are analyzed and compared to the standards to determine the compliance with the existing regulation inside the buildings. And lastly a more subjective test where air quality and thermal comfort is analyzed in the eyes of the students with the help of surveys and then compared to the Percentage of People Dissatisfied (PPD) and the Predicted Mean Vote (PMV) indices, computed using a thermal comfort tool from the Center for the Built Environment at Berkeley, to see the validity of the model and the actual comfort felt by the occupants regardless of what the standards say.

*Ventilation rate calculation*

To calculate the ventilation rate Fanger's equation was used. The room was filled up with $CO_2$ due to the presence of occupants. By analyzing the total data from the built-up period and the drop down in concentration the approximate rate of ventilation was measured. Depending on the room, and how the easiness to harvest said data, two different equations were used. A first approximation by analyzing the decay process and by approximating with two points when possible as it proved to be more accurate. This equation comes from the mass balance equation and in terms is reduced to:

$$\lambda = \frac{1}{t} \cdot \ln \frac{c_0 - c_{out}}{c - c_{out}}$$

Where $\lambda$ corresponds to the air exchange rate, t to the difference in time and $c_o$ is the max concentration and $c_{out}$ is the concentration of $CO_2$ outside.

When this wasn't possible the built up method was used where the room was empty at first and then filled up with students to generate $CO_2$ to a point of stability. For this method the same equation was used but further approximations to estimate the steady state concentration as in many cases it is not known.

*Standards*

For this work multiple standards were analyzed to compare the results obtained to the national and international guidelines making special emphasis on three different topics: allowed concentration of $CO_2$, minimum ventilation rate and allowed gas concentration limits being all summed up in the next tables. Table 1 is the result of the application of the ASHRAE 62.1 minimum ventilation requirements to each room taking into account the surface area and the expected occupancy.

*Table 1. Minimum ventialtion rate*

| Location | nº people | Area ($m^2$) | Ventilation rate (l/s) |
|---|---|---|---|
| Office | 3 | 20 | 13,5 |
| Bedroom | 1 | 15,5 | 7,15 |
| Living room | 2 | 23,5 | 12,05 |

In the case of Table 2 a recompilation of the maximum allowed concentrations for different gaseous pollutants and particulate matter (PM) is presented. The concentration limits are averaged over certain period of time and might refer to different standards since not all of them cover all topics.

*Table 2 Maximum pollutant concentration indoors*

| Parameter | Exposure time | Guidelines | Source |
|---|---|---|---|
| $SO_2$[µg/m³] | 10-minute mean | 500 | WHO, 2005 |
| | 24-hour mean | 20 | |
| $O_3$[µg/m³] | 1-hour mean | 200 | |
| | 8-hour mean | 100 | |
| | annual mean | 40 | |
| $NO_2$[µg/m³] | 1-hour mean | 200 | |
| | annual-mean | 40 | |
| $PM_{2.5}$[µg/m³] | 24-hour mean | 25 | |
| | annual mean | 10 | |
| $PM_{10}$[µg/m³] | 24-hour mean | 50 | |
| | annual mean | 20 | |
| CO [mg/m³] | 15-minute mean | 100 | WHO, 2010 |
| | 1-hour mean | 35 | |
| | 8-hour mean | 10 | |
| | 24-hour mean | 7 | |
| $CO_2$[ppm] | 15-minute mean | 5000 | ASHRAE Standard 62.1-2016 |
| | 8-hour mean | 3000 | |
| TVOC [µg/m³] | 8-hour mean | 500 | WELL, 2017 |

*Survey*

Lastly surveys were developed to analyze the thermal comfort and indoor air quality perception of students. The most relevant question asked were the following for the rolex library:

a) How would you rate the temperature at Rolex?
b) How satisfied are you with the temperature at Rolex?

c) How satisfied are you with the air quality at Rolex?
d) How would you rate the following issues?

And the following for the atrium residency:

a) How would you normally rate the temperature in the common area?
b) How would you normally rate the temperature in your room?
c) How satisfied are you with the air quality inside of the apartment?
d) How satisfied are you with the air quality inside of your room?
e) How would you rate the following issues?

## RESULTS

### Ventilation rate and $CO_2$

*Office*

The measurements of $CO_2$ concentration were performed 24 hours a day during nearly two weeks. During this time the average $CO_2$ concentration was 695 ppm. The minimum concentration was observed at the beginning of the day at 399 ppm, with the highest concentration being 1539 in the early afternoon on April 1st, 2019. Overall the 18.4% of the time of occupancy was above the 1000 ppm limit established by ASHRAE as can be seen in Table 4. When evaluating the evolution of $CO_2$ concentration in the room, the ventilation rate was found out to be 3,62 l/s far below the minimum requirement as can be seen in Table 3.

*Atrium living room*

In this case the measurements were taken over a small window of time, so multiple days' time average was not possible. During the period of measurement, the maximum CO2 concentration was 1096 ppm and the minimum concentration was 314 ppm. During the two days the limit of 1000 ppm was only surpassed during 1.4% of the time and the mean CO2 concentration was of 507 ppm. Similarly, to before in this case the ventilation rate is also below the minimum.

*Atrium bedroom*

During the time of analysis and when the window in the room was closed, the $CO_2$ concentration reached a maximum value of 1412, with the minimum being 373 ppm corresponding to the beginning of the measurement period. The overall mean of the $CO_2$ concentration was 892 ppm with the 1000 ppm limit being surpassed in 43.7% of the time. When computing the ventilation rate, it can still be seen a clear deficit in natural ventilation in the room.

*Table 3 Ventilation rate vs minimum requirement*

| Location | Ventilation rate | Ventilation rate (l/s) (req) |
|---|---|---|
| Office | 3.,62 | 13,5 |
| Bedroom | 4,05 | 7,15 |
| Living room | 4,65 | 12,05 |

*Table 4 Compilation of highest lowest and average values of ventilation data*

| Parameter | Lowest Record | | | | Highest Record | | | | Average | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | OF | BD | LR | RX | OF | BD | LR | RX | OF | BD | LR | RX | |
| T(ºC) | 18.4 | 19.5 | 19.2 | 23.52 | 26.3 | 24.3 | 21.8 | 25.11 | 22.4 | 21.5 | 20.9 | 24.03 | 20-24 |
| RH (%) | 16.3 | 31.3 | 36.9 | 27.01 | 68.3 | 40.4 | 58.8 | 37.7 | 30.1 | 36.25 | 43.5 | 30.77 | 30-70 |
| $CO_2$ (ppm) | 399 | 373 | 314 | 686 | 1539 | 1412 | 1096 | 1071 | 695 | 892 | 507 | 861 | <1000 |

## Concentration of gases

*Office*

The result of comparison between guidelines and measured values in the target office is summarized below (Table 5). It is shown that $SO_2$ is the only pollutant whose concentration exceeds the chosen guideline values (regulated by the World Health Organization) while other pollutants all respect their guidelines respectively.

$O_3$ concentration is obviously stable with a mode of 19.6 μg/m$^3$ accounting for about 80% of the whole measurement duration and with a low mean value (19.0μg/m$^3$).CO level is also far below the regulatory values with an overall mean of 0.6 mg/m$^3$ during the whole period. Meanwhile, there is no $NO_2$ in the office at most of the time series with only two non-zero measured data (56.4 and 37.6 μg/m$^3$ respectively). When it comes to the TVOC level, it can be noticed that TVOC concentration varies between 80 (92) and 390 (331) μg/m$^3$ on 5-minute (8-hour) average.

On the other hand, particulate matters staying in the objective office show a satisfactory level with respect to the regulatory values. $PM_{2,5}$ contains a maximal mean value of 5.88μg/m$^3$ (compared to 25μg/m$^3$) for 24-hour exposure while $PM_{10}$ with a maximal mean of 20.75μg/m$^3$ (50μg/m3as a regulatory threshold).It is also suggested that $PM_{2,5}$ and $PM_{10}$ levels are relatively stable and do not fluctuate much.

*Living room*

For the living room, $O_3$ concentration is mostly nonexistent with a 0 μg/m$^3$ concentration for 96.3% of the time and peaking at 39.2 μg/m$^3$ in only four measurement during the entire process. CO level is also far below the regulatory values, with higher concentrations during the first day during cooking periods but peaking at 0.8 mg/m$^3$. Meanwhile, $NO_2$ is not present in the air in this situation being its average over the entire measured period of 0 μg/m$^3$. When it comes to the TVOC level, similarly to CO we can see a spike in the air concentration due to the activity performed during the first day and the dishes cooked. On the second day, with a better ventilation as stated in section 4.1.2 , TVOC reduces nearly in half, having a peak in April 6$^{th}$ at around 1350 μg/m$^3$ and much smaller peak at around 800 μg/m$^3$ on April 7$^{th}$ (conversion from ppb to μg/m$^3$ made assuming an average 100 molecular weight). As it can be observed the average 8-hour mean for TVOC in the kitchen is twice as much as

| Parameter | Exposure time | Office | Kitchen | Guidelines |
|---|---|---|---|---|
| $SO_2$[μg/m$^3$] | 10-minutes mean | 1074 | 175 | 500 |
| | 24-hour mean | 264 | 110 | 20 |
| $O_3$[μg/m$^3$] | 1-hour mean | 46 | 6.87 | 200 |
| | 8-hour mean | 39 | 2.75 | 100 |
| $NO_2$ [μg/m$^3$] | 1-hour mean | 7.9 | 0 | 200 |
| $PM_{2,5}$ [μg/m$^3$] | 24-hour mean | 6.41 | 6.16 | 25 |
| $PM_{10}$ [μg/m$^3$] | 24-hour mean | 26.9 | 28.9 | 50 |
| CO [mg/m$^3$] | 15-minutes mean | 1.72 | 0.76 | 100 |
| | 1-hour mean | 1.48 | 0.73 | 35 |
| | 8-hour mean | 1.18 | 0.56 | 10 |
| | 24-hour mean | 0.94 | 0.21 | 7 |
| TVOC[μg/m$^3$] | 8-hour mean | 650 | 1030 | 500 |

the allowed concentration by the standards. This can be explained due to the intentional closure of the windows during cooking times, habit that usually doesn't happen but still denotes and confirms a lack of ventilation that was already observed in the previous section.

## Surveys

### *Rolex*

The questionnaire at Rolex was performed at the end of the first day of measurements on May 7th, 2019. The questionnaire was explained to the students and filled via their mobile phone through an app. At the time the students had been in the building for about 2 hours and were about to take a break at around 17:00. During the time the students were present in the building as can be seen in Table 4 the conditions were: $T_a$ = 24ºC, RH = 30.77% and $CO_2$ = 894 on average.

In terms of thermal comfort 41.7% of the people felt *"somewhat dissatisfied"* and 16.7% answered *"very dissatisfied"* with the indoor temperature making the overall perception of the TC in the Rolex building as not satisfactory. Some even noted that this sometimes makes them lose focus or take breaks more often.

Concerning the indoor air quality, the results denoted a better appreciation of the IAQ with only 16.7% of the people being *"somewhat dissatisfied"* with the quality of the air at Rolex and 8.7% being *"very dissatisfied"* and 75% of the people feeling either being neutral about it or with a satisfactory response.

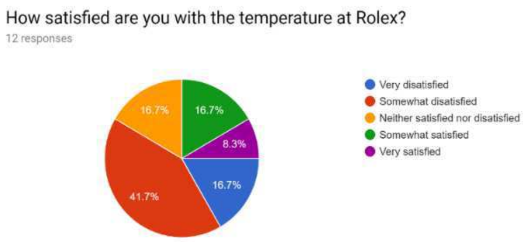


*Figure 2 Survey: satisfaction of temperature in rolex*

When appreciating the quality of the air in the Rolex building, the students find the air as being of good quality. When rating multiple problems that generally occur indoors only the air smelling air was reported as stuffiness/staleness being a major problem in only 16.6% of the time and 58.3% considering it not an issue or a very minor one. Air cleanliness was very positively appreciated with 50% of the students considering it not a problem and with only one considering it as a major problem. Finally, the biggest problem noticed by the students was the bad smell (body odor) around the study areas, with only a 25% considering it not a problem and 25% considering it a major problem but overall having satisfactory results.

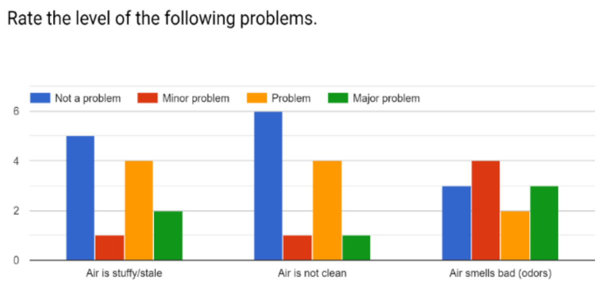


*Figure 3 Survey: Air quality issues rating at Rolex*

### *Atrium residency*

The people answering the questionnaire about the atrium residency ranged in age from 20 to 23 years old. Due to finding it hard to get people to answer the questionnaire, only 7 students participated in the study, with 71.4% being male and 28.6% being female. In this case the clo average was hard to assess since most students vary the way they dress during the day while being at home.

In the answer to the first question *"How would you normally rate the temperature in the common are?"*, 57.1% of the students find the temperature inside the apartments is satisfactory, with only 28.6% finding it *"Somewhat cold"* and

14.3% finding it *"Somewhat hot"*. When the same question was answer regarding the bedroom thermal comfort, 71.4% of the students answered, *"Neither hot nor cold"* with only 28.6% of them finding the temperature to be "*Somewhat hot"*.

Concerning the indoor air quality inside of the apartment, the results highlight a poor IAQ, with 42.9% of the responses being *"Somewhat dissatisfied"* and 14.3% of them being *"Very dissatisfied"*. Thus, this makes more than 50% of the participants in the survey not happy with the air they breathe in a daily basis in their apartment. When the same question was asked about the IAQ of the individual bedrooms the responses were very different with only 28.6% of the participant being dissatisfied, although none answered with a positive response either.

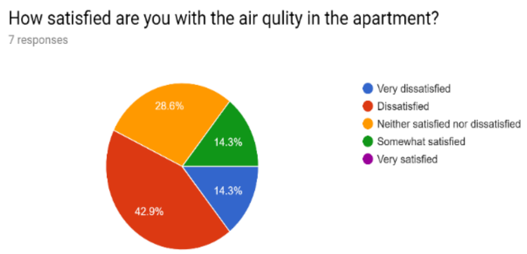


*Figure 4 Evaluation of atrium living room IAQ*

When asked to rate the magnitude of certain problems regarding IAQ, out the 7 participants, 4 of them found the air being stuffy/stale as a *"Problem"* or "*Major problem"*. In regard to the air cleanliness, only 3 out of the 7 participants consider it to be *"Problem"* or "*Major problem"*. The most observed problem by the students was the bad smell indoors with it being a "*Major problem*" in 4 out of 7 answers and a "*problem*" in 2 of 7 responses making it the biggest issue inside of the residence.

**PMV and PPD indices**

To evaluate these values a tool from the Center of Built Environment at Berkeley was used. The parameters imputed for the environmental condition were the mean, minimum and maximum values for the parameters measured, the air velocity was considered as 0.1 (m/s) as an approximation for normal indoor spaces since no measurement was available. The metabolic rate considered is one of an individual sitting doing some rudimentary work such as typing, reading or writing since it is the most common activity of students inside the spaces studied. Finally, the clothing insulation was considered to be of 0.74 clo apartment (sweatpants and a long sleeve shirt) for inside the, and 0.96 (jacket, trousers and long sleeve shirt) in the Rolex library after discussing with the participants of the study their habits and by observation. To compare the results of the questionnaires to the PMV and PPD values, the results for Fanger's indices can be found in Table 6.

**PD based on $CO_2$ concentration**

In rooms where the $CO_2$ concentration is mainly due to the occupants, it is recommended to determine the percentage of dissatisfied people as a function of $CO_2$ concentration.

*Table 5 PD in different environments*

| | Living room | Bedroom | Rolex library | Office |
|---|---|---|---|---|
| $CO_2$ (ppm) | 507 | 892 | 861 | 695 |
| C (ppm) | 157 | 542 | 511 | 345 |
| PD (%) | 5.5% | 17.1% | 16.32% | 10.85% |

*Table 6 PPD adn PMV with max min and average values*

| Parameters | Atrium living room | | | Atrium bedroom | | | Rolex library | | | Office | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max |
| T (ºC) | 19.2 | 20.9 | 21.8 | 19.5 | 21.5 | 24.3 | 23.52 | 24.08 | 25.11 | 18.4 | 22.4 | 26.3 |
| RH (%) | 36.9 | 43.5 | 58.5 | 31.3 | 36.25 | 40.48 | 27.01 | 30.77 | 37.7 | 16.3 | 68.3 | 30.1 |
| M (met) | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| $I_{clo}$ (clo) | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 |
| V (m/s) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| PMV | -1.4 | -0.89 | -0.55 | -1.35 | -0.77 | 0.03 | 0.06 | 0.22 | 0.52 | -1.21 | 0.06 | 0.75 |
| PPD | 46% | 22% | 11% | 43% | 17% | 5% | 5% | 6% | 11% | 36% | 5% | 17% |

## Discussion

*Atrium living room*

Across the result obtained in this room the ventilation rate obtained by using the two-point decay method is too low as stated by the standard ASHRAE 62.1. In term of gaseous pollutant, the levels seem to be maintained in check over the entire period of measurement, being the only outlier the $SO_2$ in some punctual situations.

When comparing the results of thermal comfort evaluations Fanger's model shows worst ratings than the survey does. These results reflect that the overall conditions in this room is quite good and well inside of the standards, however due to occupancy values not being well recorded and thus not being used the average temperature and other parameters averages might be lower than during the true exposure to the indoor environment that the survey suggest.

In terms of air quality, larger dissatisfaction is observed with more than 50%, whereas the value obtained by using the PD concentration suggest only a 5.5% of people dissatisfied. This discrepancy is considered to be due to the sporadic presence of people in the living room and hence low concentration of $CO_2$ produced by occupants but large quantities of other gases and particles such as the trash can and food but that is not considered in the equation used. This reasoning is further reinforced by the answer from the occupants identifying bad smell of the air as a major problem while the air is not considered to be particularly dirty.

*Atrium bedroom*

From the results obtained during the project it is noticeable higher averages in temperature, and $CO_2$ concentration in this room. This can be explained by the low ventilation rate in this room of only 4.65 l/s below the minimum requirement.

The comparison of thermal comfort between the survey performed, the PPD and PMV values in this case show a slight difference in the perceived temperature from the analytical method and the standard. With a 71% of the answers from the survey being neutral and a PMV denoting only 17% of PPD. Overall the condition are satisfactory none the less.

Regarding the IAQ, the survey shows a slight dissatisfaction from the occupants of atrium with 29% of the participants slightly dissatisfied while the rest responded with a neutral answer. The results from using the PD concentration shows a 17.1% of people dissatisfied. Overall both valuations are similar, mostly due to less odors being emitted by objects foreign to the occupants as was the case for the kitchen.

*Rolex library*

The Rolex library registered the highest average temperature of the rooms analyzed, with it being 24.03 ºC and surpassing the limit for a category II building. Its relative humidity is on at the lower limit of the comfort range, and the average $CO_2$ concentration, even if not above 1000 ppm is somewhat high at 861 ppm. Some of this value are due to the lack of operable windows as well as the high exposure to the sun through the glass walls.

In terms of thermal comfort, the survey shows a high dissatisfaction rate, with 41.7% of people being somewhat dissatisfied and more than 50% having a negative response and overall considering the temperature as being hot or too hot. When compared to the PMV value a big difference can be seen. With a value of 0.22 and only 6% PPD by the EN15251 standard the thermal comfort should be accomplished but most people reported low satisfaction rates. When asked about the topic participants considered the difference between the outside and inside temperature significant, especially due to the clothing worn.

Regarding IAQ, the survey shows answers in ranges from -2 to 2 in a five-point scale question but being most of the answers positive and only 25% of the people being unhappy with the air quality. Comparing this to the PD calculated with the $CO_2$ concentration, which result is a value of 16.32 percent dissatisfied, a conclusion is reached that the overall IAQ inside of the Rolex building is satisfactory, being thus the only problem in said building the thermal comfort.

*Office*

In terms of thermal comfort, by analyzing Fangers indexed a big range of values is found in the PMV, this is mainly due to the low temperature during the night that cool down the room when the occupants arrive in the morning, and high temperatures in the afternoon with direct exposure to the sun which heats up the room through the windows. With average values of the comfort parameters resulting in a 0.06 PMV, the results are quite satisfactory, but the range of values observed might hinder the occupant's comfort since inside an office it is harder to adapt in terms of clothing.

In regard to IAQ, since no survey was performed for this space, only the PD based on the $CO_2$ concentration is available. With a result of 10.85% of people dissatisfied, and by comparing the values in Table 13 with the standards, the IAQ of the room is deemed to be quite satisfactory for the occupants as no big concentration of pollutant is observed except for $SO_2$, but being this due to outdoor sources it is not likely that it affects the IAQ in the average day throughout the year.

## CONCLUSION

In this study the TC and IAQ of multiple locations of the EPFL has been studied. The environmental parameters influencing TC and IAQ and compared with other gases concentration and the subjective assessment of the occupants.

The study shows that the ventilation in all locations was below the minimum required ventilation rate as per the standard ASHRAE 62.1. This causes, in some spaces such as the Atrium living room, low perceived comfort values in terms of IAQ. The concentration of $CO_2$, even though not particularly high, proved to raise above the limit in multiple occasions, making the rooms sometimes feel stuffy or allowing bad odors from body bio effluents or from other sources.

The thermal comfort proved to be sometimes not adequate for the occupants. The ranges in PMV are quite big, making the environments highly dynamic, with big changes between the morning and the afternoon with higher sun exposure, reaching temperatures above 25 ºC.

Overall, the conditions in the buildings at EPFL seem to provide satisfactory IAQ and TC conditions, however more controlled or regulated ventilation systems should be studied to be provide better results. Some of the proposed systems proposed to be explored would be: ventilation based on $CO_2$ concentration and temperature, or even exploring personal ventilation in some cases such as the individual bedroom where $CO_2$ concentration reach high levels if the windows are kept closed at night or the Rolex library were, due to the high concentration of people, bad odors and discomfort is common among students.

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# DOCUMENTO I

# MEMORIA

## Content

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# PARTE I

# MEMORIA

# 1. ABSTRACT

This work shows the result of a field study about indoor thermal comfort (TC) and indoor air quality (IAQ) at some EPFL buildings. The surveys here presented were performed at EPFL and answered by students of said university.

The study was performed by monitor IAQ parameters and surveys questionnaires. Both the measurements and surveys were performed during the same time frames. The measurement campaign consisted in measuring the air temperature (T), the air relative humidity (RH), $CO_2$ concentration as well as the particulate matter and other gaseous pollutants concentration such as $NO_2$, CO, $SO_2$ and TVOC. With these data as well as Fanger's comfort indices were calculated.

The results obtained about the TC and IAQ show that the students found the air quality in acceptable ranges in most cases, although some issues with the bad odors at Rolex and inside apartments were raised. The $CO_2$ concentration limits were at times surpasses and, as an indicator of concentration of other possible substances, was responsible in some cases of the discomfort mention. In terms of TC the results show that students are comfortable with temperature levels outside of comfort ranges, although sometimes the condition were too distant to comfort ranges.

# CAPITULO 1

## 2. INTRODUCTION

Indoor environmental quality is usually characterized by four major factors, such as Thermal Comfort, Indoor Air Quality, Acoustic Comfort and Visual Comfort. As most individuals spend up to 90% of their time indoors (Hui et al. 2006; Godwin and Batterman, 2007) the effects of air quality and thermal comfort have been considered to have a significant impact on the health and performance of people in learning facilities and their workplace. With increase concern on the use of fossil fuel energy, and an increasing trend to move to low consumption buildings, a trend for more efficient and less expensive HVAC systems has appeared. Despite the reduced emission and cost saving that might benefit the environment and building owners, thermal comfort and indoor air quality has been proven to have a significant impact on occupant's cognitive performance.

Thermal Comfort has been proven to have a significant impact on studying and test performance. Added to this, air inside offices, school buildings and residences is normally contaminated by a large variety of toxic contaminants, especially older buildings which were built with less strict regulations. Thus, ventilation has become a key factor to ensure control for human comfort and to improve indoor air quality. A lack of it can even be harmful to occupants not only in terms of performance when studying or working but also aggravating allergies or favoring Sick Building Syndromes (SBS). This may lead to signs of negative body reactions such as headaches, irritated eyes/throats and congested noses [1] and find it difficult to concentrate on their work. High temperature in a densely occupied room together with human bio effluents were regarded as main reasons why occupants feel uncomfortable, which normally take place in a space with bad ventilation. It is reported that relatively low temperature and humidity can help reduce SBS symptoms and improve the performance of the office work [2]. Wargocki et al. also found that the performance of typical office work (such as typing, arithmetical calculations and proof-reading) can be improved by removing pollution sources and increasing ventilation rate [3–5]

Recently, the indoor air quality at schools and universities has become a topic of interest (Daisey, Angell, & Apte, 2003). Usually these types of buildings are characterized by potentially high polluted environments such as classrooms or offices. This is due to crowded classes, short breaks, poor ventilation, a lack of mechanical ventilation systems and the lack of space to assign personal offices to students and faculty members, which results in an increase the number of occupants per room and the sources of emission indoors while maintaining the same levels of ventilation.

### 2.1. Exposure

When talking about the air quality in an indoor environment we first have to understand how the human exposure pattern works and the different interactions between occupants, pollutants and the indoor environment. For this a full risk model has to be taken into account to understand where the pollution is coming from, how it is transmitted to the inhabited areas, the doses that humans are exposed to and the resulting health effects from such exposure.

In Figure XX a simplified schematic of all the steps from the emission of pollutants to the intake and resulting health effects its provided. Traditionally more attention has been payed in the emissions and the transportation (concentration) of these contaminant as well as the health effect, which have been the major factors for administrative entities to take action in cities. Without knowing the exposure component of individuals and inside buildings it can not be know with certainty which components should be controlled and by how much.

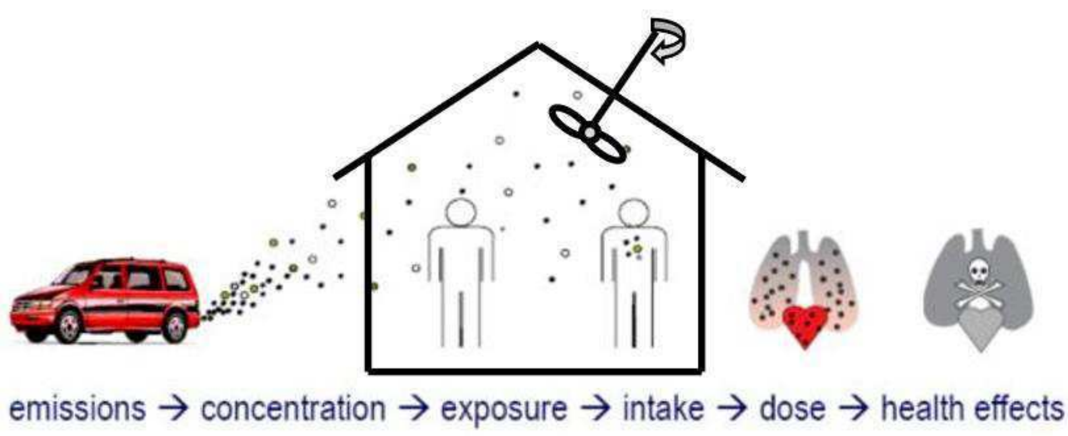



Figure 1 Schematic of pollutants life from emission to health effects

When pollutants are in the air, interaction with humans can happen through multiple pathways and coming from different sources being the most relevant ones:

- **Ingestion**: Pathway that composes pollutants that may come in contact with the human body through the digestive system. Through the mouth many products enter the human body such as water, food and air, which each can have been exposed to different contaminants before ingestion and will thus be introduced in the human body and be released into the system mainly in the stomach.
- **Contact**: A second pathway is the dermal surface of the body. Many pollutants, even thought the most common exposure is through the respiratory system, can also infiltrate the body through the dermis, even thought the doses are usually smaller but may also contribute a factor of risk.
- **Inhalation**: The most important pathway in terms of this paper is the respiratory system. Through here most of the gases and particles suspended into the air enter the body and travel through the respiratory tract to expand to the lungs at different levels.

If a closer approach is taken, the overall process of exposure and intake of pollutants can be further divided into multiple steps, thus differentiating the intake and uptake to evaluate the resulting "whole body dose", which is the transfer and assimilation in the body organs as can be seen in Figure XX.

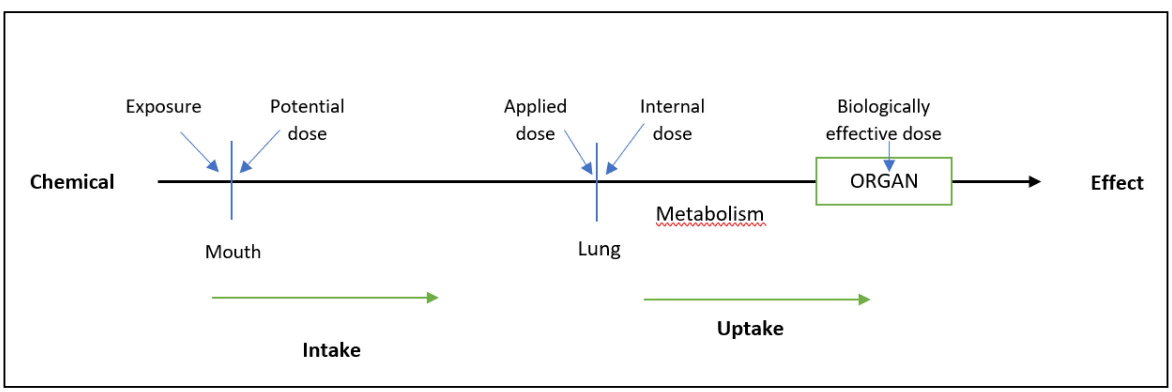



Figure 2 Full process of exposure

In the figure above it can be see that the overall exposure model of human beings is more complex that can be thought at first. As stated before this shows how knowing the concentration of certain contaminants is but the first step to understand what the overall effect of gaseous pollutants and particulate matter is on individuals but more study would be needed to fully measure the risk it presents.

Since exposure not only is linked to the concentration of pollutants in the air but also the time of exposure and the activity performed by individuals, multiple standardizations, such as the EPA exposure factors have been developed to get an idea when performing analysis of what the intake is for an average person. Since human beings spend nearly 90 percent of their time indoors, the most commonly visited indoor environments for students will be the object of the study of this paper.

In order to measure the exposure or concentration, multiple considerations have to be taken into account such as:

- **Feasibility:** Are the conditions and subjects of the study likely to comply with the requirements of the study, such as prevent contaminating the data, tolerating noice made by instruments and such?
- **Accuracy:** Level of detection and measurements required for the study to be viable?
- **Implementation:** Number of subjects or locations needed, are there seasonal trends to be taken into account?
- **Expense:** Cost of the sampling equipment and methodology used?

By knowing these criteria and by evaluation the context of the project and the budget to perform it an appropriate method to carry on with the experiment can be chosen.

In this paper, the main focus is the analysis of the concentration of pollutants and the compliance of the infrastructure surrounding individuals to tackle the issues as per the multiple regulations established and not so much the direct exposure. Seeing as multiple spaces studied are relatively small, and the time spent in the room are usually long, the study will also serve as a basis for exposure measure, but it is an issue that would need to be further explored in this context.

## 2.2. Ventilation

Ventilation inside of closed spaces is crucial for human health and comfort. The ventilation rate in indoor environments affects not only the quality of the air and the health of its occupants, but also the energy consumption of the building. The ventilation rate main objective is to reduce the high concentrations of pollutants originated from indoor emissions such as human beings, furniture, and appliances that that may have an impact on its occupant health leading to productivity problems, absenteeism from work or class and sick building syndromes.

There are three main methods of ventilation that exist at the moment, this being mechanical, natural, and mixed ventilation:

- Natural ventilation most typically present in buildings, relies on the natural forces such as winds and pressure difference between the inside and outside to exchange the air with the outdoor environment through purposely built building envelops openings such as windows, air vents or doors. This mode can usually provide high ventilation rates and is more economical since it relies on the use of natural forces. It is especially more energy efficient when heating is not required although is it highly dependent on the outdoor conditions relative to the indoor environment. We can thus observe a high variability in depending on the outdoor conditions and the architecture of the room as can be observed for a more clear explanation in Figure 3.

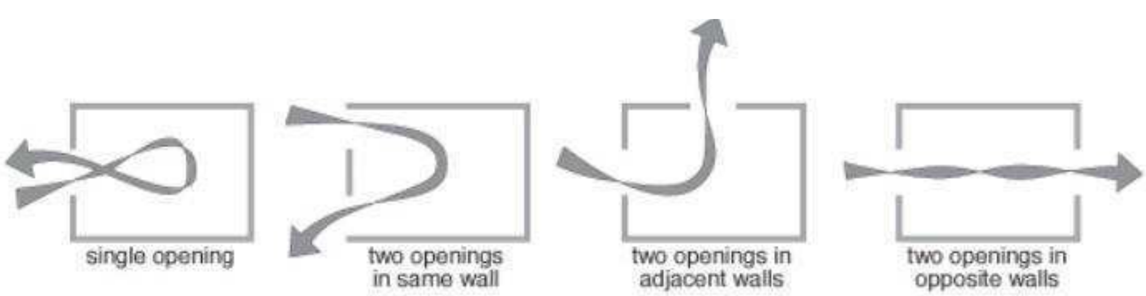



Figure 3 Different natural ventilation flows depending on widow positioning

- Mechanical ventilation is usually characterized by the use of fans powered by electricity. They can be portable or be placed on walls, windows or in ventilation ducts to move the air. They are usually more reliable than natural ventilation due to the control the user may have over it, being thus able to provide a more constant air flow rate. Added to this, filters can be used in mechanical ventilation to reduce the concentration of pollutant gases and particulate matter from outdoors or that are already inside. This method is more energy consuming and usually contains more complex mechanism making it more cost and energy consuming and with higher maintenance costs.

- Lastly there is mixed-mode ventilation, which relies on a combination of the two previously mentioned methods. In this method, mechanical ventilation is used when natural ventilation inside of the building is too low (Heiselberg Bjorn,2002).

As specified above, high enough ventilation rates need to be provided in buildings to provide a comfortable and healthy environment while trying to maintain a low energy consumption to reduce the emissions to outdoor and energy consumption that may lead to more polluted cities and bigger expenses for households and businesses.

When looking into more depth into the ecosystems created inside closed spaces and how the overall system works, we can see multiple factors come into play when talking about ventilation and not only planned ventilation. The entire model for estimating the ventilation inside of a closed space, known as the mass balance equation, targets to model the state of a room taking into account all the entering and leaving air as can be seen in Figure XX.

In said image, it can be observed the previously mentioned ventilation types, mechanical and natural ventilation, but other factors are also mentioned such as:

- **Leakage/Infiltration:** The walls of building usually contain leaks which are non-intentional exchanges of air with the outside environment. These are usually hard to measure and need special measurements technique to be able to evaluate them. When such equipment is not available, or the time and resources is not there certain assumption or other approximate methods can be used to understand the behavior of the indoor environment without having to perform such studies.

- **Deposition loss:** When the air contained indoors is polluted with a certain amount of gas concentration, and due to the dynamic of the molecules and particulate matter, the substances often tend to fall, if their wheight is high enough and deposit on the floor or carpets being captured and preventing it from being released into the air.

- **Filtration:** Lastly, apart from ventilation to clean and replace the air inside of the built environment, other types of technologies exist that allow for the capture or elimination of certain particle in the air. This can be very useful to remove allergens from the air as well as more precise contaminants. These technologies come in the form of fibrous filters but also electrostatic and membrane filters, having sometimes byproducts due to the functioning of the device such as ozone.

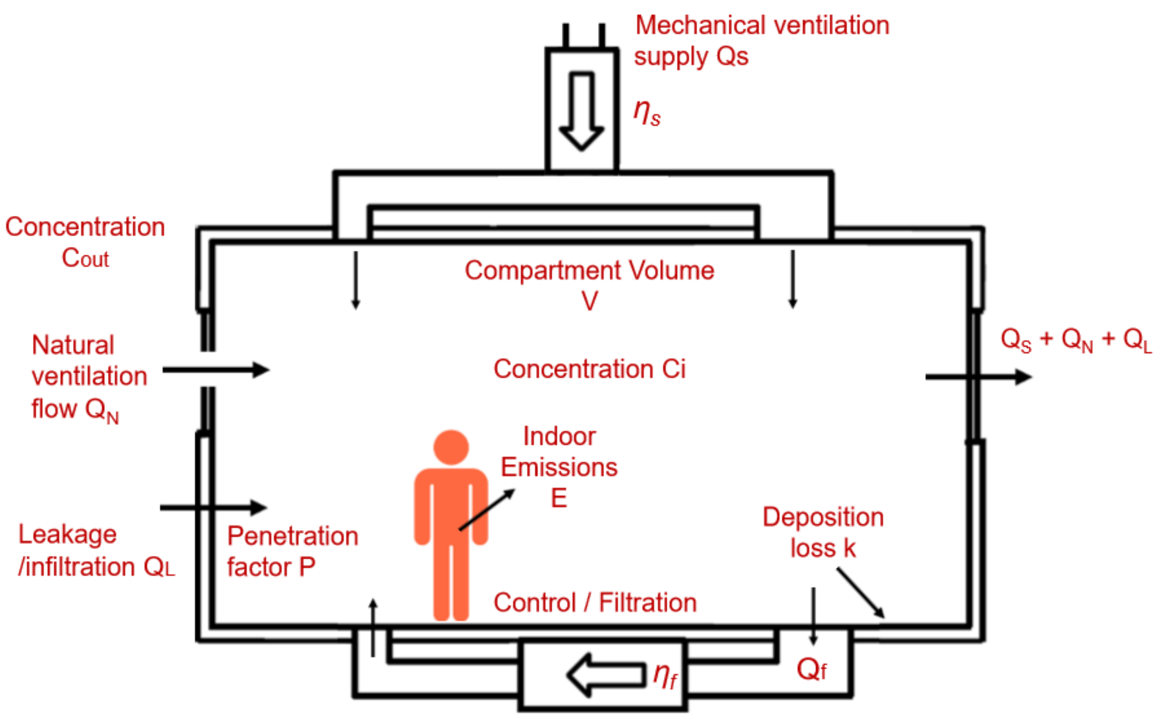



Figure 4 Full ventilation model in inside spaces

### 2.3. $CO_2$

Carbon dioxide ($CO_2$) is one of the main components of the atmosphere. Itis a colorless and odorless gas that is found in the outside air and which concentration has grown by nearly

30% in the last 40 years to about 410ppm [9]. In non-industrial settings, it's one of the major sources of indoor $CO_2$ concentration as it is one of the main bio-effluent of humans, being released in concentration of 40000 ppm in exhaled air [10]. Concentration of said gas indoors ranges from outdoor levels to several thousand parts per million (350 – 2500). Although $CO_2$ is not considered to pose serious health threats to occupants, research on the effect of $CO_2$ on human health within the higher bounds of the concentration found in indoor spaces, has shown that it can increase the appearance of acute health symptoms such as headache, respiratory system irritation and reduced performance (Panayotis et al. 2001; Daisey et al. 2003), but this is believe to happen because of the increase of other pollutants with higher concentrations of $CO_2$ [11]. Due to the characteristics previously mentioned, $CO_2$ is often used as a tracer gas to measure the ventilation inside of buildings, be it as a controlled injection of $CO_2$ or taking the metabolically generated carbon dioxide generated by the occupants in the room [12].

### 2.4. Particulate Matter

By the estimations of the World Health Organization, the presence of particulate matter (PM) in the air contributes to approximately 800,000 premature deaths each year, being thus the 13th leading cause of mortality worldwide [6].PM is a complex mixture of various small particles and liquids of very small size. Particulate matter is made up of multiple components among which we can find1

acids (such as nitrates and sulfates) organics chemicals, metals and or soil or dust particles [7]. These particles can originate from manmade processes such as combustion, vehicle emissions, cleaning, tobacco smoke and cooking activity. Being categorized in different sizes ranging in the micrograms studies show that they are responsible for a broad range of health effects but are predominantly to the respiratory and cardiovascular system in the short and long term [8].

### 2.5. Other gaseous pollutants

Nitrogen dioxide ($NO_2$) is usually a by-product on combustion of coal or cigarettes, being sometimes present in buildings due to inside smoking or traces brought by smokers into the building or through the ventilation systems. When expose to $NO_2$ the major health effects are related to respiratory symptoms and decrease in immune defense as reported by the WHO in its 2005 air quality guidelines.

Ozone ($O_3$) is a pollutant formed in the atmosphere in the presence of sunlight and other pollutants such as NOx and VOC. At high concentrations during prolonged time, health effects increase in number and severity with respiratory problems and changes in lung function being the more common as specified by WHO.

Sulfur dioxide ($SO_2$) is a gas present in motor vehicles emission and as a cause of fuel combustion, hence 99% of the $SO_2$ breathed by humans is cause by their actions. High concentration of this gas can cause changes in pulmonary functions and respiratory symptoms in exposure as short as 10 minutes.

# CAPITULO 2

## 2 PREVIOUS RESEARCH AND METHODS

### 2.1 Ventilation

While there were not many researches on ventilation rates inside of schools during the 20th century, it's starting to become more relevant as of late. The ASHRAE Standard 62.1 recommends a minimum of 7.5 l/s per person and 0.6 l/s per square meter for classrooms inside of schools. Average ventilation rates, as reported by literature and analyzed by (Daisey et al. 2003) in European and American literature, are exposed in Fig.1 of said study.

In 1993, Turk et al. reported after a study in two school in New Mexico, the ventilation rate of multiple rooms pre and post mitigation of radon with most of the results being unsatisfactory and below 3 l/s-person, well below the minimum required. Nielsen (1984), reported, after a study of 11 schools in Denmark ventilation rates in the range of 1.8 to 15.4 l/s-person, with the average being somewhat inferior to the minimum requirements for schools.

Smedje et al. (2000) showed in a study in 39 schools in Sweden that 77% of schools did not meet building codes regulation, while Seppanen and Fist (2002) found that there was an increase in prevalence of sick building syndrome between 30% to 200% in the buildings with air-conditioning when compared to natural ventilation.

### 2.2 $CO_2$

The recognized maximum concentration for indoor air quality is accepted to be 1000 ppm but concentration below those values do not guarantee an adequate ventilation inside the building for removal of other pollutants (Apte et al. 2000). In Daisey et al. we can see in Fig. 2 and 3 the average $CO_2$ concentration and ranges in schools recorded in the scientific literature in the U.S. and Canada. Concentrations near or above 1000 ppm can be seen in many situations.

Turk et al. (1993) reported average $CO_2$ concentration values ranging from 800 to 1700 ppm, values similar to Fisher et al. (1994) and Thorne (1993). In this case Brennan et al. (1991) reported the highest concentration in a study in 9 U.S. schools with concentrations between 400-5000 ppm and measurements above the ASHRAE limit in 74% of the cases. Potting et al. (1987), in an epidemiological study in four schools built after 1980, reported concentrations levels surpassing the established limit in 27 to 97% of the time. In a study in 100 schools in Denmark, [17] found that the average $CO_2$ concentration during school hours often surpassed the 1000 ppm limit for up to 56% of the school hours.

As Daisey et al. concludes, concentrations of $CO_2$ in school facilities show a tendency to surpass the limit established by ASHRAE Standard 62.1 significantly. This tied to the low ventilation rates might prove to be an acute problem and reduce academic performance.

### 2.3 Relationship between ventilation and health effects

Myhrovld et al. (1996) studied the relationship between ventilation and health symptoms in 5 schools in Norway before and after renovation. A significant partial correlation was found between symptoms such as dizziness, tiredness, difficulties concentrating and $CO_2$ concentration levels in the range of 1500 to 4000 ppm when compared to lower concentrations. Potting et al. (1987) in a study in four Dutch schools found that complaints about bad odors were associated with high $CO_2$ concentrations.

Sepannen et al. (1999) compare 41 different studies on the association of ventilation rates and carbon dioxide concentrations in non-residential and non-industrial buildings with human health. In this study multiple interesting things were highlighted. Ventilation rates below 10 l/s per person related with statistically significant worsening in one or more health or perceived air quality outcomes. There is no clear threshold of ventilation below which SBS were clearly reduced. Some studies reported increase to ventilation in range 10 to 20 l/s per person decrease the presence of SBS in the occupants. 7 out of 17 studies about $CO_2$ reported that concentrations below 800 ppm further decreased the presence of SBS. No symptom was consistently associated with increase in $CO_2$ concentration. None of the assessments found an increase of symptoms with decreasing $CO_2$ concentration. Worsened air quality as perceived by occupants and panels were associated with lower ventilation rates. Menzies et al. (1993a) performed a study varying the ventilation rate in the range of 14 to 30 l/s-person and the prevalence of SBS did not change.

## 2.4 Assessment on air quality and thermal comfort

Multiple studies have been performed about thermal comfort and indoor air quality. Dias L. et al (2014) conducted a study in Portuguese secondary schools to assess IAQ. For this IAQ and TC are analyzed by means of measurements of the indoor temperature, relative humidity and $CO_2$ concentration. The average conditions of the classroom in terms of the measurements previously mentioned were compared to the reference values marked by the IAQ standards and used to compare with the satisfaction of the occupants of said room by mean of surveys. These surveys focused on the thermal comfort and indoor air quality of the students, their thoughts on the thermal environment, and their preferences in regard to said subject with 7-point scale answers. All this data was studied in order to evaluate Fanger's thermal comfort indices, the perceived mean value (PMV) and percent of people dissatisfied (PPD).

In a similar research Alves c: et al (2013) did a study in two university sport facilities. In it, comfort parameters (temperature, relative humidity and $CO_2$), CO and TVOC were continuously monitored. In addition, $NO_2$ and particulate matter concentrations were also analyzed to assess the IAQ of both buildings. To perform the study, the ventilation rates were analyzed. The concentration of indoor air pollutants was statistically analyzed and compared to other research and international standards to evaluate the health impact it could have on the users of the facilities.

# CAPITULO 3

## 3 METHODOLOGY

### 3.1 Purpose of the study

The main purpose of this paper is to study the thermal and indoor air quality conditions inside of the EPFL buildings such as student offices, the Rolex library and the student residence of Atrium. A special focus will be made to the concentrations of CO2 to measure the ventilation of each space as well as the concentration of particulate matter in the different spaces. The concentration of gases such as Nitrogen Dioxide, Sulfur Dioxide, Carbon Monoxide and Ozone will also be considered when the data is available. All the results will be compared to the standards set by ASHRAE and the WHO and some of the results will be compared to surveys realized among the student body to compare the compliance with the international standard of the different buildings as well as note the perceived air quality and thermal comfort inside of the EPFL facilities.

### 3.2 Weather of Lausanne

The EPFL campus is located near Lausanne in the canton de Vaud in Switzerland characterized by its continental climate influenced by the proximity of Lake Geneva and the mountains. During the school year when the experiments concerning this project were performed, the temperatures ranged between a minimum average of -1ºC in winter and a maximum average temperature of 19ºC when approaching the summer. The measurements were all performed during the months of April and May, with temperature ranging from 6ºC to 19ºC and an average humidity of 66% to 67% both months.

## 3.3 Measuring instruments

When measuring for gases and particulate matter in the indoor environment multiple techniques and devices are available depending on the precision and substance to be measured. Sampling methods are usually distinguished by particle counting (no sizing), particle sizing (counting and sizing), mass and composition. Among the different techniques and devices, the most used one are:

- **Filter sampling**: characterized by filter efficiency, poor size and the filter used. These kinds of samplers allow for sufficient volume for analysis but dries the particles due to the airflow making the removal of the particles from the filter sometimes difficult.

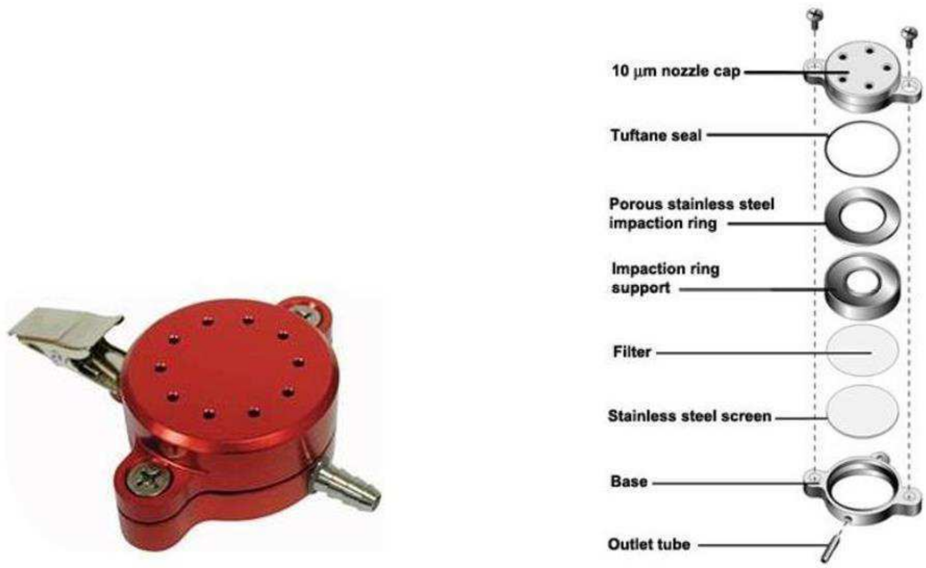



Figure 5 Filter sampling breakdown

- **Impactor sampling:** These kinds of samplers are comprised of 3 to 8 stages which allow to adjust for size resolution. The particles enter the volume and due to their size get trapped at each stage allowing for a separation by size. Similarly, as before they also dry the particles but in a smaller fashion and due to the inert surface it allows for easier extraction of the particles.

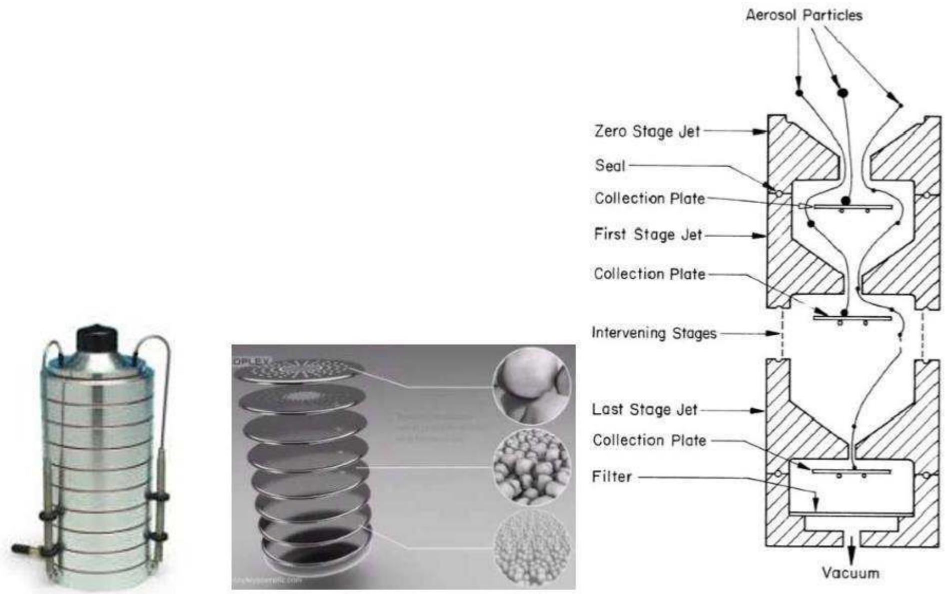
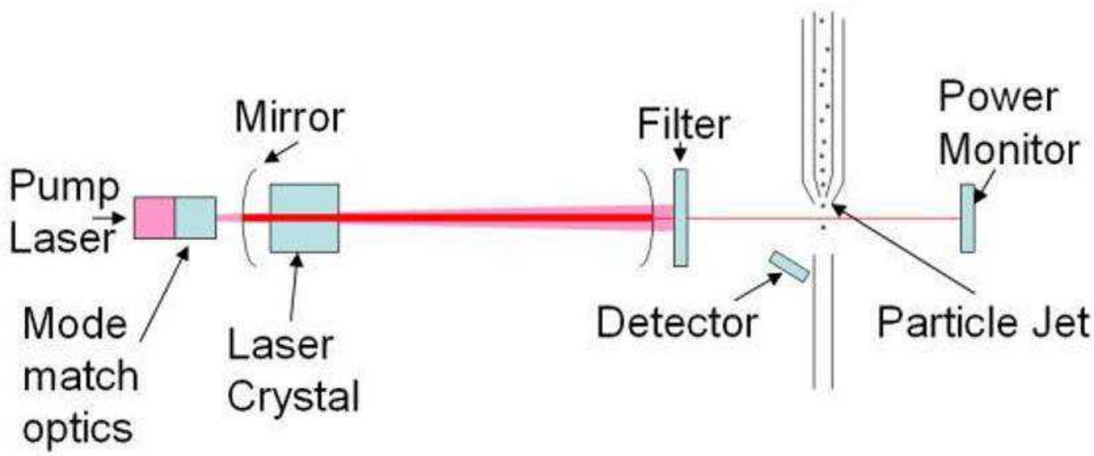



Figure 6 Impactor sampler breakdown

- **Optical particle counter:** Lastly the optical particle counter, different from the previous two function on the principle of the light being scattered by a particle under a certain illumination depending on its size, being the particle geometry and its optical properties key to identifying them.




For this project multiple instruments were used. Among them we used a gas meter (Graywolf DirectSense-II) capable of recording the real time concentration of TVOC, $CO_2$, CO, Ozone ($O_3$), $NO_2$ and $SO_2$, as well as temperature and relative humidity.

Another instrument used was the Graywolf Particle Counter 3500, corresponding to the optical particle counter explained above, capable of counting in real time the number of particles ranging from 0.3 to 25.0 micrometers, with a flow rate of 2.83 l/min and long-life laser diode technology to perform the measurements. Five channels of the 6 were used to measure $PM_{0,5}$, $PM_1$, $PM_{2,5}$, $PM_5$ and $PM_{10}$. Additionally, the HOBO MX $CO_2$ can measure the $CO_2$ concentration, temperature and relative humidity and an occupation device was used as auxiliary instruments to measure the CO2 concentration and occupancy.

## 3.4 Location

The Ecole Polytechnique Federale de Lausanne (EPFL) was officially founded on January 1969 time at which its campus began to be built. It wasn't until 1980 when the main buildings such as Cubotron, GM and GC were opened. Due to the time around which it was built the guidelines and regulations used at the time are expected to be lacking in term of today standards [13]. In 1986, the GR building, location at which another part of the study was located was built. Following this expansion, in 2010 the Rolex learning center, an incredibly innovative building with a peculiar design was opened as the new library for EPFL and UNIL students to study. Finally, in 2013, due to the increase of students attending the university the student residence Atrium was opened on the premises.

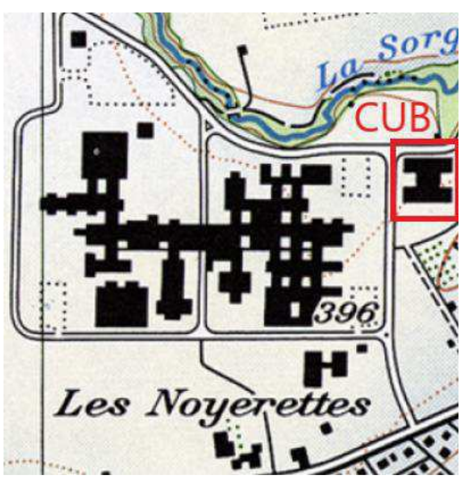



Figure 7: EPFL 1980

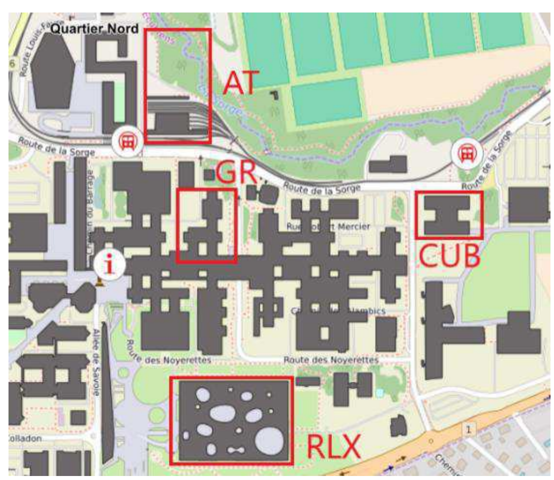



Figure 8: EPFL 2018

### 3.4.1 Office GR

The office, where part of the experiment was performed, is located at GR building at EPFL and located in the first floor. This room is situated in the west part of the building. Having its windows looking to the west, it has a small road in front of it, as well as an opened area which allows it to be exposed to the sun during the afternoon. The office dimensions are 5.4 meters in length, 3.7 meters in width and 2.7 meters in height for a total volume of 53.9 $m^3$. Added to this there is a 1 m width by 1.5 m height window and a natural ventilation system with 2 ducts, one of 0.15 m by 3.5 m located near the window and another one above the door with dimensions of 0.35m by 0.90m as shown in Figure 3 and 4.

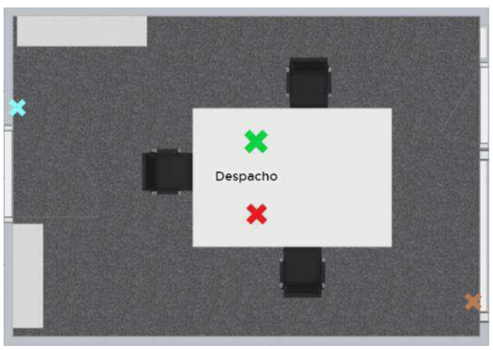



Figure 9: Office GR 01 507 top view

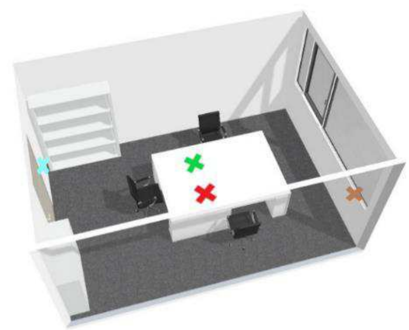


Figure 10: Office GR 01 507 3D model

The instruments were distributed around the room, having the occupancy detector (blue cross) near the door to register movement inside of the room, the gas meter and PM (green and red cross) detector placed in the middle of the room at an approximate height of 1m and at a distance of 1m from all individuals in the room. Finally, the HOBO MX CO2 (brown cross) was placed near the gas meter at first and was later changed close to the exterior wall to see the differences in $CO_2$ distribution around the room. The measurements were taken during a period of 2 weeks from March 27$^{th}$ to April 5$^{th}$.

### 3.4.2 Atrium

In the Atrium residency, located near the school and by the metro station, both a living room/kitchen and a bedroom of a two-bedroom apartment where studied. In the case of the 23,5 m$^2$ common space, as it can be seen in the blueprints in Figure 5, the PM meter and gas meter were placed close to each other in a table about 1 meter high and far from the kitchen and windows during a period of two days.

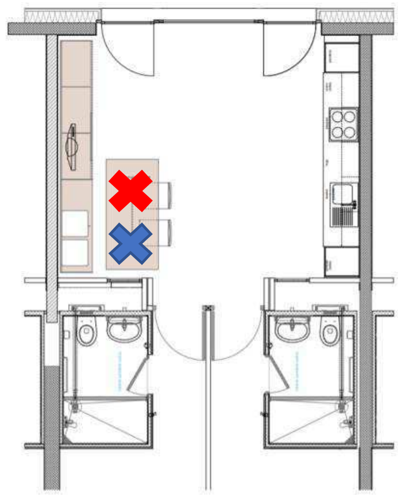


Figure 11 Atrium 2-bedroom apartment schematic

For the bedroom, due an unexpected malfunctioning from the gas meter, only the particulate matter and $CO_2$ meter were available. As we can see in the schematic below, both instruments were placed on a table at about 1 m high and the measurements were taken over the period of one day. The room area is 15,5 m$^2$.

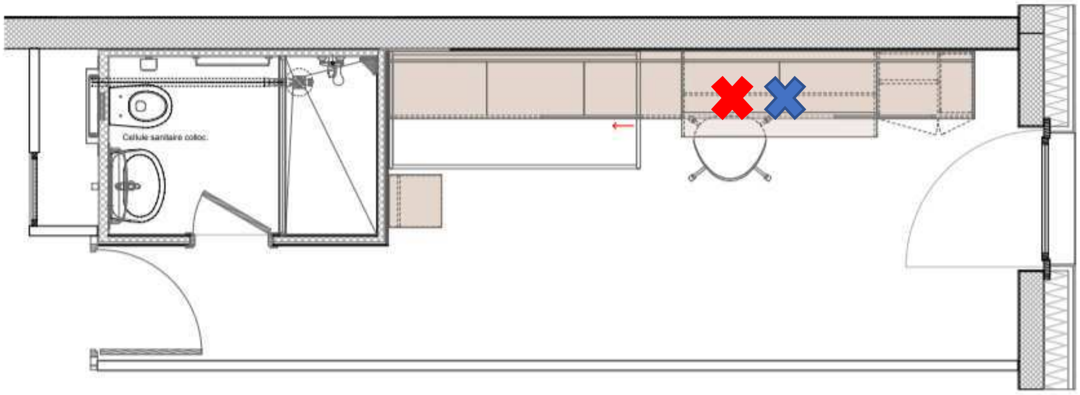



Figure 12 Atrium bedroom schematic

### 3.4.3 Rolex

In the Rolex building, the measurements were taken over a period of two days. Both days the devices were placed in zones where group work is usually performed due to the noise of the devices used. The red cross marks the placement of the first day and the blue one on the second day. Similarly, to the measurements in the room at atrium, the gas meter was unavailable for used due to some technical issue so only the PM and $CO_2$ meter were used.

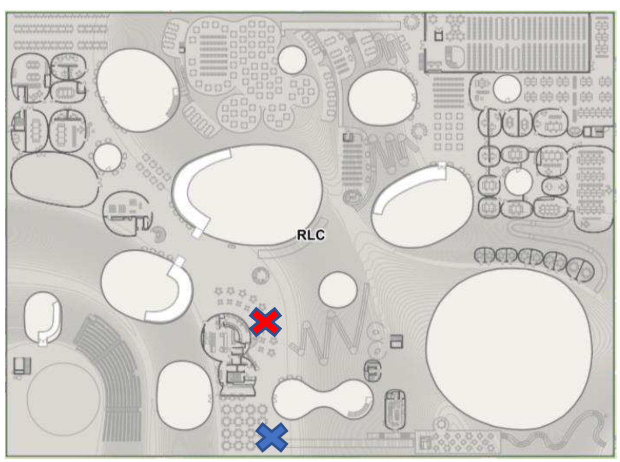



Figure 13 Rolex schematic

## 3.5 Methods

### 3.5.1 Ventilation rate calculation

In close spaces occupied by humans the concentration of $CO_2$ increases as the occupant breath and thus reducing the oxygen in the space. The $CO_2$ concentration in exhaled air is of around 40 000 ppm [14] and with it, if not enough ventilation is provided, the concentration of $CO_2$ rises as an effect.

#### 3.5.1.1 Two-point Decay method

To measure the ventilation rate multiple methods are available being the most popular one the decay method with $CO_2$ as a tracer. In it, a certain amount of $CO_2$ is introduced in the room, the room is then left empty and the concentration is measured over time, observing thus the evolution of the gas decay. Once the data is obtained it is possible to calculate the ventilation rate of the indoor space by using the mass balance equation for the gas (Grieve 1991). The equation resulting in:

$$q \cdot dt - (c_{in} - c_{out}) \cdot \lambda \cdot V \cdot dt = (\tfrac{dc}{dt}) \cdot dt \cdot V$$

Where:

- q is the tracer gas flow rate
- $c_{out}$ is the concentration of the gas outdoor
- V is the volume of the indoor space
- $c_{in}$ is the concentration of the gas indoors
- λ is the air exchange rate of the room

Reorganizing the variables, we get a non-homogenous first-order nonlinear equation:

$$\frac{dc}{dt} + \lambda \cdot c = \lambda \cdot c_{out} + \frac{q}{V}$$

If we write the initial tracer gas concentration as $c = c_{out} + c_0$ ($c_0$ being the initial concentration in the space), the last equation becomes [15]:

$$c = c_{out} + \frac{q}{\lambda \cdot V} \cdot (1 - e^{-\lambda \cdot t}) + c_0 \cdot e^{-\lambda \cdot t}$$

As the test are carried out by the tracer decay method (q = 0) the solution to find the air exchange rate is as follows:

$$\lambda = \frac{1}{t} \cdot \ln \frac{c_0 - c_{out}}{c - c_{out}}$$

As it can be seen from the above expression, to use this method only two measurements are needed. But sometimes the measurement can present an error, or it might have peaked due to some foreign event, so it is usually common to take multiple measurements at constant time intervals during the decay process to perform the air exchange rate calculation multiple times and present an average as a result.

#### 3.5.1.2 Built up method

In some cases, using the tracer gas method is complicated due to the intermittent usage of the room, or the gradual decline of people in the room as opposed to everyone exiting at once. For this, another method exists called the built-up method. It consists in the observation and measurement of the increase in CO2 concentrations following the occupancy of a room to determine the ventilation rate, with the assumptions that the CO2 generation rate and ventilation rate are constant over the study window [12]. To solve the previously mentioned, mass balance equation but in this case for the buildup period, one option is to use two sequential CO2 measurements:

$$\lambda = \frac{1}{t} \cdot \ln \frac{c_s - c_0}{c_s - c_1}$$

Where:

- $c_0$ and $c_1$ = $CO_2$ concentration measured at start and end of the observation time window
- $c_s$ = steady-state concentration

Since many times the steady state concentration is it not known when measuring, $c_s$ might be derived in multiple ways, one of them being the 2-point method by using a third measurement $C_m$ which is a midpoint between $C_0$ and $C_1$. To estimate the value using this method, the following assumptions need to be valid. A smooth and initially rapid increase in concentration with a following tendency to a more constant value. If this are true $c_s$ can be estimated as [12]:

$$c_s = (c_m^2 - c_0 \cdot c_1)/(2 \cdot c_m - c_0 - c_1)$$

### 3.5.2 Standards

#### 3.5.2.1 $CO_2$ concentration

To ensure the quality of the indoor environment standards such as ASHRAE 62.1, EN 13799 and EN15251 have been created in the past 20 years to ensure some minimal thresholds required to accomplish this. In doing so, the overall maximum value recommended for the concentration of CO2 in an indoor space is 1000 ppm to provide a healthy environment for its occupants [16]. Going into more detail, European standard EN 13799 provide a classification of four acceptable levels of CO2 concentration in indoor environments as we can see in Table 1.

Table 1 Air quality in terms of CO2 concentration - EN13779

| Category of air quality in the room | Increment of $CO_2$ with respect to outside air [ppm] |
|---|---|
| High quality | 350 |
| Medium quality | 500 |
| Moderate quality | 800 |
| Low quality | 1200 |

When looking at the ventilation rate and $CO_2$ concentration these values together with the 1000 ppm value set by ASHRAE 62.1 will be used to assess the quality of the air, as well as the satisfaction from the surveys done to some of the occupants inside of the buildings during the test.

#### 3.5.2.2 Ventilation rate requirements

To ensure the air quality mentioned in table [16], standards such as ASHRAE 62.1, and EN 15251 have tabulated the minimum required ventilation rate inside of a room depending of the type of location and taking into account it's surface and the expected occupancy.

Table 2 Minimum ventilation requirements - ASHRAE 62.1

| Location | People outdoor air rate $R_p[l/s * pers.]$ | Area outdoor air rate $R_a[l/s * m^2]$ |
|---|---|---|
| Classroom | 5 | 0,6 |
| Office space | 2,5 | 0,3 |
| Bedroom/Dinning | 2,5 | 0,3 |

By using these values, the recommended minimal ventilation rate for all the spaces measured can be obtained by only providing the normal occupancy of the room and area covered by that space. For the rooms where a ventilation rate study was performed the minimum values are:

Table 3 Minimum ventilation rates of Office, bedroom and living room

| Location | nº people | Area ($m^2$) | Ventilation rate (l/s) |
|---|---|---|---|
| Office | 3 | 20 | 13,5 |
| Bedroom | 1 | 15,5 | 7,15 |
| Living room | 2 | 23,5 | 12,05 |

### 3.5.2.3 Gases concentration limit

To assess the quality of the indoor air, and the pollution at which the occupants are usually exposed during their daily lives, multiple guidelines have been studied. Among them the World Health Organization has published specialized reports and guidelines which have been used to assess the indoor air quality of both the office and the living room of the atrium apartment (WHO 2005; WHO 2010).

Table 4 Concentration limits of various pollutants from multiple standards

| Parameter | Exposure time | Guidelines | Source |
|---|---|---|---|
| $SO_2$[µg/m$^3$] | 10-minute mean | 500 | WHO, 2005 |
| | 24-hour mean | 20 | |
| $O_3$[µg/m$^3$] | 1-hour mean | 200 | |
| | 8-hour mean | 100 | |
| | annual mean | 40 | |
| $NO_2$[µg/m$^3$] | 1-hour mean | 200 | |
| | annual-mean | 40 | |
| $PM_{2.5}$[µg/m$^3$] | 24-hour mean | 25 | |
| | annual mean | 10 | |
| $PM_{10}$[µg/m$^3$] | 24-hour mean | 50 | |
| | annual mean | 20 | |
| CO [mg/m$^3$] | 15-minute mean | 100 | WHO, 2010 |
| | 1-hour mean | 35 | |
| | 8-hour mean | 10 | |
| | 24-hour mean | 7 | |
| $CO_2$[ppm] | 15-minute mean | 5000 | ASHRAE Standard 62.1-2016 |
| | 8-hour mean | 3000 | |
| TVOC [µg/m$^3$] | 8-hour mean | 500 | WELL, 2017 |

### 3.5.3 Survey

Indoor air quality is not only measuring results and judging the condition based on them. A big part of it is the human perception of the environment and to assess that surveys are usually the best method. In this case surveys where performed on two locations, the first one being the Rolex library. The surveys were taken the same day as the measurements. A group of 12 people answered a survey focused on their subjective perception of the indoor temperature and air quality. Among the general questions, such as gender and age, the students were asked to mark the level of clothes they were wearing to be able to determine the PPD and PMV indices. All the students were between the ages of 19 and 23 years old. When explaining the survey, no doubts were raised, and all the questions were answered and registered.

These questions used during the study in regards with thermal comfort and IAQ were:

a) How would you rate the temperature at Rolex?
b) How satisfied are you with the temperature at Rolex?
c) How satisfied are you with the air quality at Rolex?
d) How would you rate the following issues?

Question a) was asked on a discrete five-point scale with the answers going from “Too cold” to “Too hot”; b) and c) were of the same format, with a five-point discrete scale but in this case ranging from “Very dissatisfied” to “Very satisfied”. Lastly question d) was a multiple part question where the students were required to qualify the following issues in a four-point discrete scale form “Not a problem” to “Major problem”.

A second questionnaire was made for the Atrium residency building. This survey was answered over a number of days due to complication to get all the participants together on the same day. Seven people participated in this survey, ranging between ages 20 and 23.

In this case the questions asked regarding thermal comfort and IAQ were:

a) How would you normally rate the temperature in the common area?
b) How would you normally rate the temperature in your room?
c) How satisfied are you with the air quality inside of the apartment?
d) How satisfied are you with the air quality inside of your room?
e) How would you rate the following issues?

With the answers to the questionnaire being the same as in the previous case.

# CAPITULO 4

## 4 RESULTS AND DATA DISCUSSION

During the entire study, the four locations where studied during different periods of time and with different instruments due to some issues with the functioning of the gas meter and the miscalculation of time needed to perform the study. Out of all the parameters study a recompilation of the thermal comfort parameters and $CO_2$ concentration can be seen in Table 5. In this table the lowest, highest and mean value of said parameters can be seen from all the measurements taken in the entire study, with OF being the office, BD the bedroom, LR the living room and RX the Rolex building. Lastly on the last column a reference value of the parameters inside of comfort conditions is introduced to compare with the results obtained.

Table 5: Summary of Thermal comfort parameters for all rooms

| Parameter | Lowest Record | | | | Highest Record | | | | Average | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | OF | BD | LR | RX | OF | BD | LR | RX | OF | BD | LR | RX | |
| T(ºC) | 18.4 | 19.5 | 19.2 | 23.52 | 26.3 | 24.3 | 21.8 | 25.11 | 22.4 | 21.5 | 20.9 | 24.03 | 20-24 |
| RH (%) | 16.3 | 31.3 | 36.9 | 27.01 | 68.3 | 40.4 | 58.8 | 37.7 | 30.1 | 36.25 | 43.5 | 30.77 | 30-70 |
| $CO_2$ (ppm) | 399 | 373 | 314 | 686 | 1539 | 1412 | 1096 | 1071 | 695 | 892 | 507 | 861 | <1000 |

In table 6 the percentage of compliance of all measurements in the parameters presented can be seen. Even if the mean $CO_2$ concentration of all the rooms studies are below the 1000 ppm limit, the $CO_2$ compliance with the standard is of 81.3%, in the case of the bedroom worse results are observed with only a 56.3% of compliance. In terms of temperature the office and Rolex building don't achieve to comply with the recommended values for comfort in more than 50% of the time, which may show low rates of thermal comfort in said rooms.

Table 6: Percentage of compliance with thermal comfort parameters in all rooms

| Location | Temperature (ºC) | Relative Humidity (%) | $CO_2$ (ppm) |
|---|---|---|---|
| Office | 46.4% | 13.9% | 81.3% |
| Bedroom | 75% | 100% | 56.3% |

| | | | |
|---|---|---|---|
| Living room | 98.5% | 100% | 98.5% |
| Rolex | 32.2% | 41.5% | 95.8% |

In this section, the office, bedroom and living room ventilation rates are going to be calculated with the measurements taken during the study, and compared to the standards of quality and try to explain with them the levels of $CO_2$ usually observed in those room and the reason for their noncompliance with the standards. The concentration of certain gases is going to be analyzed in the living room and office (only rooms where measurements of said components was possible) and lastly a thermal comfort study and calculation of PPV and PMD values will be done and compared to the results from two surveys, one in the Rolex building and the other one in the Atrium residency.

## 4.1 Ventilation Rate and $CO_2$ concentration

### 4.1.1 Office

The measurements of $CO_2$ concentration were performed 24 hours a day during nearly two weeks but only the occupancy periods as marked in Figure 8 were considered for this study. During this time the average $CO_2$ concentration was 695 ppm. The minimum concentration was observed at the beginning of the day at 399 ppm, with the highest concentration being 1539 in the early afternoon on April 1st, 2019. Overall the 18.4% of the time of occupancy was above the 1000 ppm limit established by ASHRAE.

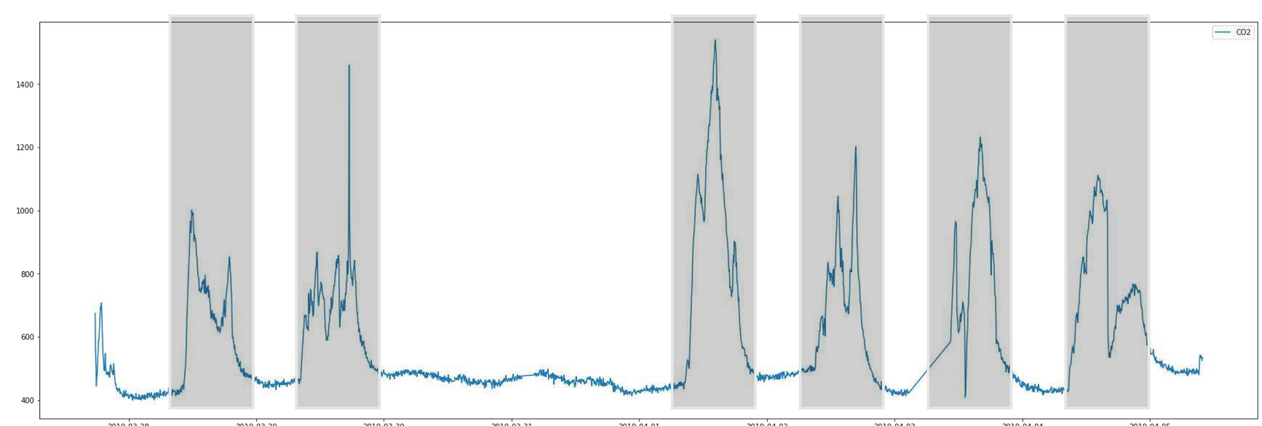



Figure 14 Evolution of CO2 concentration in office over the measurement period

In figure 3 an emphasis on the concentration on the 02/04/2019 can be seen.

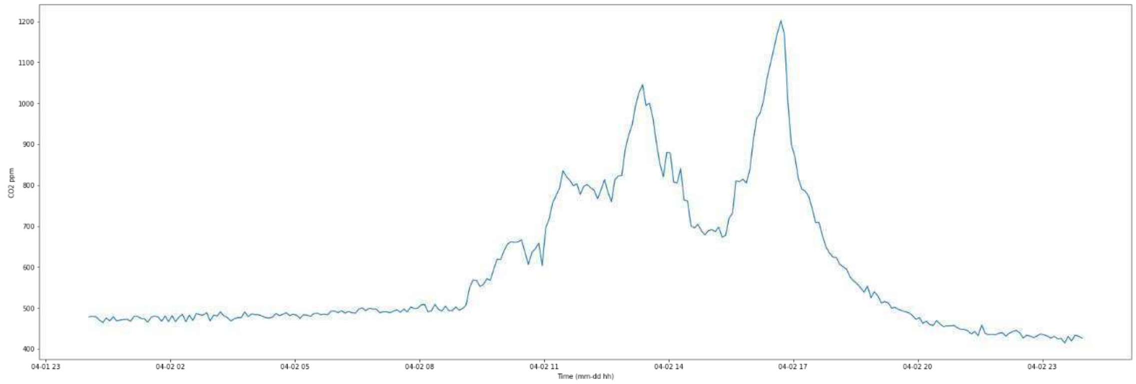



Figure 15: Evolution of CO2 concentration in the office for one day

It can be clearly seen how the $CO_2$ concentration rises during the working hours and vary with the behavior of the occupants during the day reaching a peak point in the afternoon of 1201 ppm as seen in Table 5. From this point, where the room becomes empty for the rest of the day, the $CO_2$ concentration reduces with time due to the natural ventilation in the room. In order to be able to describe and calculate the air exchange rate the two-point decay equation was used. Due to the relative uncertainty of this method multiple day and hours were taken to find multiple airflow rates distributed across time and average them to find an approximation of the real ventilation rate. Thus, obtaining Table 7 and Table 8 which depict very similar concentrations with some spikes in the second and fourth day analyzed where the 1000 ppm threshold is surpassed.

Table 7 Evolution of CO2 concentration in office over time

| Hours | Thursday 28/03 | Friday 29/03 | Monday 01/04 | Tuesday 02/04 |
|---|---|---|---|---|
| Initial concentration | 853 | 980 | 902 | 1201 |
| 1 | 573 | 815 | 647 | 676 |
| 2 | 522 | 594 | 540 | 538 |
| 3 | 473 | 544 | 483 | 490 |
| 4 | 480 | 508 | 480 | 456 |
| 5 | 464 | 492 | 477 | 434 |

By using the previously mentioned equation the air exchange rate of every time interval in relation with the initial concentration is measured, creating a mean for each day.

Table 8 Evolution of air exchange rate ($h^{-1}$) in office over time

| Hours | Thursday 28/03 | Friday 29/03 | Monday 01/04 | Tuesday 02/04 |
|---|---|---|---|---|
| 1 | 0.398 | 0.184 | 0.332 | 0.575 |
| 2 | 0.246 | 0.25 | 0.256 | 0.401 |
| 3 | 0.197 | 0.196 | 0.208 | 0.299 |
| 4 | 0.144 | 0.164 | 0.157 | 0.242 |
| 5 | 0.122 | 0.137 | 0.127 | 0.204 |
| Mean Value | 0.2214 | 0.1862 | 0.216 | 0.3442 |

The average of all airflow rates is 0.242 $h^{-1}$ and with a room volume of 53.9 $m^3$ as stated in the room description the average air exchange rate in the room is:

$$V \cdot \lambda = 0.242h^{-1} \cdot 53.9m^3 = 13.04\frac{m^3}{h} = 3.62\frac{l}{s}$$

Being the required minimum ventilation rate established by ASHRAE 62.1[16] for a 20 $m^2$ office with three occupant 13.5 l/s the ventilation of the room is significantly below the minimum required ventilation rate which explains why in multiple periods of the week theCO2concentration surpasses the 1000 ppm limit established for indoor comfort.

### 4.1.2 Atrium living room

The same process was followed for the ventilation inside of the living room at atrium. In this case the measurements were taken over a small window of time, so multiple days' time average was not possible. During the period of measurement, the maximum $CO_2$ concentration was 1096 ppm and the minimum concentration was 314 ppm. During the two days the limit of 1000 ppm was only surpassed during 1.4% of the time and the mean $CO_2$ concentration was of 507 ppm.

To calculate the ventilation rate only a single decay process was analyzed during the night of April 7th. In this case, being the environment studied a Kitchen / Living room, we can see how big peaks of $CO_2$ concentration can be observed during the afternoon, specially at times when people where using the kitchen or occupying the space. The first day, as can be seen in Figure 10, the concentrations are considerably higher due to the decision to maintain the windows of the space closed to analyze the natural ventilation of the room. As such the major movements in $CO_2$ concentration are due to the opening of the connecting doors as well as the natural ventilation in the room. Due to these reasons we can see how the maximum concentration peaks at 1100 ppm surpassing the recommended limits set by the standards.

When referring to the EN13799, if we take lowest concentration point as the outside $CO_2$ concentration  (300 ppm), we obtain an incremental $CO_2$ concentration of in periods of occupancy from 500 to 800 ppm with the windows closed, making the air inside of the room of moderate to low quality on a normal day.

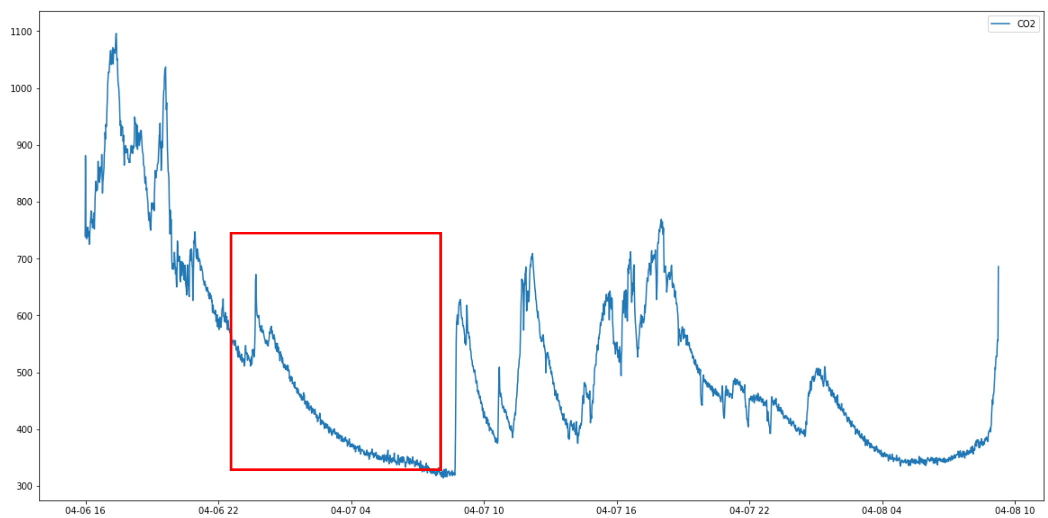



Figure 16 CO2 concentration in atrium living room over time

During the second day, the windows were opened at regular intervals during the occupation of the room resulting in much smaller concentrations compared to the preceding day. However, the same patterns of $CO_2$ generation can be observed during the second day, as the peaks in the graph are located around the same times and especially around the times when meals are being prepared and more people are in the room.

To measure the ventilation rate, the period highlighted in red in Figure 10 was used to perform the two-point decay method as done with the office, obtaining the following concentrations over time:

Table 9 CO2 concentration over time of Atrium livng room

| Time | Living room |
|---|---|
| Initial concentration | 581 |
| 1h | 481 |
| 2h | 386 |
| 3h | 367 |
| $C_R$ | 350 |

And by computing the air exchange rate with these concentrations the following values are obtained:

Table 10 Air exchange rate over time of atrium living room

| Time | Living room |
|---|---|
| 1 | 0.51 |
| 2 | 0.50 |
| 3 | 0.14 |
| 4 | 0.15 |

As seen in Table 8 the average flow rate for the entire decay period is 0.23 $h^{-1}$ and, with a volume of 63.45 $m^3$ the ventilation rate, the average air exchange rate in the room is:

$$V \cdot \lambda = 0.23h^{-1} \cdot 63.45m^3 = 14.6\frac{m^3}{h} = 4.05\frac{l}{s}$$

Being the minimum required ventilation 12,05 l/s, as stipulated by the standard ASHRAE 62.1, the ventilation in this room is considerably below the required value achieving only one third of the actual requirement.

### 4.1.3 Atrium Bedroom

In this case, the two-point decay method was not usable since the drop in $CO_2$ concentration was due to the opening of the door and window at the same time to provide current, and thus creating a peak in ventilation not reflecting the normal conditions of the room.

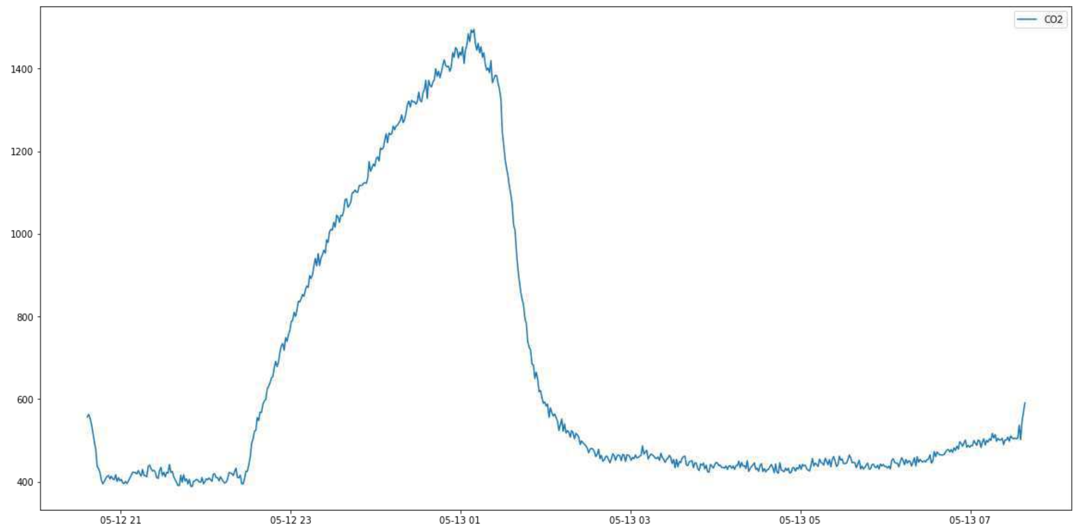



Figure 17 CO2 concentration over time in Atrium bedroom

During the time the window was closed, the $CO_2$ concentration reached a maximum value of 1412, with the minimum being 373 ppm corresponding to the beginning of the measurement period. The overall mean of the $CO_2$ concentration was 892 ppm with the 1000 ppm limit being surpassed in 43.7% of the time.

Due to conditions explained above, in this case the buildup method expressed above was used. For this, three points were used to perform the calculation:

Table 11: CO2 concentration over time of Atrium bedroom

| Time | $CO_2$ (ppm) |
|---|---|
| Initial concentration | 373 |
| Midpoint | 1040 |
| Peak | 1412 |

As explained in section 3.4.1.2, to apply this method a first estimation of the steady state concentration has to be made. In this case we obtain an estimation using a mid-point halfway in between the initial and peak point of concentration as we can see in the graph above. Thus, we obtain:

Table 12: Air exchange rate over time of atrium living room

| Cs (ppm) | λ (h) |
|---|---|
| 1692 | 0,40 |

And with a volume of 41,8 $m^3$, the equivalent ventilation rate is 16,74 $m^3/h$ or 4.65 (l/s) which again falls short of the minimum requirement specified by ASHRAE 62.1 of 7,15 l/s.

## 4.2 Concentration of gases

### 4.2.1 Office

The result of comparison between guidelines and measured values in the target office is summarized below (Table 13). It is shown that $SO_2$ is the only pollutant whose concentration exceeds the chosen guideline values (regulated by the World Health Organization) while other pollutants all respect their guidelines respectively.

$O_3$ concentration is obviously stable with a mode of 19.6 μg/$m^3$ accounting for about 80% of the whole measurement duration and with a low mean value (19.0μg/$m^3$).CO level is also far below the regulatory values with an overall mean of 0.6 mg/$m^3$ during the whole period. Meanwhile, there is no $NO_2$ in the office at most of the time series with only two non-zero measured data (56.4 and 37.6 μg/$m^3$ respectively). When it comes to the TVOC level, it can be noticed that TVOC concentration varies between 80 (92) and 390 (331) μg/$m^3$ on 5-minute (8-hour) average.

Table 13 Peak time average oncentration of gaseous pollutants in office and kitchen

| Parameter | Exposure time | Office | Kitchen | Guidelines |
|---|---|---|---|---|
| $SO_2$[µg/m$^3$] | 10-minutes mean | 1074 | 175 | 500 |
| | 24-hour mean | 264 | 110 | 20 |
| $O_3$[µg/m$^3$] | 1-hour mean | 46 | 6.87 | 200 |
| | 8-hour mean | 39 | 2.75 | 100 |
| $NO_2$ [µg/m$^3$] | 1-hour mean | 7.9 | 0 | 200 |
| $PM_{2,5}$ [µg/m$^3$] | 24-hour mean | 6.41 | 6.16 | 25 |
| $PM_{10}$ [µg/m$^3$] | 24-hour mean | 26.9 | 28.9 | 50 |
| CO [mg/m$^3$] | 15-minutes mean | 1.72 | 0.76 | 100 |
| | 1-hour mean | 1.48 | 0.73 | 35 |
| | 8-hour mean | 1.18 | 0.56 | 10 |
| | 24-hour mean | 0.94 | 0.21 | 7 |
| TVOC[µg/m$^3$] | 8-hour mean | 650 | 1030 | 500 |

On the other hand, particulate matters staying in the objective office show a satisfactory level with respect to the regulatory values. $PM_{2,5}$ contains a maximal mean value of 5.88µg/m$^3$ (compared to 25µg/m$^3$) for 24-hour exposure while $PM_{10}$ with a maximal mean of 20.75µg/m$^3$ (50µg/m3as a regulatory threshold).It is also suggested that $PM_{2,5}$ and $PM_{10}$ levels are relatively stable and do not fluctuate much as can be seen in Figure 18 where $PM_{2,5}$ never reaches the limit of 25 [µg/m$^3$] and $PM_{10}$ only achieves to surpass the limit in very limited situations and for very short periods of time.

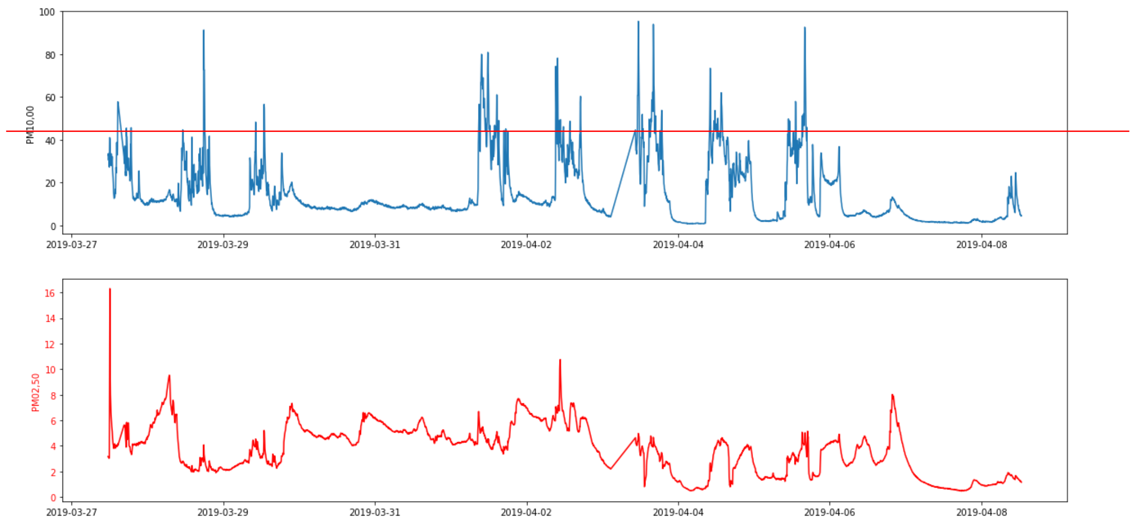



Figure 18 Particulate matter concentration in office over measurement campaign

### 4.2.2 Living room

For the living room, $O_3$ concentration is mostly nonexistent with a 0 μg/m$^3$ concentration for 96.3% of the time and peaking at 39.2 μg/m$^3$ in only four measurement during the entire process. CO level is also far below the regulatory values, with higher concentrations during the first day during cooking periods but peaking at 0.8 mg/m$^3$. Meanwhile, $NO_2$ is not present in the air in this situation being its average over the entire measured period of 0 μg/m$^3$. When it comes to the TVOC level, similarly to CO we can see a spike in the air concentration due to the activity performed during the first day and the dishes cooked. On the second day, with a better ventilation as stated in section 4.1.2 , TVOC reduces nearly in half, having a peak in April 6$^{th}$ at around 1350 μg/m$^3$ and much smaller peak at around 800 μg/m$^3$ on April 7$^{th}$ (conversion from ppb to μg/m$^3$ made assuming an average 100 molecular weight). As it can be observed the average 8-hour mean for TVOC in the kitchen is twice as much as the allowed concentration by the standards. This can be explained due to the intentional closure of the windows during cooking times, habit that usually doesn't happen but still denotes and confirms a lack of ventilation that was already observed in the previous section.

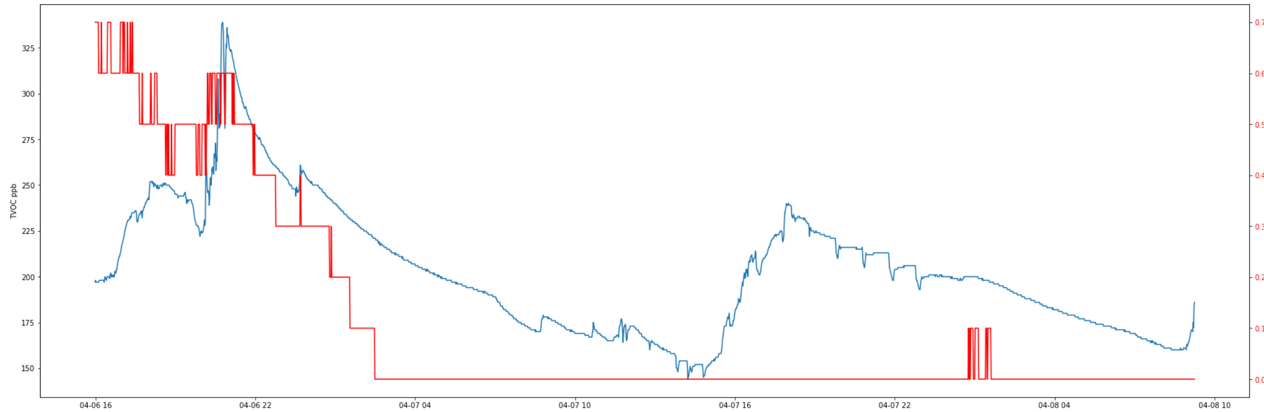



Figure 19 TVOC and CO concentration over time in atrium living room

On the other hand, particulate matter, both $PM_{2,5}$ and $PM_{10}$, stay compliant to the established 8-hour mean limit set by WHO. Both values stay stable over the entire measuring process, except for one large peak during cooking time but that does not spread over time.

## 4.3 Surveys

### 4.3.1 Rolex

#### 4.3.1.1 Rolex conditions

The questionnaire at Rolex was performed at the end of the first day of measurements on May 7$^{th}$, 2019. The questionnaire was explained to the students and filled via their mobile phone through an app. At the time the students had been in the building for about 2 hours and were about to take a break at around 17:00. During the time the students were present in the building as can be seen in Table XX the conditions were: $T_a$ = 24ºC, RH = 30.77% and $CO_2$ = 894 on average.

#### 4.3.1.2 Rolex – answers from the questionnaires

The people answering the questionnaire ranged in age from 19 to 23 years old, and due to complication of gathering people to answer only 12 answers were provided. From these, 66.7% were male and 33.3% were females.

The answers to the first question “*How would you rate the temperature at Rolex?* ”, people were in majority judging the temperature as hot, with 50% of people rating the temperature as *“somewhat hot”* and 25% as *“very hot”*, with only 8.3% of the people rating it as

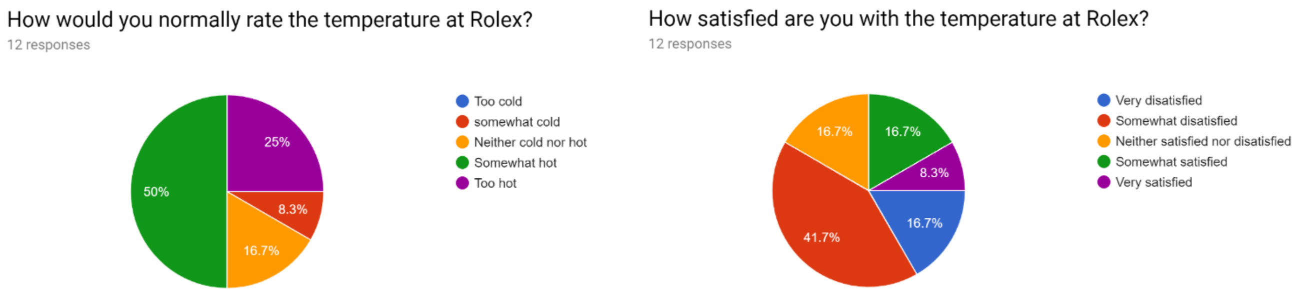



Figure 20 Survey results: evaluation of Rolex temperature (left) and satisfaction of temperature (right)

*“somewhat cold”* and none referring to it as *“Too cold”*.

In figure 13 (right), we can see that in terms of thermal comfort 41.7% of the people felt *“somewhat dissatisfied”* and 16.7% answered *“very dissatisfied”* with the indoor temperature making the overall perception of the TC in the Rolex building as not satisfactory. Some even noted that this sometimes makes them lose focus or take breaks more often.

Concerning the indoor air quality, the results denoted a better appreciation of the IAQ with only 16.7% of the people being *“somewhat dissatisfied”* with the quality of the air at Rolex and 8.7% being *“very dissatisfied”* and 75% of the people feeling either being neutral about it or with a satisfactory response.

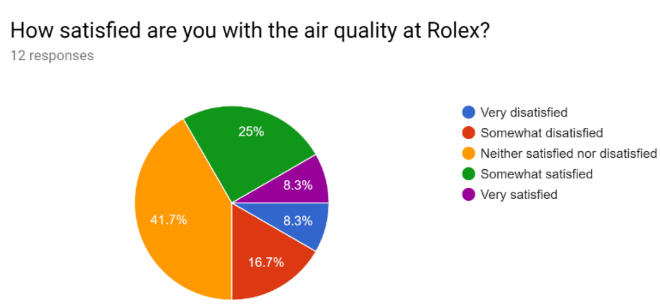



Figure 21: Survey: IAQ satisfaction Rolex

When appreciating the quality of the air in the Rolex building, the students find the air as being of good quality. When rating multiple problems that generally occur indoors only the air smelling air was reported as stuffiness/staleness being a major problem in only 16.6% of the time and 58.3% considering it not an issue or a very minor one. Air cleanliness was very positively appreciated with 50% of the students considering it not a problem and with only one considering it as a major problem. Finally, the biggest problem noticed by the students was the bad smell (body odor) around the study areas, with only a 25% considering it not a problem and 25% considering it a major problem but overall having satisfactory results.

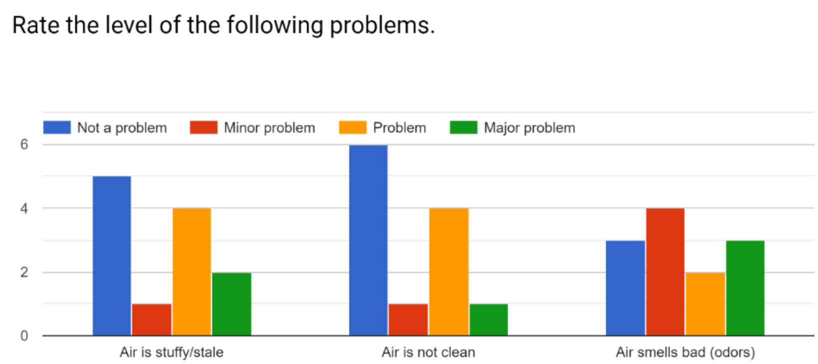



Figure 22 Survey: Air quality issues rating at Rolex

### 4.3.2 Atrium

### 4.3.3 Atrium conditions

The people answering the questionnaire about the atrium residency ranged in age from 20 to 23 years old. Due to finding it hard to get people to answer the questionnaire, only 7 students participated in the study, with 71.4% being male and 28.6% being female. In this case the clo average was hard to assess since most students vary the way they dress during the day while being at home.

#### 4.3.3.1 Atrium – answers from the questionnaires

In the answer to the first question *"How would you normally rate the temperature in the common are?"*, 57.1% of the students find the temperature inside the apartments is satisfactory, with only 28.6% finding it *"Somewhat cold"* and 14.3% finding it *"Somewhat hot"*.

When the same question was answer regarding the bedroom thermal comfort, 71.4% of the students answered, *"Neither hot nor cold"* with only 28.6% of them finding the temperature

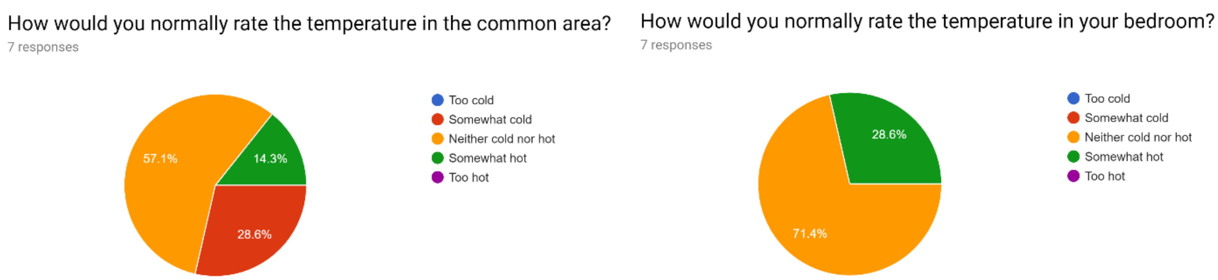



Figure 23 Survey results: evaluation of Atrium living room temperature (left) and bedroom temperature (right)

to be "*Somewhat hot"*.

Concerning the indoor air quality inside of the apartment, the results highlight a poor IAQ, with 42.9% of the responses being *"Somewhat dissatisfied"* and 14.3% of them being *"Very dissatisfied"*. Thus, this makes more than 50% of the participants in the survey not happy with the air they breath in a daily basis in their apartment.

When the same question was asked about the IAQ of the individual bedrooms the responses were very different with only 28.6% of the participant being dissatisfied, although none answered with a positive response either.

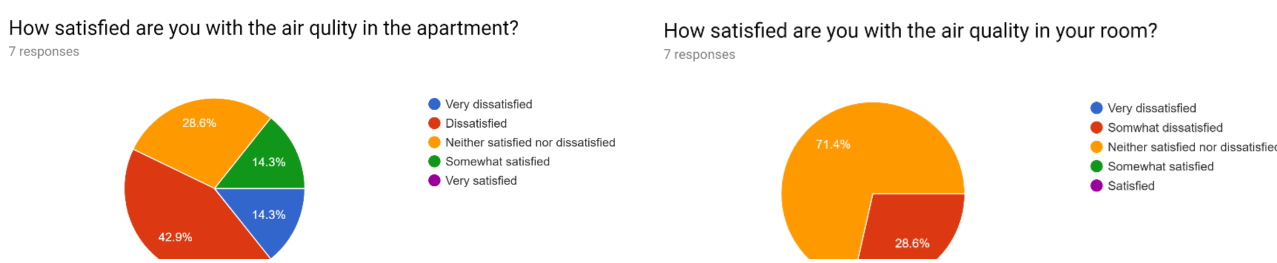



Figure 24 Survey results: evaluation of Atrium living room IAQ (left) and bedroom IAQ (right)

When asked to rate the magnitude of certain problems regarding IAQ, out the 7 participants, 4 of them found the air being stuffy/stale as a *"Problem"* or "*Major problem"*. In regard to the air cleanliness, only 3 out of the 7 participants consider it to be *"Problem"* or "*Major problem"*. The most observed problem by the students was the bad smell indoors with it being a "*Major problem*" in 4 out of 7 answers and a "*problem*" in 2 of 7 responses making it the biggest issue inside of the residence.

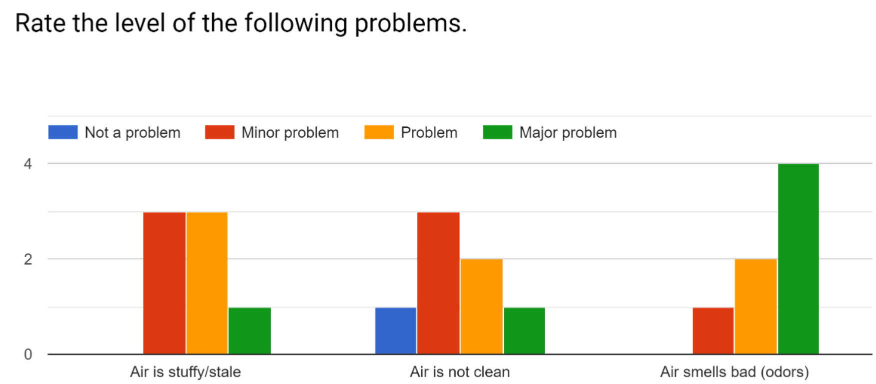



Figure 25 Survey: Air quality issues rating at Atrium

#### 4.3.3.2 PMV and PPD indices

With the data in Table 5, where the data is statistically gather into minimum, maximum and mean values for the measured period, the PMV and PPD values were calculated with the help of Thermal comfort tool from the Centre for the Built Environment at Berkeley while using the EN15251 European standard for thermal comfort to evaluate Fanger's thermal comfort indices. The parameters imputed for the environmental condition were the mean, minimum and maximum values for the parameters measured, the air velocity was considered as 0.1 (m/s) as an approximation for normal indoor spaces since no measurement was available. The metabolic rate considered is one of an individual sitting doing some rudimentary work such as typing, reading or writing since it is the most common activity of students inside the spaces studied. Finally, the clothing insulation was considered to be of 0.74 clo apartment (sweatpants and a long sleeve shirt) for inside the, and 0.96 (jacket, trousers and long sleeve shirt) in the Rolex library after discussing with the participants of the study their habits and by observation.

To compare the results of the questionnaires to the PMV and PPD values, the results for Fanger's indices can be found in Table 14.

Table 14 PMV and PPD indexes for atrium rooms and rolex library

| Parameters | Atrium living room | | | Atrium bedroom | | | Rolex library | | | Office | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max |
| T (ºC) | 19.2 | 20.9 | 21.8 | 19.5 | 21.5 | 24.3 | 23.52 | 24.08 | 25.11 | 18.4 | 22.4 | 26.3 |
| RH (%) | 36.9 | 43.5 | 58.5 | 31.3 | 36.25 | 40.48 | 27.01 | 30.77 | 37.7 | 16.3 | 68.3 | 30.1 |
| M (met) | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| $I_{clo}$ (clo) | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 |
| V (m/s) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| PMV | -1.4 | -0.89 | -0.55 | -1.35 | -0.77 | 0.03 | 0.06 | 0.22 | 0.52 | -1.21 | 0.06 | 0.75 |
| PPD | 46% | 22% | 11% | 43% | 17% | 5% | 5% | 6% | 11% | 36% | 5% | 17% |

#### 4.3.3.3 PD based on $CO_2$ concentration

In rooms where the $CO_2$ concentration is mainly due to the occupants, it is recommended to determine the percentage of dissatisfied people as a function of $CO_2$ concentration. To achieve that the equation below provided be the European Concerted Action (ECA,1992) can be used [28]:

$$PD = 395 \cdot e^{-15.15 \cdot C^{-0.25}}$$

Where PD is the percentage of dissatisfied and C is the $CO_2$ concentration in the room above the outdoor level. As the outdoor concentration was not measured the standard EN-15251 recommends the use of 350 ppm as a typical value.

Table 15 PD based on CO2 concentration with respect to the outside air

| | Living room | Bedroom | Rolex library | Office |
|---|---|---|---|---|
| $CO_2$ (ppm) | 507 | 892 | 861 | 695 |
| C (ppm) | 157 | 542 | 511 | 345 |

| | | | | |
|---|---|---|---|---|
| PD (%) | 5.5% | 17.1% | 16.32% | 10.85% |

### 4.4 Discussion

When looking at EN 15251, the buildings analyzed fall under category II (new buildings and renovations). Based on this result the expected PPD should be <10% and PMV should vary between ±0.5.

#### 4.4.1 Atrium living room

In regard to the Atrium building, when analyzing and comparing the results obtained over the study, it can be noticed that some of the parameters and results obtain do not comply with the established standards as is the PPD and the ventilation rate. In section 4.1.2, even thought we observe low concentrations of $CO_2$ over the entire period of measurement, the ventilation rate obtained using the two point decay method show a lack of ventilation inside of the indoor space with only being at a third of the minimum required ventilation as stated by the standard ASHRAE 62.1, none the less the concentrations of gaseous pollutants seems to be maintained in acceptable ranges over the entire period. The only outlier is the $SO_2$ concentration, which might have been caused by the cooking inside of the room at some points but being this a sporadic activity, it does not explain surpassing the 24-hour limit for this gas.

When comparing the results of the thermal comfort evaluation, the PPD and PMV from the analytical results using Fanger's equation show worse satisfaction levels than the survey performed. The survey answers ranged in values from -1 to 1 in a five-point scale with a 57% majority having a neutral/satisfactory answer whereas when computing the PMV the result is more negative with a -0.89 perceived mean value. These results reflect that the overall conditions in this room is quite good and well inside of the standards, however due to occupancy values not being well recorded and thus not being used the average temperature and other parameters averages might be lower than during the true exposure to the indoor environment that the survey suggest. One of the main reasons for this is the opening of the windows, and thus decrease in temperature during times when the students are not in the room.

In terms of indoor air quality, the survey suggests large dissatisfaction with the air inside of the apartment with more than 50% of the people being dissatisfied, whereas the value obtained by using the PD concentration suggest only a 5.5% of people dissatisfied. This discrepancy is considered to be due to the sporadic presence of people in the living room and hence low concentration of $CO_2$ produced by occupants but large quantities of other gases and particles such as the trash can and food but that is not considered in the equation used. This reasoning is further reinforced by the answer from the occupants identifying bad smell of the air as a major problem while the air is not considered to be particularly dirty.

### 4.4.2 Atrium bedroom

When looking at the values obtained for the bedroom at atrium and the same values are analyze, higher averages in temperature, and $CO_2$ concentration are observed. This is due to the lower ventilation by use of the window and the more prolonged periods of time where someone is present in the room. In section 4.1.3, where the ventilation rate was calculated by means of the buildup method, the result of ventilation is more satisfactory than in the living room, but it is still lacking by minimum requirements established by the standards ASHRAE 62.1, with a value of 4.65 l/s when it should be of at least of 7.15 l/s.

The comparison of thermal comfort between the survey performed, the PPD and PMV values in this case show a slight difference in the perceived temperature from the analytical method and the standard. The survey answers were in the range of 0 to 1 in a five point scale answer with 71.4% of the answers being neutral, whereas the PMV shows a result of -0.77 which translate to slightly cold with a 17% percent of people dissatisfied surpassing the range of ±0.5 allowed in a category II building by the standards EN15251. Overall the conditions are satisfactory none the less since, as denoted by other research [29], the range of thermal comfort of people is usually larger than specified by the standards.

Regarding the IAQ, the survey shows a slight dissatisfaction from the occupants of atrium with 29% of the participants slightly dissatisfied while the rest responded with a neutral answer. The results from using the PD concentration shows a 17.1% of people dissatisfied.

Overall both valuations are similar, mostly due to less odors being emitted by objects foreign to the occupants as was the case for the kitchen.

### 4.4.3 Rolex library

The Rolex library registered the highest average temperature of the rooms analyzed, with it being 24.03 ºC and surpassing the limit for a category II building. Its relative humidity is on at the lower limit of the comfort range, and the average $CO_2$ concentration, even if not above 1000 ppm is somewhat high at 861 ppm. Some of this value are due to the lack of operable windows as well as the high exposure to the sun through the glass walls.

In terms of thermal comfort, the survey shows a high dissatisfaction rate, with 41.7% of people being somewhat dissatisfied and more than 50% having a negative response and overall considering the temperature as being hot or too hot. When compared to the PMV value a big difference can be seen. With a value of 0.22 and only 6% PPD by the EN15251 standard the thermal comfort should be accomplished but most people reported low satisfaction rates. When asked about the topic participants considered the difference between the outside and inside temperature significant, especially due to the clothing worn.

Regarding IAQ, the survey shows answers in ranges from -2 to 2 in a five-point scale question but being most of the answers positive and only 25% of the people being unhappy with the air quality. Comparing this to the PD calculated with the $CO_2$ concentration, which result is a value of 16.32 percent dissatisfied, a conclusion is reached that the overall IAQ inside of the Rolex building is satisfactory, being thus the only problem in said building the thermal comfort.

### 4.4.4 Office

Lastly, in the office space analyzed, the measurements gather in Table 5 show average values of temperature inside of comfort values for category II buildings while the relative humidity is relatively low with minimum values reaching 16.3%. In this case no survey was done since the measurements were part of another study.

In terms of thermal comfort, by analyzing Fangers indexed a big range of values is found in the PMV, this is mainly due to the low temperature during the night that cool down the room when the occupants arrive in the morning, and high temperatures in the afternoon with direct exposure to the sun which heats up the room through the windows. With average values of the comfort parameters resulting in a 0.06 PMV, the results are quite satisfactory, but the range of values observed might hinder the occupant's comfort since inside an office it is harder to adapt in terms of clothing.

In regard to IAQ, since no survey was performed for this space, only the PD based on the $CO_2$ concentration is available. With a result of 10.85% of people dissatisfied, and by comparing the values in Table 13 with the standards, the IAQ of the room is deemed to be quite satisfactory for the occupants as no big concentration of pollutant is observed except for $SO_2$, but being this due to outdoor sources it is not likely that it affects the IAQ in the average day throughout the year.

# CAPITULO 5

## CONCLUSION

In this study the TC and IAQ of multiple locations of the EPFL has been studied. The environmental parameters influencing TC and IAQ and compared with other gases concentration and the subjective assessment of the occupants.

The study shows that the ventilation in all locations was below the minimum required ventilation rate as per the standard ASHRAE 62.1. This causes, in some spaces such as the Atrium living room, low perceived comfort values in terms of IAQ. The concentration of $CO_2$, even though not particularly high, proved to raise above the limit in multiple occasions, making the rooms sometimes feel stuffy or allowing bad odors from body bio effluents or from other sources.

The thermal comfort proved to be sometimes not adequate for the occupants. The ranges in PMV are quite big, making the environments highly dynamic, with big changes between the morning and the afternoon with higher sun exposure, reaching temperatures above 25 ºC.

Overall, the conditions in the buildings at EPFL seem to provide satisfactory IAQ and TC conditions, however more controlled or regulated ventilation systems should be studied to be provide better results. Some of the proposed systems proposed to be explored would be: ventilation based on $CO_2$ concentration and temperature, or even exploring personal ventilation in some cases such as the individual bedroom where $CO_2$ concentration reach high levels if the windows are kept closed at night or the Rolex library were, due to the high concentration of people, bad odors and discomfort is common among students.

# CAPITULO 6

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# PARTE II

# HOJAS DE CARACTERÍSTICAS

# IAQ at EPFL and Unil

Survey to assess the thermal comfort and ventilation at EPFL and UNIL buildings. The question will mainly focus around classrooms and the rolex library.

* Required

1. **What is your gender?** *
   *Mark only one oval.*

   - Female
   - Male
   - Prefer not to say

2. **How would you normally rate the temperature in your classrooms?** *
   *Mark only one oval.*

   - Too cold
   - somewhat cold
   - Neither cold nor hot
   - Somewhat hot
   - Too hot

3. **How satisfied are you with the temperature in the classroom?** *
   *Mark only one oval.*

   - Very disatisfied
   - Somewhat disatisfied
   - Neither satisfied nor disatisfied
   - Somewhat satisfied
   - Very satisfied

4. **Overall, does your thermal comfort in the classroom affect your performance?** *
   *Mark only one oval.*

   - Negatively
   - Somewhat negatively
   - Not really
   - Somewhat positively
   - Postively

## Air Quality

5. **How satisfied are you with the air quality in the calssroom?** *
*Mark only one oval.*

- Very disatisfied
- Somewhat disatisfied
- Neither satisfied nor disatisfied
- Somewhat satisfied
- Very satisfied

6. **Rate the level of the following problems.** *
*Mark only one oval per row.*

| | Not a problem | Minor problem | Problem | Major problem |
|---|---|---|---|---|
| Air is stuffy/stale | | | | |
| Air is not clean | | | | |
| Air smells bad (odors) | | | | |

7. **Overall, does the air quality in the classroom enhance or interfere with your ability to get your job done?** *
*Mark only one oval.*

- Negatively
- Somewhat negatively
- Neither negatively nor positively
- Somewhat positively
- Positively

# Rolex

# Thermal Comfort

8. **How would you normally rate the temperature at Rolex?** *
*Mark only one oval.*

- Too cold
- somewhat cold
- Neither cold nor hot
- Somewhat hot
- Too hot

9. **How satisfied are you with the temperature at Rolex?** *
*Mark only one oval.*

- Very disatisfied
- Somewhat disatisfied
- Neither satisfied nor disatisfied
- Somewhat satisfied
- Very satisfied

10. **Overall, does your thermal comfort in the classroom affect your performance?** *
*Mark only one oval.*

- Negatively
- Somewhat negatively
- Neither negatively nor positively
- Somewhat positively
- Positively

## Air quality

11. **How satisfied are you with the air quality at Rolex?** *
*Mark only one oval.*

- Very disatisfied
- Somewhat disatisfied
- Neither satisfied nor disatisfied
- Somewhat satisfied
- Very satisfied

12. **Rate the level of the following problems.** *
*Mark only one oval per row.*

| | Not a problem | Minor problem | Problem | Major problem |
|---|---|---|---|---|
| Air is stuffy/stale | | | | |
| Air is not clean | | | | |
| Air smells bad (odors) | | | | |

13. **Overall, does the air quality at Rolex enhance or interfere with your ability to get your job done?** *
*Mark only one oval.*

- Negatively
- Somewhat negatively
- Neither snegatively nor disatisfied
- Somewhat satisfied
- Very satisfied

# IAQ at Atrium apartments

Survey to assess the thermal comfort and ventilation at the Atrium student residence.

* Required

1. **Whas is your gender? ***
   *Mark only one oval.*
   - Female
   - Male
   - Prefer not to say

2. **How would you normally rate the temperature in the common area?**
   *Mark only one oval.*
   - Too cold
   - Somewhat cold
   - Neither cold nor hot
   - Somewhat hot
   - Too hot

3. **How would you normally rate the temperature in your bedroom? ***
   *Mark only one oval.*
   - Too cold
   - Somewhat cold
   - Neither cold nor hot
   - Somewhat hot
   - Too hot

## Air Quality

4. **How satisfied are you with the air qulity in the apartment? ***
   *Mark only one oval.*
   - Very dissatisfied
   - Dissatisfied
   - Neither satisfied nor dissatisfied
   - Somewhat satisfied
   - Very satisfied

5. **Rate the level of the following problems.** *

*Mark only one oval per row.*

| | Not a problem | Minor problem | Problem | Major problem |
|---|---|---|---|---|
| Air is stuffy/stale | ⬭ | ⬭ | ⬭ | ⬭ |
| Air is not clean | ⬭ | ⬭ | ⬭ | ⬭ |
| Air smells bad (odors) | ⬭ | ⬭ | ⬭ | ⬭ |

6. **How would you qualify the ventilation of the apartment?** *

*Mark only one oval.*

- ⬭ Very bad
- ⬭ Bad
- ⬭ Neutral
- ⬭ Good
- ⬭ Very good

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**For 20 years, GrayWolf has been transforming the way that environmental measurements are taken. And now we have acted on the feedback from our many worldwide IAQ, HVAC, IH and Green Building customers to introduce a range of very *smart* probes with highly advanced features.**

- Up to eight (8) sensors per probe.
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# DIRECTSENSE® II

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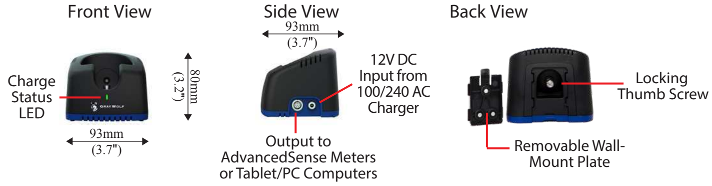
ACC-DSII-CRDL CHARGING CRADLE




SPECIFICATIONS:

| | |
|---|---|
| **General:** | |
| Dimensions: | Probe: 83mm (3.3in.) w. x 295mm (11.6in.) h. x 55mm (2.2in) d.<br>Cradle: 93mm (3.7in.) w. x 80mm (3.2in.) h. x 93mm (3.7in) d. |
| Construction: | Probe: Rugged polycarbonate plastic with rubberized handle grip.<br>Cradle: Rugged polycarbonate plastic. |
| Weight: | Probe: not including sensors which are ~10 gr each; 460gr (1lb)<br>Cradle: not including AC adapter; 180 gr (6.4 oz.) |
| Wireless: | Bluetooth for connection to AdvancedSense Pro or to Windows tablet, standard. Optional IEEE 802.11 b/g/n Wi-Fi Module to directly relay probe readings to Cloud. |
| Mounting: | ¼" - 20 tpi brass thread for belt clip, etc. (& for included mini tripod/stand). Also M3 brass thread for security thumb-screw. |
| Operating Range: | -10ºC to 50ºC (15ºF to 122ºF), 0 to 100 %RH non-condensing (certain specific sensors have a more limited range). |
| **Connectors:** | |
| Probe: 1 x 10 pin Lemo socket for cable connection to AdvancedSense meter or tablet/laptop.<br>Cradle: 1 x 10 pin Lemo socket and 1 x 2.1mm 12VDC power socket. | |
| **Power:** | |
| Battery: | 6600 mAh Lithium Ion rechargeable |
| Battery Life: | 35+ hours typical with PID & NDIR sensors installed, fan on.<br>80+ hours w/o PID, NDIR. Significantly longer with fan off. |
| Recharge time: | 3 hours typical (in cradle). Probes may be continuously powered from meter/tablet/PC, but will not recharge.<br>Red/green front cradle LED displays charging/fully charged status. |
| Power supply: | 100/240VAC, 50-60Hz external charger. Specify local plug. |

**All specifications are subject to change without further notice**

| Model | Basic Description |
|---|---|
| DSII-3 | DirectSense II probe with smart °C/°F, %RH sensors and 1 available socket for smart PID, NDIR or EC sensor.* |
| DSII-5 | DirectSense II probe with smart °C/°F, %RH sensors and 3 available sockets for smart PID, NDIR or EC sensors.* |
| DSII-8 | DirectSense II probe with smart °C/°F, %RH sensors and 6 available sockets for smart PID, NDIR or EC sensors.* |
| DSII-3/5/8-KIT | The KITs include the relevant probe, but additionally include charging cradle, AC adapter, 1m connection cable, mini-tripod and belt clip. |

*All DSII Probes have a built-in fan, Bluetooth wireless and come with a sensor insertion tool and hex screwdriver.

| Accessories | |
|---|---|
| ACC-DSII-FLANGE | Flange and bracket to secure DSII probes into ducts, test chambers, etc. |
| ACC-FIL6-DSII | Temporary filters to protect DSII probe sensors in dusty/dirty environments. |
| ACC-HD9 | Hood for use when pumping samples across a DSII probe. |
| AD-DSIIL8-1M | 1m cable for DirectSense II probes to connect to AdvancedSense meters. |
| AD-DSIIUSB-1M | 1m cable for DirectSense II probes to connect to Tablets/Laptops/PCs. |
| CA-HD4-A1 | A1 series smart sensor (DirectSense II) calibration cap. |
| CA-HD5-B1 | B1 series smart sensor (DirectSense II) calibration cap. |
| GWLive-ST | 1 year access to GrayWolfLive. Allows remote, interactive WiFi access (via PCs, iPads, Android devices, etc.). |
| GWLive-Alerts | 1 year access to GrayWolfLive. This version also sends alerts (via text and/or e-mail). |
| PCC-20A/T | Hard-shell Security case with foam cutouts for AdvancedSense or tablet and sensor exposure for 1x DSII probe. |
| PCC-25A/T | Hard-shell Security case with foam cutouts for AdvancedSense or tablet and sensor exposure for 2x DSII probes. |
| PCC-35P/36P | Hard-shell Security case with foam cutouts for AdvancedSense or tablet and sensor exposure for 1x DSII probe plus a particulate meter. |

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Belt clips (included) accommodate hands-free surveys for 1 or multiple probes.

**AD-DSIIL8-1M** 1 meter cable, included, connects to AdvancedSense meters. **AD-DSIIUSB-1M** USB-A version for tablets/laptops.

**CA-HD4-A1** calibration cap.

**ACC-HD9** sampling hood.

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## Handheld Particle Meters

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- 0.1 CFM (2.83 LPM) flow rate
- Long life laser diode technology
- Measures up to 6 channels of simultaneous data
- Approximates mass concentration in µg/m$^3$ with density and refractive index corrections, including **PM2.5**, **PM10** and **TSP**
- Integrated handle for one-handed operation
- Large easy-to-use icon driven color touch screen display
- Optional, direct-connect %RH, C°/F° probe available
- Stores up to 45,000 sample records, 1,000 sample locations and 50 recipes internally, broader options when connected to AdvancedSense®/Tablet
- Annotation function allows user to save 32 character notations to a sample record
- Real-Time Meter for detecting particle contamination sources
- Easy configuration and transferable from instrument to instrument
- Connect using RS-232, Ethernet, USB or (optional) Wireless 802.11 b/g, RS 485
- Displays and externally prints reports for ISO 14644-1, EU GMP Annex I and FS 209E
- Internal audible alarm
- User-definable reports
- User-selectable channel sizes
- Complies with ISO 21501-4 and JIS B9921 standards
- Seamless integration into a facility monitoring system
- Lightweight high-impact injection molded plastic enclosure
- 2 year warranty on instrument, except filters, 1 year on other accessories

---

- The PC-3500 Handheld Particle Counter measures 0.3 µm to 25.0 µm with a flow rate of 0.1 CFM (2.83 LPM).
- Easy to configure, this instrument displays up to 6 user-selectable size channels as well as temperature and relative humidity.
- The PC-3500 mass concentration mode approximates density in µg/m$^3$ and allows for density and refractive index corrections to ensure accuracy.
- The PC-3500 counters can be controlled and monitored remotely via web browser.
- Export data to (included) GrayWolf WolfSense® PC data-download software or view data and generate ISO 14644-1, EU GMP Annex 1 or FS 209E reports on screen or in real time through the versatile PC-3500 output options.
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| | |
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| *Size Range* | 0.3 to 25µm |
| *Size Channels* | Factory calibrated at 0.3, 0.5, 1.0, 2.5, 5.0, 10.0 µm variable binning |
| *Flow rate* | 0.1 CFM (2.83 LPM) |
| *Concentration Limit* | 10,000,000 Particles/ft³ @ 10% coincidence loss |
| *Battery Run Time* | 10 hours |
| *Light Source* | Long life laser diode |
| *Counting Efficiency* | 50% @ 0.3 µm; 100% for particles >0.45 µm per JIS |
| *Zero Count* | <1 count / 5 minutes (<2 particles/ft³) (per ISO 21501-4 & JIS) |
| *Count Modes* | Automatic, manual, real-time meter, cumulative/differential, mass concentration, count or concentration |
| *Count Alarms* | 1 to 9,999,999 counts |
| *Calibration* | NIST traceable |
| *Display* | 4.3" (10.9 cm) WQVGA (480x272) color touch screen |
| *Printer (Optional)* | External thermal printer |
| *Vacuum Source* | Internal pump with automatic flow control |
| *Filtered Exhaust* | Internal HEPA filter |
| *Number of Channels* | 6 |
| *Custom Size Channels* | Calibration for custom size channels available |
| *Audible Alarm* | Adjustable built-in alarm |
| *Battery* | Removable Li-ion |
| *Battery Recharge Time* | 4 hours within instrument (<2 hours with external battery charger) |
| *Reports* | ISO 14644-1, EU GMP Annex 1, FS 209E |
| *Recipes* | 50 user-configurable recipes |
| *Communication Modes* | RS232, Ethernet and USB |
| *Optional Comms Mode* | Wireless 802.11 b/g, RS485 |
| *Environmental Sensor* | Optional temperature and relative humidity probe 32º to 122ºF (0º to 50ºC) ±1ºF (0.5ºC), 15-90% ±2% relative humidity |
| *Alarm* | Alarms on counts for all particle sizes, low battery, sensor failure, environmental sensors and flow |
| *Standards* | ISO 21501-4 and JIS B9921 |
| *Calibration* | Recommended minimum once per year |
| *External Surface* | High impact injection molded plastic |
| *Dimensions (L x W x H)* | 10" x 5" x 4.5" (25.4 cm x 12.9 cm x 11.4 cm) includes handle and does not include probes |
| *Weight* | 2.2 lb (1.0 kg) |
| *Included Accessories* | PCC-GW3500 hard-shell carrying case, quick start guide, operating manual on USB flash drive, isokinetic probe, purge filter, battery, belt clip, WolfSense PC data download software, USB cable, power supply & cable |
| *Optional Accessories* | PCC-35P security case, printed manual, TRH probe, spare battery, external battery charger, external printer and isokinetic probes |
| *Buffer Memory* | *45,000 sample records (rotating buffer) including particle count data, environmental data, locations and times. Scrollable on screen or printout* |
| *Sample Locations* | *Up to 1,000 locations 20 characters long and 50 user defined recipes* |
| *Sample Time* | 1 second to 99 hours |
| *Power* | 110 to 240 VAC 50/60 Hz universal in-line power supply |
| *Operating Conditions* | 41º to 104ºF (5º to 40ºC) / 20% to 95% non-condensing |
| *Storage Conditions* | 32º to 122ºF (0º to 50ºC) / Up to 98% non-condensing |
| *Warranty* | 2 years on instrument, 1 year on accessories, no warranty on filters |

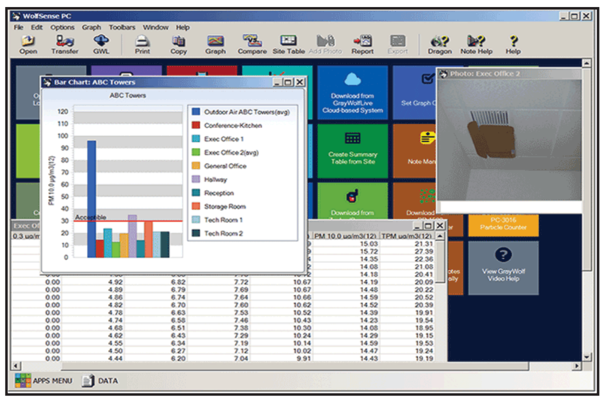
**GrayWolf Sensing Solutions reserves the right to change specifications without notice.**

✓Measure Smart


Example ▲
AdvancedSense Screen
(interface enables GrayWolf's powerful in-situ features for particulate data; audio, photo, text notes and much more).

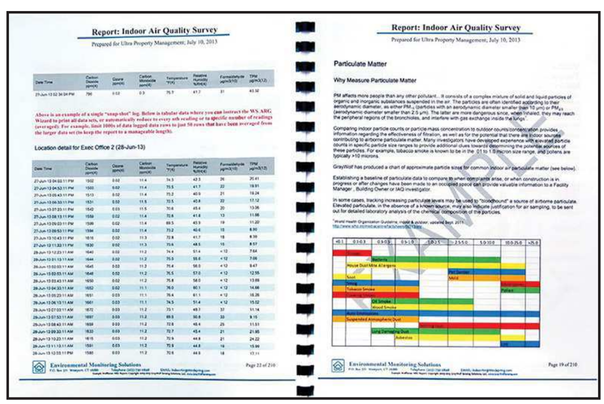
✓Report Efficiently

Optional PCC-35P Hard-shell Security case with cutouts for AdvancedSense meter, sensor exposure for DSII probe plus space & inlet exposure for internal PC-3500 ▼



◀ Example WolfSense PC Screen data transfer & analysis software (supplied as standard)

▶ Example WolfSense ARG report (optional automated report generation software)

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# HOBO® MX $CO_2$ Logger (MX1102) Manual


## HOBO MX $CO_2$ Logger

MX1102

*Included Items:*

- Four AA 1.5 V alkaline batteries

*Required Items:*

- HOBOmobile app and Device with iOS or Android™ and Bluetooth

*OR*

- HOBOware 3.7.3 or later and USB cable

*Accessories:*

- Mounting kit with mounting brackets, screws, tie wraps, and Command™ strip

The HOBO MX $CO_2$ data logger records carbon dioxide, temperature, and relative humidity (RH) data in indoor environments using non-dispersive infrared (NDIR) self-calibrating $CO_2$ sensor technology and integrated temperature and RH sensors. This Bluetooth® Low Energy-enabled logger is designed for wireless communication with a mobile device and also supports a USB connection. Using the HOBOmobile® app on your phone or tablet or HOBOware software on your computer, you can easily configure the logger, read it out, and view plotted data. The logger can calculate minimum, maximum, average, and standard deviation statistics and can be configured to trip audible or visual alarms at thresholds you specify. In addition, it supports burst logging in which data is logged at a different interval when sensor readings are above or below certain limits. This logger also has a built-in LCD screen to display the current $CO_2$ level, temperature, RH, logging status, battery use, memory consumption, and more.

## Specifications

**Temperature Sensor**

| | |
|---|---|
| **Range** | 0° to 50°C (32° to 122°F) |
| **Accuracy** | ±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F), see Plot A |
| **Resolution** | 0.024°C at 25°C (0.04°F at 77°F), see Plot A |
| **Drift** | <0.1°C (0.18°F) per year |

**RH Sensor***

| | |
|---|---|
| **Range** | 1% to 70% RH when $CO_2$ sensor is enabled (non-condensing)<br>1% to 90% RH when $CO_2$ sensor is disabled (non-condensing) |
| **Accuracy** | ±2% from 20% to 80% typical to a maximum of ±4.5% including hysteresis at 25°C (77°F); below 20% and above 80% ±6% typical |
| **Resolution** | 0.01% |
| **Drift** | <1% per year typical |

**$CO_2$ Sensor**

| | |
|---|---|
| **Range** | 0 to 5,000 ppm |
| **Accuracy** | ±50 ppm ±5% of reading at 25°C (77°F), less than 70% RH and 1,013 mbar |
| **Warm-up Time** | 15 seconds |
| **Calibration** | Auto or manual to 400 ppm |
| **Non-linearity** | <1% of FS |
| **Pressure Dependence** | 0.13% of reading per mm Hg (corrected via user input for elevation/altitude) |
| **Operating Pressure Range** | 950 to 1,050 mbar (use Altitude Compensation for outside of this range) |
| **Compensated Pressure Range** | -305 to 5,486 m (-1,000 to 18,000 ft) |
| **Sensing Method** | Non-dispersive infrared (NDIR) absorption |

**Response Time**

| | |
|---|---|
| **Temperature** | 12 minutes to 90% in airflow of 1 m/s (2.2 mph) |
| **RH** | 1 minute to 90% in airflow of 1 m/s (2.2 mph) |
| **$CO_2$** | 1 minute to 90% in airflow of 1 m/s (2.2 mph) |

**Logger**

| | |
|---|---|
| **Radio Power** | 1 mW (0 dBm) |
| **Transmission Range** | Approximately 30.5 m (100 ft) line-of-sight |
| **Wireless Data Standard** | Bluetooth Low Energy (Bluetooth Smart) |
| **Logger Operating Range** | 0° to 50°C (32° to 122°F); 0 to 95% RH (non-condensing) |

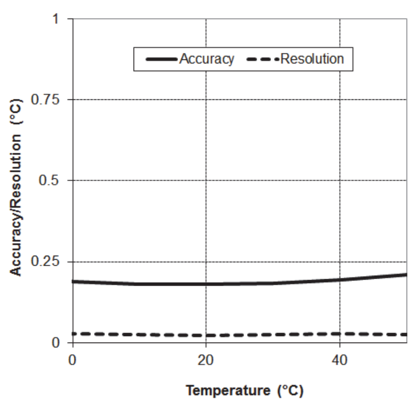
*Per RH sensor manufacturer data sheet

Note: The HOBO U-Shuttle (U-DT-1) is not compatible with this logger.

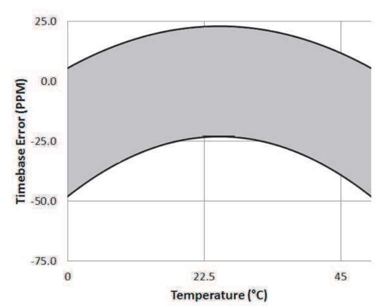
## Specifications (continued)

| | |
|---|---|
| **Logging Rate** | 1 second to 18 hours |
| **Logging Modes** | Fixed interval (normal, statistics) or burst |
| **Memory Modes** | Wrap when full or stop when full |
| **Start Modes** | Immediate, push button, date & time, or next interval |
| **Stop Modes** | When memory full, push button, date & time, or after a set logging period |
| **Time Accuracy** | ±1 minute per month at 25°C (77°F), see Plot B |
| **Power Source** | 4 AA 1.5 Volt batteries (user replaceable) or USB power source (5 V DC, 2 Watts) |
| **Battery Life** | 6 months, typical with logging and sampling intervals of 5 minutes or slower; 6 months or less with logging and sampling intervals faster than 5 minutes while logging $CO_2$. Entering burst logging mode will impact battery life. With HOBOmobile use, battery life can be reduced by remaining connected, excessive readouts, checking of Full Status Details, audible alarms, and paging. Visual/audible alarms and other events can have a marginal impact on battery life. |
| **Memory** | 128 KB (84,650 measurements, maximum) |
| **Download Type** | USB 2.0 interface or via Bluetooth Smart |
| **Full Memory Download Time** | 20 seconds via USB; approximately 60 seconds via Bluetooth Smart, may take longer the further the device is from the logger |
| **LCD** | LCD is visible from 0° to 50°C (32° to 122°F); the LCD may react slowly or go blank in temperatures outside this range |
| **Size** | 7.62 x 12.95 x 4.78 cm (3.0 x 5.1 x 1.88 inches |
| **Weight** | 267.4 g (9.43 oz) |
| **Environmental Rating** | IP50 |
| | The CE Marking identifies this product as complying with all relevant directives in the European Union (EU). |
| | See last page |

*Per RH sensor manufacturer data sheet
Note: The HOBO U-Shuttle (U-DT-1) is not compatible with this logger.

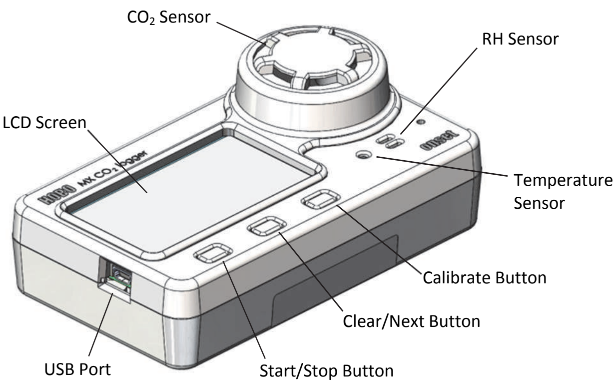



**Plot A: Temperature Accuracy and Resolution**




**Plot B: Time Accuracy**

## Logger Components and Operation




**USB Port:** Use this port to connect the logger to a computer for use with HOBOware or to power the logger for longer deployments or if faster logging intervals are required.

**Start/Stop Button:** Press this button for 3 seconds to start or stop logging data, or to resume logging on the next even logging interval. This requires configuring the logger with a push button start or stop (see *Choosing Logger Settings*). You can also press this button for 1 second to record an internal event (see *Recording Internal Logger Events*), to silence a beeping alarm (see *Setting up Alarms*), or to turn the LCD screen on if the option to turn off the LCD has been enabled (see *Choosing Logger Settings*).

Press both the Start/Stop button and the Clear/Next button simultaneously for 3 seconds to reset a logger password.

**Clear/Next Button**: Press this button for 1 second to switch between statistics, alarm readings, and the current sensor readings as applicable or to silence a beeping alarm. Press this button for 3 seconds to clear a visual alarm if the logger was configured to maintain the alarm until the button is pressed (see *Setting up Alarms*).

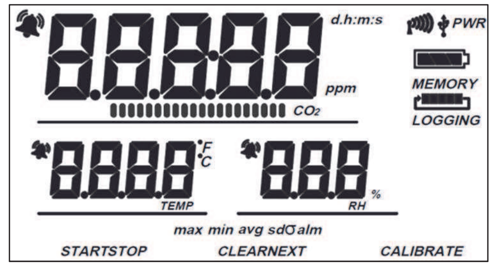
**Calibrate Button:** Press this button to start a five-minute manual calibration process of the $CO_2$ sensor. This requires configuring the logger with the manual calibration $CO_2$ sensor setting enabled in HOBOmobile or HOBOware and bringing the logger into a fresh air environment (see *Calibrating the Logger*).

**Temperature Sensor:** This sensor is located to the right of the LCD screen below the large $CO_2$ sensor.

**RH Sensor:** This sensor is located behind the vented panel in the logger case to the right of the temperature sensor.

**$CO_2$ Sensor:** This sensor is located below the large vented circular panel to the right of the LCD screen.

**LCD Screen:** This logger is equipped with an LCD screen that displays details about the current status. The example shows all symbols illuminated on the LCD screen followed by definitions of each symbol in the table.




| LCD Symbol | Description |
|---|---|
|  | The logger Is currently communicating with HOBOmobile via Bluetooth. The more bars there are, the stronger the Bluetooth signal. |
|  | The logger is currently communicating with HOBOware via USB cable. |
| PWR | The logger is currently being powered by USB cable. |
|  | The battery indicator shows the approximate battery power remaining. |
|  | The logger has been configured to stop logging when memory fills. The memory bar indicates the approximate space remaining in the logger to record data. When first started, all five segments in the bar will be empty. In this example, the logger memory is almost full (only one segment in the memory bar is empty). |
|  | The logger has been configured to never stop logging (wrapping). The logger will continue recording data indefinitely, with newest data overwriting the oldest data until the batteries die or the logger is reconfigured. When first launched, all five segments in the memory bar will be empty. In this example, the memory is full (all five segments are filled in) and new data is now overwriting the oldest data. |
| LOGGING | The logger is currently logging. |
|  | A sensor reading is above or below the high or low alarm limit that you configured. Press and release the Clear/Next button until the "alm" symbol (described later in this table) is displayed on the screen. This symbol at left will clear depending on how alarms were configured to be cleared in the software. If the alarm was set to clear when the logger is reconfigured or relaunched, this symbol will remain on the LCD until the next time the logger is configured (see *Setting up Alarms*). Otherwise, it will clear when the sensor reading is back within the alarm limits or by pressing the Clear/Next button for 3 seconds. |
| START | The logger is waiting to be started. Press and hold the Start/Stop button for 3 seconds to start the logger. |
| STOP | The logger has been started with push button stop enabled; press and hold the Start/Stop button for 3 seconds to stop the logger. |
| CLEAR | An alarm displayed on the LCD is ready to be cleared. This will only appear if the logger was configured to maintain the alarm until the Clear/Next button is pressed (for 3 seconds). Note that an audible alarm can be silenced by pressing the Start/Stop button or Clear/Next button for 1 second. |
| NEXT | Press this button to view the latest statistics (if enabled) or the sensor reading associated with a tripped alarm. |

| LCD Symbol | Description |
|---|---|
| CALIBRATE | Press this button for 5 seconds to manually calibrate the $CO_2$ sensor (if enabled). “Calibrate” and “$CO_2$” will blink on the LCD during the 5-minute manual calibration process. |
| max<br>min<br>avg<br>sdσ | These symbols show the maximum, minimum, average, and standard deviation values most recently calculated by the logger (if enabled). Press the Next/Clear button for 1 second to cycle through the available statistics and then back to the current sensor reading (or to the alarm value if applicable). |
| alm | This is the farthest out-of-range sample displayed during the logger deployment. Press the Clear/Next button to view this reading. Press the Clear/Next button again to cycle through any statistics (defined above) and ultimately back to the current sensor reading. |
| 637 ppm $CO_2$ | This is an example of a $CO_2$ reading in parts per million. **If the logger is powered by battery:** A new segment appears in the status bar every 15 seconds to indicate how long until the display will be updated. In this example, there are 18 segments. This means it has been 4 minutes and 30 seconds since the $CO_2$ reading was updated on the LCD. There are 30 seconds left (two segments) before the reading will be updated on the LCD. **If the logger is powered by USB cable:** The segmented status bar is not displayed and the current reading is updated every second. |
| 80.82 °F TEMP | This is an example of a temperature reading. Temperature units are determined by the settings in the software. To switch between Celsius and Fahrenheit, change the units in the software and then reconfigure the logger. Temperature readings are updated on the LCD every 15 seconds if the logger is battery-powered or every second if it is USB-powered regardless of logging interval. |
| 38.0 % RH | This is an example of an RH reading. RH readings are updated on the LCD every 15 seconds if the logger is battery-powered or every second if it is USB-powered regardless of logging interval. |
| 05:38 d:h:m:s | The logger has been configured to start logging on a particular date/time. The display will count down in days, hours, minutes, and seconds until logging begins. In this example, 5 minutes and 38 seconds remain until logging will begin. |
| LoAd | The configure settings are being loaded onto the logger from the software. |
| Err | An error occurred while loading the configure settings onto the logger from the software. Try reconfiguring the logger. |
| StoP | The logger has been stopped with the software or because the memory is full. |

**Notes:**

- You can disable the LCD screen in the software. When the LCD is turned off for logging, you can still temporarily view the LCD screen by pushing the Start/Stop or Clear/Next button. The LCD will then remain on for 10 minutes.
- When the logger is connected to the computer with the USB cable, the LCD screen refreshes every second regardless of logging interval.
- When the logger has stopped logging, the LCD screen will remain on with “STOP” displayed until the logger is offloaded (unless the LCD screen was turned off in the software). Once the logger has been offloaded, the LCD will turn off automatically after 2 hours.
- The LCD screen flashes “HELLO” when you page the logger from HOBOmobile (see *Getting Started with HOBOmobile*).
- The LCD screen flashes “CHIRP OFF” when an audible alarm is cleared.

## Setting up the Logger

**Important:** The $CO_2$ sensor within this logger can experience measurement drift during storage and shipment. It is strongly recommended that a manual calibration be performed prior to deploying the logger. Start the logger as described in this section and perform a manual calibration. See *Calibrating the Logger* for more details; follow the manual calibration steps in that section. Improper manual calibration can cause incorrect sensor readings.

Install the batteries in the logger. Use a Phillips-head screwdriver to open the battery cover on the back of the logger and insert four AA batteries observing polarity (see *Battery Information*). Screw the cover back in place.

You can use both the HOBOmobile app and HOBOware software with this logger. The following sections provide an overview for using the logger with both programs. You can switch back and forth between the two programs (for example, configure the logger in HOBOware, and read it out in HOBOmobile). However, you can only connect to one program at a time. If you attempt to use HOBOmobile while the logger is connected to HOBOware, a message appears in HOBOmobile indicating a live USB session is underway. If you attempt to use the logger in HOBOware while it is connected to HOBOmobile, the device will not be found. If you want to connect to HOBOmobile after using the logger with HOBOware, you will need to disconnect the USB cable once you are done with HOBOware.

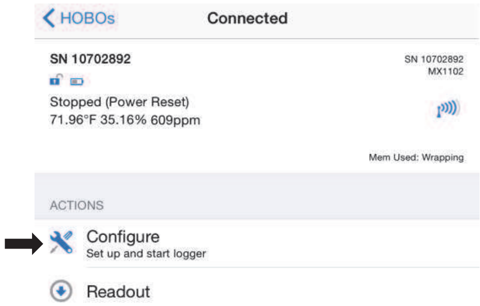
### *Getting Started with HOBOmobile*

These steps provide an overview of setting up the logger with HOBOmobile. For complete details, see the *HOBOmobile User’s Guide*.

1. Go to the App Store® or Google Play™ and download HOBOmobile to your phone or tablet.
2. Open HOBOmobile and enable Bluetooth in your device settings if prompted.
3. Tap  and then tap the logger in the In Range list to connect to it. If the logger does not appear in the list, follow these tips for connecting:
   - Make sure the logger is within range of your mobile device. The range for successful wireless communication is approximately 30.5 m (100 ft) with full line-of-sight.
   - If your device can connect to the logger intermittently or loses its connection, move closer to the logger, within sight if possible.
   - If the logger appears in the In Range list, but you cannot connect to it, close HOBOmobile and power cycle the

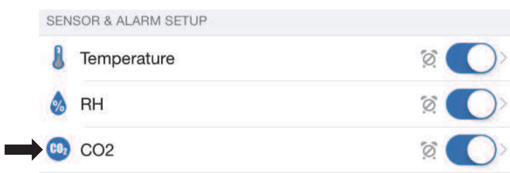
mobile device. This forces the previous Bluetooth connection to close.

4. Once connected, tap Configure.

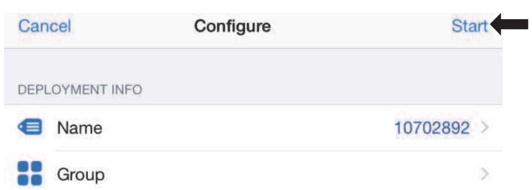



5. Choose your logger settings in the Configure screen. See *Choosing Logger Settings* for details on the available settings.

6. Tap the $CO_2$ sensor and select manual and/or auto calibration (both are selected by default). Select Altitute Compensation and enter the altitude above or below sea level. Tap Done. See *Calibrating the Logger* for more details on calibration settings.




7. Tap Start in the upper right corner of the Configure screen.




Logging will begin based on the settings you selected. Deploy the logger using the included mounting materials (see *Mounting the Logger*). After logging begins, you can read out the logger at any time (see *Reading Out the Logger* for details).

**Note:** The sensor readings displayed within HOBOmobile may not match what is displayed on the logger. The readings in the HOBOs screen are updated every minute and the readings in the Connected screen and Status Details screen are updated every 5 seconds.

When connected to the logger, the following actions are also available in addition to configure:

- **Readout.** Offload logger data. See *Reading Out the Logger*.
- **Full Status Details.** Check the battery level and view the configuration settings currently selected for the logger.
- **Start Logging.** This option appears if On Button Push is selected as a Start Logging setting as described in the *Choosing Logger Settings*.
- **Stop Logging.** Stop the logger from recording data (this overrides any Stop Logging settings described in *Choosing Logger Settings*).
- **Page.** Press and hold the Page icon and the logger will beep to help you locate a deployed logger (tap the Page icon if you only want the logger to beep once). "HELLO" also appears on the LCD when the logger is paged.
- **Clear Audible Alarm.** If audible alarms are enabled as described in *Setting up Alarms*, use this to clear a beeping alarm on the logger.
- **Logger Password.** Select this to create a password for the logger that will be required if another mobile device attempts to connect to it. To reset a password, simultaneously press both the Start/Stop button and the Clear/Next button for 3 seconds or tap Reset to Factory Default in the Set Logger Password screen.
- **Update Firmware.** When new logger firmware is available, this action appears in the list. Select it and follow the instructions on the screen. A logger readout will be completed automatically at the beginning of the firmware update process. If the connection is lost between the logger and the mobile device during the firmware update, a Firmware Update Pending Status displays for the logger in the HOBOs list. Connect to the logger and select Restore Logger (or Update Firmware if that option is available) to continue updating the firmware.

**Important:** Before updating the firmware on the logger, check the remaining battery level by selecting Full Status Details and make sure it is no less than 30%. Make sure you have the time to complete the entire update process, which requires that the logger remains connected to the device during the upgrade.

- **Force Offload.** This may appear if an error was encountered when loading configure settings. Select this to offload all the data on the logger before reconfiguring the logger.

### *Getting Started with HOBOware*

These steps provide an overview of setting up the logger with HOBOware. For complete details, see the HOBOware Help.

1. Install HOBOware on your computer.

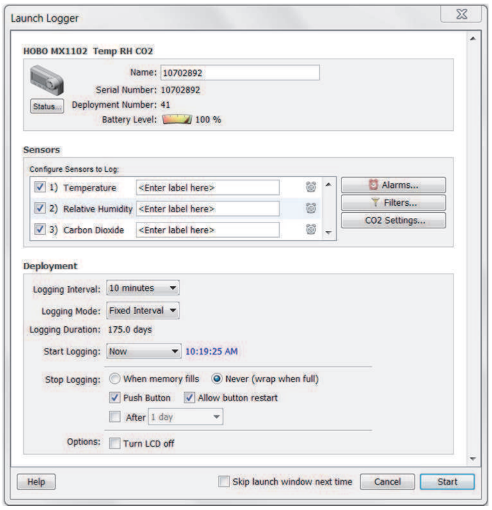
2. Connect the logger to the computer with a USB cable.

**Important:** USB 2.0 specifications do not guarantee operation outside the range of 0°C (32°F) to 50°C (122°F).

3. From the device menu in HOBOware, select Launch.

4. Choose your logger settings. See *Choosing Logger Settings* for details on the available settings.

5. Click the $CO_2$ Settings button and select manual and/or auto calibration (both are selected by default). Select "Use Carbon Dioxide sensor altitude compensation" and enter the altitude above or below sea level. Click OK. See *Calibrating the Logger* for more details on calibration settings.




6. Click the Start button when finished. Note that the Start button text changes based on your Start Logging selection.

Logging will begin based on the settings you selected. Deploy the logger using the included mounting materials (see *Mounting the Logger*). After logging begins, you can read out the logger at any time (see *Reading Out the Logger* for details).

### *Choosing Logger Settings*

The following table lists the available settings when configuring the logger with HOBOmobile or HOBOware.

| Logger Setting | Action |
|---|---|
| Name | Enter a name for the logger up to 20 characters. This name will be used as the title on the graph and in the file name. A name also helps identify the logger in the HOBOs screen in HOBOmobile. If no name is entered, the logger serial number is used. |
| Group (HOBOmobile only) | Add the logger to the Favorites group or a custom group to help identify the logger and its resulting data files. |
| Logging Interval | Select how often the logger will record data. |
| Start Logging Options | Choose one of the following:<br>• **Now.** Logging will begin 15 seconds after selecting Start.<br>• **On Next Logging Interval.** Logging will begin at the next even interval as determined by the selected logging interval.<br>• **On Button Push.** Logging will begin 15 seconds after you press the Start/Stop logging button on the logger for 3 seconds.<br>• **On Date/Time.** Logging will begin at a date and time you specify. |
| Stop Logging Options | Choose a memory option:<br>• **When Memory Fills.** The logger will continue recording data until the memory is full.<br>• **Never (Wrap When Full).** The logger will continue recording data indefinitely, with newest data overwriting the oldest. This option is not available if the Logging Mode is set to Burst (see *Burst Logging*).<br>Choose this stop logging option if desired:<br>• **On Button Push.** Select this if you want to be able to stop logging by pushing the Start/Stop button on the logger. Note that if you also choose On Button Push for the Start Logging option, then you will not be able to stop logging until 30 seconds after logging begins.<br>Choose a Stop Logging time-based option.<br>• **Never.** Select this if you do not want the logger to stop at any predetermined time frame.<br>• **On Date/Time.** Select this if you want the logger to stop logging on a specific date and time. Select the date and time and then tap Done.<br>• **After.** Select this if you want to control how long the logger should continue logging once it starts. Choose the amount of time you want the logger to log data and then tap Done. For example, select 30 days if you want the logger to log data for 30 days after logging begins. |
| Sensor & Alarm Setup | Enable the sensor measurement types that will be logged: temperature, RH, and/or $CO_2$. Both temperature and RH are required to calculate dew point, which is an additional data series available for plotting after reading out the logger. You can configure alarms for sensors. See *Setting up Alarms*. If logging $CO_2$, you can select calibration settings. See *Calibrating the Logger*. |
| Logging Mode | Choose a logging mode:<br>• **Fixed Interval Logging.** The logger will record data for all enabled sensors at the selected logging interval.<br>• **Burst Logging.** In burst mode, logging occurs at a different interval when a specified condition is met. See *Burst Logging* for more information.<br>• In HOBOmobile, select Normal if you want the logger to log current readings. Select each statistic you want the logger to log.<br>In HOBOware, select Statistics and then select Current Reading if you want sensor readings to be logged. Select each statistic you want the logger to log.<br>Current readings and statistics are logged at the logging interval rate. See *Statistics Logging* for more information. |
| Show LCD | Enable or disable to control whether the LCD remains illuminated while the logger is logging. If you disable the LCD, the logger will not show the current reading, status, or other information while the logger is logging. You will, however, be able to temporarily turn the LCD screen on by pressing the Start/Stop button on the logger for 1 second. |

## Calibrating the Logger

The $CO_2$ sensor in the logger requires altitude compensation and regular calibration to ensure accurate readings are being taken in the location where it is deployed. Both auto and manual calibration are selected by default when first configuring the logger. Altitude compensation should be used if you are monitoring $CO_2$ at elevations above or below 305 meters (1,000 feet).

Some $CO_2$ measurement drift may occur during shipment and storage. A manual calibration immediately after logging begins is recommended for best accuracy.

**Important:** If performing a manual calibration, be sure to follow the instructions later in this section. Improper manual calibration can result in incorrect sensor readings.

The following $CO_2$ settings are available in both HOBOmobile and HOBOware:

- **Manual calibration.** Manual calibration is the best way to calibrate your logger. Use this option if you want to manually calibrate the logger to 400 ppm using the Calibrate button on the logger. This requires taking the logger outside in fresh air on a dry day or to an indoor location that is unoccupied and has no connection to a ventilation system for five minutes on a regular basis. Press the Calibrate button on the logger for 5 seconds to manually calibrate the $CO_2$ sensor. "Calibrate" and "$CO_2$" will blink on the LCD during the 5-minute manual calibration process in which 300 measurements are taken to get the average and create the offset from 400 ppm. (See the steps later in this section for more details on manual calibration.) This is recommended if the logger is deployed in a building that is always occupied, if you want the logger to be calibrated more frequently than every eight days (the normal auto calibration schedule), or if you want to calibrate the logger immediately after logging begins. **Note:** Once a manual calibration is performed, the 24-hour auto calibration is canceled and an auto calibration will be performed eight days from the time the manual calibration occurred.
- **Auto calibration.** Use this option if you want the logger to automatically calibrate within the first 24 hours after logging begins and then every eight days thereafter. The logger will be calibrated based on the average of the three $CO_2$ measurements that follow the lowest $CO_2$ value identified during the 24-hour or 8-day time period as applicable.

  **Important:** Accurate auto-calibration requires the building or location where the logger is deployed to be empty at least once during the eight-day period (for example, an empty office building during the weekend or overnight will typically have background $CO_2$ levels of 400 to 450 ppm).

  If the logger is deployed in an area where the $CO_2$ level does not go down to 400 ppm during the eight-day time period, then manual calibration should be performed regularly instead or inaccurate $CO_2$ readings will be reported. If you plan on using auto calibration but the A mabuilding will be occupied during the first day after logging begins, then you can use the manual calibration option as well. You can manually calibrate the logger immediately after logging begins and use auto calibration thereafter. **Note:** Every time the logger is started, auto calibration will occur after 24 hours and then again after eight days unless a manual calibration is performed first.
- **Altitude compensation.** The $CO_2$ sensor must compensate for locations above or below 305 meters (1,000 feet) to provide an accurate reading. You must enter the altitude above or below sea level in either meters or feet when configuring the logger if it will be deployed at a location above or below sea level. In normal use, the $CO_2$ measurement will vary by approximately 0.135% of the reading for each mbar change in barometric pressure (the sensor is calibrated at 1,013 mbar). Use altitude compensation when deploying the logger for the best $CO_2$ accuracy possible.

**To access calibration and altitude compensation settings in HOBOmobile:**

1. Connect to the logger.
2. Tap Configure.
3. Tap the $CO_2$ sensor.
4. Select auto calibration, manual calibration, or both.
5. Select "Altitude Compensation" and enter the altitude above or below sea level where the logger will be deployed in either meters or feet. You can also tap Use Location if you want the location services within the phone or tablet to calculate altitude.
6. Tap Done.
7. Tap Start to load settings to the logger.

**To access calibration and altitude compensation settings in HOBOware:**

1. Connect the logger to the computer with the USB cable.
2. From the Device menu in HOBOware, select Launch.
3. Click the $CO_2$ Settings button.
4. Select auto calibration, manual calibration, or both.
5. Select "Use Carbon Dioxide sensor altitude compensation" and enter the altitude above or below sea level where the logger will be deployed in either meters or feet.
6. Click OK.
7. Click Start in the Launch Logger window to load settings to the logger.

**Note:** If both auto calibration and manual calibration are selected, the logger will automatically calibrate within 24 hours after logging begins unless a manual calibration occurs during that time period. In addition, when both calibration settings are selected, the eight-day calibration cycle will be reset any time a manual calibration is performed.

**To manually calibrate the $CO_2$ sensor:**

**Important:** If you do not follow these manual calibration instructions as described, the sensor readings will be incorrect and you will need to manually calibrate the logger again.

1. Take the logger outside in fresh air on a dry day where the carbon dioxide level is 400 ppm. You can also use an indoor location for manual calibration if it is unoccupied and is not exposed to a ventilation system.
2. Press the Calibrate button on the logger for 5 seconds until it beeps. The logger will then calibrate for 5 minutes. The $CO_2$ and Calibrate symbols on the LCD will flash while the calibration is underway. A time- and date-stamped manual calibration event is logged in the data at the end of the 5-minute calibration sequence.
3. Once the Calibration process is complete, return the logger to its deployment location. Repeat this process at least once every eight days for best accuracy.

## Setting up Alarms

You can set an alarm to trip on the logger when a sensor reading rises above or falls below a specified value. This can alert you to problems so you can take corrective action. To set up a sensor alarm:

1. In HOBOmobile: Connect to the logger and tap Configure.

   In HOBOware: From the device menu, select Launch. Click the Alarms button in the Launch Logger window.
2. Select the sensor that you want to set up with an alarm condition.
3. Enable the High Alarm if you want an alarm to trip when the sensor reading rises above the high alarm value. Drag the slider to the reading that will trip the alarm or type a specific reading.
4. Enable the Low Alarm if you want an alarm to trip when the sensor reading falls below the low alarm value. Drag the slider to the reading that will trip the alarm or type a specific reading.
5. Set the duration before an alarm is tripped.
6. Select either Cumulative Samples or Consecutive Samples. If you select Cumulative Samples, then the alarm will trip when the time the sensor is out of range over the course of the deployment is equal to the selected duration. If you select Consecutive Samples, then the alarm will trip when the time the sensor is continuously out of range is equal to the selected duration. For example, the high alarm for temperature is set to 85°F and the duration is set to 30 minutes. If Cumulative is selected, then an alarm will trip once a sensor reading has been at or above 85°F for a total of 30 minutes since the logger was configured; specifically, this could be 15 minutes above 85°F in the morning and then 15 minutes above 85°F again in the afternoon. If Consecutive is selected, then an alarm will trip only if all sensor readings are 85°F or above for a continuous 30-minute period.
7. Repeat steps 2–6 for any other sensors if desired (tap Done in HOBOmobile first).
8. Enable Audible Alarms if you want a beep to sound on the logger every 30 seconds when the sensor alarm trips (in HOBOmobile, enable this in the Configure screen; in HOBOware, select the Use Audible Alarm checkbox in the Configure Alarms window). The beeping will continue until the alarm is cleared from the software, a button on the logger is pressed, or 7 days have passed. Battery life will be slightly reduced when this setting is enabled. It is recommended that you only enable this feature if you have regular access to the logger so that you can easily turn off the beeping.
9. Select one of the following options for when to clear the alarm symbol that appears on the LCD (in HOBOmobile, enable this in the Configure screen; in HOBOware, select the checkbox in the Configure Alarms window).
   - **Logger reconfigured or relaunched.** The alarm icon will remain visible on the LCD until the next time the logger is reconfigured.
   - **Sensor is in limits.** The alarm icon will remain visible on the LCD until the sensor reading returns to the normal range between any configured high and low alarm limits.
   - **Alarm button is pressed.** The alarm icon will remain visible until you press the Clear/Next button on the logger.
10. In HOBOmobile: Tap Start in the Configure screen to load the alarm settings onto the logger when ready.

    In HOBOware: Click OK in the Configure Alarms window and then click Start in the Launch Logger window when ready.

**Notes about alarms:**

- The alarm icon will be illuminated on the logger LCD when the alarm trips. You can also press the Clear/Next button on the logger to view the farthest out-of-range value during the deployment.
- Alarm limits for temperature and RH sensors are checked every 15 seconds. The $CO_2$ alarm limits are checked every 15 seconds if the logger is powered by USB cable or every 5 minutes if it is powered by batteries. If you are configuring a $CO_2$ sensor alarm for a battery-powered logger, it is recommended that the duration you select is divisible by 5 and a minimum of 5 minutes.
- For USB-powered loggers, $CO_2$ alarms will not be tripped for the first 15 seconds after logging begins as the $CO_2$ sensor requires a 15-second warmup period.
- The actual values for the high and low alarm limits are set to the closest value supported by the logger. For example, the closest value to 85°F that the logger can record is 84.990°F and the closest value to 32°F is 32.043°F. In addition, alarms can trip or clear when the sensor reading is within the logger specifications of 0.02°C resolution. This means the value that triggers the alarm may differ slightly than the value entered. For example, if the High Alarm is set to 75.999°F, the alarm can trip when the sensor reading is 75.994°F (which is within the 0.02°C resolution).
- When you read out the logger, alarm events can be displayed on the plot or in the data file. See *Recording Internal Logger Events*.
- Once cleared, an audible alarm will start beeping again if the sensor values go out of the normal range. Even if an audible alarm is cleared, a visual alarm may remain on the logger LCD and in HOBOmobile (if applicable) depending on the settings selected for maintaining visual alarms or because the alarm condition may still be in effect. In addition, an audible alarm will continue beeping when the sensor values have returned to the normal range until it is cleared.
- Although an audible alarm and a visual alarm can occur at the same time when a sensor alarm is tripped, they are cleared in different ways. The audible alarm can be cleared from within the software, a button on the logger is pressed, or 7 days have passed. Meanwhile, a visual alarm is cleared as determined by the setting selected for maintaining an alarm in the software. This means you could clear a beeping audible alarm and the visual alarm will remain on the LCD and in HOBOmobile (if applicable) until the logger is reconfigured, the sensor is in limits, or the alarm button is pressed--whichever setting you selected.
- If the logger was configured to stop logging with a button push, any tripped alarms will be cleared automatically when logging is stopped and no Alarm Cleared event will be logged in the data file.

## Burst Logging

Burst logging is a logging mode that allows you to set up more frequent logging when a specified condition is met. For example, a logger is recording data at a 5-minute logging interval and burst logging is configured to log every 30 seconds when the temperature rises above 85°F (the high limit) or falls below 32°F (the low limit). This means the logger will record data every 5 minutes as long as the temperature remains between 85°F and 32°F. Once the temperature rises above 85°F, the logger will switch to the faster logging rate and record data every 30 seconds until the temperature falls back to 85°F. At that time, logging then resumes every 5 minutes at the normal logging interval. Similarly, if the temperature falls below 32°F, then the logger would switch to burst logging mode again and record data every 30 seconds. Once the temperature rises back to 32°F, the logger will then return to normal mode, logging every 5 minutes.

To set up burst logging:

1. In HOBOmobile: Connect to the logger and tap Configure.

   In HOBOware: From the Device menu, select Launch.
2. Set the Logging Mode to burst logging. (If already selected in HOBOware, click the Edit button.)
3. Select the sensor that will have burst limits.
4. Enable High Limit if you want burst logging to occur when the sensor reading rises above a specific reading. Drag the slider to the reading that will trigger burst logging or type a specific reading.
5. Enable Low Limit if you want burst logging to occur when the sensor reading falls below a specific reading. Drag the slider to the reading that will trigger burst logging or type a specific reading.
6. Repeat steps 3–5 for any other sensors if desired (tap Done in HOBOmobile first).
7. Set the burst logging interval. Select an interval faster than the logging interval. Keep in mind that the more frequent the burst logging rate, the greater the impact on battery life and the shorter the logging duration. In HOBOmobile, tap Done.
8. In HOBOmobile: Tap Done to return to the Configure screen. Tap Start to load the burst settings onto the logger when ready.

   In HOBOware: Click OK in the Burst Logging window and then click Start in the Launch Logger window when ready.

**Notes about Burst Logging:**

- Sensor alarms, statistics, and the Stop Logging option "Never (Wrapping)" are not available in burst logging mode.
- Once the logger is configured, the high and low burst limits are checked every 15 seconds. Therefore, if you set the logging interval to less than 15 seconds and the sensor reading falls outside the levels, the burst logging will not begin until the next 15-second cycle.
- If high and/or low limits have been configured for more than one sensor, then burst logging will begin when any high or low condition goes out of range. Burst logging will not end until all conditions on all sensors are back within normal range.
- The actual values for the burst logging limits are set to the closest value supported by the logger. For example, the closest value to 85°F that the logger can record is 84.990°F and the closest value to 32°F is 32.043°F.
- Burst logging mode can begin or end when the sensor reading is within the logger specifications of 0.02°C resolution. This means the value that triggers burst logging may differ slightly than the value entered. For example, if the high limit for a temperature alarm is set to 75.999°F, burst logging can start when the sensor reading is 75.994°F (which is within the 0.02°C resolution).
- Once the high or low condition clears, the logging interval time will be calculated using the last recorded data point in burst logging mode, not the last data point recorded in "normal mode." For example, a logger has a 10-minute logging interval and logged a data point at 9:05. Then, the high limit was surpassed and burst logging began at 9:06. Burst logging then continued until 9:12 when the sensor reading fell back below the high limit. Now back in normal mode, the next logging interval will be 10 minutes from the last burst logging point, or 9:22 in this case. If burst logging had not occurred, the next data point would have been at 9:15.
- A New Interval event is created each time the logger enters or exits burst logging mode. See *Recording Internal Logger Events* for details on plotting and viewing the event. In addition, if the logger is stopped with a button push while in burst logging mode, then a New Interval event is automatically logged and the burst condition is cleared, even if the actual high or low condition has not cleared.

## Statistics Logging

During fixed interval logging, the logger records data for enabled sensors and/or selected statistics at the logging interval selected. Statistics are calculated at a sampling rate you specify with the results for the sampling period recorded at each logging interval. The following statistics can be logged for each sensor:

- The maximum, or highest, sampled value,
- The minimum, or lowest, sampled value,
- An average of all sampled values, and
- The standard deviation from the average for all sampled values.

For example, a logger is configured with the temperature and $CO_2$ sensors enabled and the logging interval set to 5 minutes. The current reading and all four statistics are enabled. The statistics sampling interval is set to 30 seconds. Once logging begins, the logger will measure and record the actual temperature and $CO_2$ sensor values every 5 minutes. In addition, the logger will take a temperature and $CO_2$ sample every 30 seconds and temporarily store them in memory. The logger will then calculate the maximum, minimum, average, and standard deviation using the samples gathered over the previous 5-minute period and log the resulting values. When reading out the logger, this would result in the following 10 data series (not including any derived series): two sensor series (with temperature and $CO_2$ current readings logged every 5 minutes) plus eight maximum, minimum, average, and standard deviation series (four for temperature and four for $CO_2$ with values calculated and logged every 5 minutes based on the 30-second sampling rate).

To set up statistics:

1. In HOBOmobile: Connect to the logger and tap Configure.

   In HOBOware: From the Device menu, select Launch.
2. In HOBOmobile: Tap Logging Mode and then select Fixed Interval Logging.

   In HOBOware: Select Statistics for the logging mode.
3. Select Normal in HOBOmobile or Current Reading in HOBOware to record the current reading for each enabled sensor at the logging interval selected. Do not select this if you only want to log statistics.
4. Select the statistics you want the logger to record at each logging interval: Maximum, Minimum, Average, and Standard Deviation (average is automatically enabled when selecting Standard Deviation). Statistics will be logged for all enabled sensors. In addition, the more statistics you record, the shorter the logger duration and the more memory is required.
5. Set the statistics sampling interval. The rate selected must be less than, and a factor of, the logging interval. For example, if the logging interval is 1 minute and you select 5 seconds for the sampling rate, then the logger will take 12 sample readings between each logging interval (one sample every 5 seconds for a minute) and use the 12 samples to record the resulting statistics at each 1-minute logging interval. Note that the more frequent the sampling rate, the greater the impact on battery life. In HOBOmobile, tap Done.
6. In HOBOmobile: Tap Done to return to the Configure screen. Tap Start to load the burst settings onto the logger when ready.

   In HOBOware: Click OK in the Burst Logging window and then click Start in the Launch Logger window when ready.

Once logging begins, press the Clear/Next button on the logger to cycle through the current maximum, minimum, average, and standard deviation data on the LCD screen. Note that the logger will always display the current sensor readings in HOBOmobile (If applicable) even if they are not being logged. You can plot the statistics series once you read out the logger.

## Reading Out the Logger

To offload data from the logger to HOBOmobile:

1. Connect to the logger and tap Readout.
2. Tap Data Files to view a mini-graph of the offloaded data.
3. Tap the mini-graph to view a larger version of the graph or to share the file. See the *HOBOmobile User's Guide* for details on viewing graphs and sharing data. Data can also be uploaded automatically to HOBOlink, Onset's web-based software. For details on working with data in HOBOlink, refer to the HOBOlink Help.

To offload date from the logger to HOBOware:

1. Connect the logger to the computer with the USB cable.
2. From the Device menu, select Readout.
3. Save the data file when prompted. See the HOBOware Help for details on plotting and exporting data in HOBOware.

**Note:** Data files read out from the logger in one program are not automatically available in the other. To open HOBOmobile files in HOBOware, share the file and select HOBO as the file type. Email the file and then open it in HOBOware. Files in HOBOware cannot be viewed in HOBOmobile. You can, however, export data in HOBOware to a text or Excel file that you can open on your mobile device. See the *HOBOmobile User's Guide* and HOBOware Help for details on sharing or exporting data.

## Recording Internal Logger Events

The logger records the following internal events to track logger operation and status.

To plot events in HOBOmobile, tap a mini-graph and then tap ☰ in the upper right corner. Select the events you wish to plot and then tap ☰ in the upper left. You can also view events in shared or exported data files.

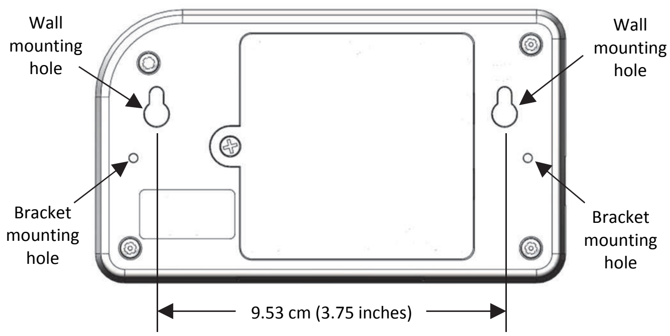
To plot events in HOBOware, select the events you wish to plot in the Plot Setup window when opening a data file. The following events may occur:

| Internal Event Name | Definition |
|---|---|
| Host Connected | The logger was connected to the mobile device or computer as applicable. |
| Started | The Start/Stop button was pressed to begin or resume logging. |
| Stopped | The logger received a command to stop recording data (from the software or by pushing the Start/Stop button). |
| Button Up/Button Down | The Start/Stop button was pressed for 1 second. |
| Chan <#> Alarm Tripped | A sensor alarm has tripped; <#> is the sensor number, where 1 is $CO_2$, 2 is temperature, and 3 is RH. |
| Chan <#> Alarm Cleared | A sensor alarm has cleared; <#> is the sensor number, where 1 is $CO_2$, 2 is temperature, and 3 is RH. This event also contains the value that was furthest out of range for the sensor before the alarm cleared, which is only available in a shared or exported file. |
| New Interval | The logger has entered or exited burst logging mode. |
| Automatic Calibration | The $CO_2$ sensor has been calibrated automatically; the data file will show the offset calculated in PPM during the calibration. |
| Manual Calibration | The $CO_2$ sensor has been manually calibrated; the data file will show the offset calculated in PPM during the calibration. |
| Safe Shutdown | The battery level dropped below 3.7 V; the logger performs a safe shutdown. |

## Mounting the Logger

There are several ways to mount the logger using the materials included:

- Attach Command strips to the back of the logger to mount it to a wall or other flat surface.
- Screw in the brackets onto both sides of the logger using the two small holes labeled in the diagram below and then use tie wraps to mount it to a pole or pipe.
- Mount the logger to the wall or a flat surface using two screws and the included template. The dimensions are also shown in the following example.




## Protecting the Logger

The logger is designed for indoor use and can be permanently damaged by corrosion if it gets wet. Protect it from condensation. If the message FAIL CLK appears on the LCD screen, there was a failure with the internal logger clock possibly due to condensation. Remove the battery immediately and dry the circuit board.

**Note: Static electricity may cause the logger to stop logging.** The logger has been tested to 8 KV, but avoid electrostatic discharge by grounding yourself to protect the logger. For more information, search for “static discharge” on onsetcomp.com.

## Battery Information

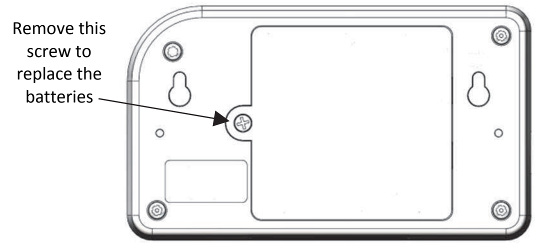
The logger requires four user-replaceable AA 1.5 V alkaline or optional lithium batteries for operation at the extreme ends of the logger operating range. Expected battery life varies based on the ambient temperature where the logger is deployed, the logging or sampling interval, frequency of offloading and connection to a mobile device, number of channels that are active, audible alarms duration, use of burst mode or statistics logging, and battery performance. New batteries typically last 6 months with logging and sampling intervals greater than 5 minutes.

Deployments in extremely cold or hot temperatures, or a logging or sampling interval faster than 5 minutes can impact battery life. Estimates are not guaranteed due to uncertainties in initial battery conditions and operating environment.

The logger can also be powered by the USB cable if faster logging intervals are desired or when the remaining battery voltage is too low for it to continue logging. Connect the logger to the computer, click the Readout button on the toolbar in HOBOware, and save the data as prompted. Replace the battery before launching the logger again.

To install or replace the batteries:

1. Use a Phillips-head screwdriver to unscrew the battery cover on the back of the logger.




2. Remove any old batteries.
3. Insert four new batteries observing polarity.
4. Screw the battery cover back in place.

**WARNING:** Do not cut open, incinerate, heat above 85°C (185°F), or recharge the lithium batteries. The batteries may explode if the logger is exposed to extreme heat or conditions that could damage or destroy the battery case. Do not dispose of the logger or batteries in fire. Do not expose the contents of the batteries to water. Dispose of the batteries according to local regulations for lithium batteries.

**Note:** $CO_2$ sensor readings may temporarily appear as 0 ppm in HOBOmobile when replacing the batteries until the logger begins logging again.

**Federal Communication Commission Interference Statement**

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one of the following measures:

- Reorient or relocate the receiving antenna
- Increase the separation between the equipment and receiver
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected
- Consult the dealer or an experienced radio/TV technician for help

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

**FCC Caution:** Any changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate this equipment.

**Industry Canada Statements**

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

**Avis de conformité pour l'Industrie Canada**

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

To comply with FCC and Industry Canada RF radiation exposure limits for general population, the HOBO MX logger must be installed to provide a separation distance of at least 20 cm from all persons and must not be co-located or operating in conjunction with any other antenna or transmitter.

**NCC Statement**

經型式認證合格之低功率射頻電機，非經許可，公司、商號或使用者均不得擅自變更頻率、加大功率或變更原設計之特性及功能。

低功率射頻電機之使用不得影響飛航安全及干擾合法通信；經發現有干擾現象時，應立即停用，並改善至無干擾時方得繼續使用。前項合法通信，指依電信法規定作業之無線電通信。低功率射頻電機須忍受合法通信或工業、科學及醫療用電波輻射性電機設備之干擾。

**Translation:**

**Article 12**

Without permission granted by the NCC, any company, enterprise, or user is not allowed to change frequency, enhance transmitting power or alter original characteristic as well as performance to an approved low power radio-frequency device.

**Article 14**

The low power radio-frequency devices shall not influence aircraft security and interfere with legal communications. If found, the user shall cease operating immediately until no interference is achieved. The said legal communications means radio communications is operated in compliance with the Telecommunications Act. The low power radio-frequency devices must be susceptible with the interference from legal communications or ISM radio wave radiated devices.