D1.3
REPORT ON 1ST STEP. SCAN ANALYSIS

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ABBREVIATIONS AND ACRONYMS

ACRONYMS	DESCRIPTION
ACT	Asthma Control Test
AISBE	Integrated Healthcare District of Barcelona-Esquerra
AMG	Adjusted Morbidity Groups
AT	Austria (ISO 3166 country code)
AI	Artificial Intelligence
ALDS	Ambulatory Lung Diagnosis System
AQLQ	Asthma Quality of Life Questionnaire
CAN	Canteen (Scenario)
CAPSBE	Eixample Primary Health Care Consortium
CAT	COPD Assessment Test
CEIm	Ethical Committee for Human Research at HCB
CHSS	Catalan Health Surveillance System
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
D	Deliverable
DE	Germany (ISO 3166 country code)
EA	Ethical Approval
EMC	Erasmus Medical Center
ES	Spain (ISO 3166 country code)
FEV	Forced Expiratory Volume
FOT	Forced Oscillation Technique
FS	Flow Spirometry
FVC	Forced Vital Capacity

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GDPR	General Data Protection Regulation
HCB	Hospital Clinic Barcelona
HIMSS	Healthcare Information and Management Systems Society
HOM	Home (Scenario)
HOS	Hospital (Scenario)
HCB	Hospital Clinic Barcelona
HPLC	High-Performance Liquid Chromatography
HEPA	High-Efficiency Particulate Air
HVAC	Heating, Ventilation and Air Conditioning
I2M	Innovation to Market Company
IAQ	Indoor Air Quality
ICHOM	International Consortium for Health Outcomes Measurement
IQR	Interquartile Range
JCA	Joint Controllers Agreement
K-HiA	K-HEALTHinAIR
KPI	Key Performance Indicators
LEC	Lecture hall (Scenario)
M	Month
M+H	Mann+Hummel
MET	Metro station (Scenario)
MKT	Market (Scenario)
ML	Machine Learning
mMRC	Modified Medical Research Council
MUW	Medical University of Wien
NIO	Nofer Institute
NL	Netherlands (ISO 3166 country code)

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NO	Norway (ISO 3166 country code)
NO_x	Nitrogen Oxides
O_3	Ozone
OAQ	Outdoor Air Quality
OUT	Outpatients
P1	Pilot 1 (Spain)
P2	Pilot 2 (The Netherlands)
P3	Pilot 3 (Norway)
P4	Pilot 4 (Germany)
P5	Pilot 5 (Poland/Austria)
PAHs	Polycyclic aromatic hydrocarbons
PL	Poland (ISO 3166 country code)
PM	Particulate Matter
PROMIS	Patient-Reported Outcomes Measurement Information System
PROMS	Patient-Reported Outcome Measures
QoL	Quality of Life
REF	Refractory to standard therapy
RES	Residence home (Scenario)
RET	Senior home (Scenario)
RH	Relative Humidity
SBS	Sick-building syndrome
SCH	School (Scenario)
SD	Standard Deviation
SE	Standard Error
SIKT	Norwegian Agency for Shared Services in Education and Research
SNOT-22	Sino-Nasal Outcome Test

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T	Temperature
TAI-12	Test of Adherence to Inhalers 12
tVOC	Total Volatile Organic Compound
UiA	University of Adger
UVGI	Ultraviolet Germicidal Irradiation
VOC	Volatile Organic Compound
WHO	World Health Organization
WP	Work Package
WUT	Warsaw University Polytechnical

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EXECUTIVE SUMMARY

The content of the current document, *D1.3 Report on 1st Step: Scan Analysis,* is based on very preliminary results generated so far by the five pilot studies, encompassing ten different scenarios, as described in *D1.2 Report on Monitoring Data (Version 1) and D1.7 Coordination program for pilots (Version II)*. It is of note, however, that the lessons learnt during the process of deployment of the different pilots, and the characteristics of the information collected, are already pointing toward well-defined directions that should lead toward a successful accomplishment of the expected outcomes within the project lifetime.

The introductory section of the report provides a high-level description of the strategies and methods to be applied for data analyses to assess the hypotheses formulated in *D2.2 AI algorithms for scenarios (Version 1)* and support the WP2 in the advance data analysis. Those analyses will cover four intertwined items:

- Characterization of timewise levels of each individual indoor pollutant considered in the project in each scenario. Also, the study of the relationships between IAQ and OAQ.
- Assessment of the relationships between IAQ and health status considering individual pollutants. The analyses will be carried out at pilot level, but also by scenario across the entire project.
- Explore synergistic interactions among pollutants on health status, analyzing potential deleterious effects of subthreshold levels of the individual pollutants. Current knowledge is prompting the need for the study of the interactions between oxidants and other pollutants on health.
- Enhanced characterization of the episodes of exacerbation with the two well-defined aims: prediction of the episode and early management aiming at preventing emergency room and/or hospital admissions. The approach may significantly increase the sensitivity of the detection of the effects of poor IAQ on health.

The outcomes of the above studies will modulate subsequent action plans. Firstly, the final design and execution of potential *in vivo* & *in vitro* studies. Also, elaboration and testing of preventive steps and last, but not least, citizen empowerment for prevention of acute events.

Then, as the document's core is included a descriptive analysis of the preliminary results and summary description of the lessons learnt from each pilot site and the different scenarios. Such initial results are indicating future directions and needed corrections of the project work plan.

The results, data analysis, and preliminary conclusions are presented in a structured manner for each of the pilots, analyzing scenario by scenario. As a common conclusion, it can be stated that further information collection and additional analysis are still necessary for defining the determinants in each scenario. Additionally, basal concentrations of indoor pollutants scenarios are generally low and comply with regulatory standards within the data extracted from the monitoring tools. Another preliminary common conclusion is that outdoor PM infiltration is observed, particularly in areas closer to the buildings' entrances being this parameter the most relevant.

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Regarding the hospital, the time series analysis reveals recurrent peaks of aldehydes and other VOCs, which may have health implications and, within the VOCs sampling, formaldehyde, acetone, and chloroform are being identified as potential candidates for further investigation due to their elevated concentrations and known health effects.

PM/PAHs sampling (school and home) reveals higher concentrations in winter, indicating potential health risks associated with breathing indoor air during colder seasons.

High levels of bacterial and fungal contamination indicate low air exchange rates and potential sources of indoor pollution (lecture hall, canteen, school and home).

The roadmap of core actions for the subsequent period of the project (M18 to M34), including the associated key performance indicators (KPI), are proposed in Section 3. The main purpose being to foster a productive debate during the incoming 3rd consortium meeting to be held in Ludwigsburg on 6th – 7th March 2024. The final outcomes should be the generation of an operative action plan for the period. The conclusions highlight the steps to be adopted aiming at mitigating acknowledged risk of the project.

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1 INTRODUCTION

Deliverable 1.3. Report on 1st step. Scan Analysis.

Report describing the methodology and results of the first step of the process. Determinant's definition.

1.1 General approach

K-HEALTHinAIR aims to deliver structured knowledge, coming from the monitoring, characterization and research stages formed by extensive and accurate data sets, relevant indicators, qualitative and quantitative information about health risks and eventual negative effects and guidelines in an easy and fully open access format to support public authorities, policy makers and many stakeholders. K-HEALTHinAIR will also deliver innovative solutions and associated tools to the citizens as main final users enabling them to monitor IAQ for identifying health risks and suggesting suitable solutions to mitigate them.

K-HEALTHinAIR aims to characterize IAQ in relevant indoor environments with an integrated monitoring campaign. IAQ is highly dependent of the environment and the settings, that the Project has established as scenarios. One way for addressing the health determinants' identification is an IAQ systematized characterization to select those worse pollutants according their harmful effects, the people attending, type of population group and exposure time among other factors. Many determinants keep unknown, although can be harmful at very low concentrations, because they do not appear all the time. Then, especially for chronic effects, exposome (the measure of all the exposures of an individual in a lifetime and how those exposures relate to health) is a relevant concept that must be included in data analysis for determinants identification.

Thus, K-HEALTHinAIR carries out two different study approaches to identify determinants of IAQ effects on health.

Firstly, the analysis of the relationships between indoor air quality (IAQ) and health status aims to identify potential determinants of acute deleterious effects of indoor pollution on health status. The scenario named as Outpatients (OUT) will study these acute events. These acute effects are mainly suffered by high-risk outpatients with some health problems and chronic effects in the short, medium, and long-term and, in principle, can affect everyone according to their conditions, population group, exposure, etc.

The second approach of the Project is the characterisation of different indoor scenarios: i) Hospital (HOS); ii) City market (MKT); iii) Metro station (MET); iv) Senior home; v) Canteen; vi) Students' residence; vii) Lecture hall (LEC); viii) Home (HOM) and ix) School (SCH).

The results obtained from these two lines of action should lead to identifying potential determinants of indoor air pollution on health status, causality analyses, and, finally, exploration and proposal of preventive actions.

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1.2 Analysis strategy

The setup and launch of the various pilots within the K-HEALTHinAIR project have presented significant challenges, resulting in accumulated delays across all pilots, as reported in *D1.7 Coordination program for pilots (version II)*. These delays have led to a partial reduction in the planned monitoring time for carrying out the initial data analysis (Table 1).

Table 1. Deployment state of the K-HiA pilots.

K-HEALTHinAIR Scenarios. Deployment state.										
K-HEALTH inAIR	OUTPATIENTS	HOSPITAL	METRO STATION	MARKET	SENIOR HOME	CANTEEN	STUDENTS RESIDENCE	LECTURE HALL	HOME	SCHOOL
Starting date	03/23	03/23	03/23	03/23	03/23	03/23	03/23	03/23	03/23	03/23
Launching data collection	11/23(P#1) 03/24(P#2)	06/23(P#1) 10/23(P#2)	Approval pending	03/24	12/23	11/23(P#3) 06/23(P#4)	03/24(P#3)	10/23(P#4) 6/23(P#4)	08/23	10/23
Deployment state	60%	100%	0%	0%	20%	100%	10%	100%	100%	100%
Study period	Nov23-Feb26	Jun23-Feb26	May24-Feb26	Mar24-Feb26	Mar24-Feb26	Apr23-Feb26	Mar24-Feb26	Jun23-Feb26	Jul23-Feb26	Jun23-Feb26

Therefore, this deliverable provides an initial analysis with extracted results, but no determinants for the project scenarios have been identified yet. As a contingency measure due to the lack of definition of determinants at the end of task 1.2, data collection will continue during the next monitoring stage, task 1.3, and potential sources of determinants will be evaluated in parallel.

Consequently, the data analysis has been fragmented into three consecutive steps in alignment with the foundations of the statistical analyses described in D2.2 AI algorithms for scenarios (Version 1). This document sets the framework for data-driven analysis and artificial intelligence strategies within the project (WP2), offering a comprehensive overview of the data to be collected across different scenarios and outlining hypotheses to be addressed.

Step 1: Preliminary Data Analysis (M18):

As detailed in this document, the initial phase aims to conduct an exploratory analysis of indoor air quality (IAQ) across all pilots to characterize each scenario in detail. This characterization is essential to:

1. Identify patterns in air quality and understand IAQ behaviour in specific locations. This involves exploring continuous monitoring data and discrete samplings, inspecting time-series patterns, and extracting summary statistics.
2. Draw initial conclusions within each pilot and scenario, updating hypotheses and strategies based on ongoing systematic review.
3. Assess challenges related to data collection and adjust strategies as needed to ensure data representativeness, quality, and quantity. Different pre-processing choices will be assessed to ensure data quality, including scaling, handling missing values, normalization, handling outliers, and addressing inconsistent data points.

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Step 2: Completion of 12 Months of IAQ Data Across Pilots

Following, a detailed characterization of individual data, and hypothesis-specific analysis strategies will be implemented once one complete year of data has been collected across the pilots. This analysis will involve:

1. Studying trends, seasonality, stationarity, and correlations between various parameters.
2. Investigating underlying mechanisms affecting IAQ parameters over time, such as external factors or specific scenario conditions.
3. Characterizing timewise levels of individual determinants of indoor pollutants and studying the relationships between IAQ and OAQ.
4. Exploring the behaviour and dynamics among chemical and biological pollutants, including their interactions and potential synergistic effects
5. Informing the final design and execution of potential in vivo and in vitro studies.

Step 3: Studying the Health Effects of IAQ Exposure

In the final step, the assessment of IAQ's impact on health status, exploration of synergistic interactions among pollutants, and enhanced characterization of exacerbation episodes will be conducted at both pilot and scenario levels. This step also includes:

1. Completion of *in vivo* and *in vitro* studies.
2. Designing targeted preventive actions in selected scenarios based on the identification of determinants.

1.3 IAQ guidelines

On the other hand, during the initial phase of the project and within the framework of work packages 1, 2, and 3, an initial Indoor Air Quality (IAQ) guideline has been developed, which includes parameter limits as a reference for assessing air quality. This preliminary guideline is a first proposal based on reference values from recognized international such as WHO and national organizations in various countries. It is worth noting that while these reference values are scientifically supported, few countries have legislation in place to support their implementation. This preliminary guideline will serve as a starting point for evaluating and improving indoor air quality within the project's context, aiming to establish effective and practical standards that promote healthy environments in educational and workplace settings.

Furthermore, this activity is also part of a joint task proposed within the IDEAL cluster in the framework of the WG4 Standardization, aiming to define an Indoor Air Quality (IAQ) index that can be standardized internationally and implemented in air quality monitors.

As part of the work within this work package, and in collaboration with WP2 and WP3, Table 2 has been set up to identify the recommended maximum levels for each of the parameters being analyzed (see annex I for a full description of the work developed).

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Table 2. Guideline's levels for the key pollutants in the K-HEALTHinAIR project (Preliminary table configured from existing references).

POLLUTANT	Averaging time	Preliminary K-HiA guideline level	References
$PM_{2.5}$ (μg/m³)	Annual	5	WHO
	24-hour	15	WHO
PM_{10} (μg/m³)	Annual	15	WHO
	24-hour	45	WHO
TVOC (μg/m³)	Annual	200 μg/m³	The Netherlands
	8-hour	600 μg/m³	Portugal
Formaldehyde (μg/m³)	30-minutes	100	WHO
	8-hour	60	Austria
CO_2 (ppm)	1-hour	900	Multiple*
Radon (Bq/m³)	value	100	WHO
O_3 (μg/m³) Outdoor	Peak season	60	WHO
	8-hour	100	WHO
NO_2 (μg/m³) Outdoor	Annual	10	WHO
	24-hour	25	WHO
	1-hour	200	WHO

* *Still under discussion depending on the scenario*

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2 BARCELONA PILOT #1 (ES)

The dual approach of the K-HEALTHinAIR project, focusing on both studying the relationships between IAQ and acute health problems and characterising different indoor scenarios, is implemented in Pilot #1 in Barcelona through many specific actions:

Identify potential determinants of acute deleterious effects of indoor pollution on health status:

- Follow-up of 200 high-risk respiratory outpatients (HOM01).
- Exhaustive follow-up of 10 high-risk outpatients with asthma* resistant to standard treatments (HOM02).

* The involvement of the severe asthma unit at the Hospital Clínic of Barcelona resulted in the inclusion of a subgroup of patients with severe asthma resistant to traditional therapies in the study. This subgroup constitutes 40% of the cohort in the HOM01 group and comprises 100% of the participants in the HOM02 study, as elaborated in *D1.7 Coordination program for pilots (version II)*.

- Characterisation of different indoor scenarios:

✓ Hospital scenario (HOS01).

✓ Metro station scenario (MET01).

✓ Market scenario (MKT01).

By implementing these activities, Pilot #1 in Barcelona covers both aspects of the project's approach. It examines the direct effects of IAQ on the health of high-risk respiratory outpatients in their homes while characterising IAQ in various indoor environments representative of different scenarios. This comprehensive approach allows a nuanced understanding of how IAQ impacts health across different contexts, from individual homes to public spaces like hospitals, metro stations, and markets.

This 18M report does not contain correlation analyses of IAQ and health status, as the recruitment of the cohorts has not concluded yet. Only baseline information on the recruited patients has been collected at this stage. As a result, comprehensive correlation analyses between IAQ and health outcomes have yet to be conducted. However, despite this limitation, preliminary characterization of the monitored environments can still be performed to provide valuable insights into IAQ profiles and a first screening of potential determinants.

2.1 Hospital scenario (ES-HOS01)

2.1.1 Rationale

IAQ in relevant environments with high presence of vulnerable groups such as healthcare institutions and its relationship with acute health events is a critical issue.

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On the one hand, nosocomial infections, encompassing bacterial, viral, and fungal pathogens, pose significant risks in hospital settings, necessitating comprehensive interventions to monitor and mitigate the presence of harmful biological agents to prevent infections. Bacterial infections, particularly from *Staphylococcus aureus* and *Clostridium difficile* species, are known for their rapid spread within healthcare facilities, leading to severe infections[1–4]. Viral agents such as influenza and respiratory syncytial virus also significantly contribute to nosocomial outbreaks, especially in intensive care units where patients are more susceptible to respiratory infections[5,6]. Additionally, fungal infections caused by *Candida spp.* and *Aspergillus spp.* pose serious risks to immunocompromised patients, particularly those undergoing invasive procedures or long-term antibiotic therapy[7–9]. These examples underscore the diverse range of pathogens contributing to nosocomial infections and the importance of robust infection control measures in healthcare settings. In addition, the COVID-19 pandemic has brought heightened awareness of the importance of air quality control in hospital settings. The airborne transmission of the SARS-CoV-2 virus highlighted the role of indoor air quality in disease transmission. Conversely, this triggered healthcare facilities worldwide to reassess their ventilation systems and implement additional air purifying solutions, such as high-efficiency particulate air (HEPA) filters, ultraviolet germicidal irradiation (UVGI) systems, and other advanced air purification technologies.

On the other hand, the extensive use of disinfectants and sterilizers to prevent infections introduces a range of volatile organic compound VOCs into the hospital environments. These VOCs often include aldehyde compounds such as formaldehyde and glutaraldehyde, commonly used as disinfectants, sterilizers like ethylene oxide and various alcohols[10]. Also, Limonene-based cleaning products, frequently used for their antibacterial properties, might contribute to the VOC load in healthcare facilities[11]. Numerous studies have identified these compounds as significant sources of indoor air pollution in hospitals, highlighting their potential to impact IAQ and human health[12,13].

Furthermore, PM, especially those with a diameter smaller than 2.5 μm, has been linked to adverse health effects in hospital environments[14–16]. $PM_{2.5}$ particles are small enough to penetrate the respiratory system, potentially causing respiratory issues and exacerbating existing health conditions among patients, visitors, and healthcare workers. These findings underscore the importance of monitoring indoor air quality in healthcare facilities and implementing measures to mitigate the potential health risks associated with exposure to VOCs and PM pollutants.

Despite the importance of IAQ in hospitals, our understanding of the relationships between indoor air chemical and microbial pollution and acute health problems still needs to be improved. Therefore, the current study protocol aims to i) comprehensively characterize IAQ in various areas of the Hospital Clinic of Barcelona and ii) evaluate its potential associations with the health status of hospital staff, with a particular focus on acute health effects, and iii) provide the information needed to design innovative approaches for the IAQ risk assessment and prevention of nosocomial infections.

The hypothesis supporting this research are the following:

Pre-Hypothesis Work: General screening of the IAQ/OAQ potential pollutants and characterisation of the scenario (trends, seasonality, correlations, etc.)

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Hypothesis H1: Personnel exposed to a poor IAQ might be prone to suffer acute pulmonary/respiratory diseases.

Hypothesis H2: Developing integral interventions to monitor the presence of harmful biological agents in hospital environments might provide insights into preventing nosocomial infections.

2.1.2 IAQ Massive monitoring INBIOT sensors

The IAQ extensive monitoring initiative within the hospital setting (initiated on June 2023) involved the installation of 18 sensors strategically positioned in five distinct areas, offering a nuanced understanding of IAQ dynamics across diverse hospital settings. These areas are delineated as follows:

1. Common Spaces and Waiting Rooms (ES-HOS-01-001): Encompassing the hospital hall and two waiting rooms in the basement. This area is a representative section for general hospital traffic and visitor congregation.
2. General Hospitalization Ward (ES-HOS-01-002): This section incorporates IAQ monitoring in the nursing area, one medical office, and five individual rooms within the general hospitalization ward. Comprehensive data collection in this domain contributes to understanding the indoor air quality implications for both medical staff and inpatients.
3. Intensive Care Ward (ES-HOS-01-003): Encompassing the nursing area, one medical office, and two intensive care boxes. This monitoring aids in assessing air quality conditions with potential implications for the health outcomes of critically ill patients.
4. Outpatient Consultation Facilities (ES-HOS-01-004): IAQ monitoring extends to two waiting rooms designated for outpatient visitors in this area.
5. Pathological Anatomy Labs (ES-HOS-01-005): Focused IAQ monitoring in the pathological anatomy labs includes coverage of two distinct laboratory spaces. The sensitivity of laboratory environments necessitates precise monitoring to ensure the occupational health of laboratory personnel.

An additional sampling point has been considered for the comparative assessment of OAQ and IAQ, however there are no MICA sensors installed in this area: Outdoors (ES-HOS-01-000). MICA devices cannot be installed outdoors.

The installed sensors (MICA – InBIOT: https://www.inbiot.es/productos/dispositivos-mica/mica) provide continuous monitoring of temperature, relative humidity, total VOC (tVOC), formaldehyde concentration and PM concentration (1, 2.5, 4 and 10 µm of particle size).

As reported in D1.2 "Report on monitoring data", the average concentrations of indoor pollutants are within the legal limits stipulated by current legislation. A comprehensive and detailed comparative assessment of the monitored parameters across the five designated areas is presented in the subsequent sections.

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2.1.2.1 Temperature

Figure 1 displays a comparative assessment of the temperature across the five monitored areas. Throughout the monitored period, the average temperature was recorded at 24 °C. The monitoring encompassed warm and cold seasons, registering the highest temperature peak of 33.7 °C during the summer and the lowest temperature of 12.9 °C in winter. It is worth highlighting that the minimum and maximum temperatures were registered in the Hospital's Hall, where doors are always open. In contrast, the hospitalization areas, where the HVAC systems meticulously control temperature, exhibited less pronounced temperature fluctuations.

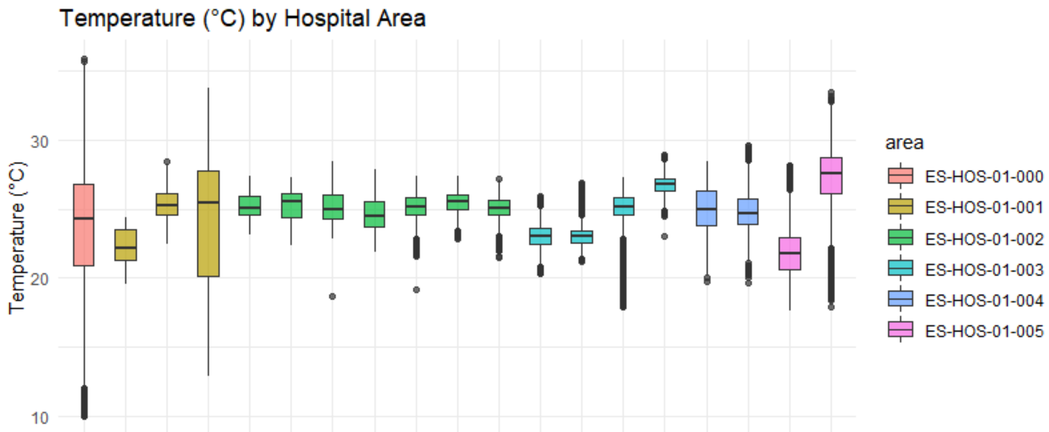

Figure 1. Comparative assessment of the measured temperature of the 18 sensors installed in the HCB (ES-HOS-01-001 to ES-HOS-01-005) over six months (Jul-Dec 2023). Outdoor (ES-HOS-01-000) values have been taken from myInbiot platform.

2.1.2.2 Relative Humidity

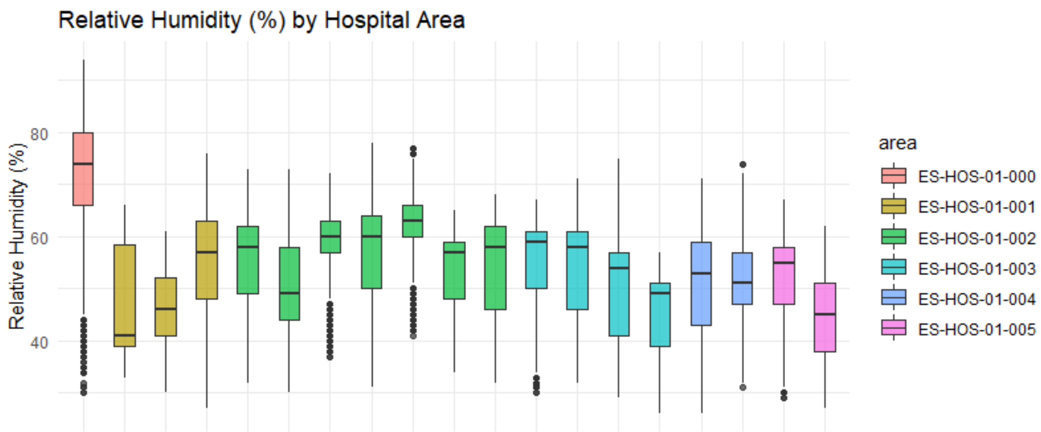

Figure 2. Comparative assessment of the measured relative humidity of the 18 sensors installed in the HCB (ES-HOS-01-001 to ES-HOS-01-005) over six months (Jul-Dec 2023). Outdoor (ES-HOS-01-000) values have been taken from myInbiot platform.

Figure 2 presents the evaluation of relative humidity across the five designated areas. Over the monitoring period, the mean relative humidity averaged 53%, with the highest peak recorded at 78% and the lowest at 26%. The conventional hospitalization area exhibited values marginally above the average, while the pathological anatomy labs reported values slightly below the mean. Indoors, relative humidity tends to be substantially lower than outdoors, where average

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values often exceed 75% of saturation. This discrepancy is particularly noticeable in Barcelona due to the city's proximity to the sea.

2.1.2.3 CO_2

Figure 3 presents the evaluation of CO_2 concentration across the five designated areas. The default value for CO_2 sensor calibration is set to 400 ppm, which represents the baseline concentration of CO_2 in outdoor air. Over the monitoring period, the mean CO_2 concentration averaged 535 ppm, with the highest peak recorded at 2,398 ppm in the conventional hospitalization area. Overall, the conventional hospitalization area exhibited values above the average. It is important to note that the average CO_2 measurements recorded in one of the waiting rooms of the outpatient consultations were 831 ppm. Despite being a room with high occupancy, this CO_2 level suggests a deviation from the expected norm. Elevated CO_2 concentrations can indicate both ventilation issues and potential sensor miscalibration. This prompts further exploration to identify and address the underlying cause.

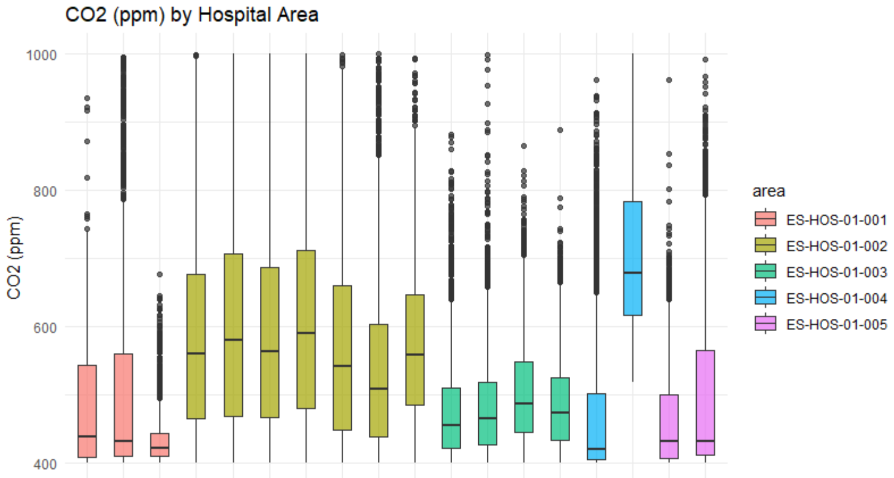

Figure 3. Comparative assessment of the measured CO_2 of the 18 sensors installed across the five monitored areas in the HCB over six months (Jul-Dec 2023).

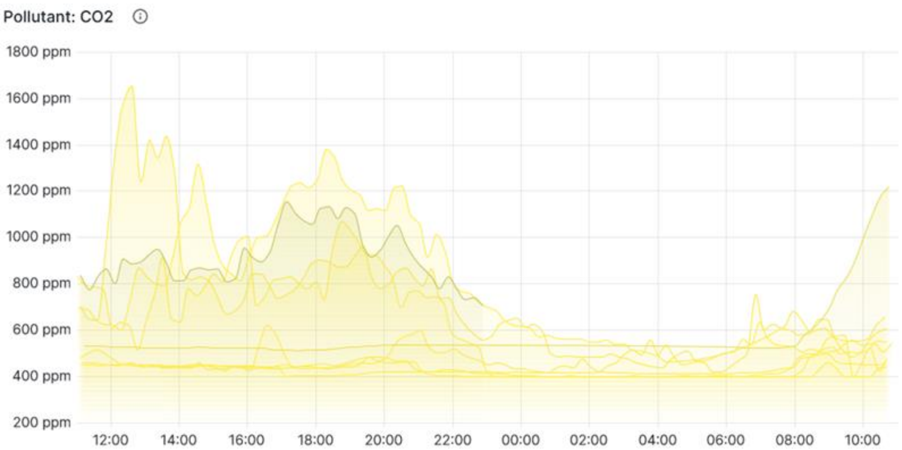

Figure 4. Snapshot of the graphical view of the CO_2 levels (ppm) during 24 hours in the HCB (generated with K-HEALTHinAIR platform).

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Figure 4 illustrates the variations in CO_2 levels within the hospital, showing a clear correlation with room occupancy (using time as indicator), with human activity as the primary factor influencing these fluctuations.

2.1.2.4 Formaldehyde

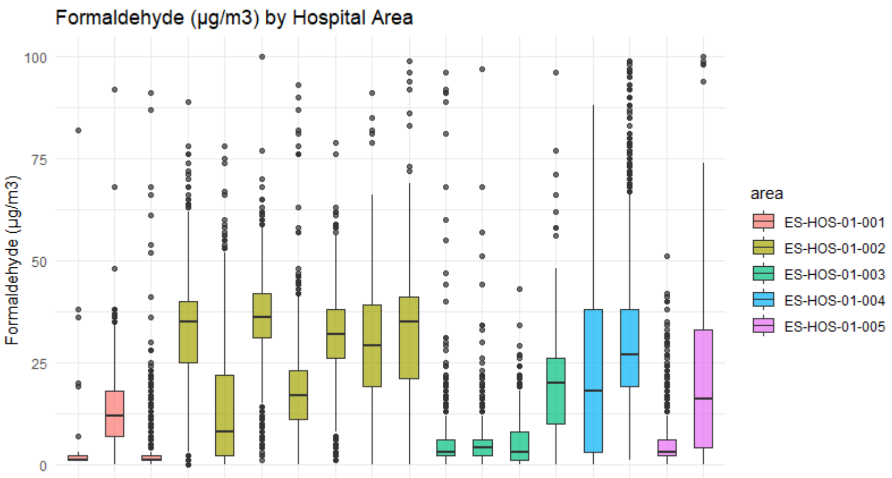

Figure 5. Comparative assessment of the measured formaldehyde of the 18 sensors installed across the five monitored areas in the HCB over six months (Jul-Dec 2023).

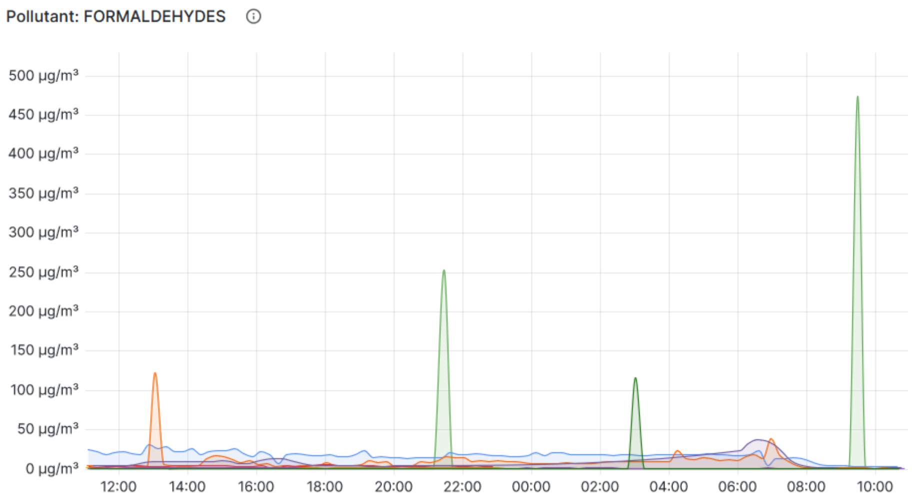

Figure 6. Snapshot of the graphical representation of the formaldehyde concentration (µg/m³) during 24 hours in the HCB (generated with K-HEALTHinAIR platform).

Figure 5 shows the assessment of formaldehyde concentrations across the five specified areas. Throughout the monitoring duration, the mean formaldehyde concentration maintained an average of 25 µg/m³, with the most notable peak reaching 6,214 µg/m³ in the intensive care ward. The conventional hospitalization area exhibited values slightly above the average. While the overall baseline of formaldehyde levels remained relatively low, the temporal analysis of the data series reveals periodic peaks indicative of elevated formaldehyde concentrations (Figure 6). These peaks might be associated with using formaldehyde-releasing cleaning and antiseptic products during sterilization procedures, particularly in critical areas such as

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operating rooms, patient rooms, or intensive care wards. This observation instigates further investigation to discern and rectify the underlying factors contributing to these periodic peaks.

2.1.2.5 TVOC

Figure 7 presents an overview of the assessment of tVOC concentrations across the specified five areas. Throughout the monitoring period, the average tVOC concentration maintained a level of 1,764 ppb. Notably, measurements in various areas exceeded the maximum detection rates of 60,000 ppb. Specifically, the intensive care unit exhibited consistently higher concentrations of tVOC. These elevated levels may be attributed to the use of antiseptic products during sterilization procedures. Further investigation is needed to establish correlations between tVOC peaks, daily cleaning routines, and the cleaning procedures following room deoccupation. Moreover, the results of the periodic VOC sampling through chromatography procedures will offer detailed information on the nature of these volatile compounds (Section 2.1.4).

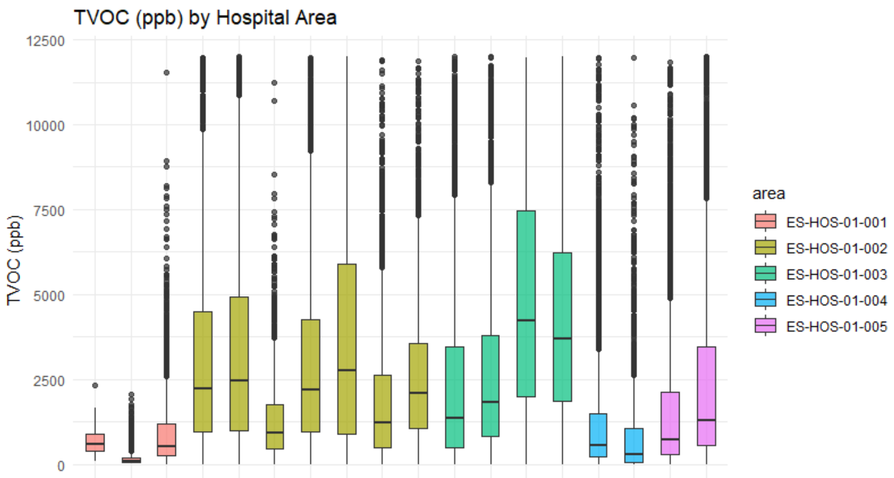

Figure 7. Comparative assessment of the measured tVOCs of the 18 sensors installed in the five monitored areas in the HCB over six months (Jul-Dec 2023).

2.1.2.6 PM

Figure 8 summarizes the assessment of PM concentrations with different diameters (1/2.5/4/10 µm) across the specified five areas.

Over the monitoring period, the average PM concentration remained consistent for all particles examined, ranging from 3.7 to 4.3 µg/m^3. Notably, the hospital hall exhibited the highest basal concentrations of PMs, primarily attributed to outdoor sources. On the other hand, the conventional hospitalization area experienced the highest peaks in PM concentrations. In contrast, the Intensive Care Ward showed negligible levels of PM concentration.

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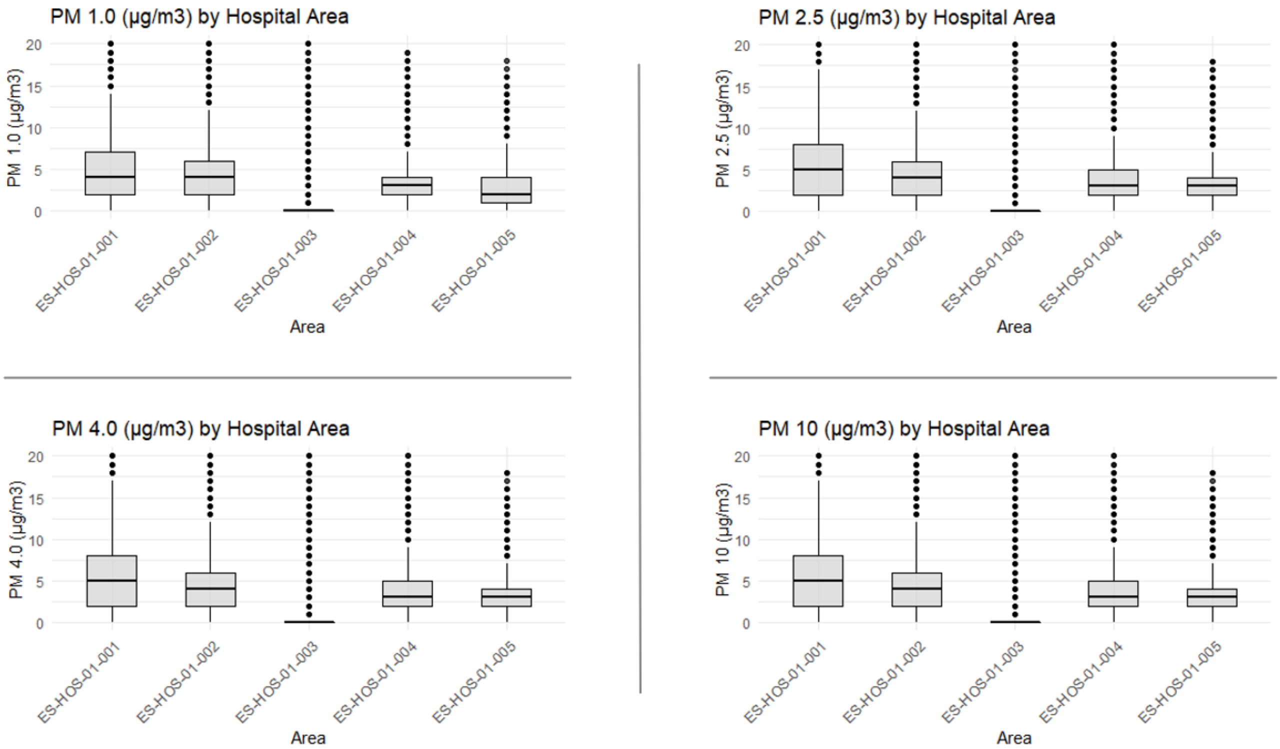

Figure 8. Comparative assessment of the measured PM 1/2.5/4/10 of the 18 sensors installed across the five monitored areas in the HCB over six months (Jul-Dec 2023).

Given the homogeneous distribution of PM across different particle sizes, Figure 9 exclusively focuses on the concentrations of $PM_{2.5}$.

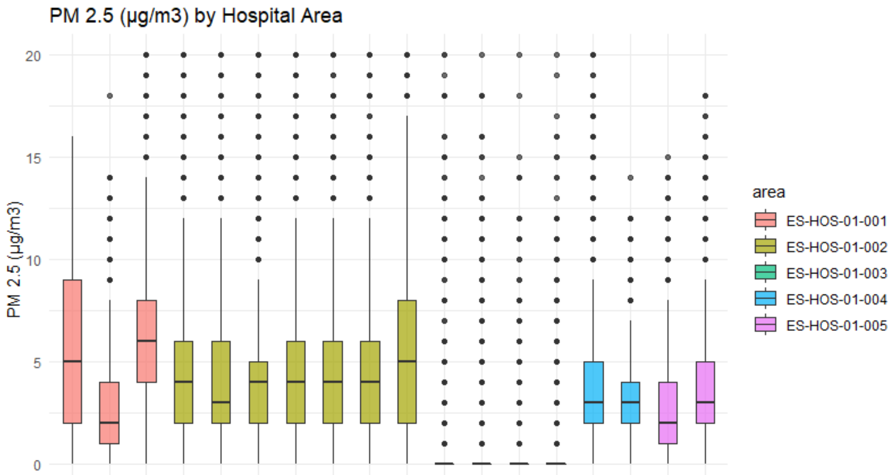

Figure 9. Comparative assessment of the measured $PM_{2.5}$ of the 18 sensors installed across the five monitored areas in the HCB over six months (Jul-Dec 2023).

Figure 9 reveals comparable readings among the sensors installed across the hospital area, except for those in the intensive care ward, where air undergoes meticulous filtration processes and consistently exhibit lower average levels, and the areas closer to the main gates, such as the hospital hall and the waiting room of the blood extraction area, consistently exhibit higher average values. This observation strengthens the notion of outdoor sources for these pollutants

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infiltrating indoor spaces, such as vehicular emissions, construction activities, or other outdoor sources brought in by foot traffic and natural air exchange. This is an important fact because it allows for the assessment that one of the vectors proposed in the transmission of certain viruses and bacteria could be particulate matter of various natures[17–19].

A relevant aspect to mention here is that the PM sensors in air quality monitors are also capable of counting aerosols. This means that they are not only sensitive to solid particles but also to liquid droplets that can be dispersed indoors, for example, through the use of spray cleaning products.

2.1.3 OAQ modelled data from AerisWeather

As previously mentioned, the quality of outdoor air is a factor that also influences many indoor environmental scenarios. As shown in Deliverable D1.2, information regarding outdoor air quality has been collected on the platform since the start of monitoring. However, functionalities of the platform that enable the analysis of this information and, more importantly, facilitate clear comparisons between indoor and outdoor environments to identify potential correlations are still being developed.

The analysis of outdoor air quality information around the hospital will begin by evaluating the overall profiles for the period from June to December 2023. This approach reveals the range of values for each parameter and also allows for the assessment of which parameters are closer to the recommended limits and should be considered. Below are the profiles of temperature and relative humidity, as well as the concentrations of CO, O_3, $PM_{2.5}$, and NO_2.

2.1.3.1 Temperature and relative humidity

Both the temperature and relative humidity outdoors are within normal ranges for the city of Barcelona. Temperatures are mild, decreasing as summer transitions to autumn, while relative humidity remains relatively high, as expected for a coastal location.

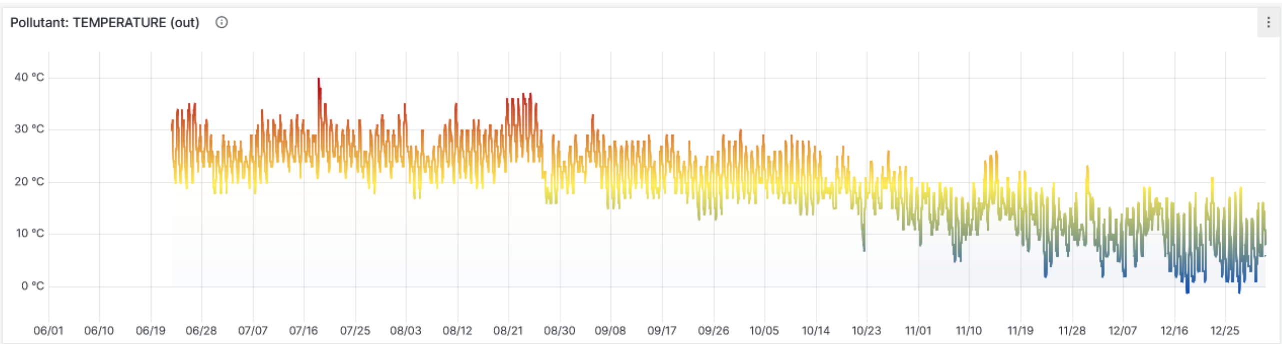

Figure 10. Outdoor temperature data provided by Aerisweather platform in the HCB area between June and December 2023 (generated with K-HEALTHinAIR platform).

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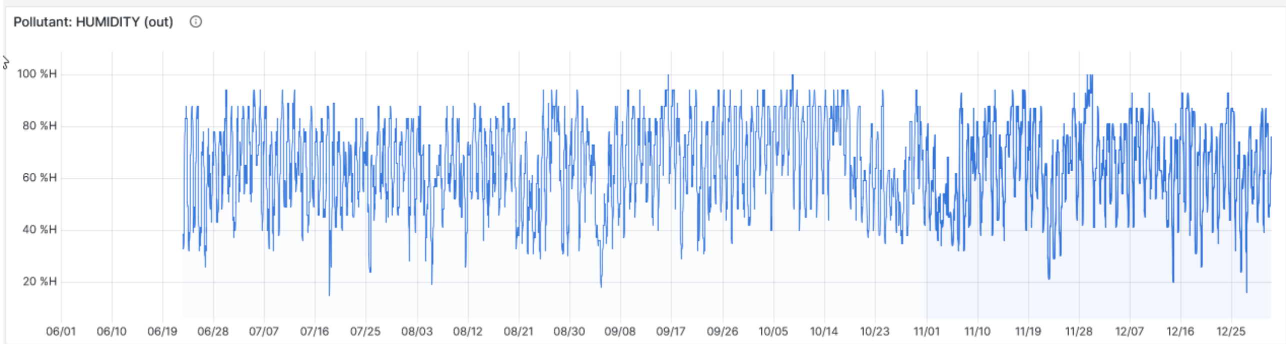

Figure 11. Outdoor relative humidity data provided by Aerisweather platform in the HCB area between June and December 2023 (generated with K-HEALTHinAIR platform).

2.1.3.2 CO

Regarding the concentration of CO in the Figure 12, it can be observed that the values recorded for the study period never exceed 3.5 ppb and rarely exceed 1 ppb. Considering that European legislation (Directive 2008/50/EC of the European Parliament and of the Council, of 21 May 2008, on ambient air quality and cleaner air for Europe[1]) establishes that average values over 8 hours outdoors should not exceed 10 mg/m^3 (equivalent to 8 ppb), it can be generally stated that this parameter does not seem to pose problems indoors at the hospital. Additionally, OAQ data has been obtained from the Catalonia Authority service for the station in the city of Barcelona closer to the pilot location, *Barcelona Eixample*[2]. Figure 13 corroborates the low levels of CO in the city. However, some differences between both sources are understandable considering the different location between pilot site and station location, and that Aerisweather platform models the values and some uncertainty in calculation.

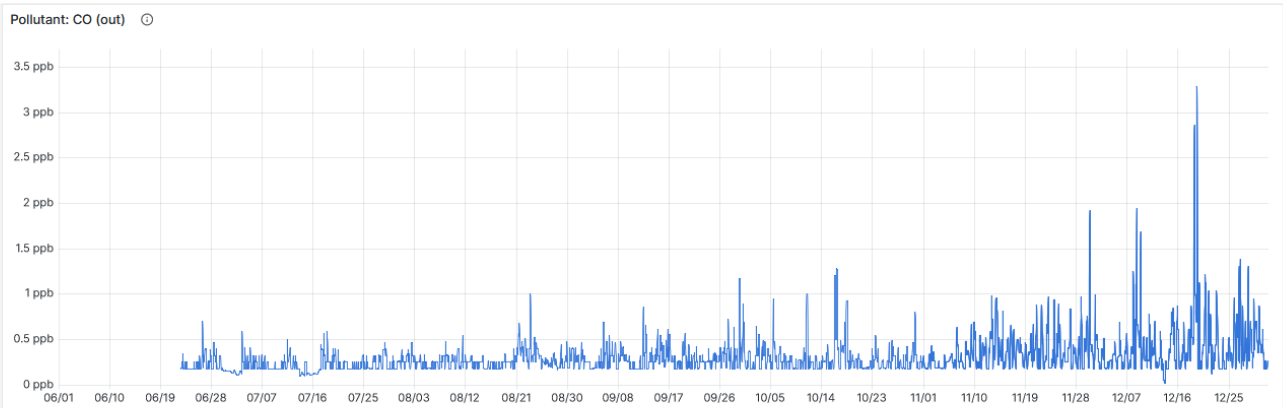

Figure 12. Outdoor carbon monoxide data provided by Aerisweather platform in the HCB area between June and December 2023 (generated with K-HEALTHinAIR platform).

[1] https://eur-lex.europa.eu/eli/dir/2008/50/oj/por

[2] https://mediambient.gencat.cat/es/05_ambits_dactuacio/atmosfera/qualitat_de_laire/vols-saber-que-respires/descarrega-de-dades/descarrega-dades-automatiques/index.html

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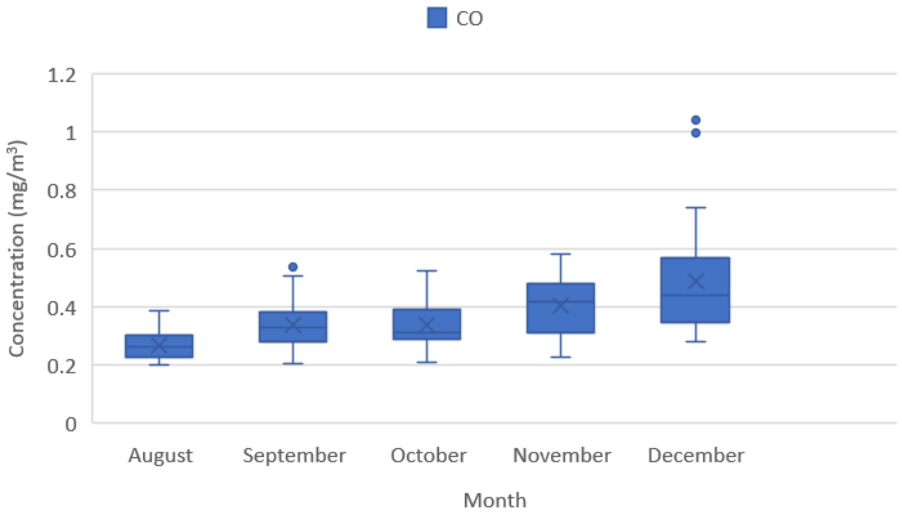

Figure 13. Monthly (Aug-Dec 2023) evolution summary of CO concentration in Barcelona Eixample air quality station.

2.1.3.3 O_3

The concentration of tropospheric ozone exhibits significant variability both seasonally and daily. Typically, during the summer months (when there are higher concentrations of VOC and, especially, increased solar UV radiation), O_3 concentrations are higher compared to autumn or winter. Additionally, ozone levels typically increase with increasing solar irradiation.

The values collected for the outdoor area of the hospital (see Figure 14) range from nearly zero to some concentration peaks of more than 40 µg/m^3. The most restrictive limit levels are those recommended by WHO. They recommend not exceeding an average value of 60 µg/m^3 over six months and not exceeding 100 µg/m^3 as an average value over 8 hours. As can be seen, so far, the six-month average values have not been exceeded. This will be carried out when the platform allows for this functionality and it will be focused on the analysis in the outpatient's scenario when values do not over pass the recommended ones.

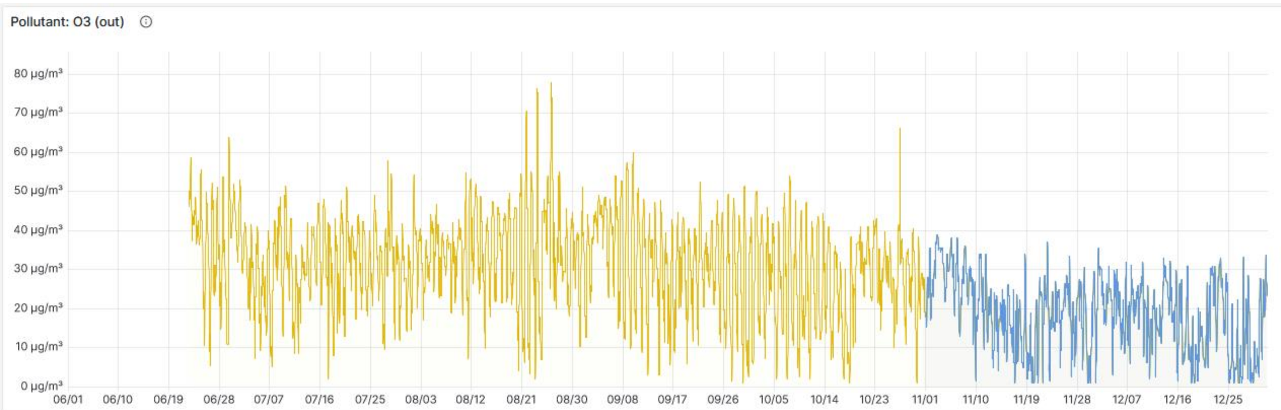

Figure 14. Outdoor ozone concentration data provided by Aerisweather platform in the HCB area between June and December 2023 (generated with K-HEALTHinAIR platform).

As previously for CO, an additional study has been done with data provide by *Barcelona Eixample* city station for ozone. Figure 15 shows the monthly evolution of O_3, $PM_{2.5}$ and NO_2

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concentrations. Figure 15 also includes the other two parameters that will be commented below. As it can be seen, ozone levels are similar than the ones provided by the Aerisweather platform.

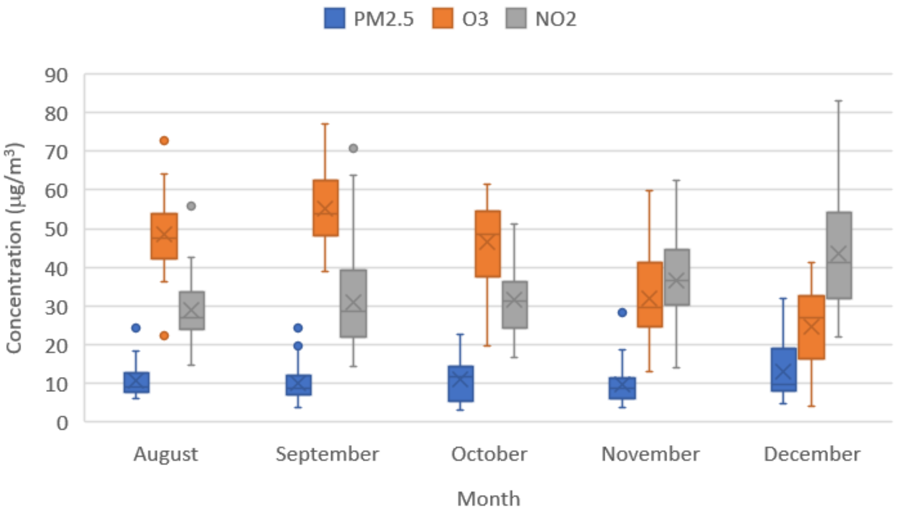

Figure 15. Monthly (Aug-Dec 2023) evolution summary of O_3, $PM_{2.5}$ and NO_2 concentrations in Barcelona Eixample air quality station.

2.1.3.4 PM

Regarding the concentration of particulate matter, the profiles collected range from nearly zero to some notable peaks. Based on the general trend, it can be visually established that the average value may be close to 25 µg/m^3, $PM_{2.5}$, especially during the summer season.

These values are relevant because they exceed the recommended values by the World Health Organization (5 µg/m^3 annual average and 15 µg/m^3 average over 24 hours, see Table 2), which are the most stringent, but they are also in the vicinity of those set by European legislation (Directive 2008/50/EC of the European Parliament and of the Council, of 21 May 2008, on ambient air quality and cleaner air for Europe) for $PM_{2.5}$ at 25 µg/m^3 as average of 24 hours.

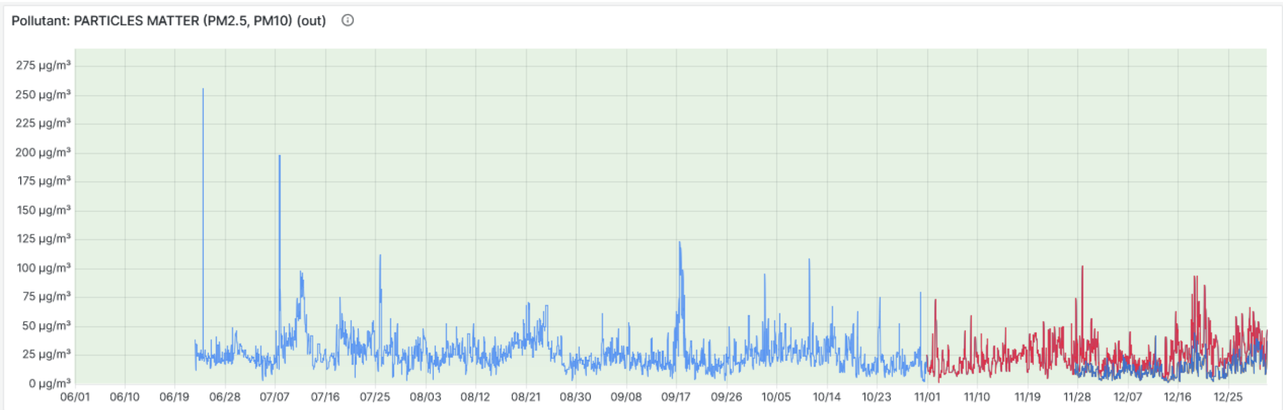

Figure 16. Outdoor PM_{10} and $PM_{2.5}$ concentration data provided by Aerisweather platform in the HCB area between June and December 2023 (generated with K-HEALTHinAIR platform).

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When the platform allows, the number of exceedances of the aforementioned values in the area will be studied, and the degree of influence this may have on the values recorded inside the building will be examined. A preliminary exploratory analysis will be further presented with the currently available information.

As an additional source of information, Urban $PM_{2.5}$ Atlas, Air Quality in European Cities has been consulted for the city of Barcelona[20].

As shown in the Figure 16, the annual mean values for the sampled stations range between 10 and 20 µg/m^3, also in line with the information gathered by the *Barcelona Eixample* city station showed in Figure 17, which are not far from the values mentioned earlier. What is interesting to assess is the origin of the particles. Residential sources contribute the most, followed by traffic. Additionally, and somewhat unusually, there is a significant contribution from maritime traffic, almost at the level of road traffic.

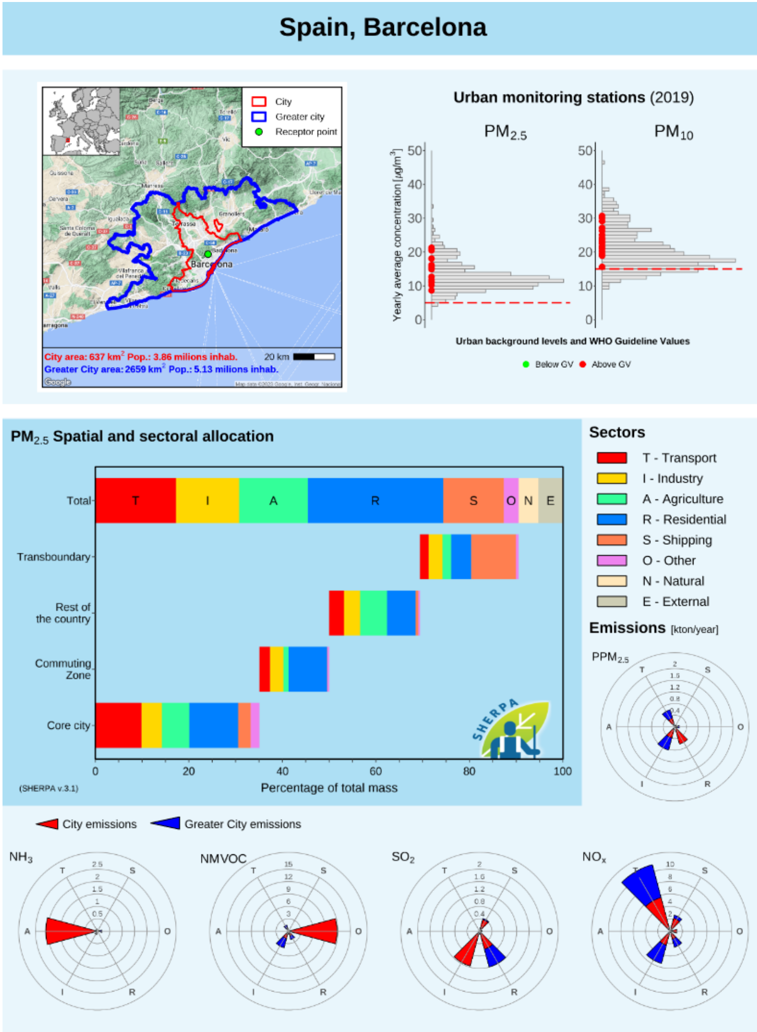

Figure 17. $PM_{2.5}$ pollution in Barcelona (Spain). Urban PM2.5 Atlas, Air Quality in European Cities, 2023 Report p. 138[20].

2.1.3.5 NO_2

Regarding NO_2 in the Figure 18, the profile of concentrations collected in Barcelona from June to December 2023 can be seen. As can be observed, there are significant daily variations in concentration that respond to the typical profiles usually present in urban areas. At the beginning of the day, there is a peak due to the first rush hour of traffic, which then subsides until the second rush hour at the end of the day when another peak, usually of lower intensity, occurs. Generally, lower values are registered on weekends due to a minor traffic intensity.

Based on the graph and without having the data to perform appropriate statistical calculations, the average value seems to be between 10 and 15 ppb. These values are slightly lower than data provided by the *Barcelona Eixample* city station. However, as commented before, differences between both sources are understandable considering the different location and that Aerisweather platform models the values and some uncertainty in calculation. Considering that the legal values established by the Directive are 40 as an annual average and not exceeding 18

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exceedances of 200 as an hourly average, it appears that currently, the area around the hospital location complies with the legislation in this regard. However, considering the recommendations suggested by the WHO (10 µg/m^3 annual average, 25 µg/m^3 average over 24 hours, and 200 µg/m^3 as an hourly average), it would be necessary to consider whether the levels of outdoor air infiltration into the hospital are high.

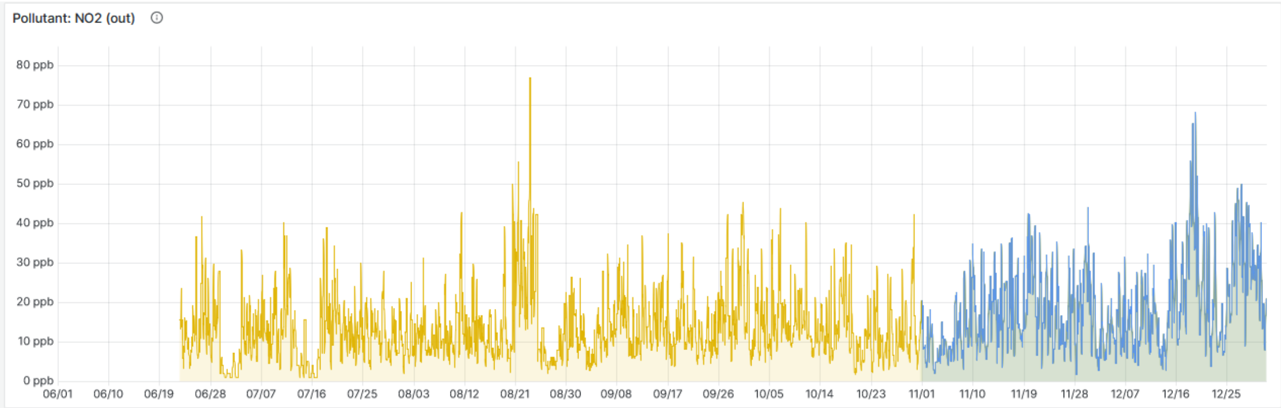

Figure 18. Outdoor NO_2 concentration data provided by Aerisweather platform in the HCB area between June and December 2023 (generated with K-HEALTHinAIR platform).

2.1.3.6 Comparison indoors versus outdoors

Additionally, as an auxiliary study to be completed later when all the planned functionalities for the platform are developed, the profiles of various common parameters both indoors and outdoors have been graphically evaluated.

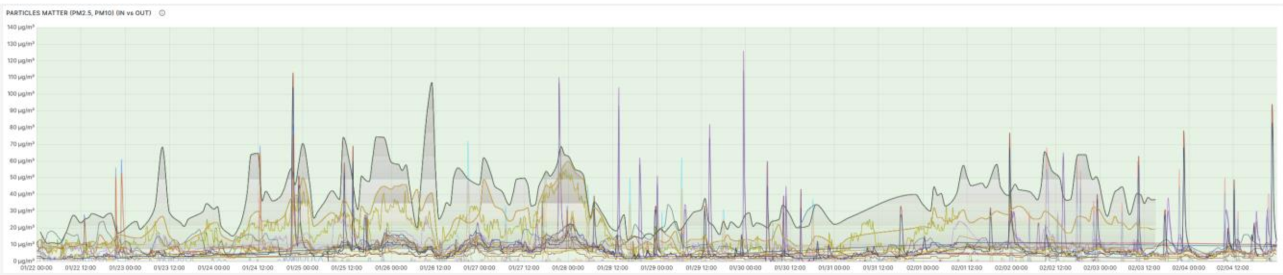

Figure 19. Evolution of PM (1, 2.5, 10) concentration outdoors and indoors in the HCB between 22/01/24 and 04/02/24 (generated with K-HEALTHinAIR platform).

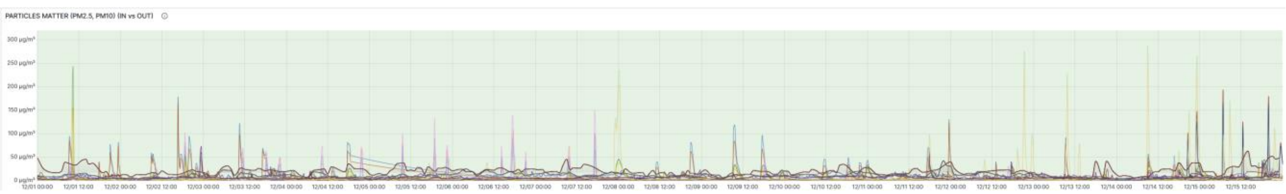

Figure 20. Evolution of PM (1, 2.5, 10) concentration outdoors and indoors in the HCB between 01/12/23 and 15/12/23 (generated with K-HEALTHinAIR platform).

After this preliminary analysis of particulate matter, no correlations indicating significant infiltration of this contaminant from outdoors to indoors were found. For example, two-week periods are shown here. The thicker line corresponds to outdoor values, while the thinner lines represent indoor areas (specifically, in this graph, sensors in the entrance hall). In the first period

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(Figure 19), PM concentrations outdoors are higher than indoors and follow different trends. In the second period (Figure 20), there is also no clear correlation, and multiple indoor peaks exceeding 250 µg/m^3 are recorded.

This is only, as mentioned, a preliminary study. A more in-depth analysis will be conducted in the subsequent phase when the platform allows for correlation between recorded variables. Additionally, graphical evaluations of the differences between indoor and outdoor temperatures and relative humidity have been conducted. No graphs are shown here from this analysis as it is not considered necessary to demonstrate that outdoor temperatures and relative humidity undergo much greater daily variations than indoor ones, which are much more controlled.

2.1.4 VOCs sampling

The VOCs sampling was initiated in June 2023, and periodically repeated in a monthly basis. The analysis allowed the quantification of 89 chemical compounds, among which 23 were not detected in any sample or location and omitted from the report.

Particularly, Figure 21 depicts the average concentrations of indoor VOCs found in the hospital, regardless of the sampling date or the area, is it to note that only those chemical compounds with a concentration higher than 1 µg/m^3 have been displayed. The main contributor of VOC pollution was chloroform exhibiting the highest indoor mean concentration of 4,068.54 µg/m^3. Cyclopentane, ethylene glycol butyl ether, nonanal, n-hexane, o-xylene, and m-xylene & p-xylene also show notable indoor concentrations. None of the average values reported exceed the recommended thresholds issued by the regulatory bodies.

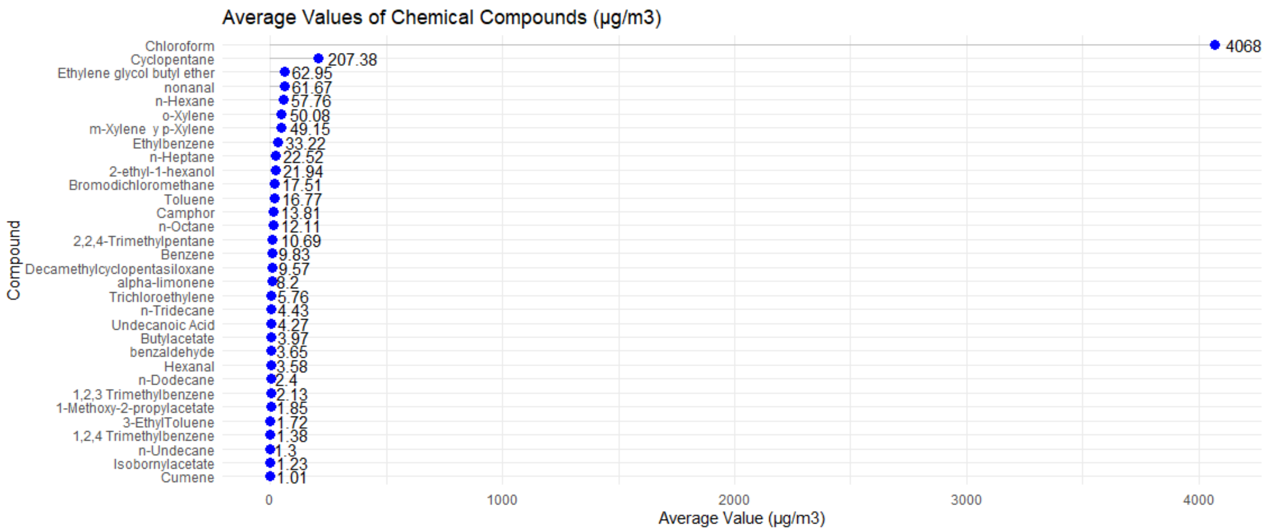

Figure 21. Average concentrations of indoor VOCs (µg/m^3) found in the HCB, regardless of the sampling date or the area.

Figure 22 provides a visual representation of the relative concentrations of the top 5 VOCs encountered in different hospital areas, displaying their average concentrations. For instance, outdoors (ES-HOS-01-000) chloroform dominates with a significantly high average value and frequency, followed by cyclopentane, n-hexane, bromodichloromethane, and n-heptane.

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Similarly, the remaining indoor areas exhibit varying compositions of VOCs, with chloroform followed in the second term by cyclopentane consistently appearing as a dominant pollutant. The remaining common VOCs are the following bromodichloromethane, n-heptane, n-hexane, nonanal, 2-ethyl-1-hexanol, ethylene glycol butyl ether, ethylbenzene, m-xylene, p-xylene, o-xylene.

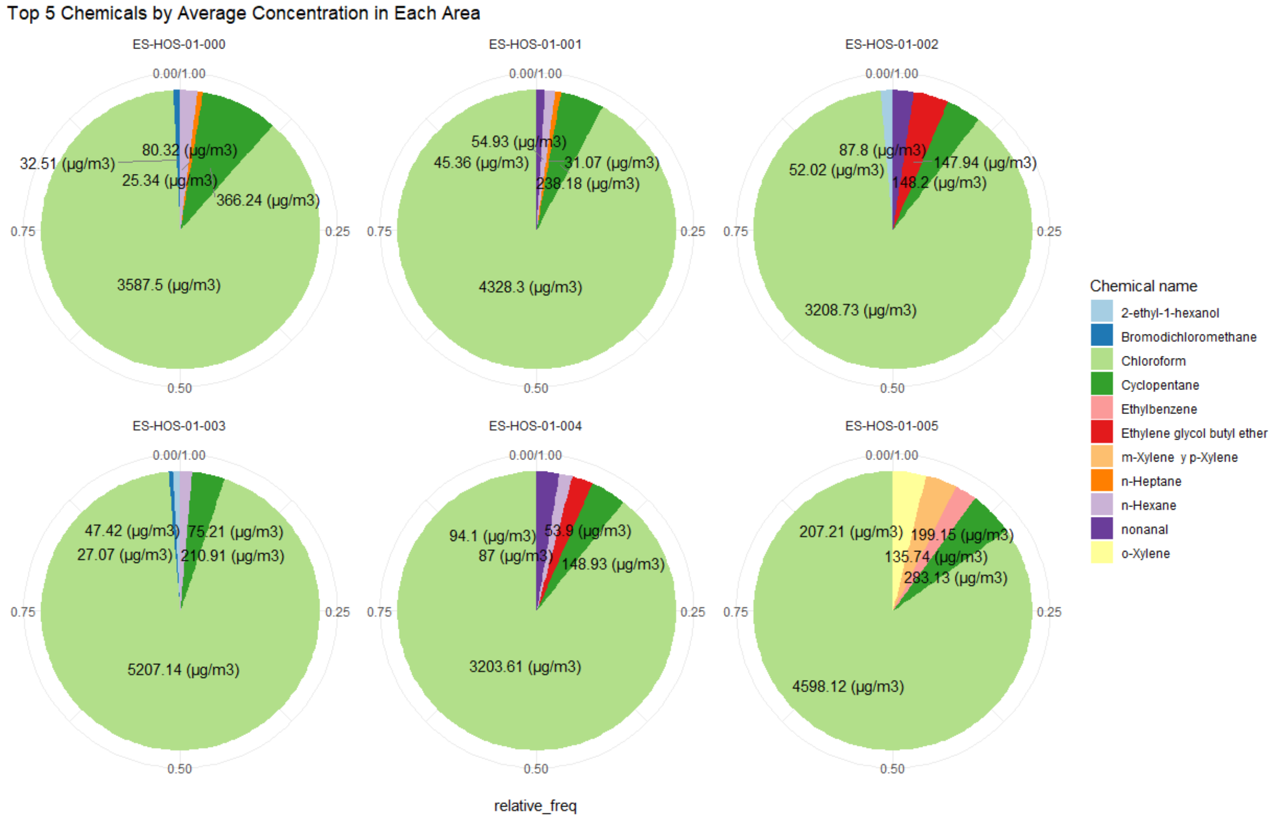

Figure 22. Top 5 VOCs found in the different HCB areas.

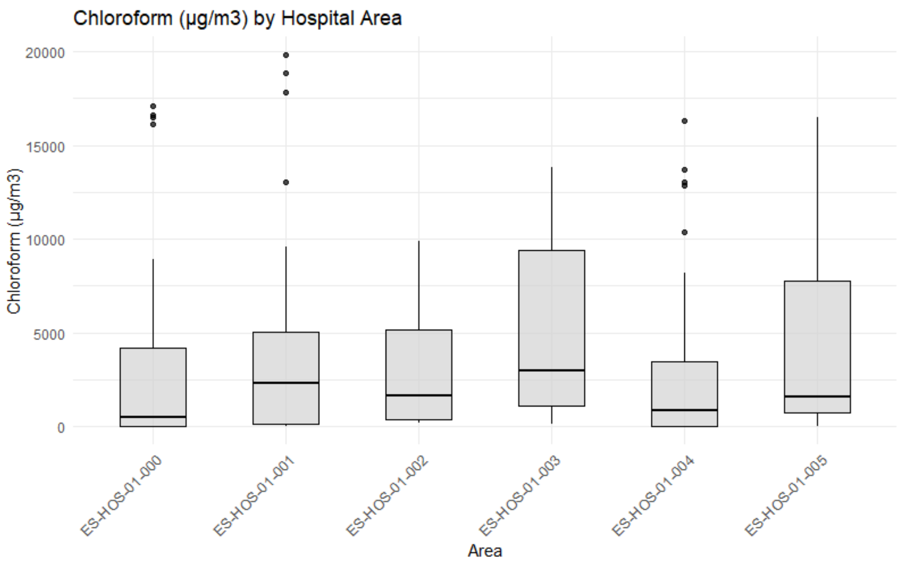

Figure 23. Comparative assessment of the measured Chloroform across the five sampling points distributed across the HCB (ES-HOS-01-001 to ES-HOS-01-005) and outdoors (ES-HOS-01-000) during seven months (Jun-Dec 2023).

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Figure 23 illustrates the assessment of chloroform concentrations across the five specified areas. Throughout the monitoring duration, the mean chloroform concentration maintained an average of 4,068.54 μg/m^3, with the most notable peak reaching 19,795 μg/m^3 in the hospital hall. The intensive care area exhibited values slightly above the average (5,207 μg/m^3). While the overall baseline chloroform levels remained below the threshold of 10,000 μg/m^3, it is noted that a few observations exceed the specified limits.

Chloroform pollution in hospital settings can occur due to various factors, including using certain medical supplies and equipment, cleaning products, disinfection procedures, and certain building materials. Chloroform is a VOC that can be released into the air through disinfection with chlorine-containing products, using chlorinated solvents for cleaning, or off-gassing from materials like PVC.

In hospitals, chloroform exposure may be particularly concerning due to its potential health effects. Chronic exposure to chloroform has been associated with respiratory irritation, liver and kidney damage, and even carcinogenic effects in animal studies[21–23]. Therefore, is crucial to monitor and manage chloroform levels to ensure the health and safety of patients, staff, and visitors.

The observed levels of chloroform in the indoor air samples are of significant concern due to their potential health effects. Therefore, it is imperative to conduct further investigations to identify the sources of chloroform pollution. One noteworthy observation is the substantial increase in chloroform concentrations during and after the sampling conducted on October 23 (Figure 24), across various areas including the main hospital building, outpatient consultation building, and outdoors. This consistent rise in chloroform levels across different spaces raises the possibility of exogenous contamination of the samples. As such, it is essential to conduct additional quality checks to ensure the validity and reliability of these results.

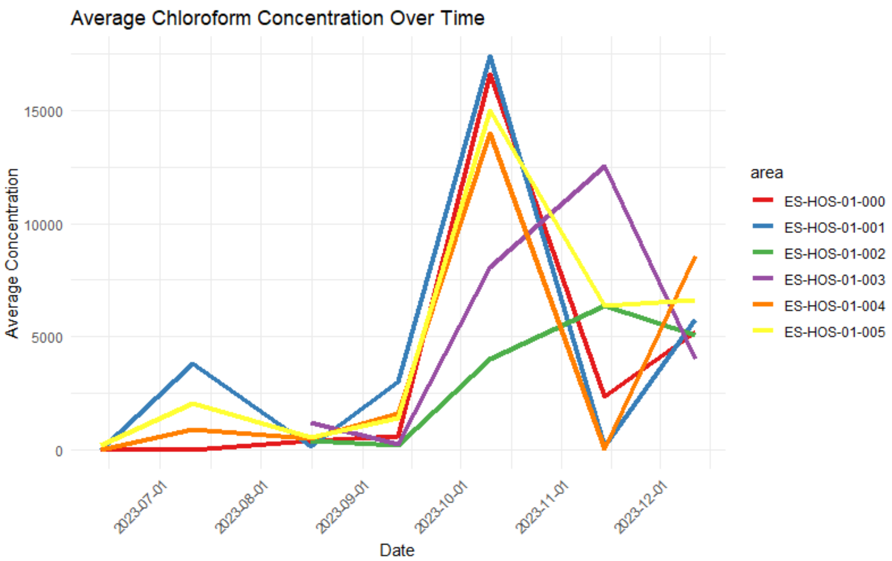

Figure 24. Average chloroform concentration per date across the six sampling points distributed across the HCB during seven months (Jun-Dec 2023).

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2.1.5 Formaldehyde sampling

Collecting aldehydes and ketones, particularly formaldehyde, from indoor air was performed monthly (starting June 2023). The compounds sampled and analysed include 2-butanone, acetaldehyde, acetone, benzaldehyde, butyraldehyde, crotonaldehyde, formaldehyde, hexaldehyde, m-tolualdehyde, methacrolein, propynaldehyde, and valeraldehyde

Indoor concentrations generally exhibit higher mean and median values than outdoor levels for most compounds, indicating indoor nature of these pollutants. Formaldehyde displays particularly notable indoor concentrations with a mean of 48.62 µg/m^3. Acetone exhibits substantially higher mean and median values in indoor air, with the mean concentration reaching 486.8 µg/m^3, suggesting potential indoor acetone sources contributing to elevated levels.

Figure 25 and Figure 26 depict the distribution of the primary pollutants analysed, specifically focusing on Acetaldehyde, Acetone, and Formaldehyde. Notably, the elevated average acetone values observed in the hospital can be attributed to the presence of acetone in pathological anatomy labs. Acetone serves multiple purposes in labs. Firstly, it acts as a fixative to preserve tissue samples for histological examination, maintaining their structure and integrity while preventing degradation and decomposition. Additionally, acetone serves as a dehydrating agent, removing water from tissue samples before embedding them in paraffin wax for sectioning, which is essential to prevent artefacts and ensure optimal tissue quality for microscopy. Furthermore, acetone's solvent properties make it valuable for cleaning laboratory equipment and glassware, effectively removing residues and contaminants to maintain a clean and sterile working environment.

It is worth mentioning that despite these elevated levels, the exposed concentrations remain well below the legal limits set for workspaces.

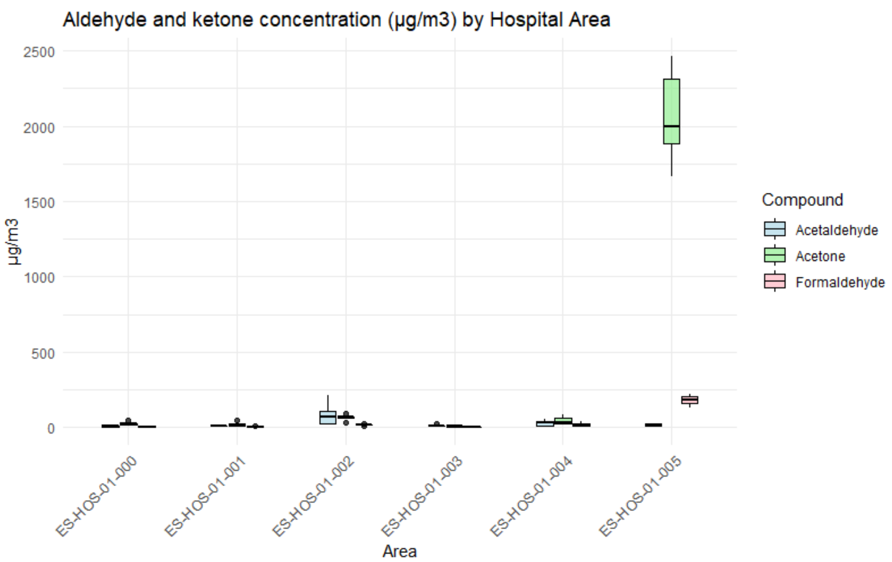

Figure 25. Comparative assessment of Acetaldehyde, Acetone, and Formaldehyde across the five sampling points distributed across the HCB (ES-HOS-01-001 to ES-HOS-01-005) and outdoors (ES-HOS-01-000) over eight months (Jul 2023 - Jan 2024).

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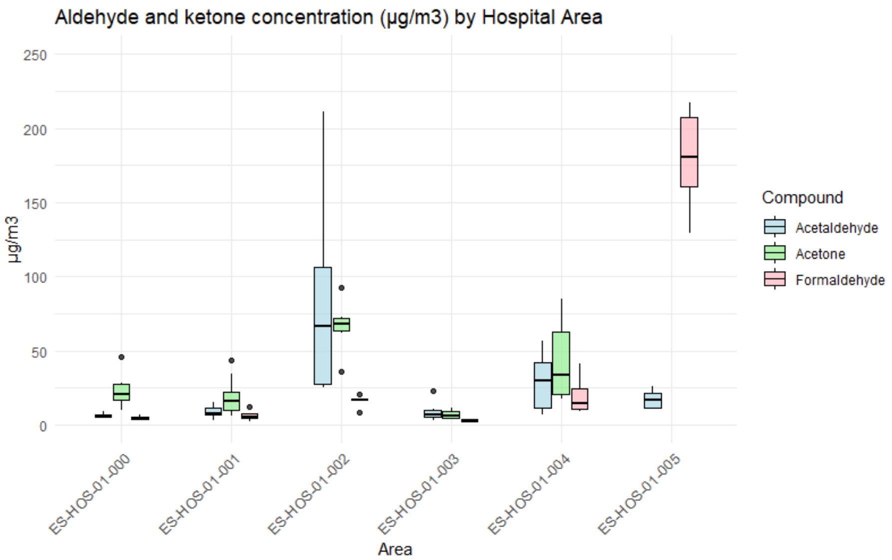

Figure 26. Comparative assessment of Acetaldehyde, Acetone, and Formaldehyde across the five sampling points distributed across the HCB (ES-HOS-01-001 to ES-HOS-01-005) and outdoors (ES-HOS-01-000) over eight months (Jul 2023 - Jan 2024). The visualization focuses on concentrations below 250 µg/m^3, providing a detailed examination of the variations in pollutant levels across different locations.

2.1.6 PM sampling

Sampling PM was performed monthly (starting June 2023), including various particle size categories ranging from $PM_{0.3}$ to PM_{10}. While the concentrations remain within the legal limits some particular behaviors are observed.

Figure 27 summarizes the assessment of PM concentrations with different diameters (0.3/0.5/1/2/5/10) across the specified five areas. The comparison between PM monitoring with MICA sensors and discrete monitoring presents intrinsic differences that hinder direct comparison. These differences include the variables used, the precision of the instruments, and the used of discrete measures, which are more susceptible to sampling biases in non-stationary environments. Nonetheless, despite these disparities, similar trends are observed. Notably, the hospital hall exhibited the highest basal concentrations of PMs, primarily attributed to outdoor sources. In contrast, the Intensive Care Ward showed negligible levels of PM concentration.

In particular, PM concentrations are generally higher outdoors and in areas closer to the main entrances. However, notable concentrations of ultrafine particles (0.3, 0.5, and 1 µm) are present in some indoor settings, such as the conventional hospitalization area, whereas they are substantially lower in other indoor environments. This discrepancy suggests the existence of additional sources of indoor pollution rather than outdoor PM penetration, warranting further investigation to comprehend these dynamics fully.

Conversely, concentrations of larger particles (2, 5 and 10 µm). are significantly greater nearer to main entrances, indicative of their outdoor origins. However, it is noteworthy that higher concentrations of PMs are observed in the hospital hall compared to outdoor measurements. Several factors may influence this observation, including the hospital hall's proximity to traffic on Villarroel Street, where the main entrance is located. In contrast, the outdoor sampling site is

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situated in the hospital's pedestrian-only backyard. Conversely, the movement of people within the hospital hall may resuspend outdoor pollution particles, exacerbating indoor exposure levels.

Given these complexities, further research is essential to assess indoor PM pollution's sources and dynamics comprehensively. Investigating traffic patterns, human activities, and building ventilation systems can provide valuable insights into mitigating indoor air pollution. In this regard, the air filtering system installed in the intensive care unit provides promising prospects.

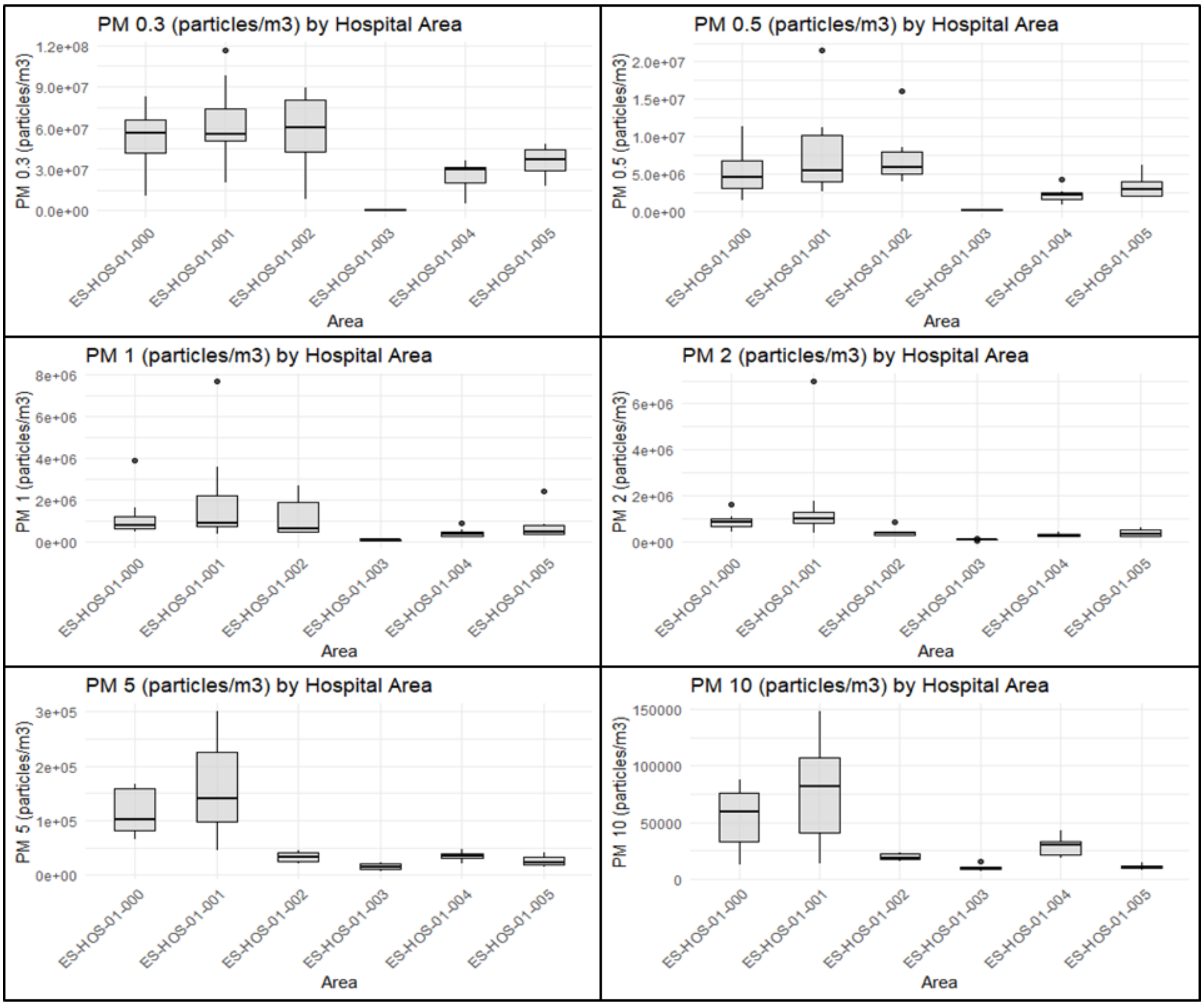

Figure 27. Comparative assessment of the PM 0.3/0.5/1/2/5/10 across the five sampling points distributed across the hospital (ES-HOS-01-001 to ES-HOS-01-005) and outdoors (ES-HOS-01-000) over eight months (Jul 2023 - Jan 2024).

2.1.7 Microbiome sampling

Airborne samples to characterize fungal and bacterial microbiomes within the hospital were collected during a bimonthly sampling campaign taking three replicates at each sampling point. A total of three samplings were conducted (i.e., September and November 2023 and January 2024). A total of 36 samples have been collected and the corresponding DNA extracted. DNA obtained is now being sequenced. The comprehensive analysis of fungal and bacterial microbiomes cannot be reported yet until the sequencing step is complete. Therefore, the full assessment of biological pollutants is pending finalization as the sequencing process is still ongoing.

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In parallel, colony-forming unit counts of bacteria and fungi were conducted during December, January, and February. Figure 28 and Figure 29 display the results of quantifying airborne microbial agents in the different hospital areas, expressed as colony-forming unit counts per 1000 liters for bacteria and fungi, respectively. The values established by UNE Standard, 171330 on indoor environmental quality were taken as reference thresholds for its analysis. Overall, neither fungi nor bacteria exceeded the established limits. Additionally, the analysis revealed no discernible trends in colony-forming unit counts concerning temperature or time of day. However, there were isolated instances where the threshold for fungi was surpassed during one sampling event in the waiting room of outpatient clinics, as well as in the hospital hall and outdoor areas, indicating a possible outdoor origin of fungi presence within the sampled areas. It is essential to highlight that substantially lower levels of biological pollutants were encountered in the hospitalization areas, both in conventional hospitalization and intensive care wards. However, it is important to note that only three sampling events were conducted, and it may be premature to draw definitive conclusions at this stage.

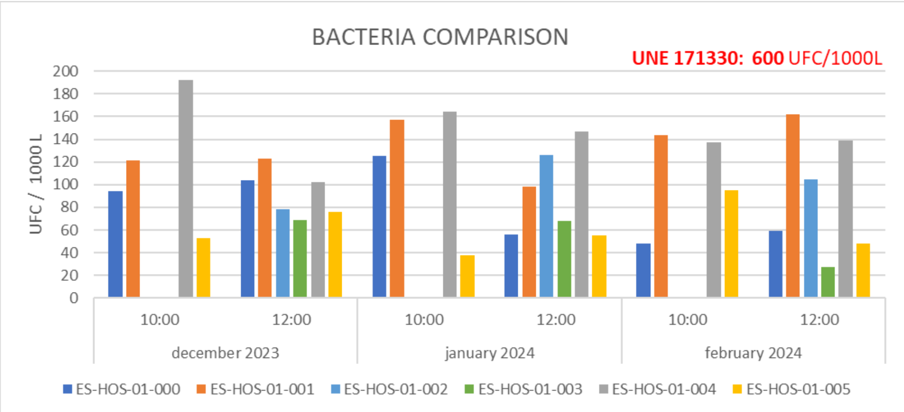

Figure 28. Comparative assessment of the quantification of bacteria UFCs across the five sampling points distributed across the HCB (ES-HOS-01-001 to ES-HOS-01-005) and outdoors (ES-HOS-01-000) over three months (Dec 2023 - Feb 2024).

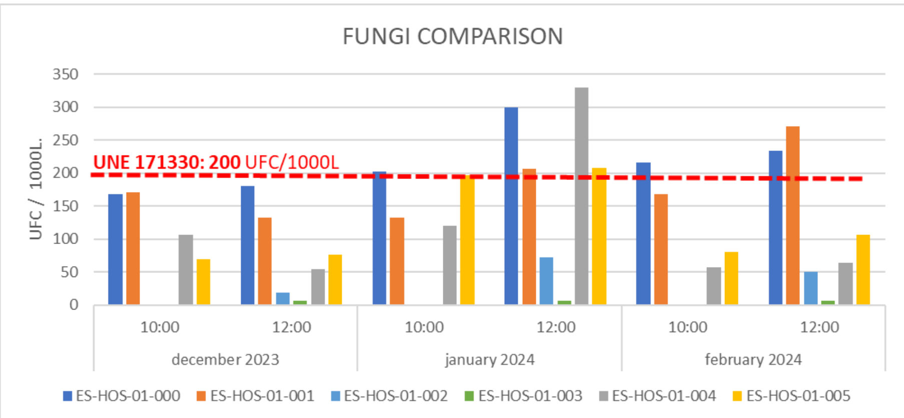

Figure 29. Comparative assessment of the quantification of fungi UFCs across the five sampling points distributed across the HCB (ES-HOS-01-001 to ES-HOS-01-005) and outdoors (ES-HOS-01-000) over three months (Dec 2023 - Feb 2024).

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2.1.8 Questionnaires

Once the 200-outpatient cohort is recruited, the recruitment and follow-up of 20 hospital workers will commence in collaboration with the hospital's Occupational Health Department. Consequently, assessing the health outcomes of the 20 candidates volunteering to participate through health questionnaires has yet to be conducted.

2.1.9 Conclusions

Basal concentrations of indoor pollutants:

1. The preliminary analysis indicates that basal concentrations of indoor pollutants in the hospital setting are low.
2. These concentrations fall within the non-harmful ranges set by regulatory bodies, suggesting overall good indoor air quality compliance.

Time series analysis of VOCs:

1. Recurrent acute peaks of liberation of aldehydes and other VOCs have been identified through time series analysis.
2. Characterizing these outliers may contribute to identifying possible determinants and sources of IAQ health impacts.
3. Compounds such as formaldehyde, acetone, and chloroform emerge as potential candidates for further investigation due to their elevated concentrations in comparison with other VOCs, as well as their well acknowledged deleterious health effects.

Microbiome analysis:

1. Delays in sequencing have prevented the analysis of the microbiome data.
2. The microbiome analysis is expected to be paramount in understanding the role of biological pollutants and characterizing the dynamics of cleaning, sterilizing processes, and the spread of bacterial and fungal communities within the hospital environment.

Infiltration of outdoor PM:

1. After this preliminary study on the outdoor air quality around the hospital building, which, as mentioned, needs to be supplemented later with more information and analysis of the collected data, it appears that of the parameters studied, only particulate matter and perhaps nitrogen dioxide would be contaminants to consider.
2. Outdoor particulate matter infiltration is prominent in areas closer to the main entrances of the hospital.
3. The influence of outdoor particulate matter decreases in other areas of the hospital, but potential indoor sources of pollution may affect some areas.
4. Seasonal fluctuations can be explored after 12M of uninterrupted monitoring.

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5. Air filtering systems in the intensive care ward show promising prospects for reducing particulate matter concentrations.

Health assessment and correlations:

1. Due to observed low pollution levels and a shallow health assessment conducted among hospital employees, it may be challenging to identify direct correlations with health effects.
2. Therefore, insights from systematic reviews and in vivo and in vitro studies will be crucial for extrapolating health risks for hospital workers and understanding the broader health implications of indoor air quality.

2.2 High-risk outpatients' scenario (ES-HOM01)

2.2.1 Rationale

Understanding the complex connections between IAQ and acute respiratory health issues among outpatients remains a pressing need[24]. It is acknowledged that poor IAQ in homes may exacerbate respiratory symptoms in high-risk outpatients, potentially leading to reduced lung function, diminished quality of life, increased healthcare visits, and even mortality. This highlights the potential of specific indoor pollutants to trigger respiratory inflammation, impair lung function, and affect heart rate variability. Therefore, exploring the physiological effects of these pollutants on respiratory patients within their homes is essential for unravelling the mechanisms triggering exacerbations.

The sources of IAQ pollutants in households, which can exacerbate respiratory symptoms, are diverse. For instance, VOCs can be emitted from various household products, such as cleaning agents, washing machine detergents, paints, adhesives, and air fresheners. PM pollutants may originate from various sources within homes, including cooking activities, smoking, burning candles or incense, and indoor dust accumulation. Additionally, moisture-related problems in homes can foster the growth of mould and mildew, which release spores and mycotoxins into the air, further contributing to IAQ pollution and respiratory health issues. In this regard, a comprehensive, long-term monitoring cohort shows promise in addressing hypotheses surrounding IAQ's impact on respiratory health and leading to personalized risk assessment.

Preventing acute episodes (exacerbations) in patients with severe respiratory conditions, such as COPD or treatment-resistant asthma, and improving the management of their overall comorbidity are two major actionable factors to reduce the societal burden of these disorders[25,26]. Furthermore, recent research has found that the progression of emphysema or the reduction in airway tree caliber can be correlated in some way with exposure to pollutants such as PM, O^3, or NO_2 through different techniques[27].

The detrimental impact of exacerbations on quality of life, resource utilization, disease progression, and prognosis are well-documented[25,28]. However, early detection and personalized treatment considering pharmacological and non-pharmacological interventions to prevent emergency room consultations and unplanned hospital admissions remain challenging. This is

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partly due to current post-hoc definitions of exacerbation relying broadly on symptomatic changes and inherent heterogeneities in patients' underlying conditions due to comorbidities.

On the other hand, leveraging an adaptive case management (ACM) paradigm alongside comprehensive patient health assessments holds promise in accurately discerning and characterizing exacerbation events. The ACM approach shows the potential to enhance the management of unplanned health events, reducing healthcare resource utilization and improving patient empowerment for self-management and continuity of care perception.

Aligned with the project's aim, the follow-up of a cohort of 200 vulnerable patients over three years provides a unique opportunity to characterize the most common home-based indoor air pollutants and their potentially harmful effects on high-risk respiratory outpatients. Nevertheless, it also offers a golden opportunity to design, implement and evaluate its potential for value generation of a novel integrated care service for enhanced management of these patients through the articulation of four main components: i) Enhanced lung function testing through oscillometry, ii) Continuous monitoring of IAQ as a potential triggering factor, iii) Digital support with an adaptive case management approach1, and iv) Predictive modelling for early identification and management of exacerbations.

The hypothesis supporting this research are the following:

Hypothesis H1: Exposure to poor indoor air quality in *HOMES* and its potential contribution to the exacerbation of respiratory symptoms in high-risk respiratory outpatients, as well as its impact on lung function and healthcare resource utilization.

Hypothesis H2: Exposure to pollutants and allergens present in indoor air inducing inflammation and irritation in the respiratory system, leading to reduced lung function, decreased oxygen delivery to the body, and alterations in heart rate variability.

Hypothesis H3: The potential effects of exposure to poor IAQ on various aspects of QoL, mental health, loneliness, disease prevalence and comorbidities, medication usage, and the emergence of IAQ-related symptoms.

Hypothesis H4: A multidimensional approach incorporating various health determinants such as health history, IAQ and OAQ exposure parameters, biological signals, Patient-Reported Outcome Measures (PROMS), and periodic assessments of pulmonary function can enhance the prediction of exacerbations of pulmonary disease.

2.2.2 IAQ Massive monitoring INBIOT sensors

Desktop WiFi-enabled MICA devices are being utilized for IAQ monitoring in the homes of 200 high-risk respiratory outpatients. The calculations displayed in the subsequent sections consider only the 62 patients recruited from mid November 2023 until the 31st of January of 2024.

2.2.2.1 CO_2

Figure 30 displays the assessment of CO_2 concentration across the different monitored homes. The default value of the CO_2 sensor calibration is set to 400 ppm, representing the baseline concentration of CO_2 in outdoor air. The mean CO_2 concentration averaged 767.46 ppm

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throughout the monitored period, with a peak reaching 6,770 ppm. Figure 31 showcases the fluctuations along 24 hours in CO_2 levels within various patients' homes.

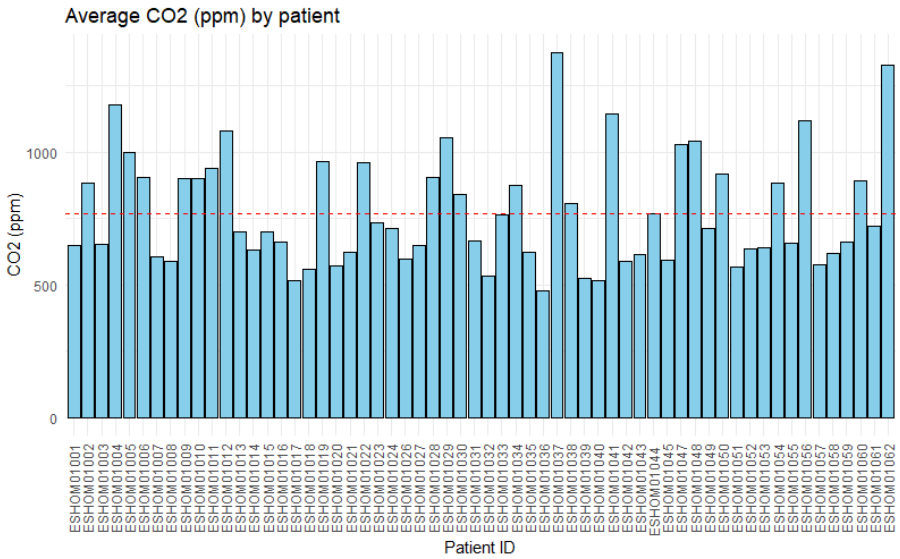

Figure 30. Average concentrations of CO_2 (ppm) registered in patients' homes in Barcelona from Dec 2023 to Jan 2024. The red dashed line displays the average concentration of CO_2 (ppm).

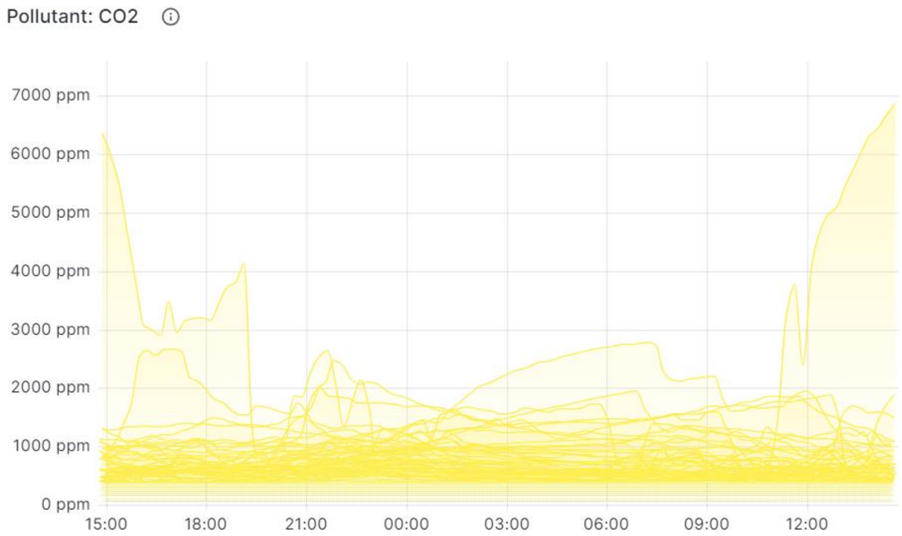

Figure 31. Snapshot of the graphical view of the CO_2 levels (ppm) during 24 hours in patients' homes in Barcelona (generated by K-HEALTHinAIR platform).

2.2.2.2 Formaldehyde

Figure 32 depicts the evaluation of formaldehyde concentration across the various monitored homes. The mean formaldehyde concentration was 29.83 µg/m^3. The highest observed formaldehyde level reached 889 µg/m^3. Heterogeneous results were observed across the different dwellings, indicating variations in formaldehyde concentrations. This analysis revealed residences where formaldehyde concentrations were notably higher than the average, with some homes exhibiting concentrations double or even four times the average level. These disparities underscore the need for further research to identify the sources of formaldehyde

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emissions within residential environments. In contrast, Figure 33 showcases the fluctuations along 24 hours in formaldehyde levels within various patients' homes.

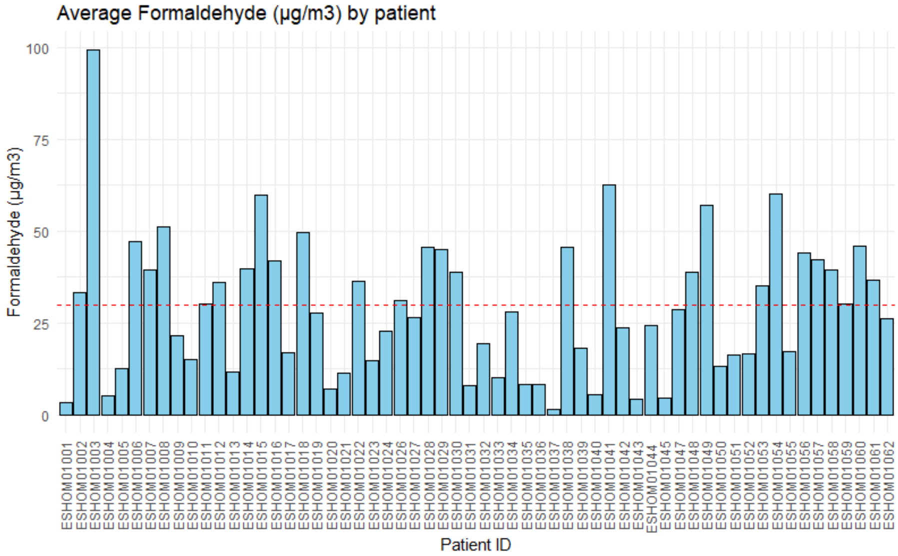

Figure 32. Average concentrations of formaldehyde (µg/m³) registered in patients' homes in Barcelona from Dec 2023 to Jan 2024. The red dashed line displays the average concentration of formaldehyde (µg/m³).

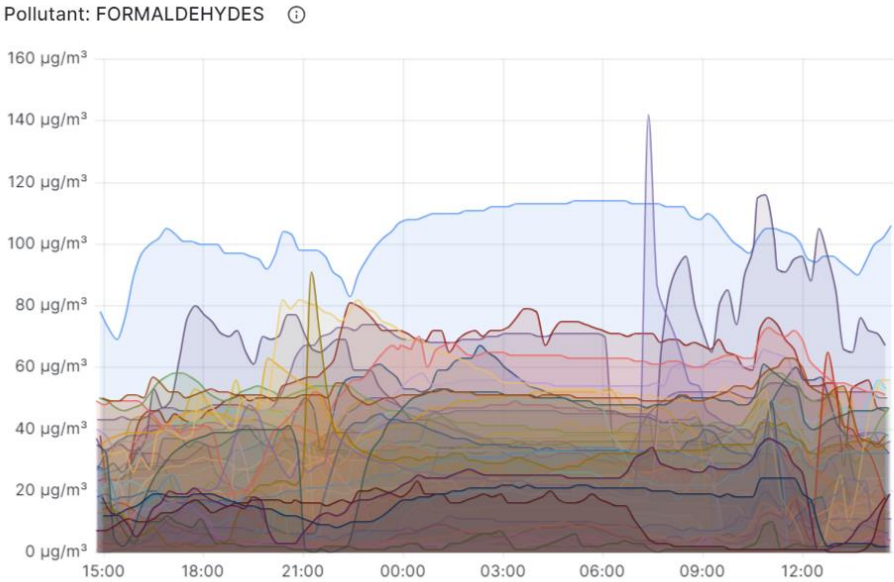

Figure 33. Snapshot of the graphical representation of the formaldehyde concentration (µg/m³) during 24 hours in patients' homes in Barcelona (generated by K-HEALTHinAIR platform).

2.2.2.3 TVOC

Figure 34 presents the assessment of TVOCs concentration across the different monitored homes. The mean TVOC concentration was 6,401 ppb. The highest observed TVOC level reached 60,000 ppb, reaching the detection limit of the sensor. This analysis revealed residences with TVOCs concentrations significantly exceeding the average. These discrepancies highlight the necessity for additional research to pinpoint the sources of TVOC emissions within residential environments.

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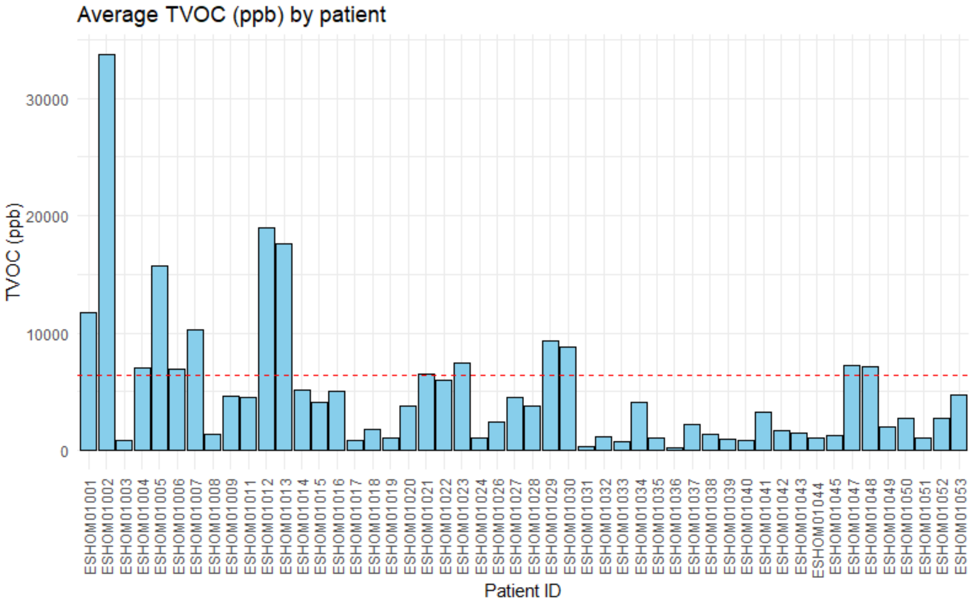

Figure 34. Average concentrations of TVOC (ppb) registered in patients' homes in Barcelona from Dec 2023 to Jan 2024. The red dashed line displays the average concentration of TVOC (ppb).

2.2.2.4 PM

Figure 35 illustrates the evaluation of $PM_{2.5}$ concentrations across the various monitored homes. The mean PM_1 concentration was 39.83 µg/m³. The highest observed PM_1 level reached 2,309 µg/m³. Similarly, for $PM_{2.5}$, the mean concentration was 43.96 µg/m³, with a maximum observed value of 2,619 µg/m³. For PM_4 and PM_{10}, the mean concentrations were 45.79 µg/m³ and 46.6 µg/m³, respectively, with maximum observed values of 2,784 µg/m³ and 2,858 µg/m³.

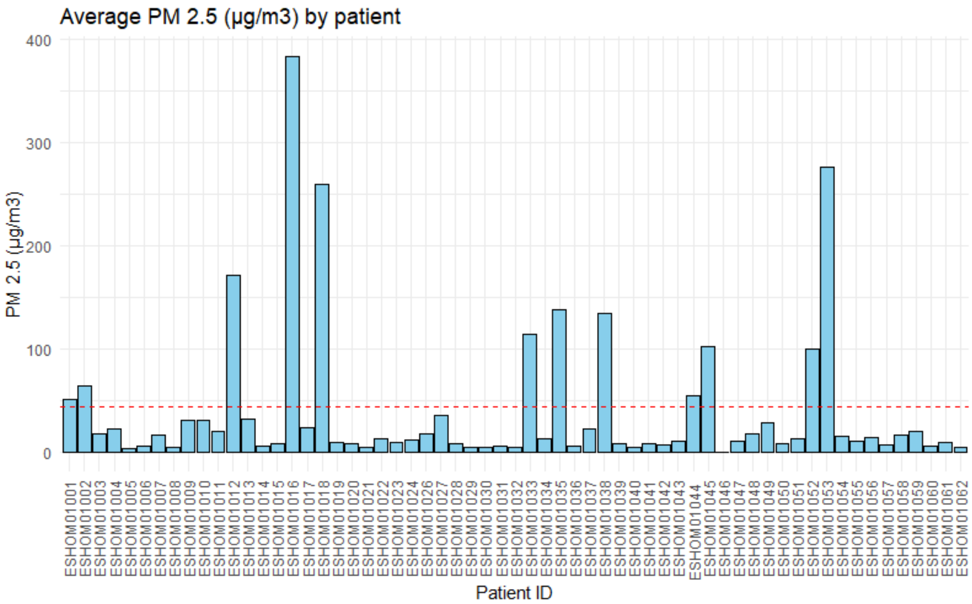

Figure 35. Average concentrations of $PM_{2.5}$ (µg/m³) registered in patients' homes from Dec 2023 to Jan 2024. The red dashed line displays the average concentration of $PM_{2.5}$ (µg/m³).

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As it is noted above, the platform includes PM_1, $PM_{2.5}$, PM_4 and PM_{10} parameters, so each location generates four fairly similar graphs. For the next platform update, only $PM_{2.5}$ will be included to make the visualization and analysis of information more convenient.

The distribution of PM was found to be symmetric across the different monitored homes, regardless of size. Additionally, a correlation was observed between PM concentration levels and the smoking habits of the dwellers. This correlation suggests that smoking behaviors are the main drivers of variations in PM concentrations within residential environments.

2.2.3 OAQ modelled data from AerisWeather

Recruiting patients is an ongoing task. We have a wide range of locations across the city, not just in the vicinity of the hospital. However, the platform currently does not allow for individual mathematical analysis, and only graphical image analysis can be performed. When these new platform functionalities become available, each patient will be individually analyzed to assess the potential impact of outdoor air quality on the interior of their homes.

However, in a generic sense and up to this point, the hospital location could be considered as the central and representative point for all locations. To avoid duplicating information regarding the same outdoor area, let's refer to the results of the Section 2.1.3.

Considering the records shown earlier, it can be noted that outdoor air quality could be important for the indoor air quality of the homes of patients with higher ventilation rates. In this regard, this will be one of the considerations to be transferred to WP2 for information analysis. Data on outdoor air quality will be correlated for the moments and patients who ventilate their homes (using CO_2 concentration to assess it), and correlations will be sought in PM concentration, which is the common parameter indoors and outdoors. Then, if high values of the other parameters of interest outdoors, O_3 and NO_2, are present at those moments, their potential presence indoors will also be assessed, even if records are not available.

2.2.3.1 Patients Health data

As reported in D1.2, only baseline information on recruited patients has been collected due to ongoing cohort recruitment. Therefore, this report does not include correlation analyses between IAQ and health status.

The collected information to explore IAQ-health status relationships is organized into two domains: IAQ information, as described above, and health-related data. Health-related data sources include i) periodically administered health questionnaires, ii) patients' self-tracked information, iii) biological data such as heart rate and physical activity, iv) clinical records, v) registry data, and vi) lung function measurements.

The analysis of this information will involve descriptive statistics (already assessed in this deliverable), correlation, and time series analyses. Descriptive statistics will summarize IAQ parameters monitored by MICA-INBIOT sensors, providing an overview of household indoor air quality profiles. Correlation analyses will examine relationships between IAQ parameters and health-related data sources, revealing potential associations between specific determinants and respiratory health outcomes. Time series analyses will explore IAQ parameter fluctuations over time and their potential impact on acute health issues among respiratory outpatients.

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Additionally, the databases will encompass physiological signals, air quality metrics, lung function, patients' disease perception, and underlying comorbidities to characterize exacerbation occurrences thoroughly. Diverse modelling strategies will be generated, tested, and compared to predict exacerbation events. Explainable AI methods will be employed to assess model covariates, determining their predictive efficacy and isolating critical signals instrumental in early identifying exacerbations.

By utilizing advanced technological tools and conducting thorough data analyses, this study aims to achieve several pivotal outcomes. The comprehensive assessment of exacerbation episodes and patient health parameters seeks to enhance precision in identifying and characterizing exacerbations. Temporal data analysis aims to unravel insights into exacerbation patterns, facilitating early intervention strategies and targeted preventive approaches. Lastly, exploring and comparing predictive modelling methodologies aims to construct robust models for forecasting exacerbation events, offering decision support tools to aid healthcare providers in efficiently managing exacerbations.

2.2.4 Conclusions

Heterogeneous profiles of indoor pollutants:

1. Observations reveal varied profiles of indoor pollutants across households.
2. Smoking habit emerges as a primary driver for indoor PM pollution.
3. Further research is necessary to pinpoint the primary sources of formaldehyde and VOCs in indoor environments.

Outdoor data pending to be studied to provide individual conclusions.

Importance of incorporating health data:

1. Correlation analysis between IAQ and clinical data in outpatients is crucial for identifying IAQ health determinants.
2. This analysis can enhance precision in identifying and characterizing exacerbations among respiratory patients and construct robust models for forecasting exacerbation events.

Potential benefits of preventive strategies:

1. Elevated pollution exposure in certain dwellings associated with unhealthy habits, such as smoking, suggests the potential benefits of preventive strategies.
2. Cognitive behavioural therapies initiated during acute episodes and extended into community settings could alleviate respiratory symptoms.

Informing recruitment strategies:

1. Preliminary results can inform the recruitment of 10 treatment-resistant asthma patients, that considers an enhanced assessment of the IAQ at chemical and biological level.

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2. Selection criteria should consider relevant clinical and IAQ profiles to ensure the study's efficacy and relevance.

2.3 High-risk outpatients' scenario (ES-HOM02)

Due to the delays explained in D1.2 and D1.7, it is essential to note that the sampling/monitoring campaign has yet to be initiated in this scenario. As per the calendar, the sampling/monitoring activity is expected to begin in March 2024. Therefore, no results are displayed in this issue of this deliverable.

2.3.1 Portable monitoring tool

In addition to the desktop IAQ sensor utilized in all the scenarios, the follow-up of this cohort considers gathering additional exposure information using a portable IAQ sensor. Information on the utilization of portable monitoring tools is described in the D3.1.

2.4 Metro station scenario (ES-MET01)

As stated in D1.2 and D1.7, the Metro authority indicated the need to stop the process due to potential problems with the Labor Unions. Therefore, the sampling/monitoring campaign has yet to be initiated in this scenario. As per the calendar, the sampling/monitoring activity in transient stop until May 2024. Therefore, no results are displayed in this issue of this deliverable.

As stated in D1.2 and D1.7, the Metro authority indicated the need to stop the process due to potential problems with the Labor Unions. Therefore, the sampling/monitoring campaign has yet to be initiated in this scenario. As per the calendar, the sampling/monitoring activity in transient stop until May 2024. Therefore, no results are displayed in this issue of this deliverable.

2.5 Market scenario (ES-MKT01)

Due to the delays explained in D1.2 and D1.7, it is essential to note that the sampling/monitoring campaign has yet to be initiated in this scenario. As per the calendar, the sampling/monitoring activity is expected to begin in March 2024. Therefore, no results are displayed in this issue of this deliverable.

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3 ROTTERDAM PILOT #2 (NL)

Pilot #2 NL covers:

· Follow-up of 50 outpatients living in their homes (HOM01) and 60 elderly patients living in senior homes (HOM02). All these outpatients have one or more chronic conditions such as frailty, COPD, bronchiectasis, asthma, cardiovascular disorders, or type II diabetes mellitus.

· Analysis of two relevant indoor settings: hospital scenario (HOS01), the dining room of retire senior home scenarios (RET01, RET02, RET03, RET04).

3.1 Hospital scenario (NL-HOS01)

Pilot #2 Rotterdam is the second pilot working with outpatients in K-HEALTHinAIR. It covers also the two approaches proposed by the Project: 1) Follow up of high-risk older outpatients with COPD or other chronic conditions and 2) analysis of 2 relevant settings, namely hospital areas and a senior home (common areas).

The study including the high-risk older people (target population: 50 high-risk outpatients living independently at home and 60 older people living independently in in their homes in so called senior homes (i.e. buildings designed and managed to accommodate older people) is focused on analysing the relationships between patient's home IAQ and health and well-being. It includes a) the collection of health and well-being-related data such as experienced health complaints, physical health symptoms, well-being, several patient-reported outcomes such as quality of life (PROMS) and via diaries and questionnaires and b) the continuous monitoring of relevant indoor IAQ parameters such as T, RH, CO_2, PM, VOCs and formaldehyde c) the use of additional health parameter monitoring such as steps per day.

The study performed in relevant settings includes the common areas of the hospital and senior home, such as dining areas or waiting rooms. The study is focused on a) monitoring of the relevant IAQ parameters such as T, RH, CO_2, PM, VOCs and formaldehyde; b) the sampling of VOCs (including formaldehyde) in the IAQ; c) the collection of OAQ in the surrounding areas and d) the collection of data on health complaints experienced among (all types of) of staff (e.g. health, social, management, volunteers, facility) working a significant amount of time in the location of the monitored settings.

In short:

· Follow-up of 50 older outpatients living independently in their homes (HOM01) and 60 older persons living independently in their homes in so called senior homes (HOM02) with regard to health and indoor air quality. All participants have one or more chronic conditions such as frailty, COPD, bronchiectasis, asthma, cardiovascular disorders, or type II diabetes mellitus.

· Analysis of two indoor air quality in two relevant indoor settings: hospital scenario (HOS01), senior home scenario (RET01, RET02, RET03, RET04). Exploratory analyses of experienced health and well-being complaints of staff (all types) spending a significant amount of time in the monitored areas.

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This 18M deliverable does not contain detailed analyses of the association between IAQ and health and well-being outcomes, as the recruitment of participants has not been finalized. Only baseline information on the recruited patients has been collected at this stage. Some preliminary descriptive information from the obtained data is presented. Information should be interpreted with caution as the number of participants is low.

The characterisation of the hospital will a) monitor of the relevant IAQ parameters such as T, RH, CO_2, PM, VOCs and formaldehyde; b) perform additional sampling of VOCs (including formaldehyde) in the IAQ; c) collect data of OAQ in the surrounding areas and d) exploration of experienced health among (all types of) staff (e.g. health, social, management, volunteers, facility) spending a significant amount of time in the monitored areas. The aim of this characterisation is to get a complete and comprehensive overview of IAQ in the assessed scenario, taking into account the OAQ, over time. The objective is to explore among staff the experienced impact on health and well-being and the potential for interventions in this scenario.

Based on the literature (see D.2.1) out hypotheses are:

- Based on interview data personal exposed to higher polluted areas may indicate experience of health complaints such as coughing, dry nose and headaches;
- IAQ parameters may be related by the purpose of use of the area at hand (e.g. in rooms where a high level of hand alcohol is used versus low-intensity used office spaces).

3.1.1 IAQ Massive monitoring INBIOT sensors

The IAQ monitoring in the hospital scenario started by the end of 2023 (September). In total 11 sensors are installed in specific areas of the hospital in order to get a comprehensive understanding of IAQ. Both areas were patients are as well as areas were staff (all types) spend time were chosen:

- Patient areas include the out- and inpatient wards of the pulmonary department. Here patients wait, are seen for treatment and interact with staff.
- Common areas such as hall ways and waiting areas for patients. In these areas people spent time shortly before their appointment, these areas can be subject to crowding.
- Offices for personal. These areas are used by staff to complete administration.
- Spirometry room. In this area specific assessments are performed with patients.

The installed sensors are similar as those in the Barcelona pilot, namely MICA sensors from InBIOT (MICA – InBIOT[3]). These sensors provide continuous monitoring of T, RH, tVOC, formaldehyde concentration and PM concentration (1, 2.5, 4 and 10 μm of particle size).

OAQ data is collected via open source data.

[3] https://www.inbiot.es/productos/dispositivos-mica/mica

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In Table 3. Aggregated data hospital scenarioTable 3 the aggregate IAQ data can be seen, high levels of TVOC are likely due to the use of alcohols for disinfection purposes.

Table 3. Aggregated data hospital scenario.

	Mean (SD)	Median (IQR)	Max	Limits
Temperature (°C)	23.36 (1.39)	23.4 (22.5-24.3)	31.5	-
Relative Humidity (%)	40.29 (9.76)	39 (34-47)	73	-
CO_2 (ppm)	436.76 (54.9)	421 (406-450)	1725	900 (ppm) – 1h
Formaldehyde (µg/m^3)	5.08 (7.54)	2 (1-5)	58	60 (µg/m^3) – 8h
TVOC (ppb)	2,602.34 (5,872.84)	516 (210-2,170)	60,000	600 (µg/m^3) – 8h. Aprox. 130 ppb
PM_1 (µg/m^3)	0.84 (1.97)	0 (0-1)	41	-
$PM_{2.5}$ (µg/m^3)	0.90 (2.07)	0 (0-1)	51	5 (µg/m^3) - Annual
PM_4 (µg/m^3)	0.90 (2.09)	0 (0-1)	52	-
PM_{10} (µg/m^3)	0.92 (2.09)	0 (0-1)	52	15 (µg/m^3) - Annual

3.1.1.1 Temperature

Figure 36 displays a comparative overview of aggregated temperature levels in the hospital. The monitoring started in September when outdoor temperatures started to drop. Great difference in temperatures recorded in the waiting room is likely due to the nearby presence of the exit, allowing cold outdoor air to come in more frequently.

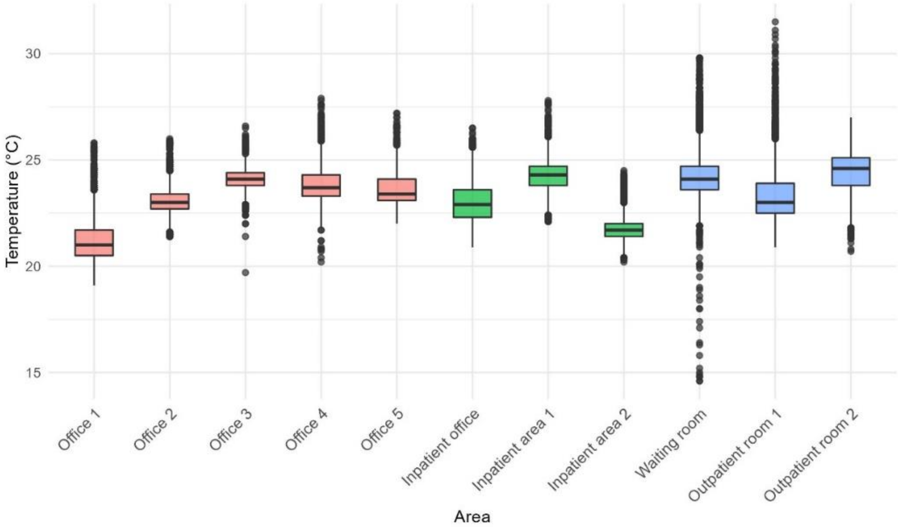

Figure 36. Comparative assessment of the measured temperature (°C) of the sensors installed across various location in the EMC over five months (Sep23-Jan24).

3.1.1.2 Relative Humidity

Figure 48 displays a comparative overview of aggregated relative humidity levels in the hospital. Levels are mostly within acceptable ranges with the highest recorded peak at 73% and the lowest at 18%. Slight differences are observed between the different areas

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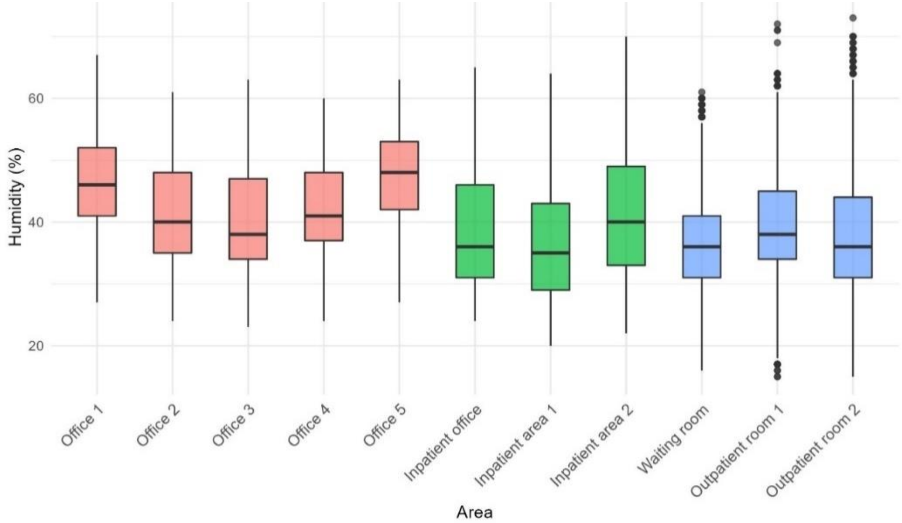

Figure 37. Comparative assessment of the measured relative humidity (%) of the sensors installed across various location in the EMC over five months (Sep23-Jan24).

3.1.1.3 CO_2

Figure 38 shows a comparative overview of aggregated CO_2 levels in the hospital. Overall the average CO_2 levels are between 400-500 ppm, which is in line with outdoor air. The highest recorded CO_2 level recorded was 1,725 ppm. Further exploration of these data is needed to get more insight in these outlier numbers.

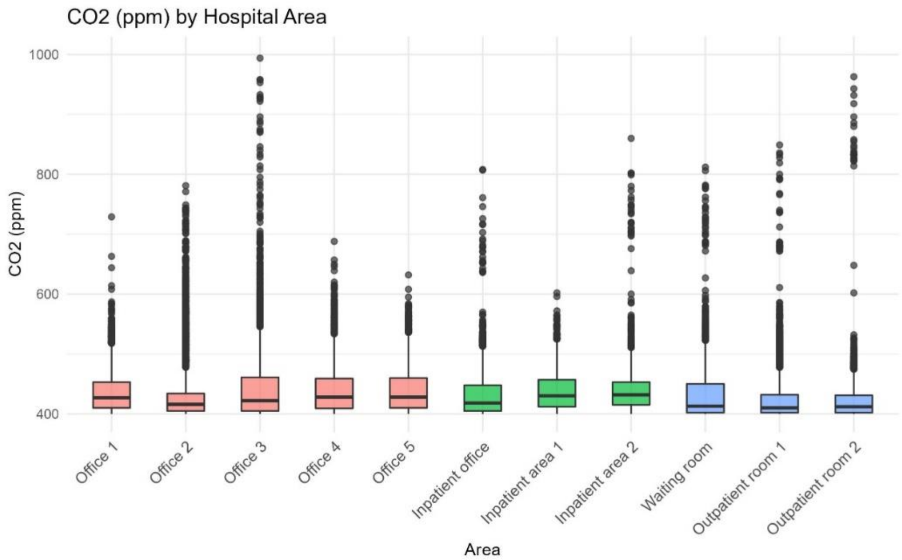

Figure 38. Comparative assessment of the measured CO_2 (ppm) of the sensors installed across various location in the EMC over five months (Sep23-Jan24).

3.1.1.4 Formaldehyde

Figure 39 shows a comparative overview of aggregated formaldehyde levels in the hospital areas that were monitored. From the graph can be observed that there is more variation between area. In follow-up we will need to explore factors present in these rooms that may

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impact these findings. Peaks of formaldehyde may be due to the use of cleaning products or other human-initiated actions.

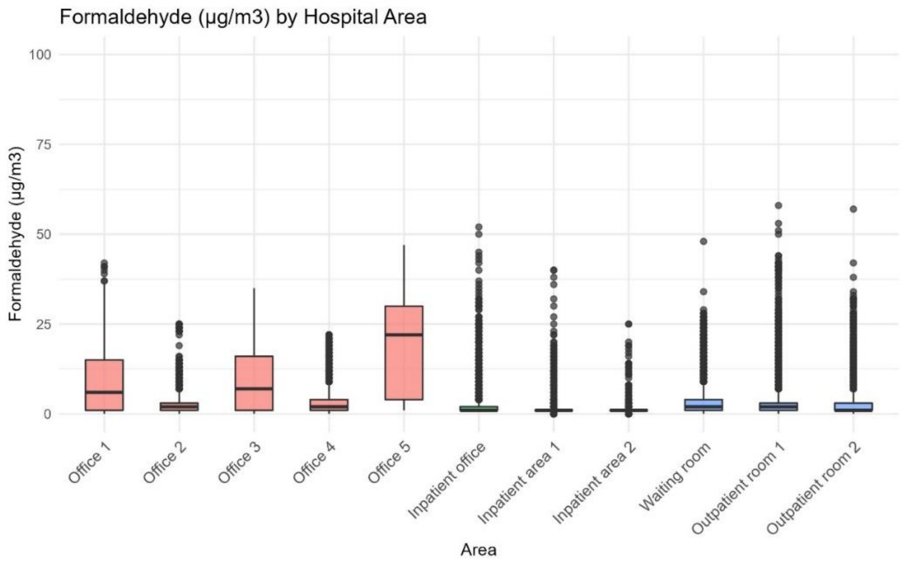

Figure 39. Comparative assessment of the measured formaldehyde (µg/m³) of the sensors installed across various location in the EMC over five months (Sep23-Jan24).

3.1.1.5 TVOC

Figure 40 shows a comparative overview of aggregated TVOC levels in the hospital. In some areas there is a higher maximum TVOC observed. As TVOC includes multiple parameters these higher values may be explored further using dedicated sampling.

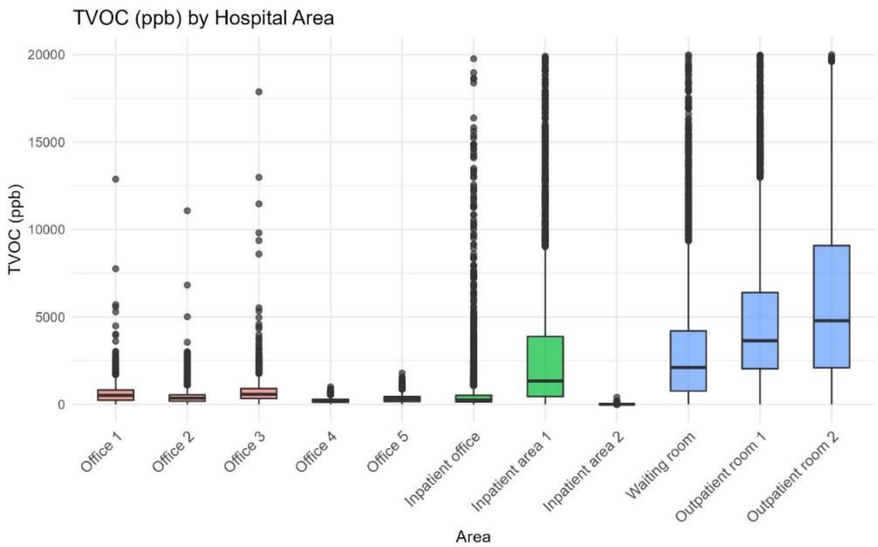

Figure 40. Comparative assessment of the measured tVOC (ppb) of the sensors installed across various location in the EMC over five months (Sep23-Jan24).

3.1.1.6 PM

Figure 41 shows a comparative analysis illustrates aggregated PM levels (PM_1, $PM_{2.5}$, PM_4, and PM_{10}) within hospital areas. PM_1 concentrations exhibit consistency across various hospital zones,

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with an overall concentration of approximately 0.84 (see Table 3). Similarly, $PM_{2.5}$ levels remain relatively consistent across different areas, with an average concentration of 0.9 µg/m^3 (refer to Table 3). The PM_4 values also demonstrate uniformity across hospital sections, with an average concentration of 0.9 µg/m^3 (Table 3). Likewise, PM_{10} concentrations show comparable levels throughout different hospital segments, with an average concentration of 0.92 µg/m^3 in the monitored areas (see Table 3).

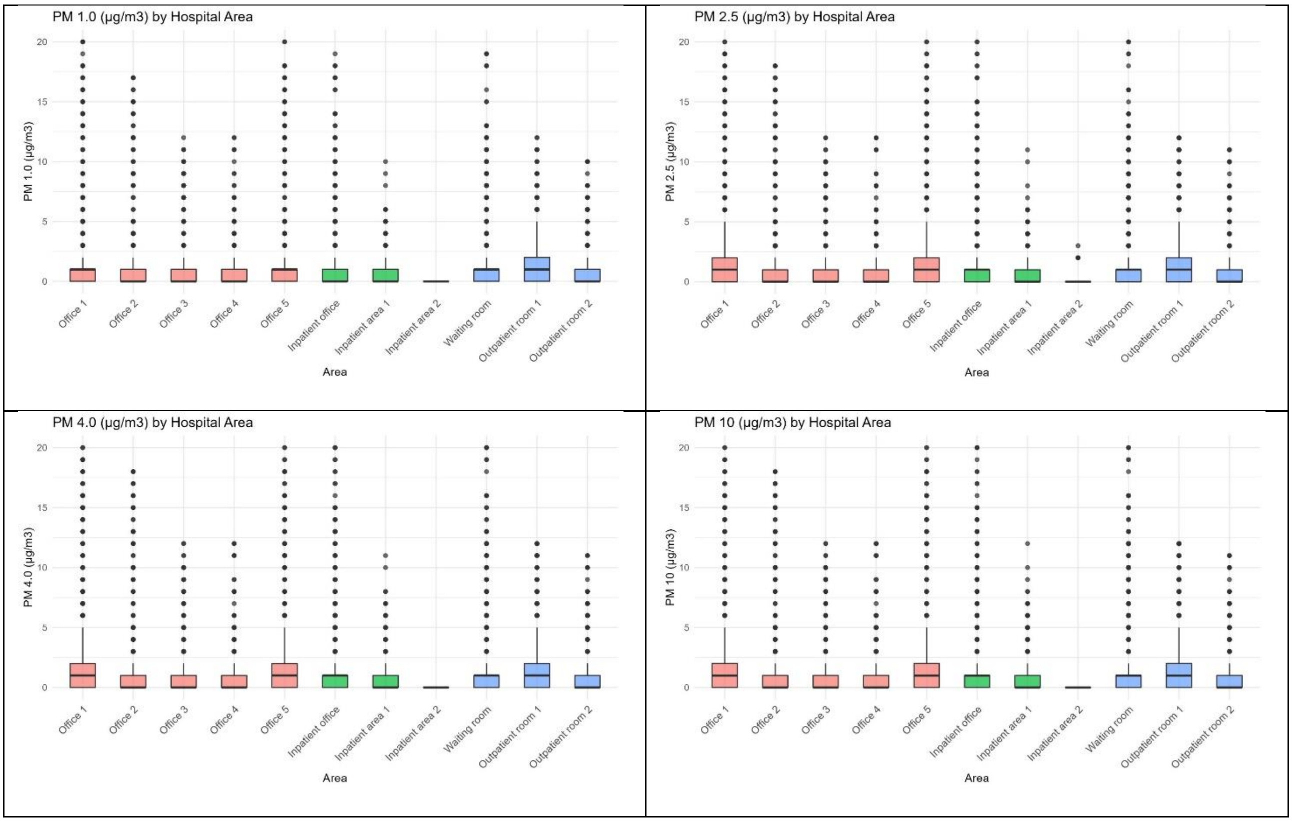

Figure 41. Comparative assessment of the measured PM_1, $PM_{2.5}$, PM_4, PM_{10} ($\mu g/m^3$) of the sensors installed across various location in the EMC over five months (Sep23-Jan24).

3.1.2 OAQ modelled data from AerisWeather

These data are being captured continuously using open source monitoring the hospital areas. At the moment these data were not available for presentation.

3.1.3 VOCs sampling

The detailed VOC sampling to explore specific parameters of IAQ in dedicated areas is scheduled to take place at in the second half of 2024.

3.1.4 Conclusions

The massive monitoring devices have been gradually installed since September 2023. Therefore, for some of the areas maximum 5 months of data is available, for others less. In the following months, more extensive data will be collected using observations and interviews to capture determinants and potential impact on health of staff spending time in the monitored areas. Based on the preliminary findings presented in this deliverable, which are mostly descriptive, some first indications for the characterization of the IAQ in the hospital areas can be given.

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Basal concentrations of indoor pollutants:

1. Overall, the IAQ parameters indicate relatively low indoor air pollutants concentration in the assessed hospital areas.
2. There is variation in maximum values measured in certain parameters, in certain areas. Further observations and data collection may explore whether there are differences between areas were patients are seen compared to office spaces.

Health assessment and correlations:

1. Up to now no interviews have been performed with staff. Given the relatively low levels of indoor air pollutant, it will be very challenging to be able to relate health complaints experienced with indoor air quality. The interviews will provide a very exploratory assessment of experienced health complaints and will need to be completed with more in-depth studies.

3.2 Senior homes scenario (NL-RET01, NL-RET02, NL-RET03, NL-RET04)

The characterisation of the senior home scenario will a) monitor of the relevant IAQ parameters such as T, RH, CO_2, PM, VOCs and formaldehyde; b) perform additional sampling of VOCs (including formaldehyde) in the IAQ; c) collect data of OAQ in the surrounding areas and d) exploration of experienced health among (all types of) staff (e.g. health, social, management, volunteers, facility) spending a significant amount of time in the monitored areas. The aim of this characterisation is to get a complete and comprehensive overview of IAQ in the assessed scenario, considering the OAQ, over time. We aim to explore among staff the experienced impact on health and well-being and the potential for interventions in this scenario.

The hypotheses are:

- Based on interview data personal exposed to higher polluted areas may indicate experience of health complaints such as coughing, dry nose and headaches;
- IAQ parameters may be related by the purpose of use of the area at hand (e.g. rooms with a high level of crowding).

3.2.1 IAQ Massive monitoring INBIOT sensors

The IAQ monitoring in the senior home scenario started by September 2023. In total 1 sensor is installed in one of the specific areas of the senior home-building in order to get a comprehensive understanding of IAQ. In four different buildings (RET01, RET02, RET03, RET04) the dining area is monitored:

o Common area: dining and activities room. In this usually larger area senior residents can join together for diner or organized activities. Also, this is the area where they can meet family for a cup of coffee. The area is not public.

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The installed sensors are similar as those in the hospital scenario, namely MICA sensors from InBIOT (MICA – InBIOT). These sensors provide continuous monitoring of T, RH, tVOC, formaldehyde concentration and PM concentration (1, 2.5, 4 and 10 µm of particle size).

OAQ data) is collected via open source data.

Table 4 presents an aggregated data observed across the monitored areas (n=4).

Table 4. Aggregated data senior home-building scenario.

	Mean (SD)	Median (IQR)	Max	Limits
Temperature (°C)	20.96 (2.07)	21 (19.1-22.9)	24.8	-
Relative humidity (%)	43.14 (10.51)	42 (36-50)	70	-
CO_2 (ppm)	461.75 (99.5)	420 (405-481)	1,170	900 (ppm) – 1h
Formaldehyde (µg/m^3)	15.97 (17.56)	7 (2-27)	142	60 (µg/m^3) – 8h
TVOC (ppb)	1,262.89 (3,714.25)	229 (125-584.5)	46,248	600 (µg/m^3) – 8h. Aprox. 130 ppb
PM_1 (µg/m^3)	3.15 (3.24)	2 (1-4)	90	-
$PM_{2.5}$ (µg/m^3)	3.6 (3.62)	3 (2-5)	94	5 (µg/m^3) - Annual
PM_4 (µg/m^3)	3.84 (3.88)	3 (2-5)	94	-
PM_{10} (µg/m^3)	3.96 (4.03)	3 (2-5)	94	15 (µg/m^3) - Annual

3.2.1.1 Temperature

Figure 42 presents a density plot showing the frequencies of different temperatures measured in the senior home building. This was done because only 1 senor has been installed. Most of the time the temperatures vary from about 19 °C to 23 °C.

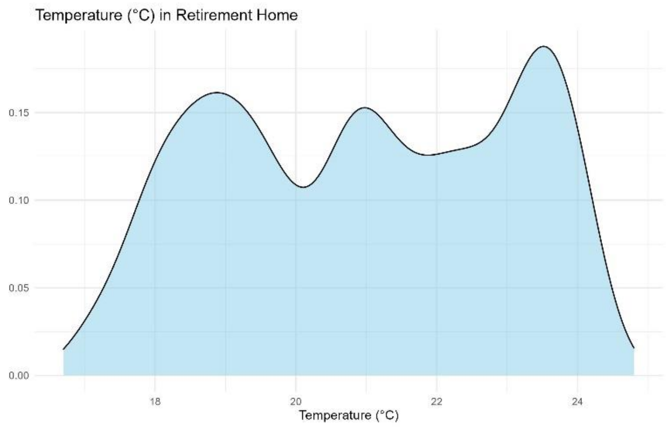

Figure 42. Density plot of measured temperature (°C) at the senior home-building.

3.2.1.2 Relative Humidity

Figure 43 displays a density plot representing the distribution of relative humidity levels measured within the senior home building. The majority of values fall between 36% and 50% relative humidity (Table 4).

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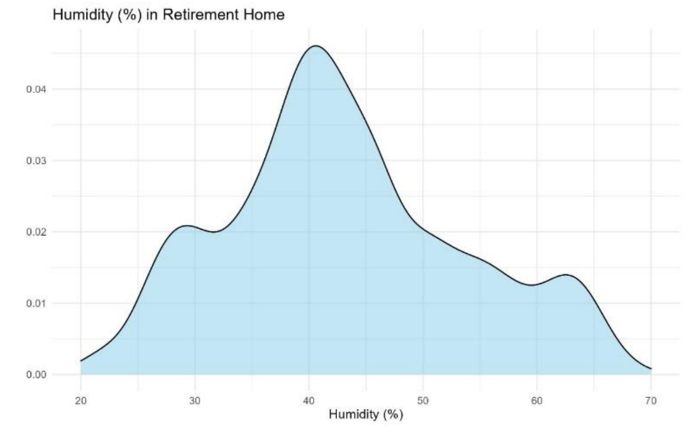

Figure 43. Density plot of relative humidity measurements (%) at the senior home-building.

3.2.1.3 CO_2

Figure 44 displays a density plot representing the distribution of CO_2 levels measured within the senior home building. The majority of values fall between 405 and 481 ppm (Table 4).

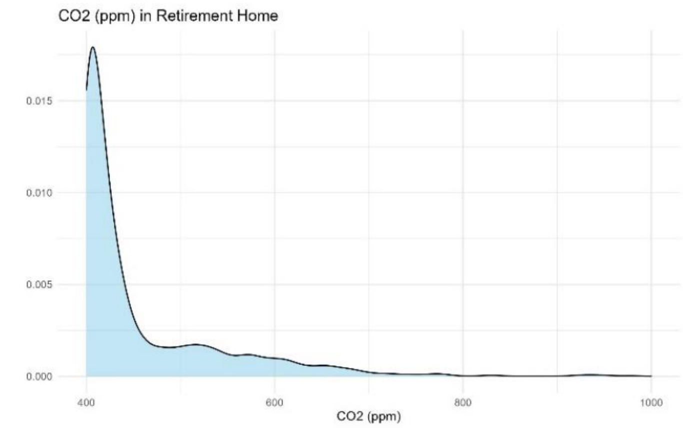

Figure 44. Density plots depicting the measured CO_2 frequencies in the senior home building.

3.2.1.4 Formaldehyde

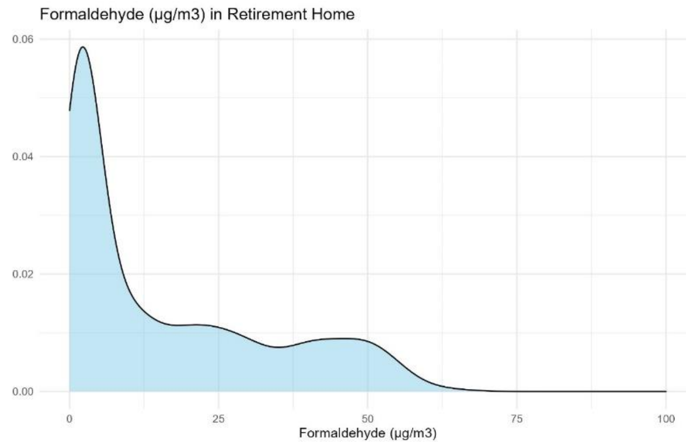

Figure 45. Density plots depicting the measured Formaldehyde at the senior home building.

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Figure 45 displays a density plot representing the distribution of formaldehyde levels measured within the senior home building. The majority of values are low and fall between 2 and 27 µg/m^3 (Table 4).

3.2.1.5 TVOC

Figure 46 displays a density plot representing the distribution of TVOC levels measured within the senior home building. The majority of values fall between 125 and 584 ppb TVOC (Table 4).

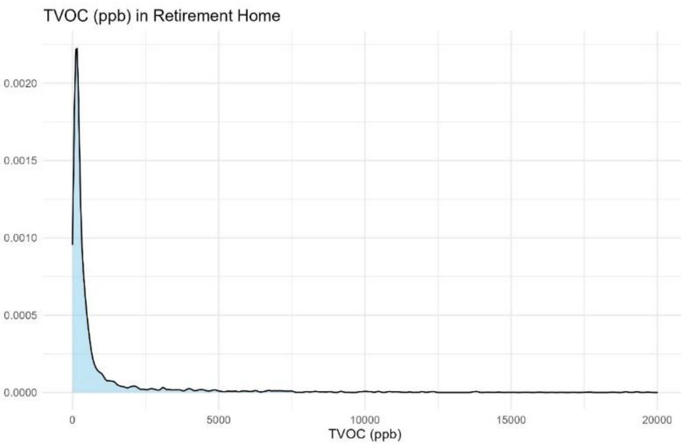

Figure 46. Density plots depicting the measured TVOC at the senior home building

3.2.1.6 PM

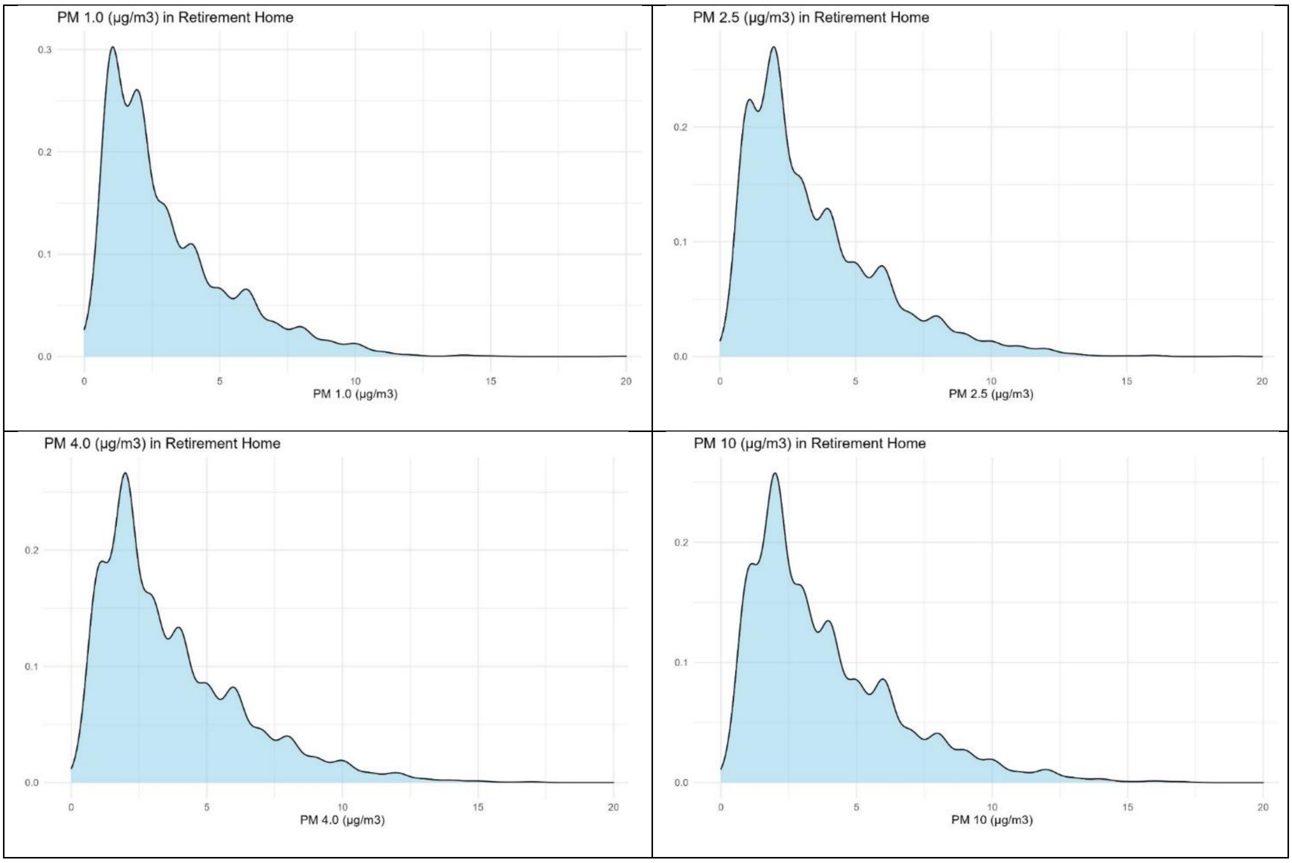

Figure 47 . Density plots depicting the measured PM_1, $PM_{2.5}$, PM_4 and PM_{10} at the senior home building.

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Figure 47 . Density plots depicting the measured PM_1Figure 47 density plots illustrates the distribution of PM levels within the senior home building. PM_1 levels predominantly ranging between 1 and 4 µg/m^3. Similarly, $PM_{2.5}$ levels, with the bulk of values falling between 2 and 5 µg/m^3. PM_4 levels, primarily ranging between 2 and 5 µg/m^3 Lastly, PM_{10} levels with the majority of values falling within the range of 2 to 5 µg/m^3 (Table 4).

3.2.2 OAQ modelled data from AerisWeather

Although this data is being recorded, access to it is still unavailable.

3.2.3 VOCs sampling

The VOC sampling is scheduled to take place at in the second half of 2024.

3.2.4 Conclusions

Only one monitoring device has been installed since October 2023. In the following months, more monitoring devices will be installed. This low amount is due to internet providing problems and switching providers. Therefore, conclusions based on this data should be taken with caution. Extensive data will be collected in the following months using observations and interviews to capture determinants and potential impact on health of staff and residents spending time in the monitored areas. Based on the preliminary findings presented in this deliverable, which are mostly descriptive, some initial indications for the characterization of the IAQ in the senior-homes areas can be given.

Basal concentrations of indoor pollutants:

1. Overall the IAQ parameters indicate relatively low indoor air pollutants in the assessed senior home building.

Health assessment and correlations:

1. Up to now no interviews have been performed with staff and residents. Given the relatively low levels of indoor air pollutant, it will be very challenging to be able to relate health complaints experienced with indoor air quality. The interviews will provide a very exploratory assessment of experienced health complaints and will need to be completed with more in-depth studies.

3.3 Outpatients scenario (NL-HOM01, NL-HOM02)

The work in this scenario is focused on analyzing the relationships between patients' home IAQ and their health status, in where the final anticipated number of participants is 110 (50 outpatients living in their home (HOM01) and 60 older outpatients living independently in their home in senior homes (HOM02)).

The characterisation of the homes will a) monitor of the relevant IAQ parameters such as T, RH, CO_2, PM, VOCs and formaldehyde; b) collect data of OAQ in the surrounding areas; c) collection of relevant IAQ parameters such as T, RH, CO_2, PM, VOCs and formaldehyde using portable monitors; and d) questionnaires covering (mental) health, well-being, frailty, ADL acute/chronic conditions (COPD and asthma specific). The aim of this characterisation is to get a complete

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and comprehensive overview of IAQ in the assessed scenario, considering the OAQ, over time. We aim to explore relation and impact IAQ and OAQ has on health and well-being on older participants living in the Rotterdam area.

The hypothesis supporting this research are the following:

Hypothesis H1: Lower IAQ is related to a lower quality of life[29].

Hypothesis H2: Lower IAQ is related to more IAQ-related health-symptoms[29].

Hypothesis H3: Lower IAQ is associated with lower mental health[30,31].

Hypothesis H4: Lower IAQ is associated with poorer lifestyle.

Hypothesis H5: Lower IAQ is associated with more care use.

Hypothesis H6: Lower IAQ is associated with having more conditions (higher comorbidity).

Hypothesis H7: Study the effect of several pre-established variables on hypothesized associations.

3.3.1 IAQ Massive monitoring INBIOT sensors

The IAQ monitoring in the home scenario started in January 2024. In total 10 sensors are installed in the homes of older people in order to get a comprehensive understanding of IAQ.

Table 5 presents an overview of the mean values aggregated data observed across multiple homes (n=10).

Table 5. Aggregated data homes scenario.

	Mean (SD)	Median (IQR)	Max	Limits
Temperature (°C)	18.92 (1.36)	18.8 (18.1-19.9)	24.3	-
Relative Humidity (%)	40.53 (5.7)	41 (36-44)	59	-
CO_2 (ppm)	648.14 (303.59)	544 (449.25-736)	2,736	900 (ppm) – 1h
Formaldehyde (µg/m^3)	24.21 (24.06)	22 (7-34)	501	60 (µg/m^3) – 8h
TVOC (ppb)	983.81 (2,204.16)	433 (183.25-973)	40,086	600 (µg/m^3) – 8h. Aprox. 130 ppb
PM_1 (µg/m^3)	7.31 (55.07)	3 (2-5)	2,826	-
$PM_{2.5}$ (µg/m^3)	8.33 (68.89)	4 (2-6)	3,357	5 (µg/m^3) - Annual
PM_4 (µg/m^3)	8.72 (73.71)	4 (2-6)	3,684	-
PM_{10} (µg/m^3)	8.89 (75.81)	4 (2-6)	3,826	15 (µg/m^3) - Annual

3.3.2 OAQ modelled data from AerisWeather

These data are being captured continuously using open source monitoring the hospital areas. At the moment these data were not available for presentation.

3.3.3 Portable monitoring tool

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The portable monitoring tool will be implemented later this year when suitable candidates have been selected.

3.3.4 Questionnaires

Questionnaire data has not been digitalized as of now. The baseline questionnaire has been distributed on paper, awaiting agreement on the JCA to further process these data.

3.3.5 Conclusions

The monitoring devices have been gradually installed since January 2024. Therefore, for some of the homes a maximum 6 weeks of data is available, for others less. In the following months more participants will be recruited to explore the impact of IAQ on health. Based on the preliminary findings presented in this deliverable, which are mostly descriptive, some first indications for the characterization of the IAQ in homes can be given.

Basal concentrations of indoor pollutants:

1. Although low, average $PM_{2.5}$ surpass the annual limit of 5 µg/m^3 on an annual basis. Further observations and data collection may explain what sources and or determinates lead the exceedance of the annual limit.
2. Secondly, variations in measured values among different homes require extensive analysis. Dairy data will help further explain variations and help Identify determinates.

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4 NORWAY PILOT #3 (NO)

Pilot #3 NO covers second approach of the K-HEALTHinAIR project, focusing on characterising different indoor scenarios through some specific actions:

- The evaluation of the impact of wood as indoor building material on health in canteen scenario.
- The analysis of IAQ in three relevant indoor settings located at Universitetet il Agder (UiA): canteen scenario (CAN01, CAN02), buildings of students' residence including the monitoring of 20 student's bedsits and single room apartments (RES01, RES02, RES03, RES04, RES05, RES06, RES07, RES08), lecture hall scenario (LEC01).
- The evaluation of IAQ on mental health, quality of life (based on standardized questionnaires) and sick building syndrome to 70 students from UiA (20 with IAQ monitoring in their rooms and 50 without it but sharing the scenarios).

This deliverable does not contain correlation analyses of IAQ and health status, as the recruitment of the students has not concluded yet. As a result, comprehensive correlation analyses between IAQ and health outcomes will be conducted. However, despite this limitation, preliminary characterization of the monitored environments can still be performed to provide valuable insights into IAQ profiles and a first screening of potential determinants.

4.1 Canteen scenario (NO-CAN01, NO-CAN02)

4.1.1 Rationale

IAQ in settings like canteens is an important consideration to ensure the health and well-being of both customers and staff. While the risks for IAQ in a canteen may be less varied than in environments like hospitals, it's still crucial to understand how construction materials and other factors can affect indoor air quality and, ultimately, people's experience in these spaces.

In a canteen, exposure to air pollutants such as cooking smoke, VOCs from construction materials and cleaning products, as well as airborne PM, can influence in the IAQ. Additionally, it is important to consider the well-being of customers and staff, especially those with sensitivities or pre-existing health conditions.

The most exposed people in the canteen scenarios are the staff as they work full time in the canteen's areas for cooking, preparation of food and coffee specialities, serving food, and dishwashing. In addition, they do clean-up and cleaning. The students buy hot and cold dishes mainly as self-service, and coffee. In addition, the canteen space is used for breaks, homework, and group work.

An important factor to consider in the IAQ of the canteen is the use of healthy construction materials, such as wood. Wood is a natural material that can positively contribute to IAQ by regulating humidity and reducing VOC accumulation compared to synthetic materials. Furthermore, the visual and tactile presence of wood can enhance overall well-being by creating

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a warm and welcoming environment. On the other hand, wood materials might emit mainly terpenes and carbonyl as VOC's and formaldehyde[32].

In summary, IAQ in a canteen is an important aspect to consider to ensure the health and well-being of people. The use of healthy construction materials, such as wood, can play a key role in improving indoor air quality and creating a healthier and more welcoming environment for customers and staff. In addition, a mapping of the sources of critical VOC's indoor and outdoor is important for the choice of actions if needed.

The hypothesis supporting this research are the following:

Hypothesis H1: Wooden surfaces effect on IAQ through comparison of the two Norway canteens with Germany pilot.

Hypothesis H2: Stability of humidity in canteen with and without a hygroscopic material (wood).

Hypothesis H3: Are staff more impacted in health by IAQ compared to students due to more time spent in canteens?

4.1.2 IAQ Massive monitoring INBIOT sensors

The monitoring includes IAQ in 2 canteens, CAN01 at the UiA Campus and CAN02 at Fagskolen i Agder. Six monitors are placed at: a) UiA eating areas (3 sensors), b) serving area (1 sensor), c) coffee shop (1 sensor) and d) kitchen (1 sensor). At Fagskolen four monitors are placed: a) 3 sensors in the eating area and b) 1 sensor in the serving area, very close to the kitchen. The questionnaires are meant for 10 members of canteen staff in total at UiA and Fagskolen i Agder

INBIOT sensors provide real-time data of T, CO_2, TVOCs, RH, PM_1, $PM_{2.5}$, PM_4, PM_{10}, and formaldehyde. From Figure 48 to Figure 57, these pollutants can be observed over the January 2024 in the canteens. It is important to note that these results constitute preliminary findings.

4.1.2.1 Temperature

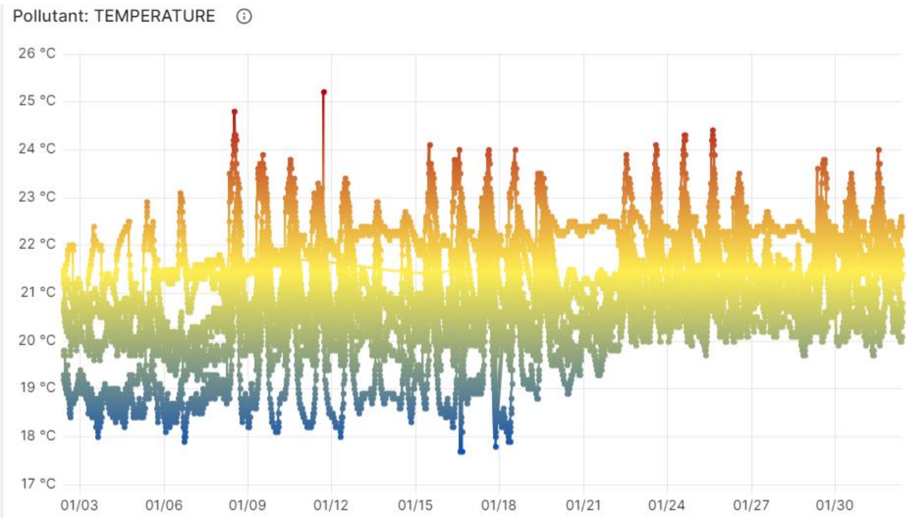

Figure 48. Snapshot of the graphical view of the temperature (°C) in the canteens in Grimstad in January 2024 (generated with K-HEALTHinAIR platform).

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The temperatures are normally comfortable for the staff, with one exception. This is the glasshouse eating area monitor CAN01001, which especially during low ambient temperature shows temperatures around 19 °C, see Figure 48.

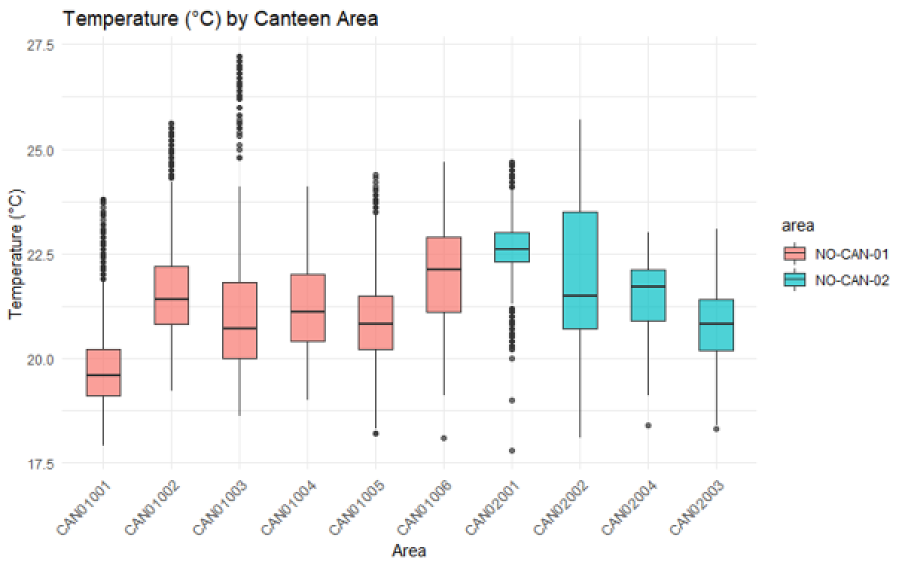

Figure 49. Comparative assessment of the measured temperature (°C) of the INBIOT sensors installed in the canteens of Grimstad over four months (Oct 2023 – Jan 2024). Values have been taken from myInbiot platform.

4.1.2.2 Relative humidity

The average humidity ranges between 25% and 35% (Figure 50), which is dry and, on the edge, of the recommended humidity levels.

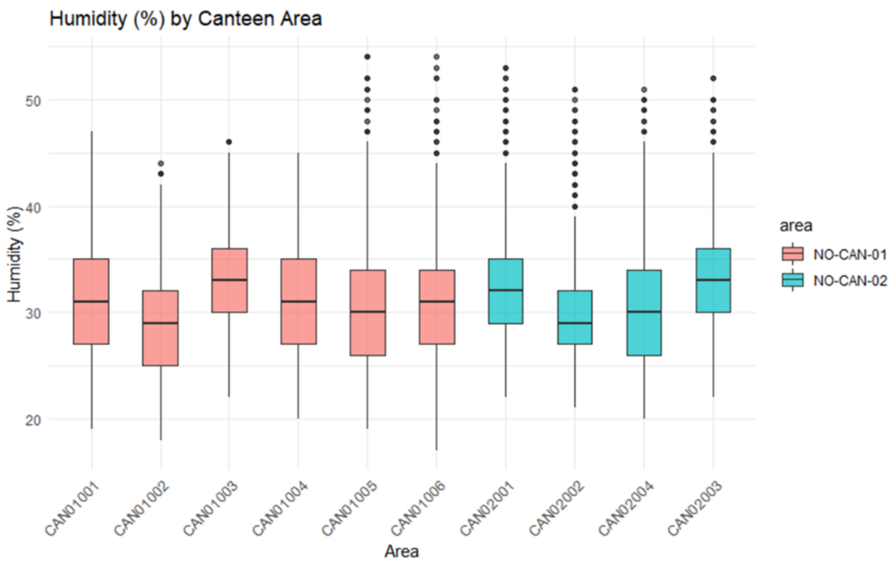

Figure 50. Comparative assessment of the measured relative humidity (%) of the INBIOT sensors installed in the canteens of Grimstad over four months (Oct 2023 – Jan 2024). Values have been taken from myInbiot platform.

4.1.2.3 CO_2

In Figure 51, it can be appreciated how the peaks are grouped in sets of 5. This is due to the occupancy of the canteens during the weekdays. During the moments of activity in the canteen,

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the levels reach an average of 600-700 ppm of CO_2. The first week of January has low concentrations due to some very snowy days hindered staff and students in entering the campus. These levels are not concerning, as they do not exceed the 900 ppm established in the guidelines (Table 2).

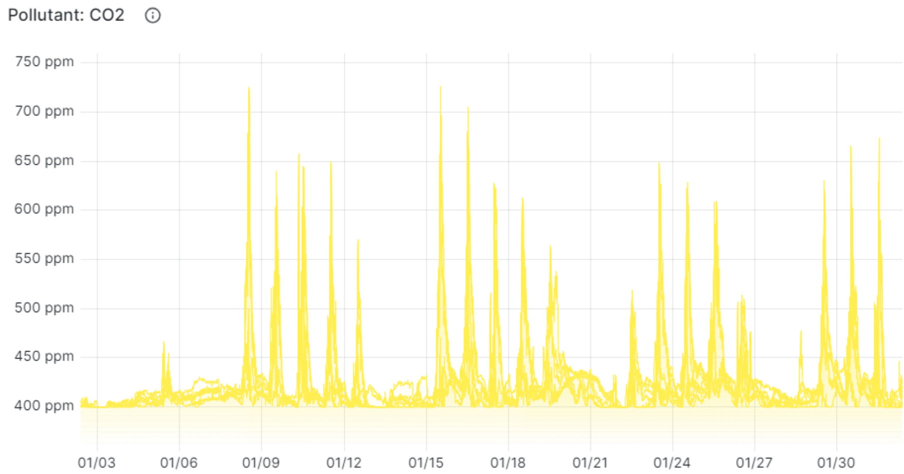

Figure 51. Snapshot of the graphical view of the CO_2 levels (ppm) in the canteens in Grimstad in January 2024 (generated with K-HEALTHinAIR platform).

4.1.2.4 Formaldehyde

Formaldehyde levels of Figure 52, in general, start to increase in the afternoon for all the sensors, and the level decrease again late-night and early morning when the ventilation returns to normal air exchange rate again. It means that the level never is problematic when people is present. A noteworthy profile is the purple one line, with consistently high values, experiencing peaks during weekdays while maintaining stability on the weekends. This also happens with the sensor yellow one. These levels are below the limits established in the guidelines: 30 minutes - 100 $\mu g/m^3$ (Table 2).

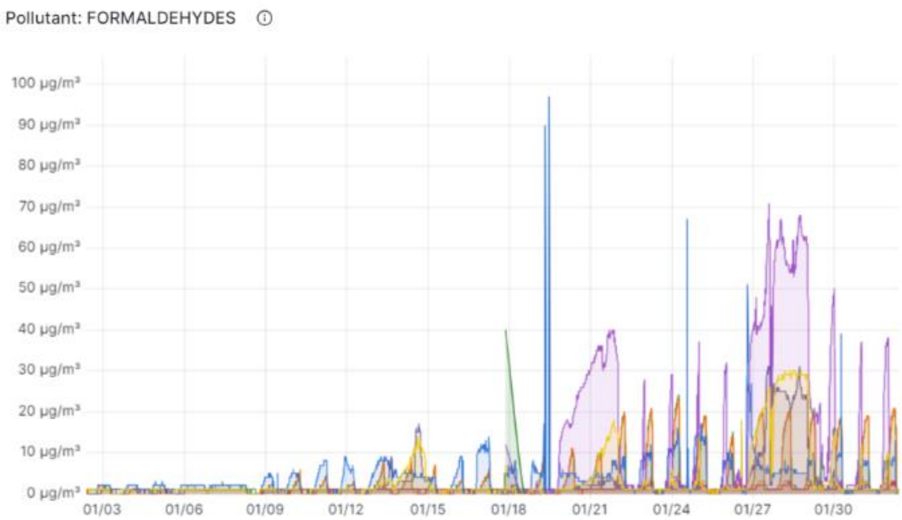

Figure 52. Snapshot of the graphical view of the formaldehyde concentration ($\mu g/m^3$) in the canteens in Grimstad in January 2024 (generated with K-HEALTHinAIR platform).

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4.1.2.5 TVOC

The VOC values for all INBIOT monitors installed in the canteens can be seen as a box plot in Figure 53. The kitchen monitor CAN01006 at UiA excels with relatively high median and upper quartiles values. This can also be seen as peeks in Figure 54. Except for the narrow peaks, the baseline is low during workhours, below 200 ppb, and above 2,000 ppb outside workhours, see Figure 55. All workdays, the maximum peak value is reached between 06:00 and 06:30, which indicates an earlier start of the ventilation is a relevant action. The rest of the canteens have lower levels in general, except for occasional peaks attributed to an event yet to be determined.

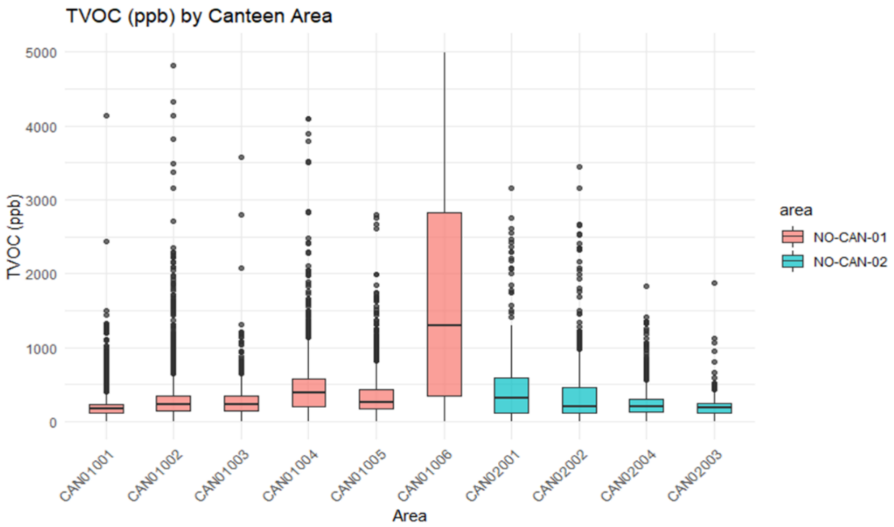

Figure 53. Comparative assessment of the VOCs measured of the INBIOT sensors installed in the canteens of Grimstad (CAN01006 in UiA and CAN02004 in Fagskolen) over four months (Oct 2023 – Jan 2024). Values have been taken from myInbiot platform.

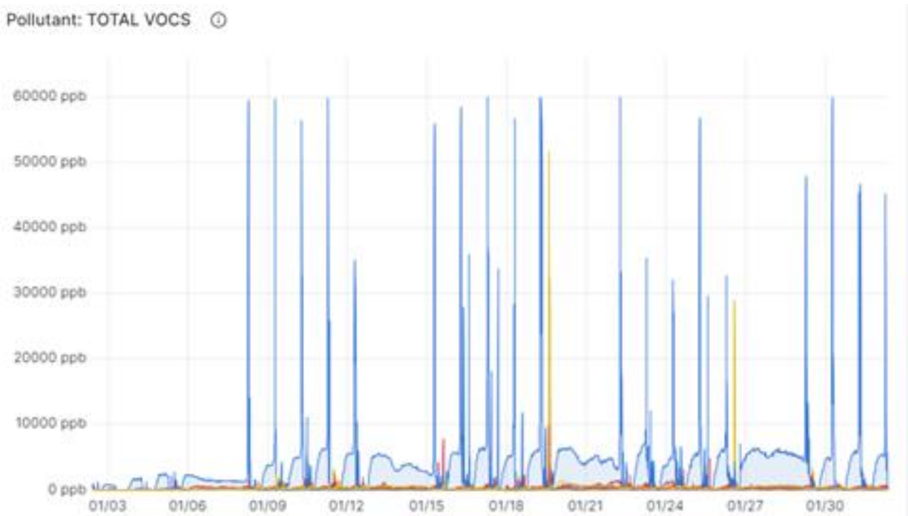

Figure 54. Snapshot of the graphical view of the tVOCs concentration ($\mu g/m^3$) in the canteens in Grimstad in January 2024 (generated with K-HEALTHinAIR platform).

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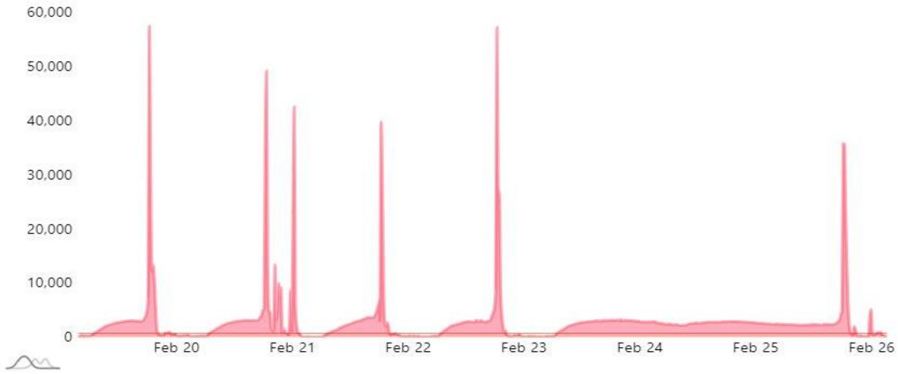


Figure 55. Snapshot of the graphical view of the tVOCs concentration ($\mu g/m^3$) in the UiA kitchen in Grimstad in one week in Jan 2024 (generated with K-HEALTHinAIR platform).

4.1.2.6 PM

In general, Figure 56 shows the median values for PM are low, 1 $\mu g/m^3$, and even the peaks are low. This means with normal indoor particles; the PM most probably does not directly represent a treat to the health.

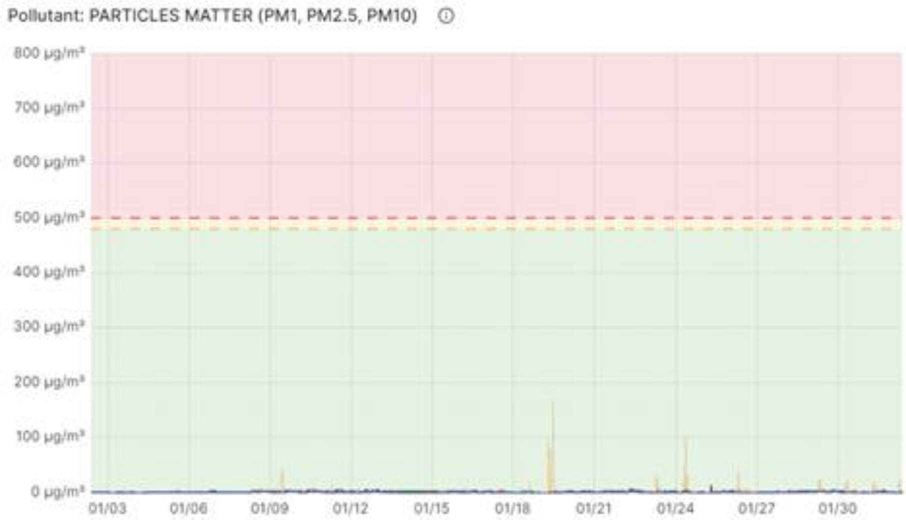
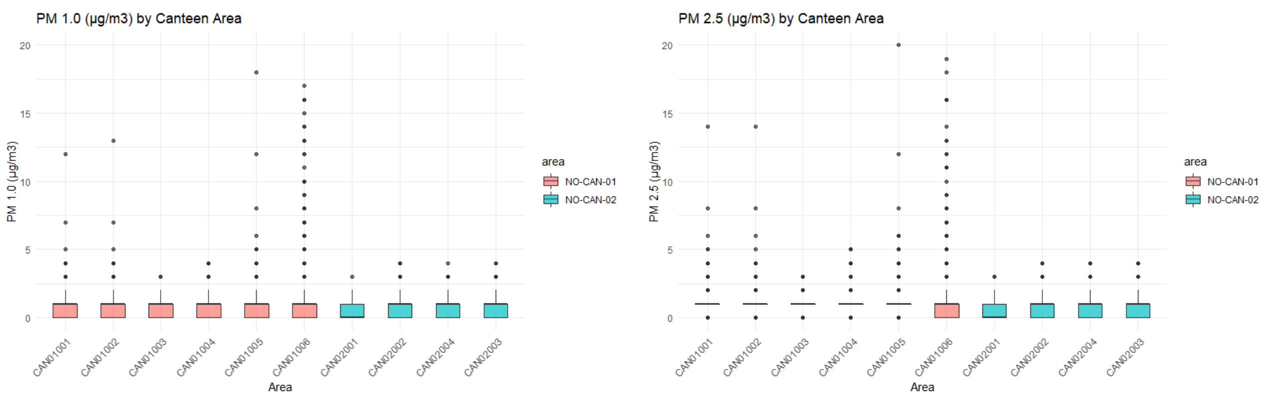


Figure 56. Snapshot of the graphical view of the PM levels ($\mu g/m^3$) in the canteens in Grimstad in January 2024 (generated with K-HEALTHinAIR platform).



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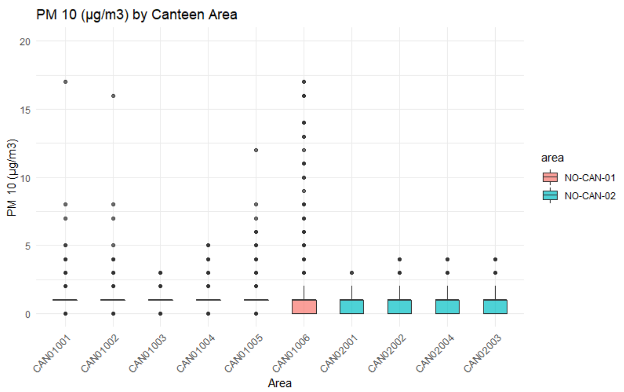

Figure 57. Comparative assessment of the PM_1, $PM_{2.5}$, and PM_{10} measured with INBIOT sensors installed in the canteens of Grimstad (CAN01006 in UiA and CAN02004 in Fagskolen) over four months (Oct 2023 – Jan 2024). Values have been taken from myInbiot platform.

In Table 6, a summary of the mean, median, and maximum values of the different parameters studied between October 2023 and January 2024 is provided.

The standard deviation of formaldehyde and VOC are many times the average value which means it is difficult to compare the different measurements. It is also necessary to take into account especially formaldehyde and TVOC have high values outside workhours where ventilation is reduced.

In general, the median values show acceptable levels of all pollutants but TVOC should be explored more due to the large standard deviation and unknown chemical VOC compounds.

Table 6. Summary of measurements October and November to the end of January 2024 for canteens.

Parameter	Mean (SD)	Median (IQR)	Max	Limits
Temperature (°C)	21.38 (1.44)	21.2 (20.4 - 22.3)	27.2	-
Relative Humidity (%)	31.05 (5.53)	30 (27 - 34)	54	-
CO_2 (ppm)	462.68 (36.71)	415 (404 - 433)	722	900 (ppm) – 1h
Formaldehyde (µg/m³)	4.4 (36.23)	1 (1 - 4)	3,975	60 (µg/m³) – 8h
TVOC (ppb)	595.05 (1,818.82)	230 (139 - 447)	54,915	600 (µg/m³) -8h Approx. 130ppb
PM_1 (µg/m³)	0.85 (2.91)	1 (0 - 1)	291	-
$PM_{2.5}$ (µg/m³)	0.93 (3.22)	1 (0 - 1)	319	5 (µg/m³) – Annual
PM_4(µg/m³)	0.95 (3.33)	1 (0 - 1)	331	-
PM_{10} (µg/m³)	0.96 (3.38)	1 (0 - 1)	336	15 (µg/m³) - Annual

4.1.3 OAQ modelled data from AerisWeather

As previously mentioned, the OAQ is a factor that also influences many indoor environmental scenarios. As shown in deliverable D1.2, information regarding OAQ has been collected on the platform since the start of monitoring. However, functionalities of the platform that enable the analysis of this information and, more importantly, facilitate clear comparisons between indoor and outdoor environments to identify potential correlations are still being developed.

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The analysis of OAQ information around the canteen begins by evaluating the overall profiles from the period from November 2023 to January 2024. This approach reveals the range of values for each parameter and also allows for the assessment of which parameters are closer to the recommended limits and should be considered. From Figure 58 to Figure 73 show the profiles of T and RH, as well as the concentrations of CO, O_3, $PM_{2.5}$, and NO_2.

4.1.3.1 Temperature and relative humidity

The ambient temperature in Figure 60 shows the modelled values follow the measured. The highest temperatures are nearly equal while the measured minimum temperatures are higher than the predicted. The average temperature measured for the actual three months is 0.4 °C with minimum 15.4 °C and maximum 11.7 °C. The corresponding relative humidity is in average 82.3%, minimum 31.7% and maximum 100%. In the selected moths the relative humidity is relatively constant with a standard deviation of 11.8% which is result of the coastal location even the temperature difference between minimum and maximum temperature is 27 °C. The low temperatures entail low water vapor content in ambient air. This again led to low indoor humidity.

Figure 58. Outdoor temperature data (°C) provided by Aerisweather platform (above) and UiA KUNAK measurement (below) in Grimstad between November 2023 and January 2024 (Aerisweather generated with K-HEALTHinAIR platform).

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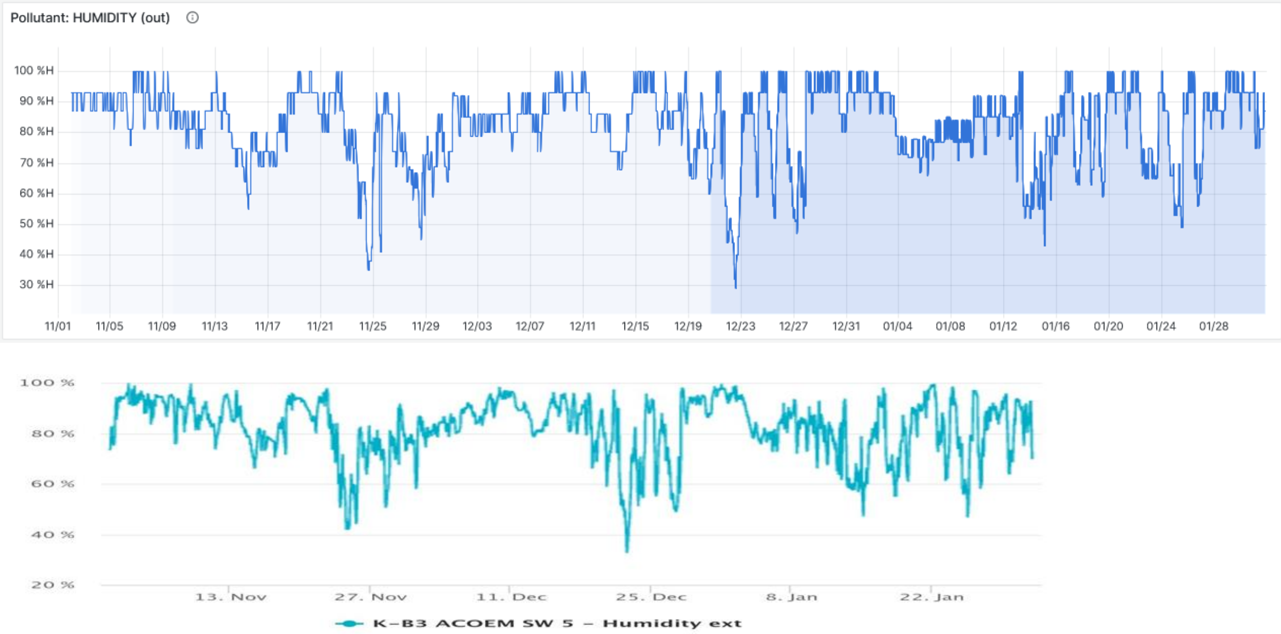

Figure 59. Outdoor relative humidity data (%) provided by Aerisweather platform in Grimstad (above) and UiA KUNAK measurement (below) in Grimstad between November 2023 and January 2024 (Aerisweather generated with K-HEALTHinAIR platform).

4.1.3.2 CO

Regarding the concentration of CO in the Figure 60, it can be observed that the values recorded for the study period never exceed 1 ppb. Considering that European legislation (Directive 2008/50/EC of the European Parliament and of the Council, of 21 May 2008, on ambient air quality and cleaner air for Europe[4]) establishes that average values over 8 hours outdoors should not exceed 10 $\mu g/m^3$ (equivalent to 8 ppb), it can be generally stated that this parameter does not seem to pose problems indoors at the canteen.

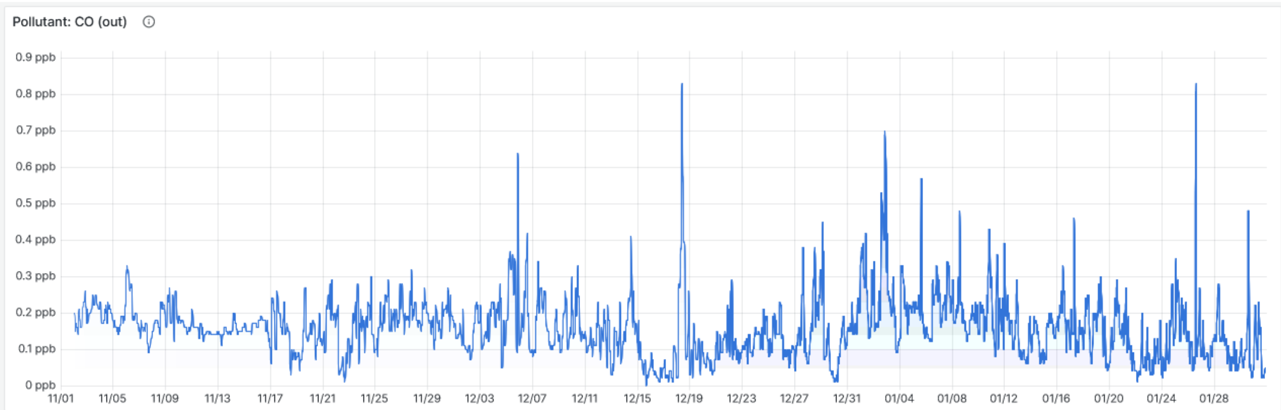

Figure 60. Outdoor CO data (ppb) provided by Aerisweather platform in the canteen area in Grimstad between November 2023 and January 2024 (generated with K-HEALTHinAIR platform).

[4] https://eur-lex.europa.eu/eli/dir/2008/50/oj/por

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4.1.3.3 PM

Regarding the concentration of PM of the Figure 62, the profiles collected range from nearly zero to some peaks. Based on the general trend, it can be visually established that the average value may be close to 5 µg/m³ modelled by AerisWeather. Data provided by the UiA KUNAK outdoor station for this period (discuss in more detailed below) shows considerably lower values (average: 1.5 µg/m³ (SD 1.5) and maximum 14.7 µg/m³ for $PM_{2.5}$ 1h). The maximum 24-hour value is 4.7 µg/m³.

These values are quite low regarding the recommended values by WHO (5 µg/m³ annual average and 15 µg/m³ average over 24 hours) (Table 2).

The study will continue in coming months in order to evaluate if seasonality can affect the PM levels. As an additional source of information, Urban PM2.5 Atlas, Air Quality in European Cities[20] has been consulted for the city of Oslo (280 km drive from Grimstad) (Figure 61). Agder it is not mentioned in the source and Oslo is the only Norwegian city.

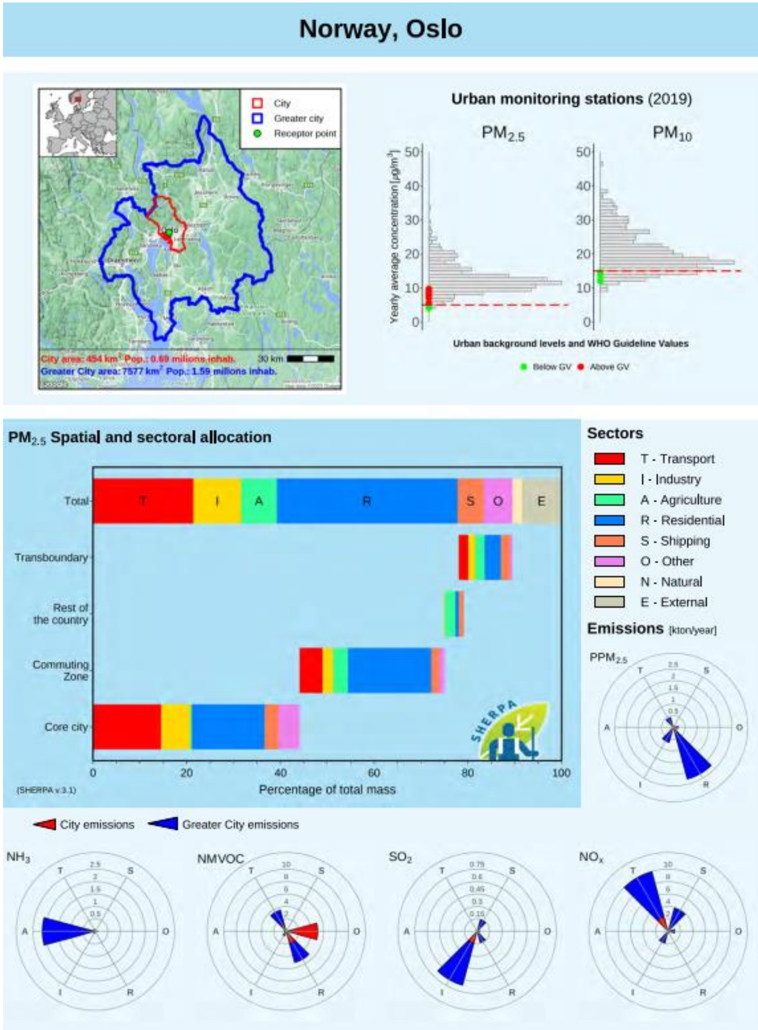
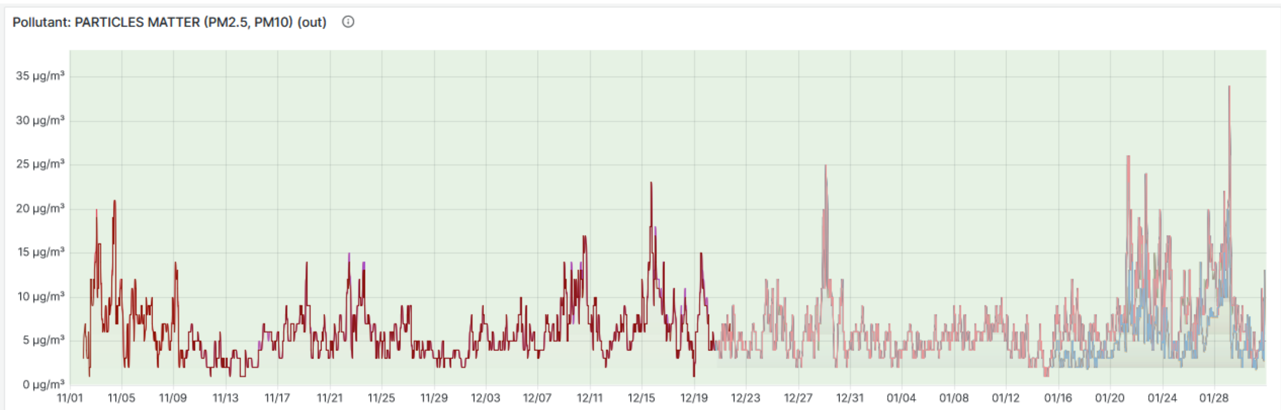


Figure 61. $PM_{2.5}$ pollution in Oslo (280 km drive from Grimstad). Urban PM2.5 Atlas, Air Quality in European Cities, 2023 Report p. 13[20].



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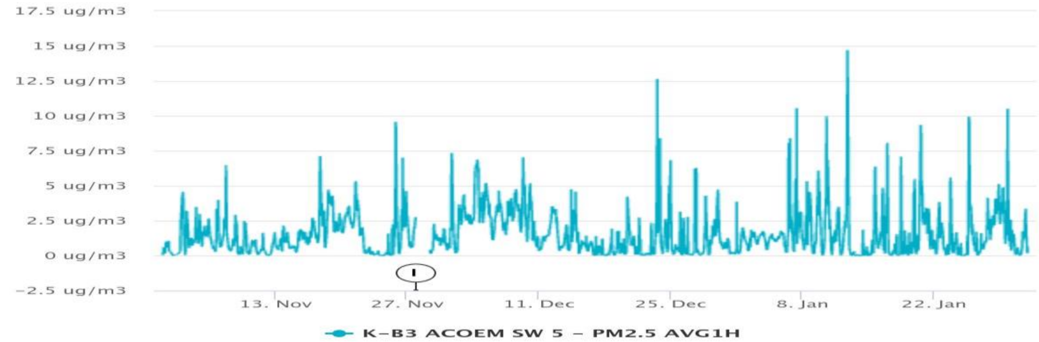

Figure 62. Outdoor $PM_{2.5}$ concentration data ($\mu g/m^3$) provided by Aerisweather platform (above) and UiA KUNAK measurement (below) in Grimstad between November 2023 and January 2024 (Aerisweather generated with K-HEALTHinAIR platform).

As shown in the Figure 62, the annual mean values for the sampled stations range between 0 and 10 µg/m^3, also in line with the information provided by Aerisweather service and KUNAK AQ station. What is interesting to assess is the origin of the particles. Residential sources contribute the most, followed by traffic.

4.1.3.4 O_3

The outdoor O_3 values collected by Aerisweather (Figure 63) range from nearly 10 to some concentration peaks of more than 40 µg/m^3. The most restrictive limit levels are those recommended by WHO. They recommend not exceeding an average value of 60 µg/m^3 over six months and not exceeding 100 µg/m^3 as an average value over 8 hours. Under this period, it is not a parameter to be follow. The study will continue with the hotter months when usually O_3 levels are higher. In addition, a comparison to the closet governmental O_3 measurement station Birkenes observatory[5] 20 km away will be carried out.

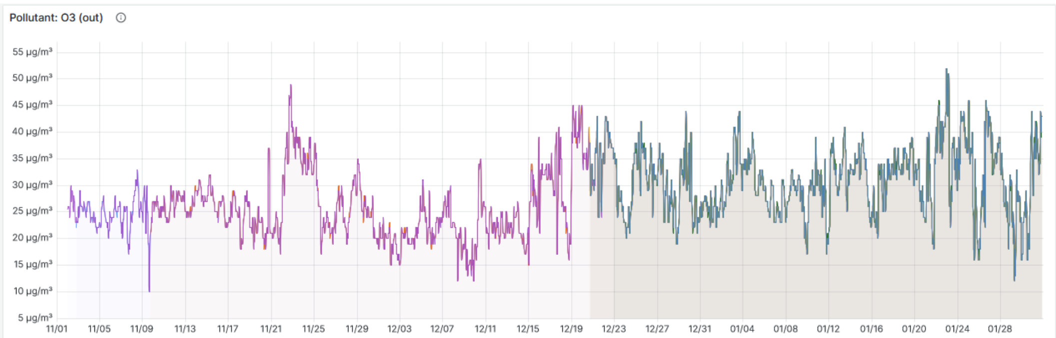

Figure 63. Outdoor O_3 concentration data ($\mu m/m^3$) provided by Aerisweather platform in the canteen area in Grimstad between November 2023 and January 2024 (generated with K-HEALTHinAIR platform).

4.1.3.5 NO_2

Regarding NO_2 in the Figure 64, the profile of concentrations modelled and measured values in UiA from November 2023 to January 2024 can be seen. The measured UiA KUNAK values have an average of 10.7 ppb (1 hour) with a standard deviation of 4.2. The maximum measured value is 33 ppb (1 hour). The measured values are in general three times higher than the modelled

[5] https://nilu.com/facility/nilus-observatories-and-monitoring-stations/birkenes-observatory/

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AerisWeather values. As can be observed, there are slight daily variations in concentration but seems to be far from the limit values except for the long-term average, where 10.7 ppb is equal to 20 µg/m³. Recommendations suggested by WHO (10 µg/m³ annual average, 25 µg/m³ average over 24 hours, and 200 µg/m³ as an hourly average) are higher. The yearly average will be calculated after the first complete operation year 31 August 2024.

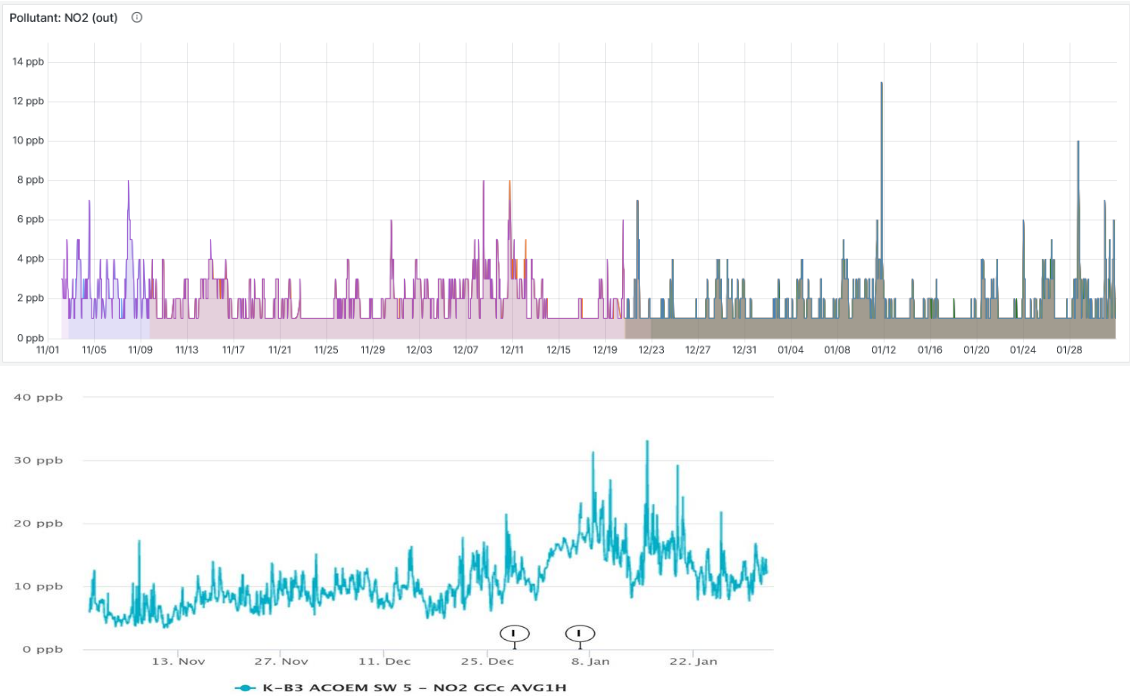
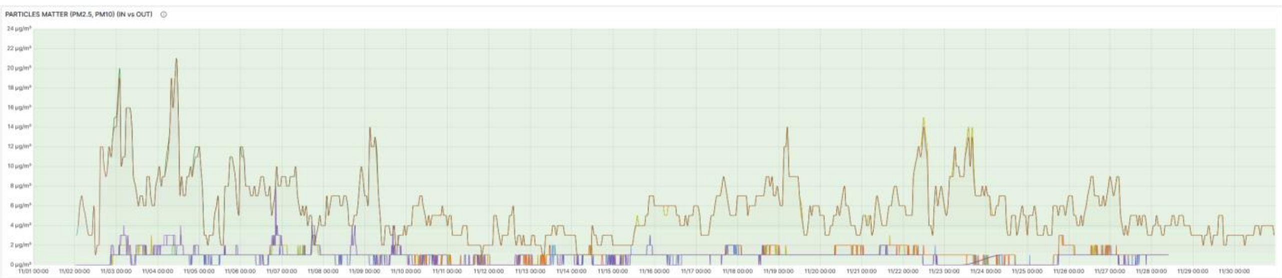


Figure 64. Outdoor NO_2 concentration data (ppb) provided by Aerisweather platform (above) and UiA KUNAK measurement (below) in Grimstad between November 2023 and January 2024 (Aerisweather generated with K-HEALTHinAIR platform).

4.1.3.6 Comparison between indoors and outdoors pollutants

Additionally, as an auxiliary study to be completed later, when all the planned functionalities for the platform are developed, the profiles of various common parameters ($PM_{2.5}$) both indoors and outdoors have been graphically evaluated in the Figure 65.

The levels recorded outdoors have been very low, so it does not seem that this parameter has an influence on IAQ, at least during the time studied so far. Especially with a median value of 1.5 µg/m³ outdoor and average of 1 µg/m³ $PM_{2.5}$ indoor and fresh air filtration.



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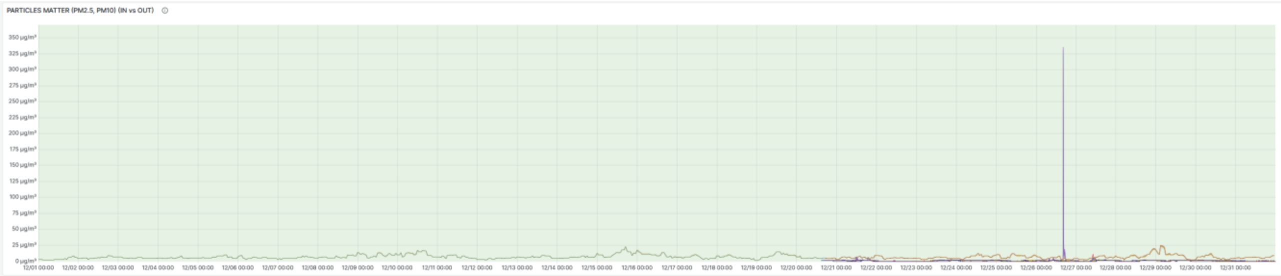

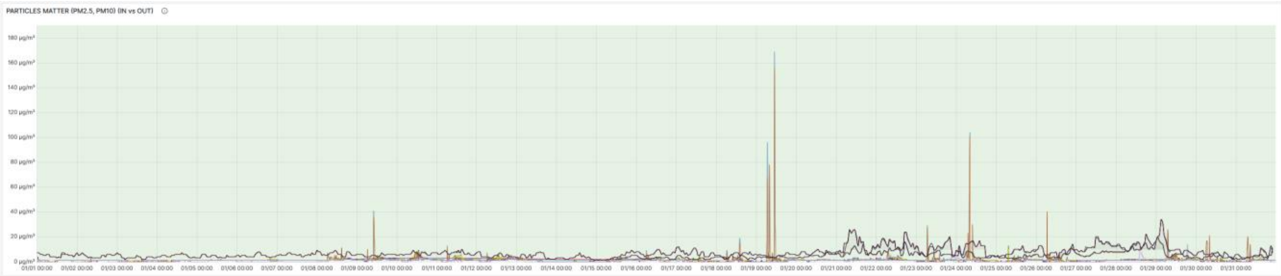

Figure 65. Evolution of PM concentration outdoors and indoors in the canteen in Grimstad between November 2023 to January 2024 (generated with K-HEALTHinAIR platform).

4.1.4 OAQ Massive monitoring Kunak sensors

Data from the locally OAQ measurement station since it was put into service are shown in Table 7. The pollutants concentrations collected by KUNAK AQ station in Grimstad are low as it can be seen in Table 7. As commented before, these values are in coherence with the ones provided by Aerisweather in the studied period.

Table 7. Outdoor pollution and temperature since 31 August 2023.

Parameter	Average	Maximum	Minimum
PM 2.5 [$\mu g/m^3$]	1.71	36.18	0.00
VOC [ppb]	0.84	22.77	0.00
NO_2 [ppb]	7.61	33.22	0.00
Temperature [°C]	5.08	29.72	-15.39

As an additional study, data from the closest official governmental outdoor measurement station Bjørdalssletta, Kristiansand, that is 40 km drive from Grimstad, have been compared with KUNAK data. This comparison is shown in Table 8, which shows the $PM_{2.5}$ concentration in Grimstad is very low compared to Kristiansand, while the NO_2 level are more similar. Also, in Table 8 it is shown the comparison between indoor (INBIOT sensors) and OAQ. This shows the fresh air filtration removes most of the outdoor peek values.

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Table 8. Measured values 8th January 2024 – 28th January 2024 outdoor Kristiansand (KRS) and Grimstad, and indoor in Grimstad. The average outdoor temperature was +0.17 °C (-12.32 – +9.82 °C).

Parameter	$PM_{2.5}$ (1h) [g/m^3]		NO_2 (1h) [g/m^3]	
Outdoor	Average	Max	Average	Max
Bjørndalssletta, NILU, KRS	10.3	51.9	33.1	159.1
UiA, Grimstad	1.6	14.7	27.3	62.5
Indoor				
Canteen				
UiA 01 (Column glass)	1	5	-	-
UiA 04 (dividing halfwall)	1	5	-	-
Fagskolen 01 (big area)	1	3	-	-
Fagskolen 02 (niche)	1	4	-	-
Lecture room				-
UiA 01 (new)	1	3	-	-
UiA 02 (old)	1	6	-	-

4.1.5 VOCs sampling

VOC sampling campaigns have not been started yet.

4.1.6 Formaldehyde sampling

Formaldehyde sampling campaigns have not been started yet.

4.1.7 Questionnaires

Letter of consent has been signed by all staff members. They have not been given access to REDCap yet as we are waiting for 20 students to accepts monitors.

4.1.8 Conclusions

Basal concentrations of indoor pollutants:

1. The preliminary analysis indicates that basal concentrations of indoor pollutants in both canteens are low.
2. Recurrent acute peaks of liberation of formaldehyde and other VOCs have been identified through time series analysis. Indoor, VOC and humidity are the main possible determinants so far.
3. Characterizing these outliers may contribute to identify possible determinants and sources of IAQ health impacts.

Infiltration of outdoor PM:

1. The comparison of the preliminary modelled and measured values for pollution outdoor has shown the model overestimate the PM and underestimate the NO_2.

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2. PM is, regardless this, very low both indoor and outdoor.
3. The NO_2 value from November 2023 to January 2024 are relatively high and an inclusion of August-October increased the average from 20 μg/m³ to 27 μg/m³. This means NO_2 has to be monitored.

4.2 Lecture hall scenario (NO-LEC01, NO-LEC02)

The load of students per m² is expected to have very high values in the lecture halls. This means the students here might be exposed to a significant ratio of the daily amount of pollutants even when the lecture halls are heavily ventilated.

Two frequently used lecture halls at UiA campus, Jon Lilletuns vei 9, were selected for mounting of INBIOT monitors. LEC01 is in the new part from 2010 while LEC02 is in a building from 1982, which was renovated in 2010. 50 students living in the residence halls are connected to the lecture hall scenario and will get the same questionnaire as the residence hall scenario.

Hypothesis H1: Noise as an indicator of the perception of IAQ[33]

4.2.1 IAQ Massive monitoring INBIOT sensors

4.2.1.1 Temperature

The temperature is within an average range of 24 °C in one lecture hall and 22 °C in the other, with a peak reaching almost 16 °C at a specific moment, but quickly recovering. Observing the tVOCs (Figure 70) and formaldehyde (Figure 69) graphs, this moment coincides with a decrease in both parameters to a minimum. This could be attributed to a ventilation event, coupled with the low temperatures outside during this period.

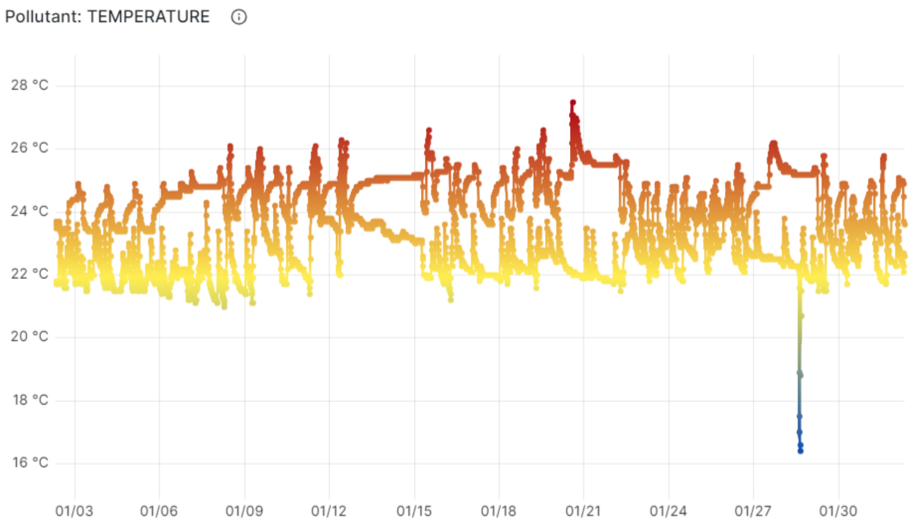

Figure 66. Snapshot of the graphical view of the temperature levels (°C) of INBIOT sensors in the lecture halls in Grimstad in January 2024 (generated with K-HEALTHinAIR platform).

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4.2.1.2 Relative humidity

Similar to the canteens, humidity levels are around 25-35% (Figure 67), below the recommended values (35-65%).

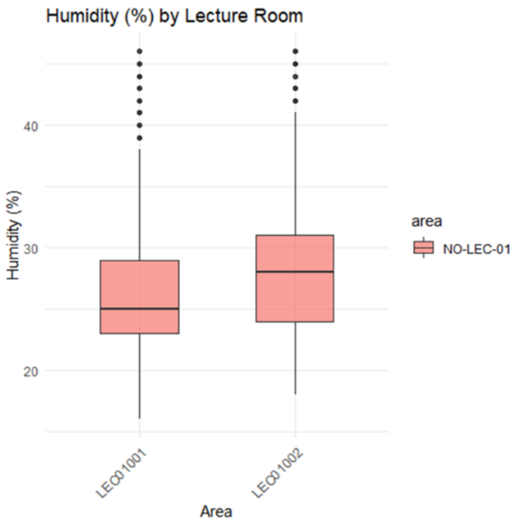

Figure 67. Comparative assessment of the measured RH (%) of INBIOT sensors installed in the lecture halls in Grimstad in January 2024. Values have been taken from myInbiot platform.

4.2.1.3 CO_2

It can be observed in Figure 68 that there is a pattern of CO_2 peaks during the weekdays, occurring in the mornings (in weekdays) in general and at similar levels. There are a couple of exceptions in one of the scenarios, with a higher peak on a day when elevated data is not present in the rest.

The values reached generally remain below the levels stipulated in the guidelines (annexes) of 900 ppm, except for the peak that reaches 2,250 ppm due to some event yet to be determined.

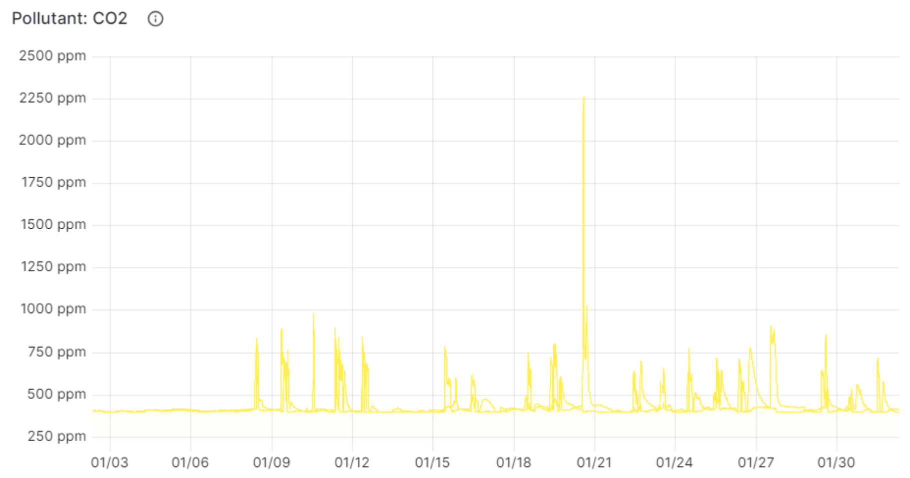

Figure 68. Snapshot of the graphical view of the CO_2 levels (ppm) of INBIOT sensors in the lecture halls in Grimstad in January 2024 (generated with K-HEALTHinAIR platform).

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4.2.1.4 Formaldehyde

Peak formaldehyde concentrations occur during the weekdays. One of the two lecture halls have levels higher than the other during the initial weeks, with peaks reaching a maximum of 35 μg/m^3, although in the last week, both scenarios equalize (Figure 69).

On the other hand, none of these values exceed the guidelines set for formaldehyde (100 μg/m^3 in 30 minutes and 60 μg/m^3 in 8 hours).

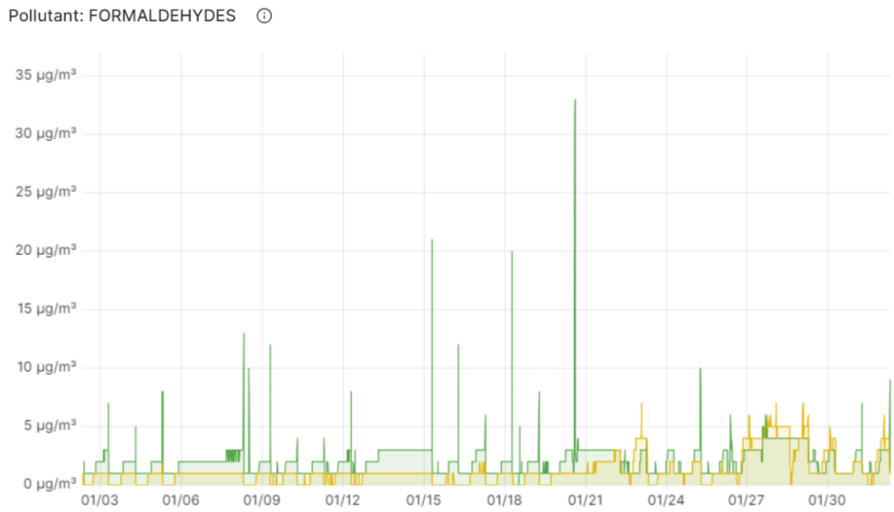

Figure 69. Snapshot of the graphical view of the formaldehyde concentration (μg/m^3) of INBIOT sensors in the lecture halls in Grimstad in January 2024 (generated with K-HEALTHinAIR platform).

4.2.1.5 TVOCs

In Figure 70 and Figure 71, both profiles are similar, with one showing higher levels than the other during the initial weeks and maintaining within the established time period. The other scenario has a lower profile, except for a few peaks at the beginning. However, in the last week, the number and value of these peaks increase, reaching up to 9,000 ppb.

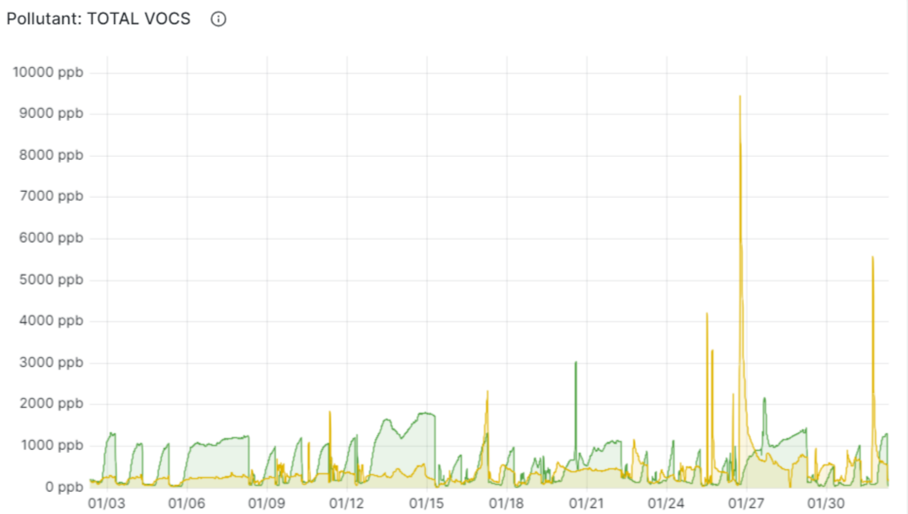

Figure 70. Snapshot of the graphical view of the tVOCs concentration (μg/m^3) of INBIOT sensors installed in lecture halls in Grimstad in January 2024 (generated with K-HEALTHinAIR platform).

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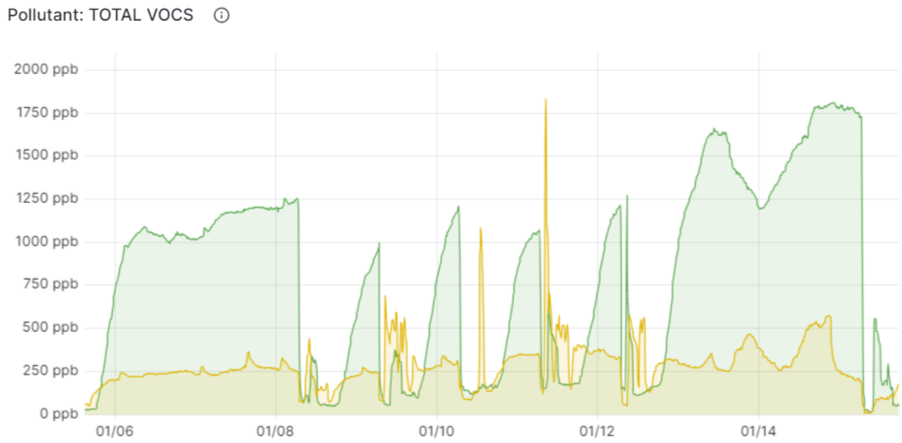

Figure 71. Snapshot of the graphical view of the tVOCs concentration (μg/m³) of INBIOT sensors installed in lecture halls in Grimstad in one week of January 2024 (generated with K-HEALTHinAIR platform).

Regarding the profiles, from Monday to Thursday, clear peaks are visible; however, the level remains stable during the weekends. To expand on the information that can be obtained from these graphs, we will analyze one week instead of one month to better observe the profiles.

As mentioned earlier, sharp declines can be observed in the early morning during weekdays, from Monday to Thursday. On Friday, Saturday, and Sunday, the level remains constant.

Indeed, these values appear to exceed the limits established in the guidelines (annual: 200 $\mu g/m^3$; 8-hour: 600$\mu g/m^3$).

Table 9 is focused on the teaching period from 8th – 28th January 2024 VOCs in which shows that the students who use the room between 08:00 and 16:00 only will be exposed to low values of the contaminants VOC and formaldehyde.

Indeed, these values appear to exceed the limits established in the guidelines (annual: 200 $\mu g/m^3$; 8-hour: 600 $\mu g/m^3$) (Table 2).

Table 9. Average values for VOCs and formaldehyde during workhours and complete days 8th - 28th January 2024.

	VOC [ppb]				Formaldehyde [$\mu g/m^3$]			
	Average		Maximum		Average		Maximum	
Lecture rooms	24/7	WH	24/7	WH	24/7	WH	24/7	WH
UiA 01 (new)	702	209	3,049	1,274	2	1	18	10
UiA 02 (old)	454	241	9,441	4,206	1	0	6	1

4.2.1.6 PM

Due to the format of this platform, the coordinate axis cannot be adjusted, making this parameter less noticeable. In general, the values of the Figure 72 are minimal (0-1 mg/m³), with the maximum value being 14 mg/m³.

These values remain below the limits established by the guidelines ($PM_{2.5}$: Annual: 5 $\mu g/m^3$, 24-hour: 15 $\mu g/m^3$; PM_{10}: Annual: 15 $\mu g/m^3$, 24-hour: 45 $\mu g/m^3$).

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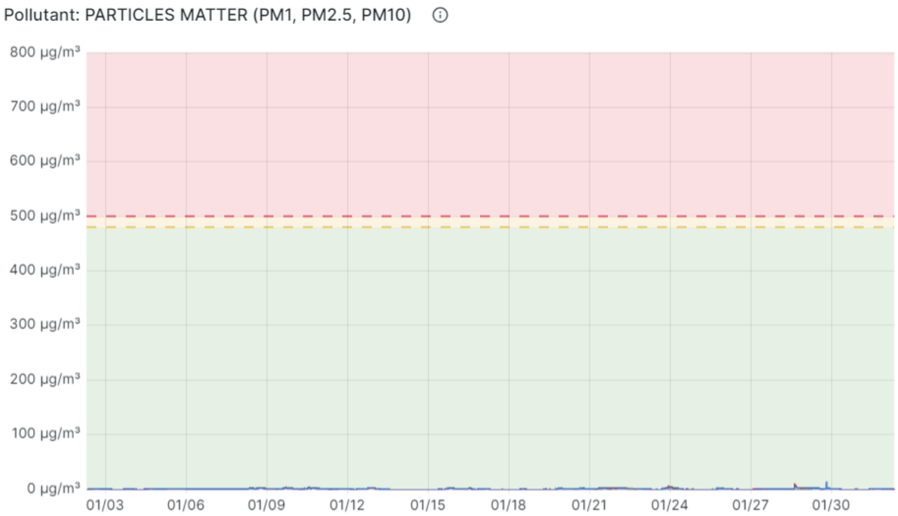

Figure 72. Snapshot of the graphical view of the PM levels (µg/m³) of INBIOT sensors in the lecture halls in Grimstad in January 2024 (generated with K-HEALTHinAIR platform).

As a brief summary, the results from the start of the measurement campaign from October 2023 to the end of January 2024 are shown in Table 10. Table 10 shows again the possible determinants might be VOC and humidity. Here the temperature in addition, might give an increased number of dissatisfied users.

Table 10. Average and median values from INBIOT monitoring sensors from 18th October 2023 to 31st January 2024.

Parameter	Mean (SD)	Median (IQR)	Max	Limits
Temperature (°C)	23.5 (1.29)	23.5 (22.3 - 24.6)	26.8	-
Relative Humidity (%)	27.19 (5.17)	26 (24 - 30)	46	-
CO_2 (ppm)	446.02 (103.89)	411 (404 - 438)	1,776	900 (ppm) – 1h
Formaldehyde (µg/m³)	2.54 (2.98)	1 (1 - 3)	25	60 (µg/m³) – 8h
TVOC (ppb)	675.33 (735.68)	404 (194 - 944)	12,058	600 (µg/m³) – 8h / Aprox. 130 ppb
PM_1 (µg/m³)	0.58 (0.66)	1 (0 - 1)	5	-
$PM_{2.5}$ (µg/m³)	0.64 (0.69)	1 (0 - 1)	5	5 (µg/m³) - Annual
PM_4 (µg/m³)	0.65 (0.69)	1 (0 - 1)	5	-
PM_{10} (µg/m³)	0.65 (0.69)	1 (0 - 1)	5	15 (µg/m³) - Annual

4.2.2 OAQ modelled data from AerisWeather

See the canteen scenario as the canteen are relatively centrally located between the student's residence halls, Section 4.1.3.

4.2.3 OAQ Massive monitoring Kunak sensors

See Section 4.1.4, where the results of all scenarios of Norway are shown.

4.2.4 VOCs sampling

This sampling is not carried out yet, waiting for recruitment of students.

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4.2.5 Formaldehyde sampling

This sampling is not carried out yet, waiting for recruitment of students.

4.2.6 Questionnaires

Questionnaires have not been deployed yet, waiting for recruitment of students.

4.2.7 Conclusions

Basal concentrations of indoor pollutants:

1. The preliminary analysis indicates that basal concentrations of indoor pollutants in the lecture halls are generally low.
2. Recurrent acute peaks of liberation of formaldehyde and other VOCs have been identified through time series analysis. Indoor.

Infiltration of outdoor PM (similar than canteen because locations are near):

1. The comparison of the preliminary modelled and measured values for pollution outdoor has shown the model overestimate the PM and underestimate the NO_2.
2. PM is, regardless this, very low both indoor and outdoor.
3. The NO_2 value from November 2023 to January 2024 are relatively high and an inclusion of August-October increased the average from 20 $\mu g/m^3$ to 27 $\mu g/m^3$. This means NO_2 has to be monitored.

4.3 Students residence scenario (NO-RES01, NO-RES02, NO-RES03, NO-RES04, NO-RES05, NO-RES06, NO-RES07, NO-RES08)

In this scenario, characterize deeply the IAQ and OAQ for 20 students living in 8 separate buildings (RES01-RES08) at UiA campus and close to the center of Grimstad. It is buildings of different age with separate heating, ventilation and air conditioning (HVAC) systems. The scenario extensively monitors both indoor and outdoor air quality and through questionnaires uncover health effects among students in the project lifetime. The questionnaire includes quality of life, mental health, and sick building symptoms, in addition to the time spent home/canteen/outdoor. The target group are 20 students (young adults). The selected students have bedsits or single room apartments with combined living room and sleeping room, i.e., most of their time home is covered by IAQ monitors.

It is expected that there will relatively big differences between the individual student's IAQ. To what extent do they cook hot food home, do they dry laundry indoor, have plants, pets, and how much do they open their windows? Noise and poor IAQ might disturb sleeping. This question will be explored with questionnaires and IAQ monitors from IoT fabrikken measuring sound, presence in addition to T, RH, CO_2, TVOC and light.

Hypothesis H1: Main factor influencing mental health, QoL, and sick building syndrome (SBS).

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Hypothesis H2: Correlation between IAQ and location, day of the year, precipitation, wind velocity, heating source, ventilation system, building age, etc.

Hypothesis H3: Comparison of OAQ Measurements: AerisWeather vs Kunak.

Hypothesis H4: Impact of noise and IAQ sleep quality.

4.3.1 IAQ Massive monitoring INBIOT sensors

No monitors have been installed yet due to delay in recruitment of students willing to have monitors.

4.3.2 IAQ Massive monitoring IoT fabrikken sensors

The IoT fabrikken monitors are waiting for recruitment of students. An example of measurement is shown in Figure 73.

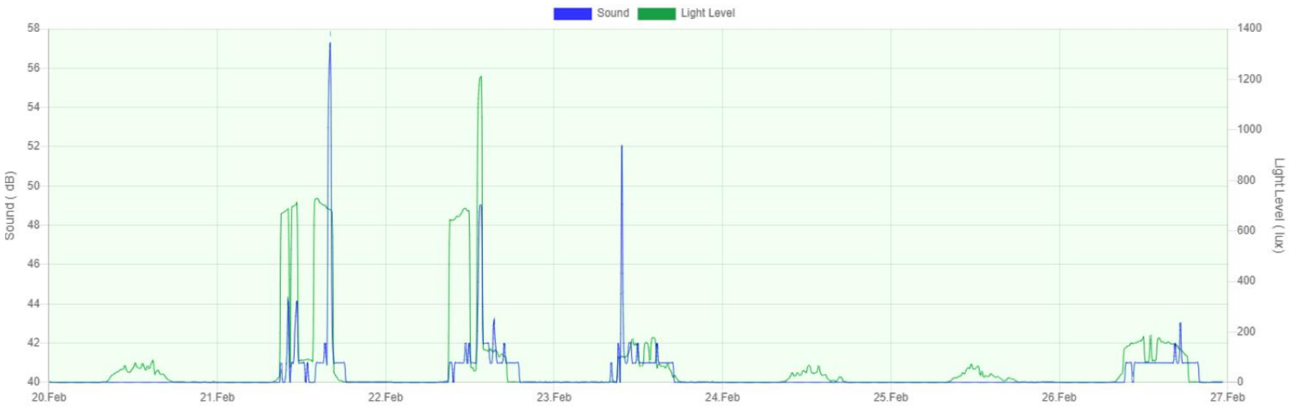

Figure 73. Development of sound and light level for UiA staff office measured with an IoT Fabrikken IAQ monitor.

4.3.3 OAQ modelled data from AerisWeather

See the canteen scenario as the canteen are relatively centrally located between the student's residence halls, Section 4.1.3.

4.3.4 OAQ Massive monitoring Kunak sensors

See Section 4.1.4, where the results of all scenarios of Norway are shown.

4.3.5 VOCs sampling

This sampling will take place after summer holidays.

4.3.6 Formaldehyde sampling

This sampling will take place after summer holidays.

4.3.7 Questionnaires

The questionnaires are waiting for the recruitment of enough interested students.

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5 GERMANY PILOT #4 (DE)

Pilot #4 DE covers second approach of the K-HEALTHinAIR project, focusing on characterising different indoor scenarios through some specific actions:

Analysis of two relevant indoor settings: 2 canteen areas scenario (CAN01, CAN02) including the staff working on them (approx. 10 people), and a lecture hall at Technical University of Munich (TUM) Campus Heilbronn (LEC01).

The results obtained from these two lines of action should lead to identifying potential determinants of indoor air pollution on health status, causality analyses, and, finally, exploration and proposal of preventive actions.

This 18M report does not contain correlation analyses of IAQ and IAQ perception and sick building syndrome, as data from questionnaires are still insufficient. As a result, comprehensive correlation analyses between IAQ and questionnaires results have yet to be conducted. However, despite this limitation, preliminary characterization of the monitored environments can still be performed to provide valuable insights into IAQ profiles and a first screening of potential determinants.

5.1 Canteen scenario (DE-CAN01, DE-CAN02)

Characterize deeply IAQ in 2 canteens (Ludwigsburg Canteen (CAN01) and Ludwigsburg Bistro (CAN02). 10 members of the canteen staff have been studied.

Ensuring the well-being of the canteen customers and their subjective IAQ perception inside the canteen is paramount to this pilot. It is recognized the importance of providing a comfortable and healthy environment to enjoy the lunch experience. As such, pilot 4 is committed to evaluating and improving indoor air quality through proactive measures.

To better understand the needs and preferences of the canteen customers regarding air quality, it is being implementing customer satisfaction questionnaires. These questionnaires will allow us to gather valuable feedback on their perception of air cleanliness, comfort, and overall well-being during their time in the canteen. By collecting this data, it is also aim to identify areas for improvement and tailor the approach to improve the IAQ improvement strategies.

In addition to gathering customer feedback to correlate with IAQ data, it is also going to be explored the implementation of efficient air purification and filtration solutions. These solutions will help to enhance indoor air quality by removing airborne contaminants and allergens, ensuring a fresher and healthier environment.

The hypothesis supporting this research are the following:

Hypothesis H1: Validation and effect of different air purifiers and filtration technology on IAQ in the CAN scenario.

Hypothesis H2: Influence of IAQ on non-specific complaints (SBS-Sick Building Syndrome).

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Hypothesis H3: Microbiome in indoor air and its impact on occupant health.

5.1.1 IAQ Massive monitoring M+H sensors

The M+H sensors provide real-time data of T, CO_2, TVOCs, RH, PM_1, $PM_{2.5}$ and PM_{10}. From the Figure 74 to Figure 78, these pollutants can be observed over the last week in the canteens. It is important to note that these results constitute preliminary findings.

Statistical analysis of the data could not be conducted because the *qlair platform*[6], which provides sensor information, does not yet allow for the download of recorded data. Additionally, as mentioned earlier, the project platform is still under development and does not have this functionality either. This analysis will be conducted later on.

Below is a preliminary analysis to assess the existing possibilities. Although the records obtained are considered, the analysis presented does not aim to establish any conclusions at this point. A greater amount of recorded information and a deeper analysis involving more comprehensive correlation studies are required.

5.1.1.1 Temperature

All canteens have temperatures between 19 °C and 24 °C, except one canteen, reaching 25 °C and 26 °C. The lowest temperatures hours correspond to the times when the canteens are not in operation, in the early morning and at the weekends (Figure 74).

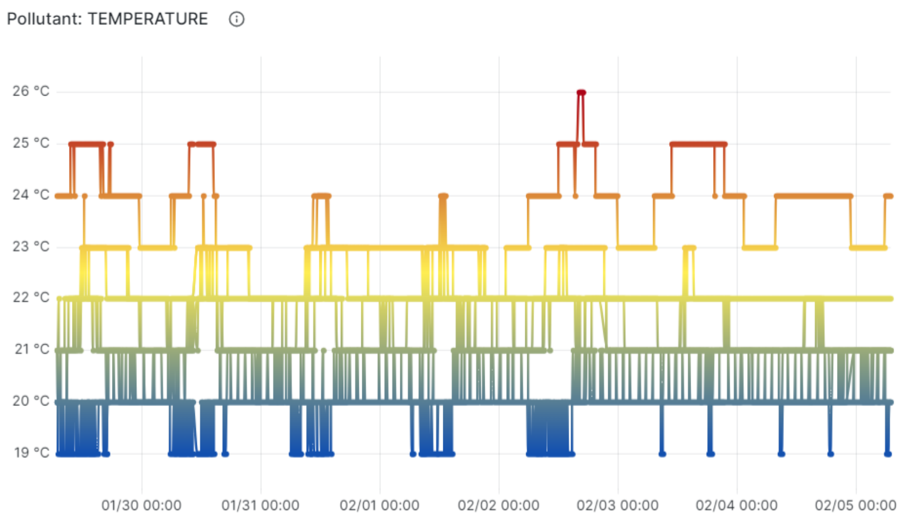

Figure 74. Snapshots of the graphical view of the T levels (°C) in the canteen in Ludwigsburg (generated with K-HEALTHinAIR platform).

5.1.1.2 Relative humidity

Humidity is between 30 and 70%, which is within the ideal indoor humidity range, although there is one canteen that is between this limit and below it constantly, and another that at times exceeds it (Figure 75).

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[6] https://i-qlair.com/ Platform that provides information from kaiterra sensors.

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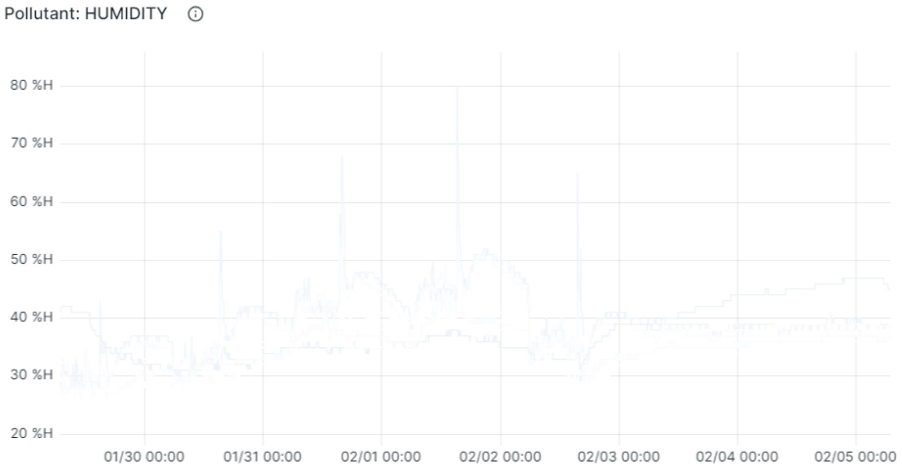

Figure 75. Snapshots of the graphical view of the RH levels (%) in the canteen (generated with K-HEALTHinAIR platform).

5.1.1.3 CO_2

The CO_2 levels show peaks corresponding to the moments of activity in the canteen during the mornings throughout the week (Figure 76). These levels do not exceed 900 ppm, established as limit values by the HVAC system.

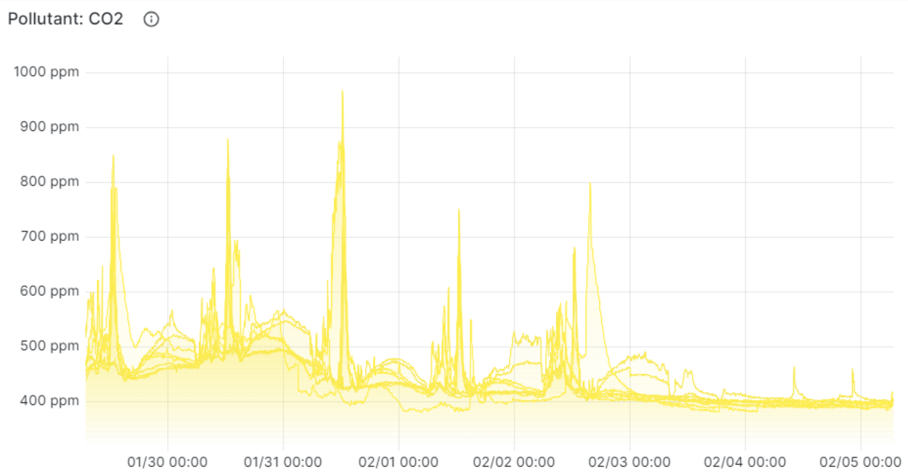

Figure 76. Snapshots of the graphical view of the CO_2 levels (ppm) in the canteen in Ludwigsburg (generated with K-HEALTHinAIR platform).

5.1.1.4 TVOCs

In the Figure 77 of one of the last weeks, isolated peaks can be observed around 12:00 am, coinciding with lunchtime. This tendency is repeated over the weeks. In the afternoons, high levels are reached in some canteens, but in general these values are lower than those detected in the mornings, except for the 31st of this week when, due to an event to be determined, the TVOCs reached levels of 7,500 ppb in one of the canteens.

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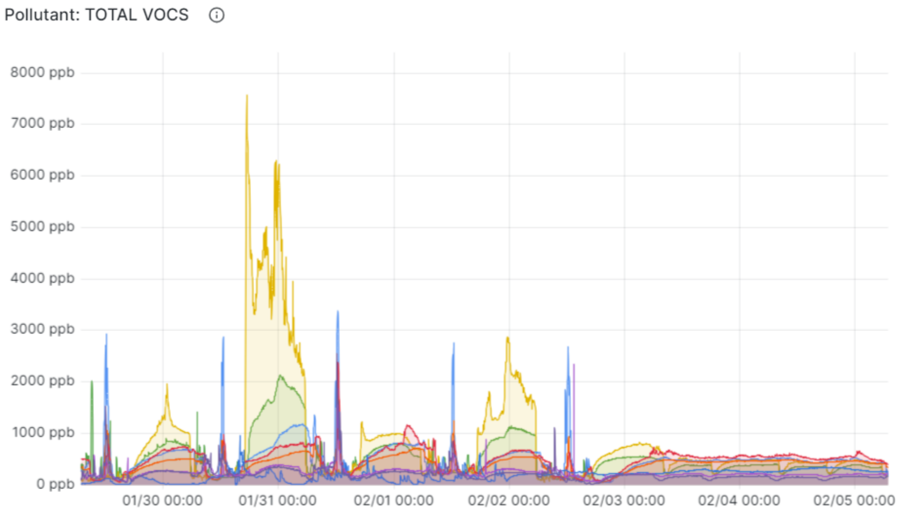

Figure 77. Snapshots of the graphical view of the TVOCs concentration (ppb) in the canteen in Ludwigsburg (generated with K-HEALTHinAIR platform).

5.1.1.5 PM

Particle levels (Figure 78) follow a similar trend on weekdays, with higher values observed between 7 am and 4 pm across all sensors. During weekends, due to the lack of activity, values remain minimal. In general, the attained values are not excessively high; the maximum includes isolated peaks above 50 µg/m³ (PM_{10}), but typically, they fall within the range of 20-30 µg/m³. The PM_1 and $PM_{2.5}$ values are lower.

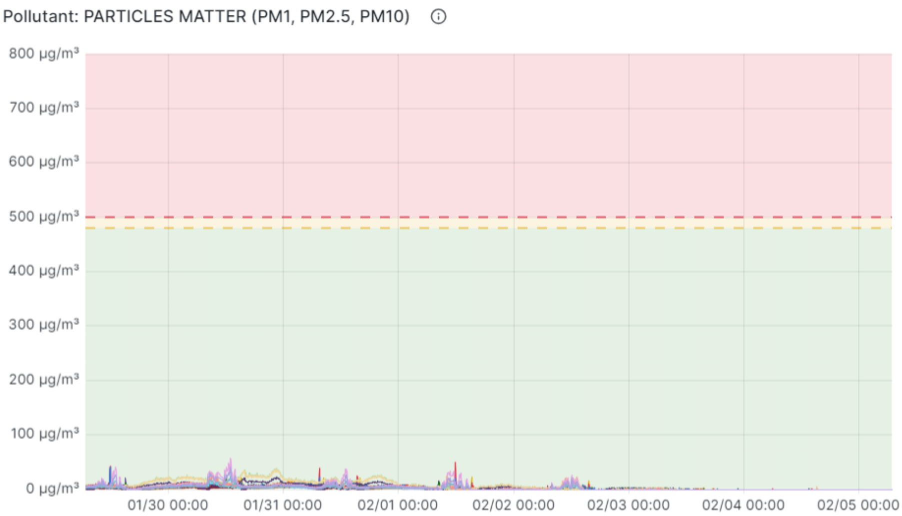

Figure 78. Snapshots of the graphical view of the PM concentration levels (µg/m³) in the canteen in Ludwigsburg (generated with K-HEALTHinAIR platform).

5.1.1.6 Comparison between Norwegian and German canteens

In this point, a preliminary comparison has been made between information in Norwegian and German scenarios. From Figure 79 to Figure 84 show, in yellow, the profile corresponding to the Norwegian canteens. The other colors corresponding to the German canteens.

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As it can be seen in Figure 79, temperature values are in general very similar. Norwegian canteens are very similar to the German average values, although Germany has some canteens with higher values.

In the case of humidity (Figure 80), Norwegian canteens are below those in Germany.

On the other hand, if we compare CO_2 levels (Figure 81), both values follow very similar trends and values.

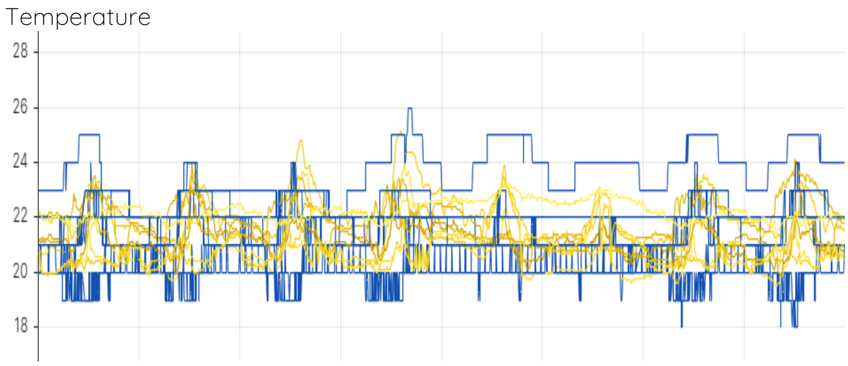

Figure 79. Temperature profiles (ºC) in Norwegian and German canteens during one week in January (generated with K-HEALTHinAIR platform).

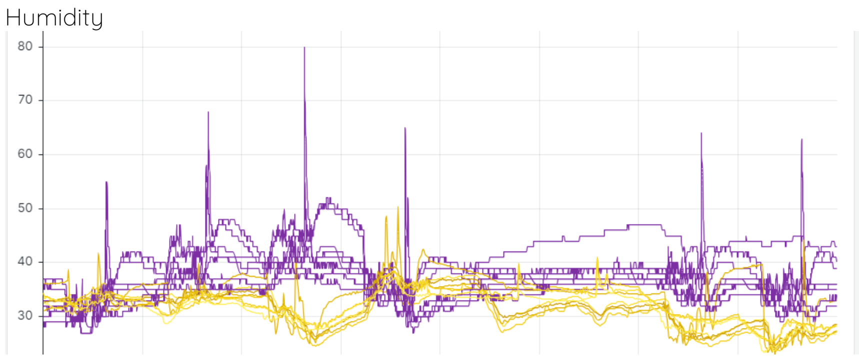

Figure 80. Relative humidity (%) profiles in Norwegian and German canteens during one week in January (generated with K-HEALTHinAIR platform).

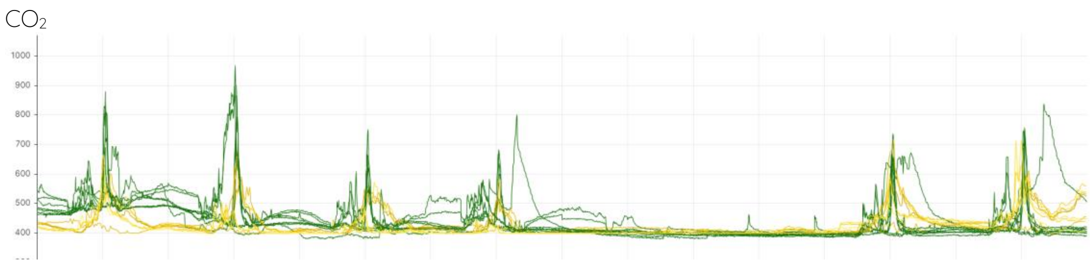

Figure 81. CO_2 concentration (ppm) profiles in Norwegian and German canteens during one week in January (generated with K-HEALTHinAIR platform).

There is not much difference in the TVOCs between the canteens of the two countries (Figure 82), except for one canteen in Norway, which is also out of the ordinary among the other canteens in this pilot. This fact can be easily appreciated by removing that "outlier" canteen from the Figure 83. Although in the German canteens, there are moments with peaks that exceed

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the Norwegian canteens, in general average values for both pilots are very similar, ranged between 100 and 500 ppb. On the other hand, these events where the values are higher, with peaks reaching the maximum ppb in both countries coincide approximately in hours, due to the busiest hours in the canteen (lunch time).

TVOCs

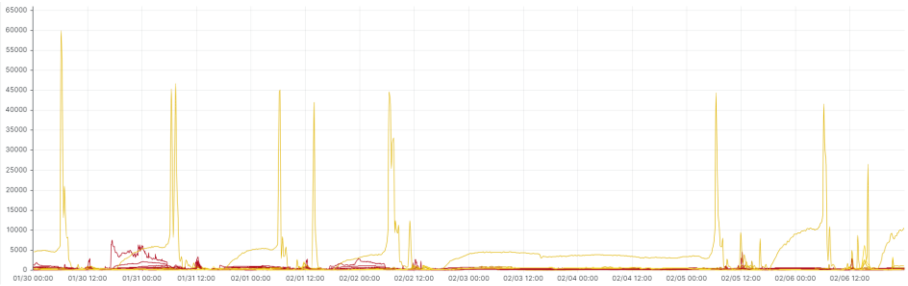

Figure 82. TVOCs concentration (ppb) profiles in Norwegian and German canteens during one week in January (generated with K-HEALTHinAIR platform).

TVOCs

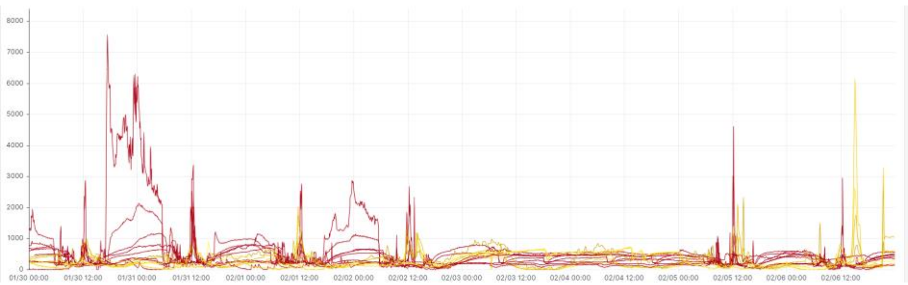

Figure 83. TVOCs concentration (ppb) profiles in Norwegian and German canteens during one week in January removing one the canteens in Norway due to the extraordinary high values (generated with K-HEALTHinAIR platform).

$PM_{2.5}$

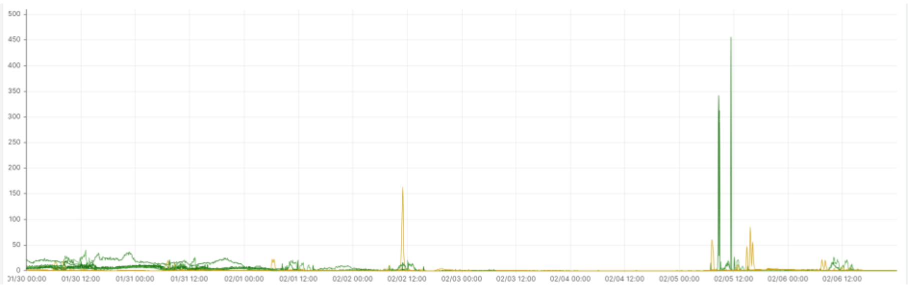

Figure 84. PM concentration (µg/m^3) profiles in Norwegian and German canteens during one week in January (generated with K-HEALTHinAIR platform).

In order to simplify the graphs, $PM_{2.5}$ has been selected to compare the PM profiles in Figure 84. Analyzing the PM profiles of two cantinas from different countries, both exhibiting notable isolated peaks. Germany stands out for having higher peak levels compared to Norway, although both countries show noteworthy peaks. Further analysis into the composition of particles, local emission sources, and environmental factors would be necessary to understand the nuances between the two countries' PM profiles comprehensively.

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5.1.2 OAQ modelled data from AerisWeather

The examination of outdoor pollutants offers insights into the external factors influencing indoor air quality over the observed timeframe. Throughout the analysis, levels of some pollutants were observed, such as PM, CO, O_3, NO_2, alongside fluctuations in humidity and temperature. These parameters pose significant implications in indoor environments, potentially infiltrating and compromising indoor air quality. By integrating data on outdoor pollutants, it can be devised proactive measures to mitigate their impact, ensuring occupants' well-being and fostering healthier indoor environments.

As shown in Deliverable D1.2, information regarding outdoor air quality has been collected on the platform since the start of monitoring. However, functionalities of the platform that enable the analysis of this information and, more importantly, facilitate clear comparisons between indoor and outdoor environments to identify potential correlations are still being developed.

The analysis of OAQ information around the German canteens in Ludwigsburg will begin by evaluating the overall profiles for the period from June to December 2023.

5.1.2.1 Temperature

The examination of outdoor pollutants offers insights into the external factors influencing indoor air quality over the observed timeframe. Throughout the analysis, levels of some pollutants were observed, such as PM, CO, O_3, NO_2, alongside fluctuations in humidity and temperature. These parameters pose significant implications in indoor environments, potentially infiltrating and compromising indoor air quality. By integrating data on outdoor pollutants, it can be devised proactive measures to mitigate their impact, ensuring occupants' well-being and fostering healthier indoor environments.

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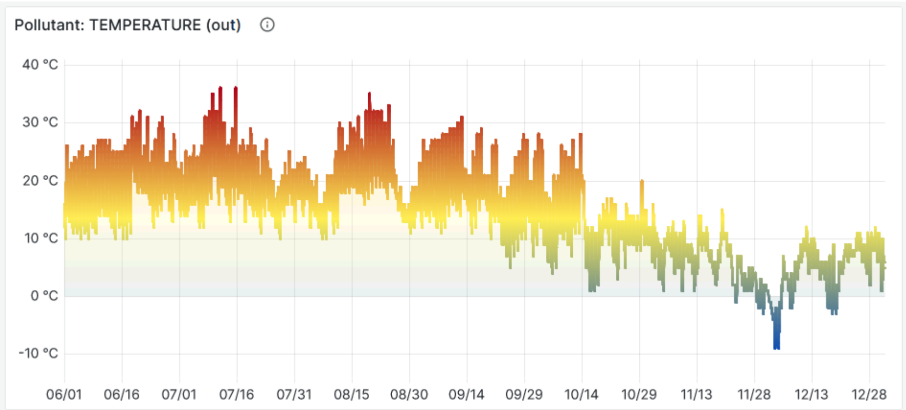

Figure 85. Outdoor temperature data (°C) provided by Aerisweather platform in the German canteens between June and December 2023 (generated with K-HEALTHinAIR platform).

The analysis of outdoor air quality information around the German canteens will begin by evaluating the overall profiles for the period from June to December 2023 (Figure 85). The

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outdoor temperature graph provides an important insight into the external environmental conditions during the period analyzed. It is observed that temperature fluctuations ranging from -10 °C as the minimum (in cold season) to 35 °C as the maximum in summer time. These variations can impact indoor environment management, as significant changes in outdoor temperature can affect ventilation efficiency and thermal comfort inside.

5.1.2.2 Relative humidity

Throughout the evaluation of Figure 86, outdoor humidity levels fluctuated between 20% and 100%, depending on the season. Outdoor humidity plays a significant role in shaping indoor air quality dynamics. Monitoring these levels is crucial for understanding potential impacts on indoor environments. Humidity levels can influence the growth of mold and mildew, as well as the comfort and health of occupants. Therefore, a comprehensive understanding of both temperature and humidity patterns is essential for effective indoor environment management. Anyway, both the temperature and relative humidity outdoors are within normal ranges for the city of Ludwigsburg.

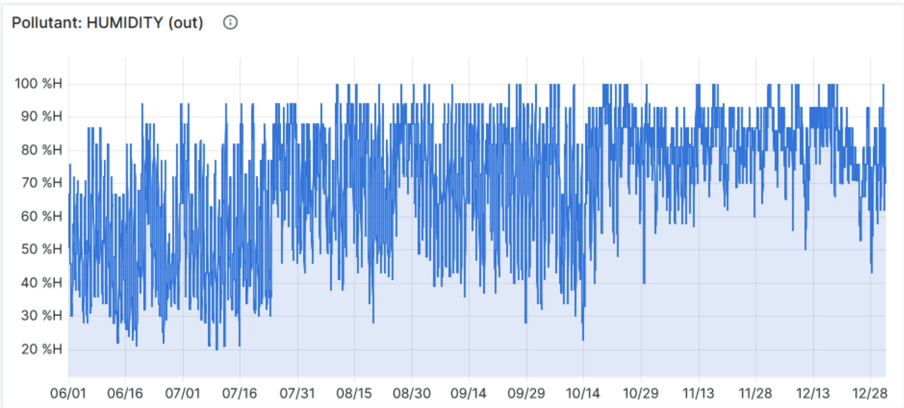

Figure 86. Outdoor RH data (%) provided by Aerisweather platform in the German canteens between June and December 2023 (generated with K-HEALTHinAIR platform).

5.1.2.3 CO

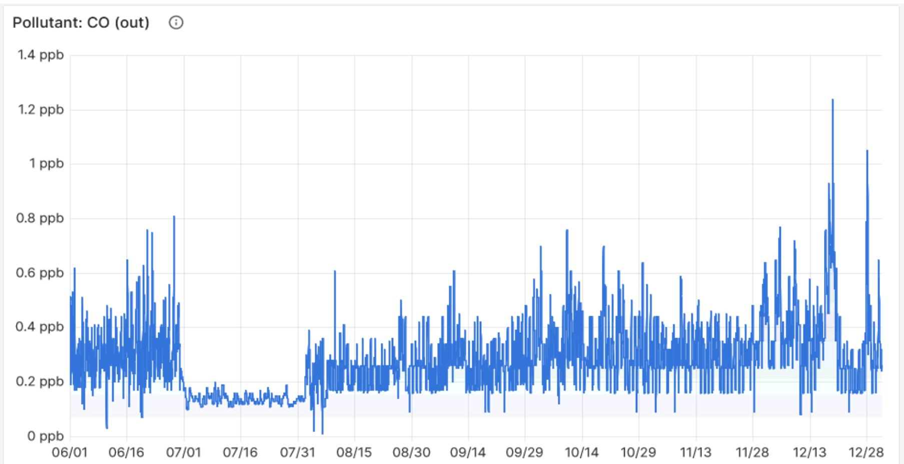

Figure 87. Outdoor CO concentration (ppb) provided by Aerisweather platform in the German canteens between June and December 2023 (generated with K-HEALTHinAIR platform).

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CO levels in Figure 87 fluctuated between 0.2 and 0.8 ppb, with an occasional spike up to 1.2 ppb. Given the provisions outlined in European legislation (Directive 2008/50/EC of the European Parliament and of the Council, dated 21 May 2008, regarding ambient air quality and promoting cleaner air for Europe), which stipulate that outdoor average values over an 8-hour period should not surpass 10 mg/m^3 (equivalent to 8 ppb), it can generally be concluded that indoor air quality should not be adversely affected by this pollutant.

5.1.2.4 O_3

The concentration of tropospheric ozone exhibits significant variability both seasonally and daily in Figure 88. Typically, during the summer months (when there are higher concentrations of volatile organic compounds and, especially, increased solar UV radiation), O_3 concentrations are higher compared to autumn or winter. Additionally, ozone levels typically increase with increasing solar irradiation.

The values collected for the outdoor area of the canteen range from nearly zero to some concentration peaks of more than 70 µg/m^3. The most restrictive limit levels are those recommended by WHO. They recommend not exceeding an average value of 60 µg/m^3 over six months and not exceeding 100 µg/m^3 as an average value over 8 hours. As can be seen, so far, the six-month average values have not been exceeded, and it will be necessary to analyze more closely if there are periods of exceeding the 8-hour values along the year. This will be carried out when the platform allows for this functionality.

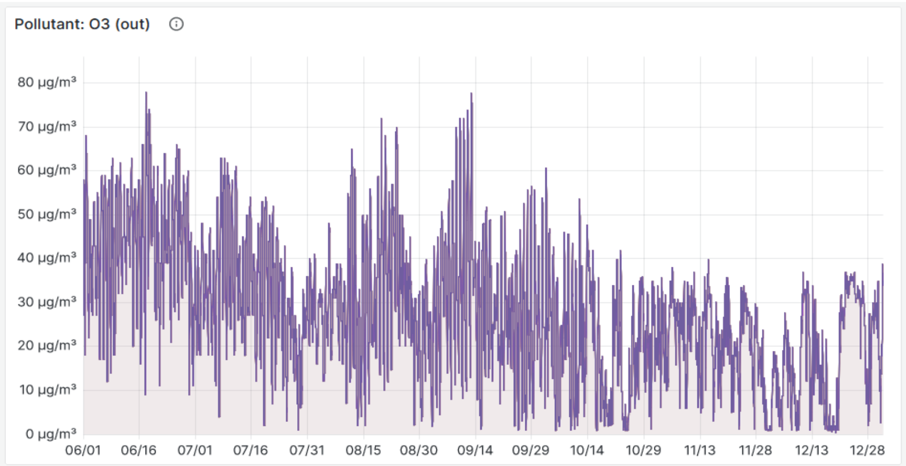

Figure 88. Outdoor O_3 concentration (µg/m^3) provided by Aerisweather platform in the German canteens between June and December 2023 (generated with K-HEALTHinAIR platform).

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5.1.2.5 PM

Regarding the concentration of PM in Figure 90, the profiles collected range from nearly zero to some notable peaks. Based on the general trend, it can be visually established that the average value may be close to 10-15 µg/m^3, especially during the summer season. These high concentrations of particulate matter are of concern, as they can penetrate indoor spaces, potentially compromising indoor air quality. Monitoring and addressing outdoor PM levels are crucial for maintaining a healthy indoor environment for occupants.

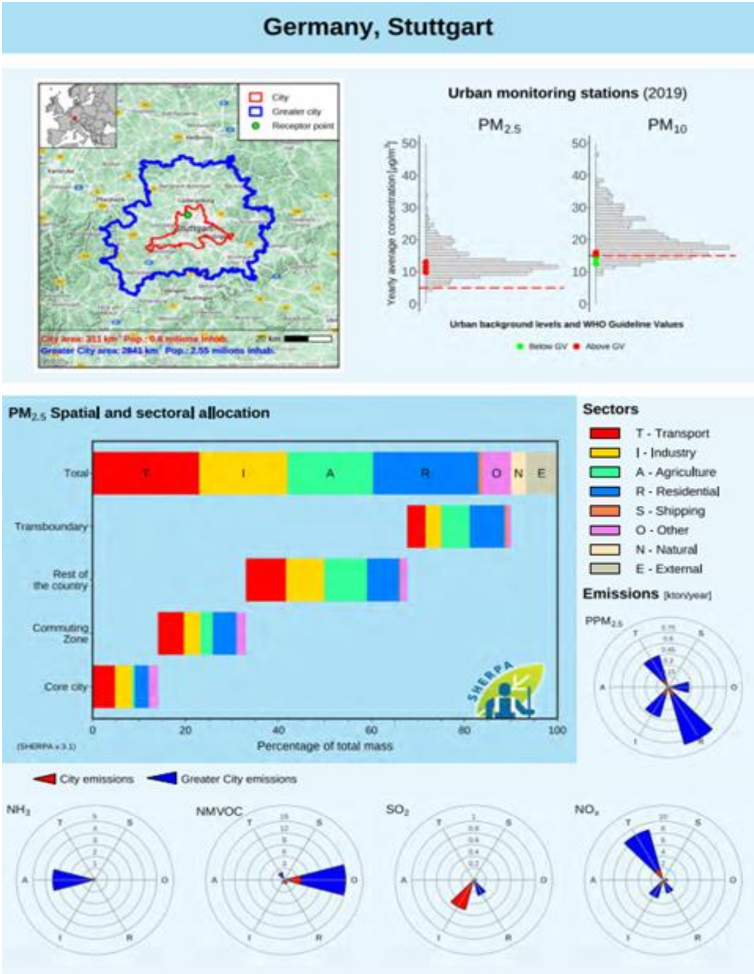

Figure 89. $PM_{2.5}$ pollution in Stuttgart (Germany). Urban PM2.5 Atlas, Air Quality in European Cities, 2023 Report p. 138[20].

These values are relevant because they exceed the recommended values by WHO (5 µg/m^3 annual average and 15 µg/m^3 average over 24 hours, see Table 2. Figure 2, which are the most stringent, but they are also in the vicinity of those set by European legislation (Directive 2008/50/EC of the European Parliament and of the Council, of 21 May 2008, on ambient air quality and cleaner air for Europe) for $PM_{2.5}$ at 25 µg/m^3 as average of 24 hours.

This analysis will be improved once the platform allows to see how much the mentioned limits are exceeded, and the influence of these on the indoor will be examined. As an additional source of information, Urban $PM_{2.5}$ Atlas, Air Quality in European Cities[20] has been consulted for the city of Stuttgart, due to its proximity to Ludwigsburg (see Figure 89). It is interesting to assess the origin of the particles: Residential sources stand out as the primary contributors, comprising a significant portion of the total. Following closely behind is traffic, which also plays a substantial role in air pollution. Furthermore, it is noteworthy to highlight the considerable influence of industrial and agricultural sources, whose impact is significant and approaches that of road traffic. This diversity of sources underscores the complexity of the air pollution issue and emphasizes the need to address multiple aspects to mitigate its effects on air quality.

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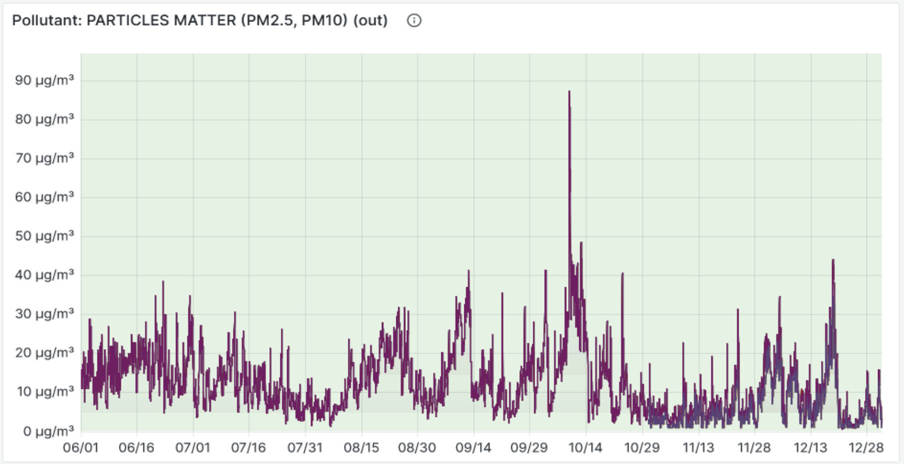

Figure 90. Outdoor PM concentration ($\mu g/m^3$) provided by Aerisweather platform in the German canteens between June and December 2023 (generated with K-HEALTHinAIR platform).

5.1.2.6 NO_2

In relation to NO_2 (Figure 91), levels initially reach up to 40 ppb, with other notable peaks observed throughout the period. It seems that the average value does not exceed considering the recommendations suggested by WHO (10 $\mu g/m^3$ annual average, 25 $\mu g/m^3$ average over 24 hours, and 200 $\mu g/m^3$ as an hourly average), but this requires a deeper analysis when the platform allows it.

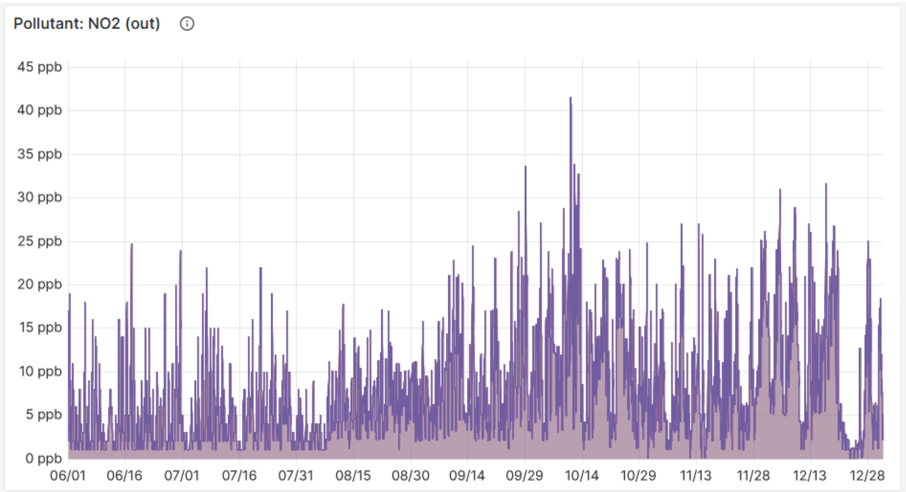

Figure 91. Outdoor NO_2 concentration data (ppb) provided by Aerisweather platform in the German canteens between June and December 2023 (generated with K-HEALTHinAIR platform).

5.1.2.7 Comparison between indoors and outdoors pollutants

Additionally, as an auxiliary study to be completed later when all the planned functionalities for the platform are developed, the profiles of various common parameters both indoors and outdoors have been graphically evaluated.

As expected, the comparison between indoor (purple line) and outdoor (blue line) temperatures in Figure 92 reveals more significant fluctuations outdoors, ranging from below 0 °C to approximately 10 °C, whereas indoors, temperatures remain relatively constant (20-25 °C).

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However, a correlation between indoor and outdoor temperatures can be seen, because the drops in outside temperature correspond to the drops inside.

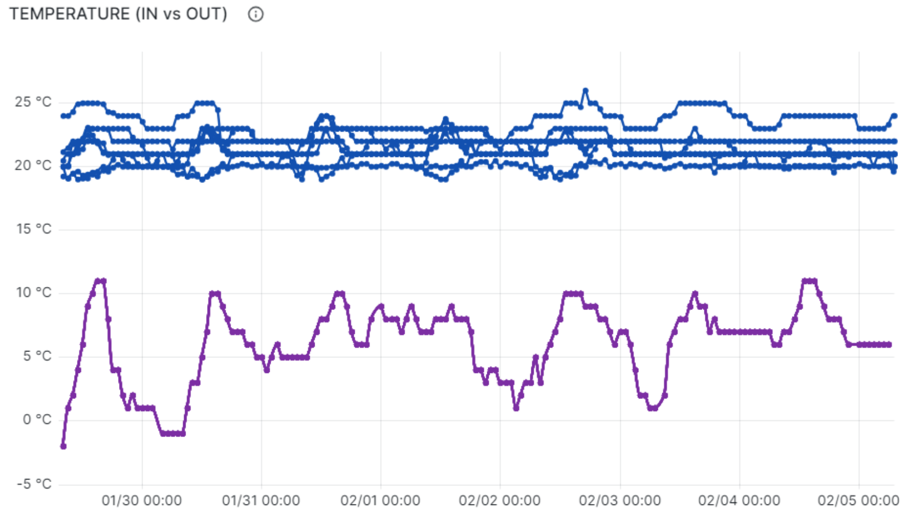

Figure 92. Outdoor and indoor temperatures (°C) in the canteen in Ludwigsburg some days in January 2024 as example (generated with K-HEALTHinAIR platform).

After this preliminary analysis of PM in Figure 93, no correlations indicating significant infiltration of this contaminant from outdoors to indoors were found. The thicker purple and higher line correspond to outdoor values, while the thinner lines represent indoor areas. Always, it can be seen that PM concentrations outdoors are higher than indoors and follow different trends. However, this analysis will be carried out when the platform was fully developed.

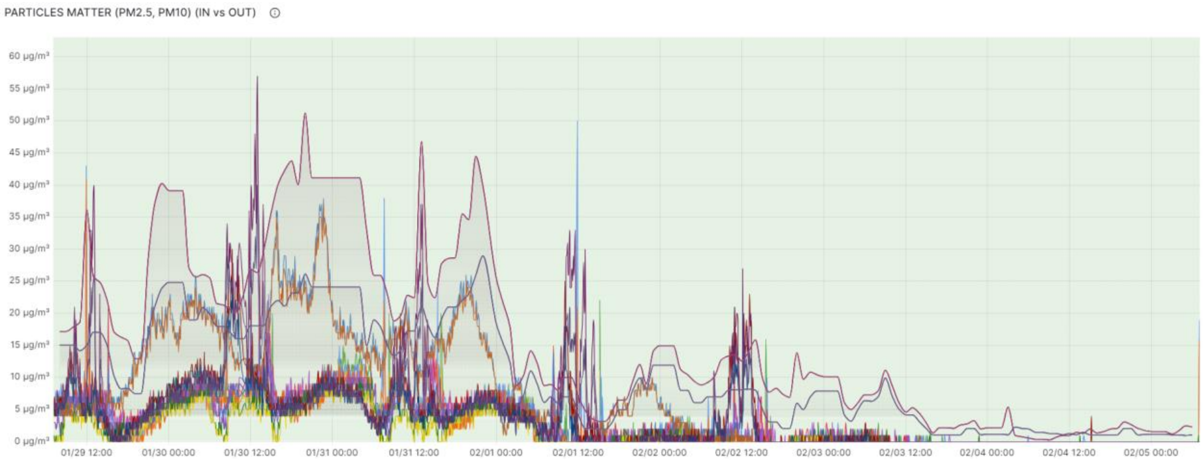

Figure 93. Outdoor and indoor PM concentration (µg/m³) in the canteen in Ludwigsburg some days in January 2024 as example (generated with K-HEALTHinAIR platform).

5.1.3 VOCs sampling

Aldehydes data (VOCs analysis in winter season is still pending at February 24).

Samples for aldehydes measurements were taken in July 2023 (summer session) and January 2024 (winter session). The concentrations of 13 aldehydes (formaldehyde (FA), acetaldehyde (AA), acetone (A), acrolein (A), propionaldehyde (PROP), crotonaldehyde (CROT), 2-butanone

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(2-BUT), methacrolein, butyraldehyde (BUTYR), benzaldehyde (BENZ), valeraldehyde (VALER), tolualdehyde and hexaldehyde (HEX)) were determined by the HPLC-UV method.

The results of the analysis for the canteen scenario and lecture rooms scenario are presented in Figure 94 and Figure 95, respectively.

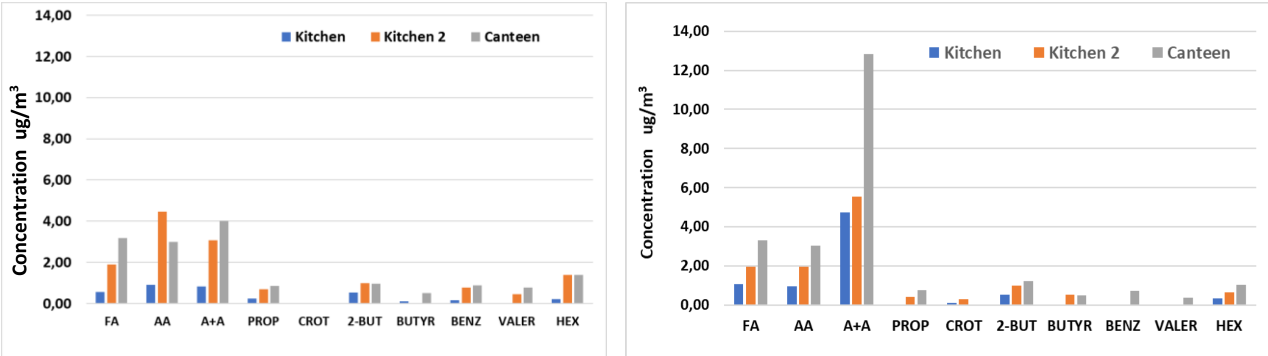

Figure 94. Concentration of aldehydes in indoor air samples taken in July 2023 (left) and January 2024 (right) (Canteen in Ludwigsburg).

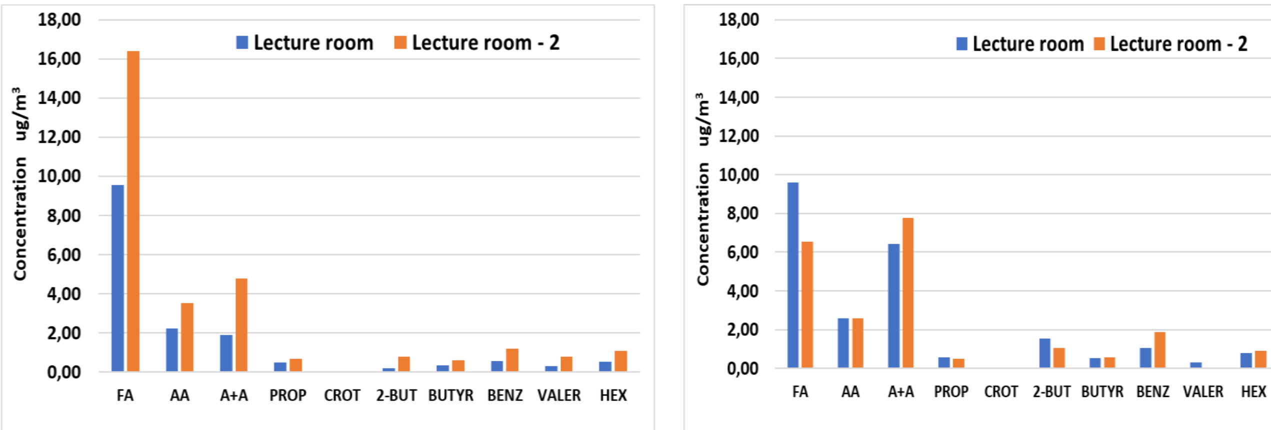

Figure 95. Concentration of aldehydes in indoor air samples taken in July 2023 (left) and January 2024 (right) (lecture hall in Heilbronn).

The analysis of the presented data reveals that, regardless of the sampling time, the most abundant compounds in both scenarios were formaldehyde, acetaldehyde, acetone, and acrolein (as the sum of two compounds). The average content of these four compounds in the sum of the concentrations of all measured aldehydes was 64% and 86% (winter session) and 83% and 80% (summer session) in the canteen and lecture hall, respectively (Table 11).

Figure 96 illustrates the concentrations of formaldehyde, acetaldehyde, and the sum of acrolein and acetone in samples collected in both scenarios during the summer and winter sampling sessions. The concentrations of formaldehyde (the most important compound from a health perspective) measured in the canteen scenario do not exceed 4 μg/m^3, while in the lecture hall scenario, they amounted to 16.4 μg/m^3 (in winter). It should be noted that the measured formaldehyde concentration values were well below the Austrian guideline value of 60 μg/m^3 (8-hour average). In all cases (in both scenarios), the sum of acrolein and acetone

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concentrations was significantly higher in summer than in winter. It appears important to modify the analytical method for aldehydes to be able to determine each of them separately.

Table 11. Mass and percentage content of four compounds (formaldehyde, acetaldehyde, acrolein and acetone) in the total amount of aldehydes determined.

Season	Sampling place	SUM of concentrations of all aldehydes measured	Sum of FA, AA, A+A concentrations	Percent of FA AA A+A	Mean
		µg/m³		%	
Winter	Kitchen	4,0	2,3	56,8	64,1
	Kitchen 2	13,6	9,5	69,3	
	Canteen	15,4	10,2	66,2	
	Lecture room	15,6	13,6	87,4	85,5
	Lecture room - 2	29,5	24,7	83,7	
Summer	Kitchen	7,7	6,8	87,6	82,6
	Kitchen 2	12,1	9,5	78,5	
	Canteen	23,5	19,2	81,6	
	Lecture room	23,0	18,6	81,0	80,0
	Lecture room - 2	21,4	16,9	79,0	

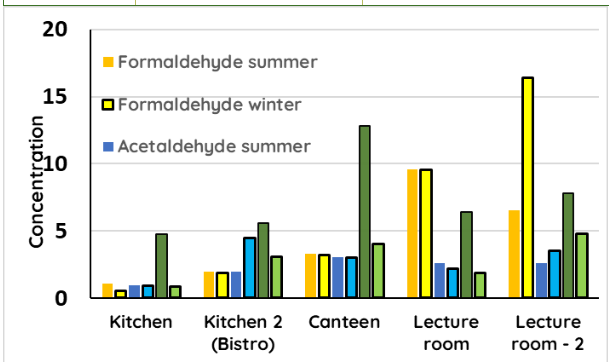

Figure 96. Concentrations of formaldehyde, acetaldehyde and sum of acetone and acrolein in indoor air samples collected during summer and winter sampling sessions in Germany.

5.1.4 PM sampling

The indoor air quality in canteen, kitchen, bistro and the lecture halls in general measured during the sampling campaign conducted in summer season (July 2023) seems to be acceptable. Especially the concentrations of most hazardous PAHs (e.g. BaP, IP, DahA, BghiP) were relatively low or the presence of these compounds was not detected at all (there concentrations were below the limit of quantification). From the group of most hazardous PAHs, only benzo(a)pyrene was detected in one of the lecture halls and indenopyrene in kitchen, but their concentrations were relatively low, as for the short-term measurement. They could be considered as not acceptable, if their concentrations would be at similar level in the long-term time horizon (e.g. a year). It should also be added, however, that the measurement campaign, the results of which are presented here, was carried out in the summer, when generally the concentrations of PM and PM-bound PAHs remain at quite low levels. It might change when comparing with the results

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from the winter campaign, carried out during the heating season. After including them more far-reaching conclusions are expected to be drawn.

5.1.5 Microbiome sampling

So far, only the first results of analyses carried out using culture-dependent methods have been obtained. Sequencing results will be available at a later date due to the time-consuming procedures and the need to sequence all samples using the same libraries.

Preliminary results allow to confirm some of the hypotheses formulated in D.2.2.

1. Total number of microorganisms in indoor air depends on a season (predominance of fungi in summer). However, it is less pronounced than in lecture halls and schools (Pilot 5), due to likely removal of fungi from the inlet air by the HVAC filtering system in canteen.

It is possible to observe in Figure 97 a clear difference between summer and winter in fungi presence, with significantly higher levels in summer. This slightly affects the indoor concentration of fungi, with lower levels in winter, except in one of the areas. The levels of indoor bacteria are higher in summer than in winter. However, unlike before, where there was a noticeable difference outside between these two seasons, this doesn't necessarily translate to the indoors

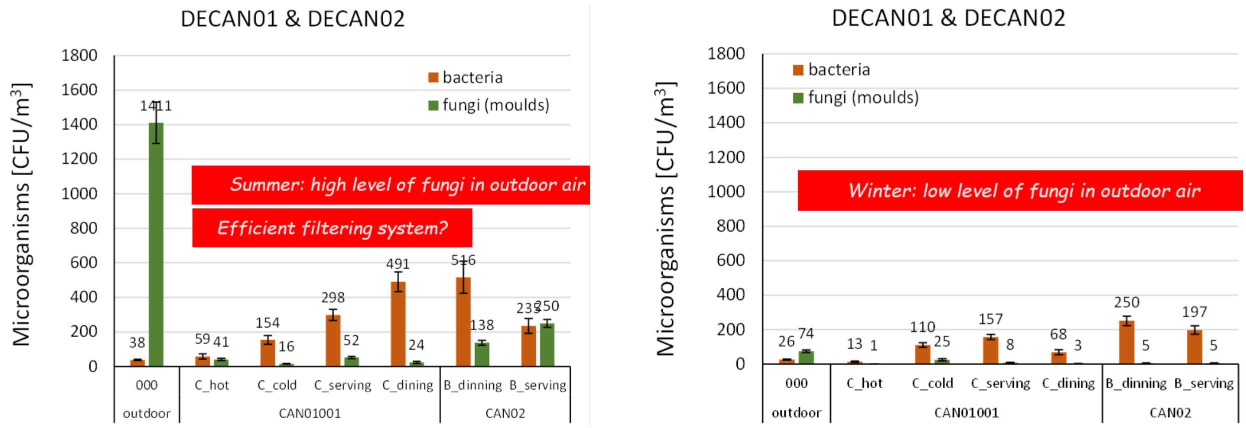

Figure 97. Comparison between canteens in Ludwigsburg in summer and winter.

2. Total number of microorganisms in indoor air depends on occupants' behaviour and ventilation conditions.

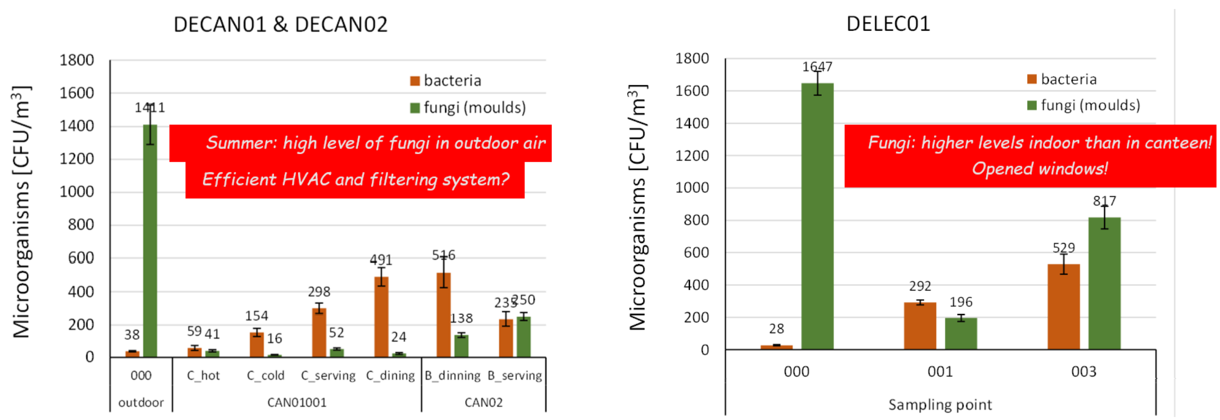

Figure 98. Comparison between German canteen and lecture hall in summer season.

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When comparing the lecture hall and the canteen in Figure 98, both using different ventilation methods, with open windows in the lecture hall and an HVAC system in the canteen, it is observed that the levels of fungi are higher in the lecture hall.

3. People in examined areas are the main source of bacterial contamination of indoor air.

In the different sampling zones, bacteria concentration varied depending on the number of people present, with the dining area showing the highest level of bacteria due to its occupancy (Figure 99).

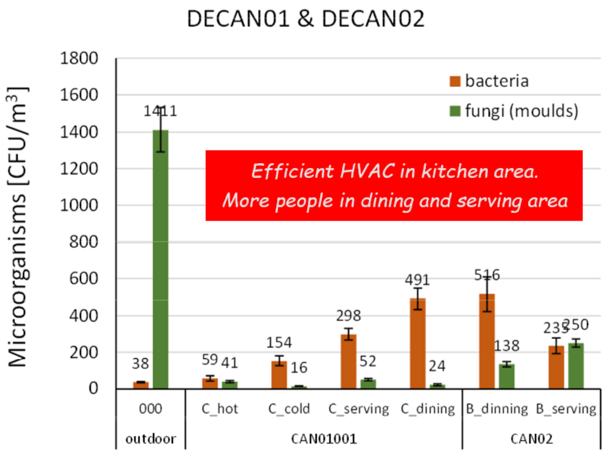

Figure 99. Microorganisms in canteens in Ludwigsburg during summer season.

4. Microbiological contamination of indoor air in schools/lecture halls is higher than in other public buildings.

When comparing a Polish school to German canteens in Figure 100, a striking disparity in bacterial concentration emerges: the bacterial levels in schools far surpass those found in canteens. This intriguing finding raises questions about the environmental factors and activities within schools that may contribute to this discrepancy.

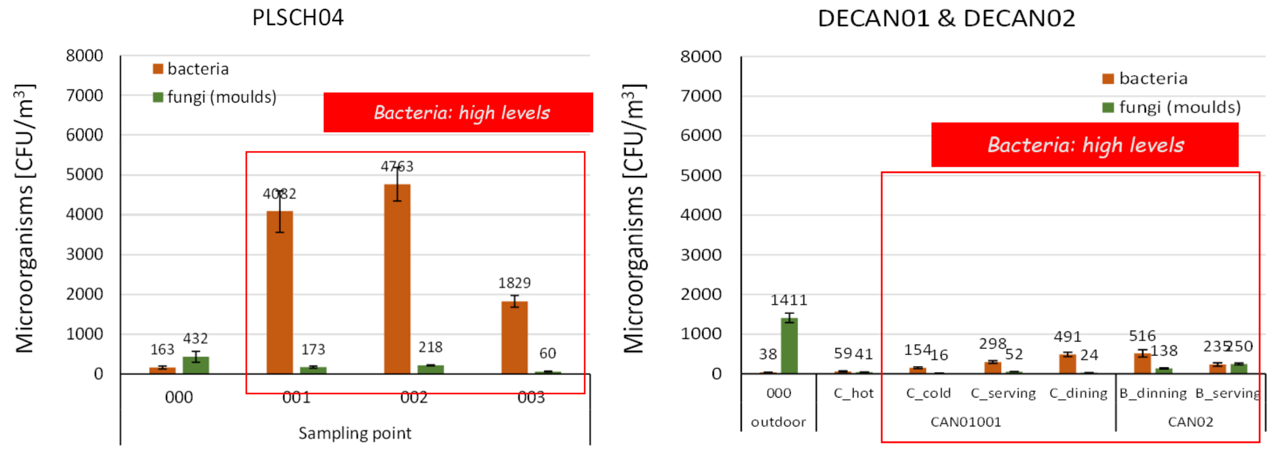

Figure 100. Comparison between German canteens and Polish schools in summer season.

Other hypotheses:

- o Geographical location shapes microbiome composition;

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- o Abundance of specific pathogenic microorganisms in indoor air is not correlated with the level of general microbial contamination;
- o Exposure of children/students and canteen workers/customers to elevated concentrations of microorganisms in indoor air is associated with health problems and unspecific subtle symptoms (e.g. headache, fatigue, low productivity, coughing, sneezing, dizziness, nausea, irritation of the eye, nose, throat, and skin).

These hypotheses will be discussed after obtaining results of DNA sequencing and comparing with data in questionnaires.

5.1.6 Questionnaires

Due to the limit number of questionnaires completed by the canteen team, drawing any conclusions is not feasible at this point. Focus is to establish a robust process to collect data through questionnaires. Risk mitigation measures are described in D1.7.

5.1.7 Conclusions

Basal concentrations of indoor pollutants:

1. The preliminary analysis indicates that basal concentrations of indoor pollutants in both canteens are low.
2. Recurrent acute peaks of liberation of formaldehyde and other VOCs have been identified through time series analysis.
3. No mayor differences have been found until now between Norwegian and German canteens.
4. More data need to be collected from PM and VOCs sampling before concluding.

Infiltration of outdoor PM:

1. After this preliminary study on the outdoor air quality around the canteens' buildings, which, as mentioned, needs to be supplemented later with more information and analysis of the collected data, it appears that of the parameters studied, only particulate matter and perhaps nitrogen dioxide would be contaminants to consider.

Microbiome analysis:

1. High level of bacterial contamination of indoor air indicates: i) low air exchange rate, ii) high occupancy of room,
2. High level of fungal contamination of air indicates: i) summer: immigration of fungi from outdoor air (low efficiency or no air filtration), ii) winter: mouldy building (internal source of fungal contamination)

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5.2 Lecture hall scenario (DE-LEC01)

Delving into the IAQ of the lecture halls at UiA Jon Lilletuns vei 9 (LEC01 and LEC02) is crucial for ensuring the well-being of occupants. These halls, located in different sections of the building, have varying construction periods, with LEC01 originating from 2010 and LEC02 being renovated in 2010 but originally constructed in 1982.

To cover occupants' 24-hour lifestyle, sensors have been strategically placed in the most frequently used lecture rooms for continuous IAQ monitoring. Additionally, satisfaction surveys are being conducted to gather qualitative feedback on air perception, thermal comfort, and overall well-being during lectures. These data and insights will aid in identifying areas for improvement and tailoring IAQ enhancement strategies.

Furthermore, advanced air purification and filtration technologies are being explored to address specific IAQ issues in each lecture hall. The aim is to promote a healthier and more conducive indoor environment for all occupants through effective interventions.

Hypothesis H1: Validation and effect of different air purifiers and filtration technology on IAQ.

Hypothesis H2: Influence of IAQ on non-specific complaints (Sick Building Syndrome - SBS).

Hypothesis H3: Microbiome effects on IAQ and health in lecture halls.

5.2.1 IAQ Massive monitoring M+H sensors

5.2.1.1 Temperature

In general, the average temperature is 21-22 °C (Figure 101), which is within the recommended range.

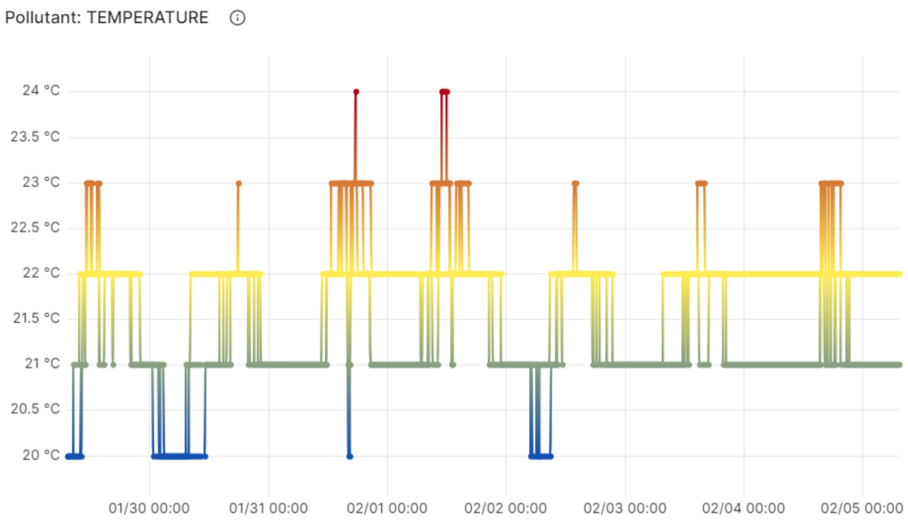

Figure 101. Snapshots of the graphical view of the temperature values (°C) in the lecture hall in Heilbronn (generated with K-HEALTHinAIR platform).

5.2.1.2 Relative humidity

The values are between 27.5 and 45% (Figure 102), which indicates that it is sometimes below the recommended value.

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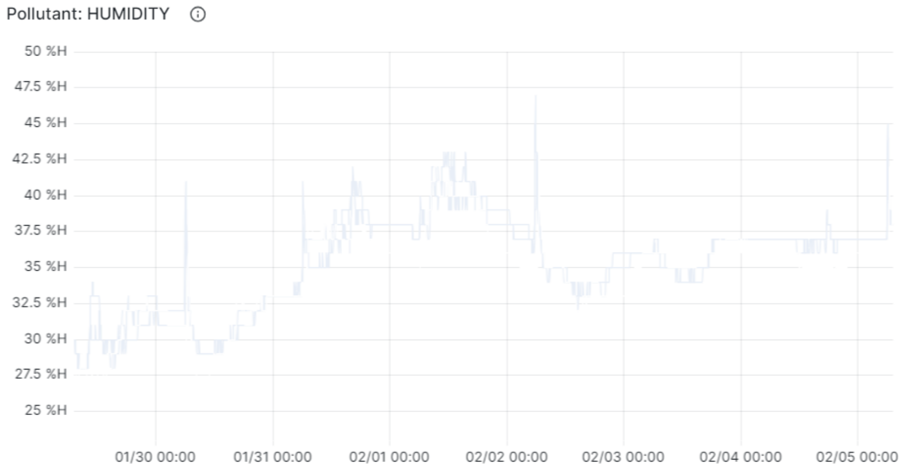

Figure 102. Snapshots of the graphical view of the RH values (%) in the lecture hall in Heilbronn (generated with K-HEALTHinAIR platform).

5.2.1.3 CO_2

The CO_2 levels (Figure 103) in the three scenarios are very similar, both in trend and values. During weekdays, higher levels are observed, attributed to increased occupancy. The average level does not exceed the established limits for CO_2 indoors (900 ppm).

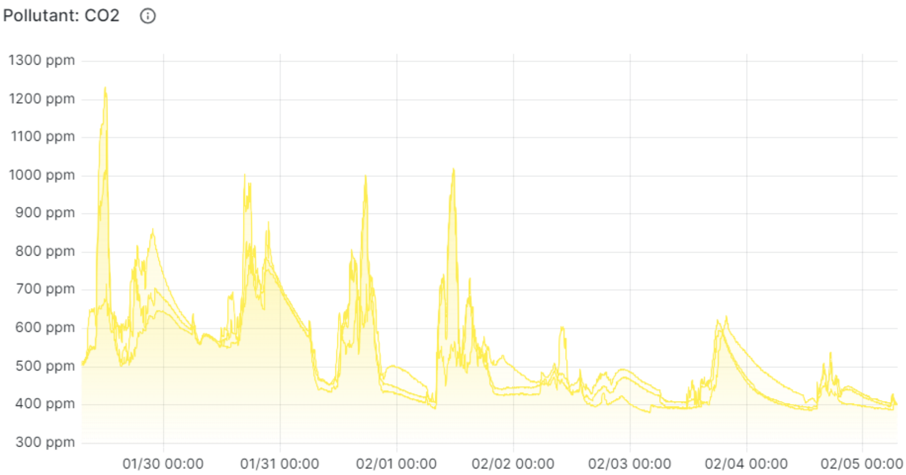

Figure 103. Snapshots of the graphical view of the CO_2 levels (ppm) in the lecture hall in Heilbronn (generated with K-HEALTHinAIR platform).

5.2.1.4 TVOCs

Similar to CO_2, the tVOCs exhibit similar trends in Figure 104, with higher values observed during weekdays. The values are comparable, and this week, there are two instances in which a peak of tVOCs is detected in two lecture halls.

The 8-hour average of tVOC values does not appear to exceed the established limits of 600μg/m^3.

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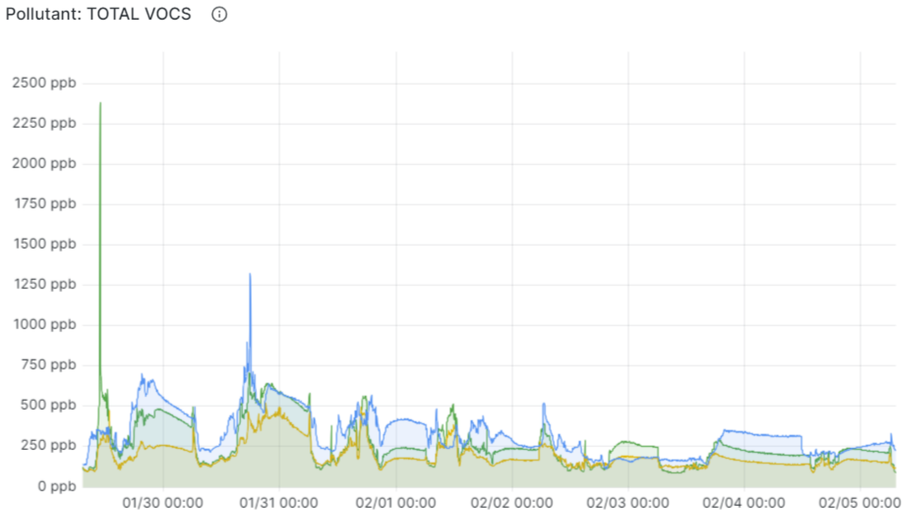

Figure 104. Snapshots of the graphical view of the tVOCs concentration (ppm) in the lecture hall in Heilbronn (generated with K-HEALTHinAIR platform).

5.2.1.5 PM

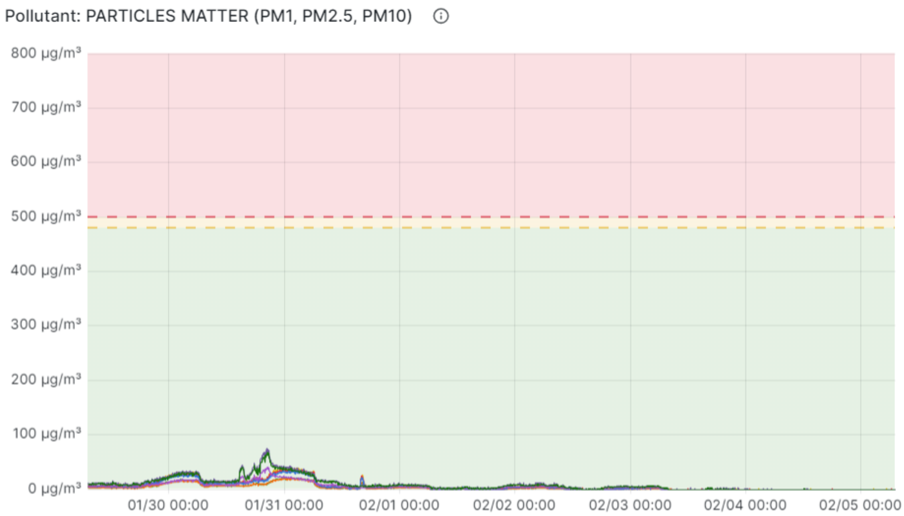

Figure 105. Snapshots of the graphical view of the PM concentration ($\mu g/m^3$) in the lecture hall in Heilbronn (generated with K-HEALTHinAIR platform).

5.2.2 OAQ modelled data from AerisWeather

The analysis of OAQ information around the German lecture hall in Heilbronn will begin by evaluating the overall profiles for the period from June to December 2023.

5.2.2.1 Temperature

The outdoor temperature provides in the Figure 106 an important insight into the external environmental conditions during the period analyzed. It is observed that temperature fluctuations ranging from -10 °C as the minimum (in cold season) to 35 °C as the maximum in summer time. These variations can impact indoor environment management, as significant changes in outdoor temperature can affect ventilation efficiency and thermal comfort inside.

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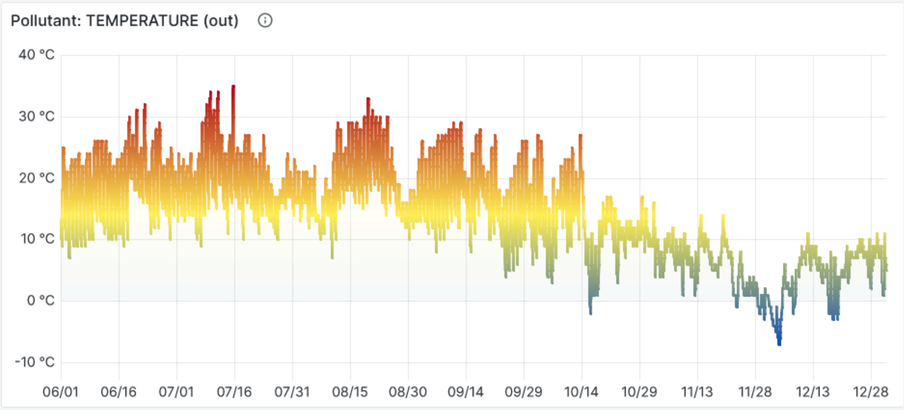

Figure 106. Outdoor temperature data (°C) provided by Aerisweather platform in the lecture hall in Heilbronn between June and December 2023 (generated with K-HEALTHinAIR platform).

5.2.2.2 Relative humidity

Throughout the evaluation of Figure 107, outdoor humidity levels fluctuated between 20% and 100%, depending on the season. Outdoor humidity plays a significant role in shaping indoor air quality dynamics. Monitoring these levels is crucial for understanding potential impacts on indoor environments. Humidity levels can influence the growth of mold and mildew, as well as the comfort and health of occupants. Therefore, a comprehensive understanding of both temperature and humidity patterns is essential for effective indoor environment management. Anyway, both the temperature and relative humidity outdoors are within normal ranges for the city of Heilbronn.

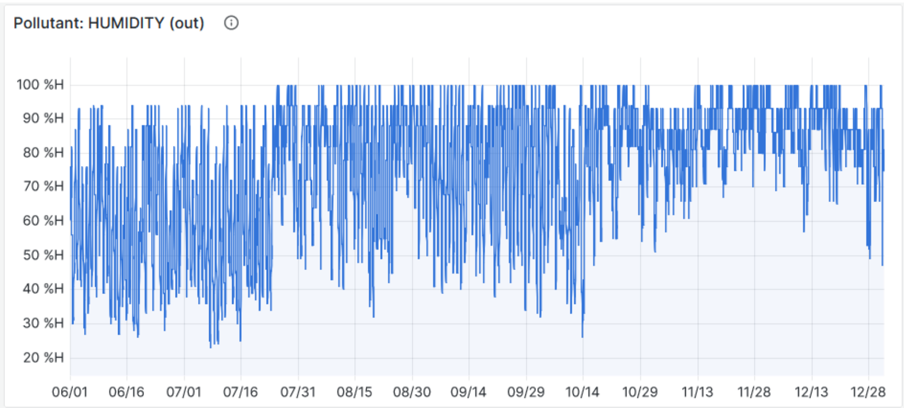

Figure 107. Outdoor relative humidity data (%) provided by Aerisweather platform in the lecture hall in Heilbronn between June and December 2023 (generated with K-HEALTHinAIR platform).

5.2.2.3 CO

CO levels fluctuated between 0.2 and 0.8 ppb, with an occasional spike up to 1.6 ppb (Figure 108). Given the provisions outlined in European legislation (Directive 2008/50/EC of the European Parliament and of the Council, dated 21 May 2008, regarding ambient air quality and promoting cleaner air for Europe), which stipulate that outdoor average values over an 8-hour period should not surpass 10 $\mu g/m^3$ (equivalent to 8 ppb), it can generally be concluded that IAQ should not be adversely affected by this pollutant.

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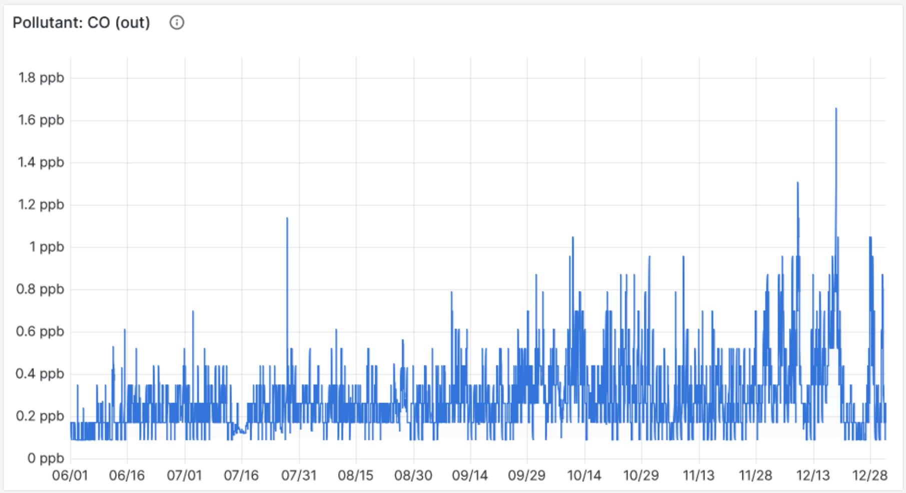

Figure 108. Snapshot of the graphical view of the CO concentration levels (ppb) in the lecture hall in Heilbronn (generated with K-HEALTHinAIR platform).

5.2.2.4 O_3

The concentration of tropospheric ozone exhibits significant variability both seasonally and daily. Typically, during the summer months (when there are higher concentrations of VOCs and, especially, increased solar UV radiation), O_3 concentrations are higher compared to autumn or winter. Additionally, O_3 levels typically increase with increasing solar irradiation.

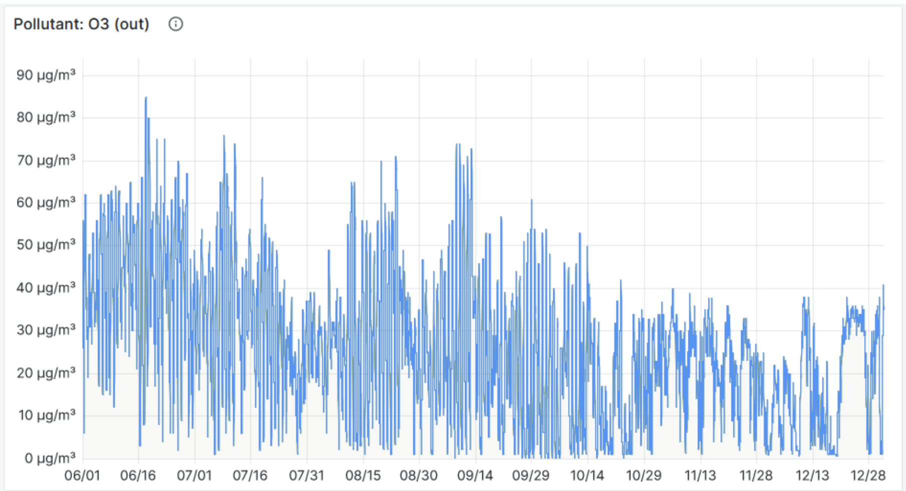

Figure 109. Snapshot of the graphical view of the O_3 concentration levels (µg/m^3) in the lecture hall in Heilbronn (generated with K-HEALTHinAIR platform).

The values collected for the outdoor area of the canteen range from nearly zero to some concentration peaks of more than 75 µg/m^3. The most restrictive limit levels are those recommended by WHO. They recommend not exceeding an average value of 60 µg/m^3 over six months and not exceeding 100 µg/m^3 as an average value over 8 hours. As can be seen in Figure 109, so far, the six-month average values have not been exceeded, and it will be necessary to analyze more closely if there are periods of exceeding the 8-hour values along the year. This will be carried out when the platform allows for this functionality.

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5.2.2.5 PM

Regarding the concentration of PM in Figure 110, the profiles collected range from nearly zero to some notable peaks. Based on the general trend, it can be visually established that the average value may be close to 10-15 µg/m^3, especially during the summer season. These high concentrations of PM are of concern, as they can penetrate indoor spaces, potentially compromising IAQ. Monitoring and addressing outdoor PM levels are crucial for maintaining a healthy indoor environment for occupants.

These values are relevant because they exceed the recommended values by WHO (5 µg/m^3 annual average and 15 µg/m^3 average over 24 hours, see Table 2, which are the most stringent, but they are also in the vicinity of those set by European legislation (Directive 2008/50/EC of the European Parliament and of the Council, of 21 May 2008, on ambient air quality and cleaner air for Europe) for $PM_{2.5}$ at 25 µg/m^3 as average of 24 hours.

This analysis will be improved once the platform allows to see how much the mentioned limits are exceeded, and the influence of these on the indoor will be examined.

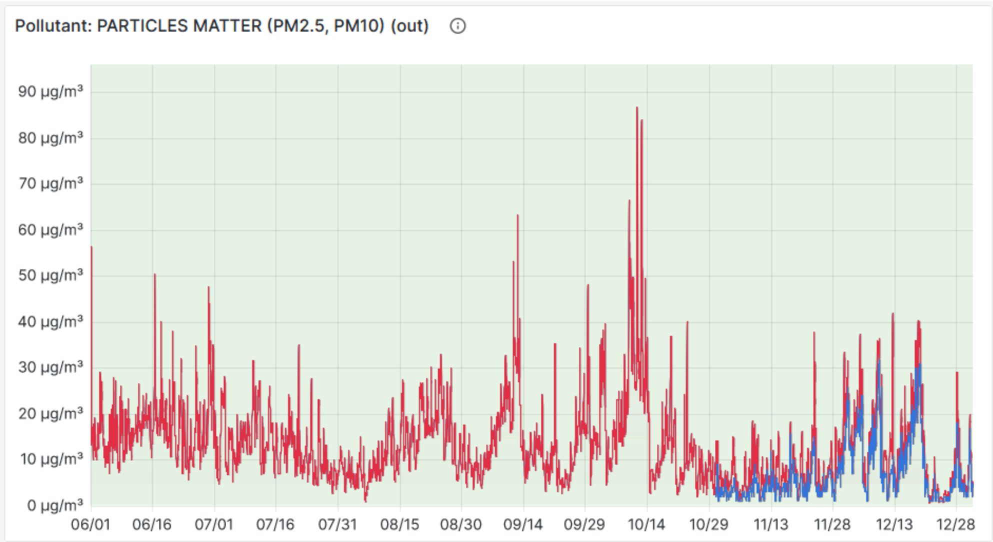

Figure 110. Snapshot of the graphical view of the PM concentration levels (µg/m^3) in the lecture hall in Heilbronn (generated with K-HEALTHinAIR platform).

5.2.2.6 NO_2

In relation to NO_2 (Figure 111), levels initially reach up to 50 ppb, with other notable peaks observed throughout the period. It seems that the average value does not exceed considering the recommendations suggested by WHO (10 µg/m^3 annual average, 25 µg/m^3 average over 24 hours, and 200 µg/m^3 as an hourly average), but this requires a deeper analysis when the platform allows it.

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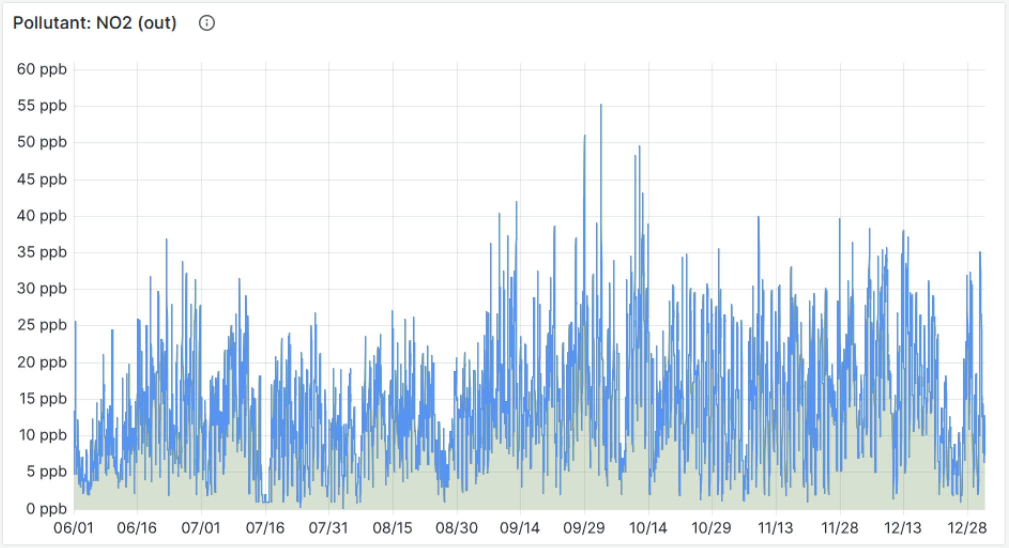

Figure 111. Snapshot of the graphical view of the NO_2 concentration levels (ppb) in the lecture hall in Heilbronn (generated with K-HEALTHinAIR platform).

5.2.3 VOCs sampling

These results have been shown in Section 5.1.3, where there is a comparison between VOCs sampling in canteens and lecture hall.

5.2.4 PM sampling

PM_4 sampling for PAHs assessment in the lecture halls of the TUM Campus Heilbronn was conducted in the same scenario and methods as for kitchen, canteen and bistro. The samples were also taken in July 2023 and January 2024. The samples from January 2024 are still being assessed in the laboratory.

Figure 112 presents the results of PAHs analyses in the lecture halls.

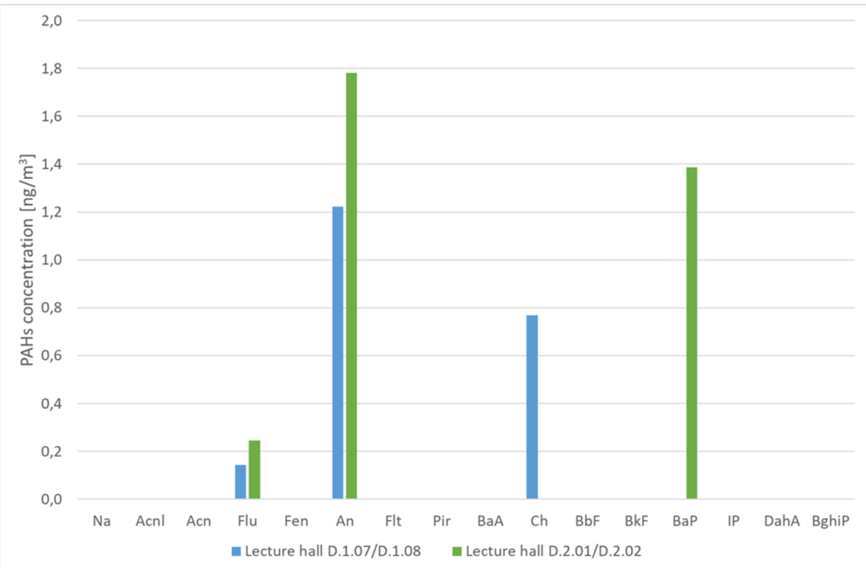

Figure 112. Concentrations of PM4-bound PAHs in 2 lecture halls located in the university buildings in TUM Campus Heilbronn measured in July 2023.

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The indoor air quality in lecture halls in general measured during the sampling campaign conducted in summer season (July 2023) seems to be acceptable. Especially the concentrations of most hazardous PAHs (e.g. BaP, IP, DahA, BghiP) were relatively low or the presence of these compounds was not detected at all (there concentrations were below the limit of quantification). From the group of most hazardous PAHs, only benzo(a)pyrene was detected in one of the lecture halls, but their concentrations were relatively low, as for the short-term measurement. They could be considered not acceptable, if their concentrations would be at similar level in the long-term time horizon (e.g. a year). It should also be added, however, that the measurement campaign, the results of which are presented here, was carried out in the summer, when generally the concentrations of PM and PM-bound PAHs remain at quite low levels. It might change when comparing with the results from the winter campaign, carried out during the heating season. After including them more far-reaching conclusions are expected to be drawn.

5.2.5 Microbiome sampling

So far, only the first results of analyses carried out using culture-dependent methods have been obtained. Sequencing results will be available at a later date due to the time-consuming procedures and the need to sequence all samples using the same libraries.

Preliminary results allow to confirm some of the hypotheses formulated in D.2.2.

1. Total number of microorganisms in indoor air depends on a season (predominance of fungi in summer).

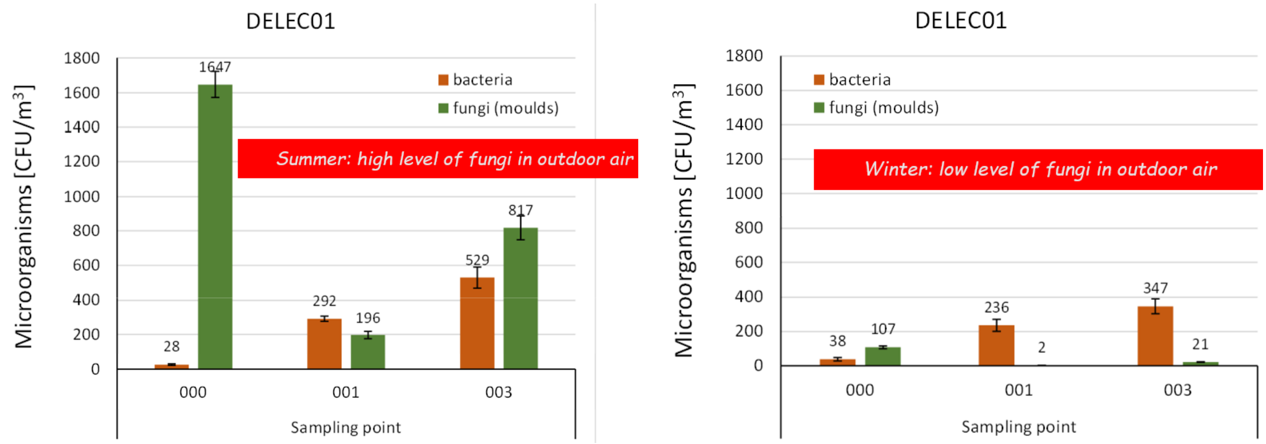

Figure 113. Comparison between lecture hall in Heilbronn in summer and winter.

Similar to what was observed in the German canteens (Figure 97), the concentration of microorganisms in summer in the lecture hall, is much higher than in winter (Figure 113). This is evident when examining the concentration of fungi, both outdoors and indoors.

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3. People in examined areas are the main source of bacterial contamination of indoor air.

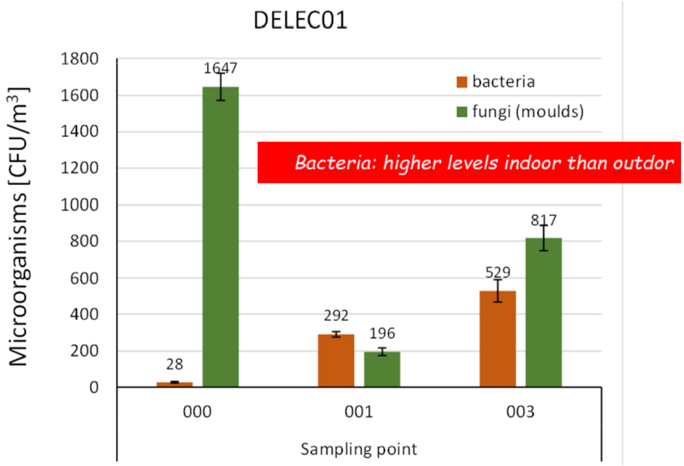

Figure 114. Microorganisms in lecture hall in Heilbronn during summer season.

5.2.6 Questionnaires

The team is in the process of defining and testing questionnaires tailored specifically for this context. The proposed approach involves conducting surveys on sick-building syndrome and IAQ perception every six. The adapted periodicity should help in keeping the engagement of students on a high level. These questionnaires are currently in development and are undergoing testing with a group of pilot students to ensure relevance and effectiveness.

5.2.7 Conclusions

Basal concentrations of indoor pollutants:

1. The preliminary analysis indicates that basal concentrations of indoor pollutants in both canteens are low.
2. More data need to be collected from PM and VOCs sampling before concluding but initially results do not show relevant levels of these pollutants.

Infiltration of outdoor PM:

1. After this preliminary study on the outdoor air quality around the canteens' buildings, which, as mentioned, needs to be supplemented later with more information and analysis of the collected data, it appears that of the parameters studied, only particulate matter and perhaps nitrogen dioxide would be contaminants to consider.

Microbiome analysis:

1. High level of bacterial contamination of indoor air indicates: i) low air exchange rate, ii) high occupancy of room,
2. High level of fungal contamination of air indicates: i) summer: immigration of fungi from outdoor air (low efficiency or no air filtration), ii) winter: mouldy building (internal source of fungal contamination)

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6 POLAND / AUSTRIA PILOT #5 (PL/AT)

This section provides a preliminary overview of the initial records and analysis of results from the pilot study conducted between Poland and Austria. The study aims to examine environmental conditions focusing on two relevant indoor settings: homes (HOM01-HOM05) and schools (SCH01).

· Four homes categories: home heating by solid fuel (wood) (HOM02), home heating by gas (HOM03), home heating by electricity, municipal heating or renewable energy source (HOM05) and newly constructed houses as an additional category without continuous monitoring.

Initially was included also an additional category for homes heated with coal (HOM01) but no houses were found available for this category as explain in D1.7. With the heating with oil (HOM04) happened the same.

Also, the category of the newly constructed houses was also initially planned. However only a few houses could fulfil this requirement. The main interest in recruiting this type of houses was to have a reference of the new constructions and evaluate the VOC emission by the new construction materials. As a contingency measure, it is applied to get data in Austria from more than 1000 newly built homes (covering more than 20 years) data from VOCs measurements. On the other hand, construction age is going to be used as an additional criterion to evaluate the impact of IAQ in all the houses.

Considering the above situation, and after several campaigns to recruit people in the Warsaw and Lodz areas without any success, it is not planned to run measurements for these categories of houses (HOM01&HOM05).

On the other hand, IAQ in relevant environments with high presence of vulnerable groups such as schools and its relationship with acute health events is a critical issue.

Despite these challenges, significant progress has been made in gathering data and conducting preliminary analyses. This report presents initial observations and analyses regarding indoor environmental conditions, setting the stage for further investigation and deeper analysis further on. The findings presented here provide valuable insights into the indoor environmental conditions and their potential implications for health. Further analysis will be conducted to explore these insights in greater detail in the updated version of this deliverable in 12 months (D1.4 - M30).

6.1 Homes scenario (PL/AT-HOM02, PL/AT-HOM03, PL/AT-HOM04, PL/AT-HOM05)

This scenario studies the variability of IAQ and determinants depending on the heating system, and its impact in dwellers' health. Homes has been enrolled according to different criteria considering heating sources, cooking systems or the age of the house. More details about the characteristics of homes can be found in Deliverables 1.7 and 1.2.

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Due to the lack of sufficient information to conduct an in-depth analysis at this point, as mentioned earlier, a series of simple considerations and analyses will be made with the information available at present.

Hypothesis H1: Study the differences (if present) of IAQ in HOMES with DIFFERENT HEATING SYSTEMS. The following methodology will be applied to determine if it influences IAQ.

Hypothesis H2: The health risk assessment. Comparison of the risks of selected health outcomes (based on literature review) among residents of the HOMES with different HEATING SYSTEMS.

Hypothesis H3: IAQ and/or OAQ affect the health and well-being of residents.

6.1.1 IAQ Massive monitoring M+H sensors

The IAQ extensive monitoring initiative within the home setting involved the installation of 59 Kaiterra and MICA-INBIOT sensors strategically positioned in three distinct types of homes with different heating systems:

- Home heating using other solid fuels (HOM02) (Poland: 8 sensors, Austria: 10 sensors).
- Home heating using natural gas and oil (HOM03) (Poland: 10 sensors, Austria: 11 sensors).
- Home heating using electric energy or renewable energy sources (e.g. heat pump) (HOM05) (Poland: 13 sensors, Austria: 7 sensors).

The sensors provide real-time data of T, CO_2, TVOCs, humidity, particle matter (PM_1, $PM_{2.5}$, PM_{10}) and formaldehyde (only with MICA-INBIOT sensors). Statistical analysis of the data could not be conducted because the *qlair platform*[7], which provides sensor information, does not yet allow for the download of recorded data. Additionally, as mentioned earlier, the project platform is still under development and does not have this functionality either. This analysis will be conducted later on. Below it is showed a preliminary analysis to assess the existing possibilities. Although the records obtained are considered, the analysis presented does not aim to establish any conclusions at this point. A greater amount of recorded information and a deeper analysis involving more comprehensive correlation studies are required.

Firstly, an analysis of the monthly evolution of the various parameters allows to assess the overall level in the different houses of that parameter and make an initial identification of the houses with levels that need to be studied.

6.1.1.1 Temperature

Figure 115, Figure 116 and Figure 117 display a comparative assessment of the temperature across the three types of monitored houses. The temperatures in the different houses don't show noticeable changes, so conclusive conclusions cannot be drawn. It can be said that in the natural gas houses, the maximum and minimum temperatures seem to be slightly higher than in the rest of the houses and in houses with electric heating systems, the maximum and minimum temperatures are the lowest. In this report, only several days of the sampling period have been

[7] https://i-qlair.com/ Platform that provides information from kaiterra sensors.

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graphed to facilitate understanding of the figure. However, similar relationships between house types can be found throughout the entire period.

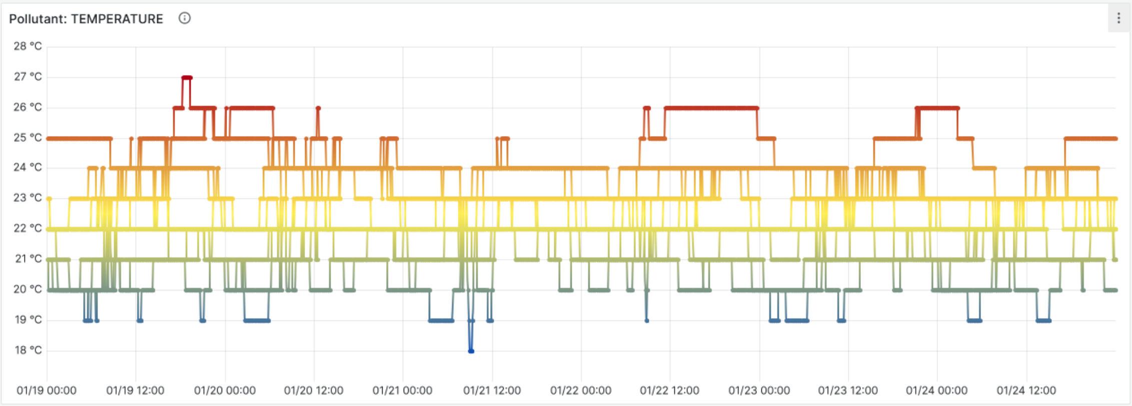

Figure 115. Snapshot of the graphical view of the T data (℃) collected of M+H sensors in the home's locations (as a whole) with solid fuels (generated with K-HEALTHinAIR platform).

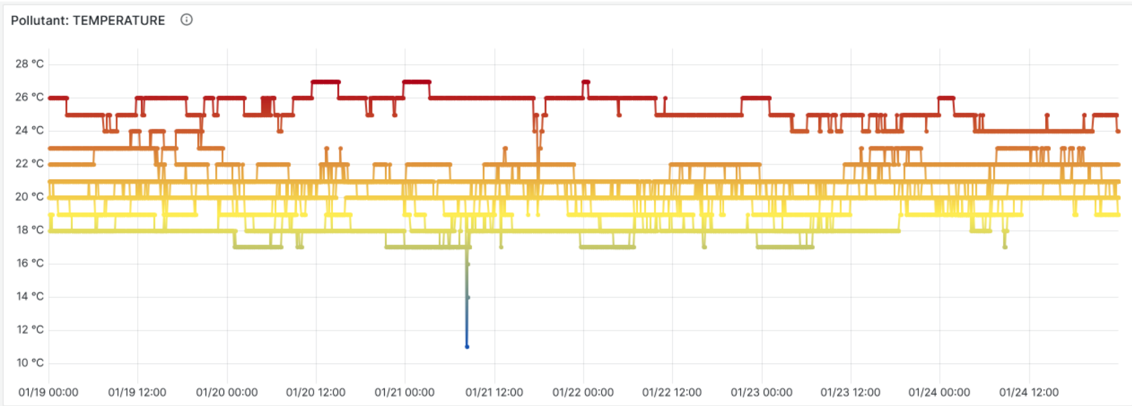

Figure 116. Snapshot of the graphical view of the T data (℃) collected of M+H sensors in the home's locations (as a whole) with natural gas (generated with K-HEALTHinAIR platform).

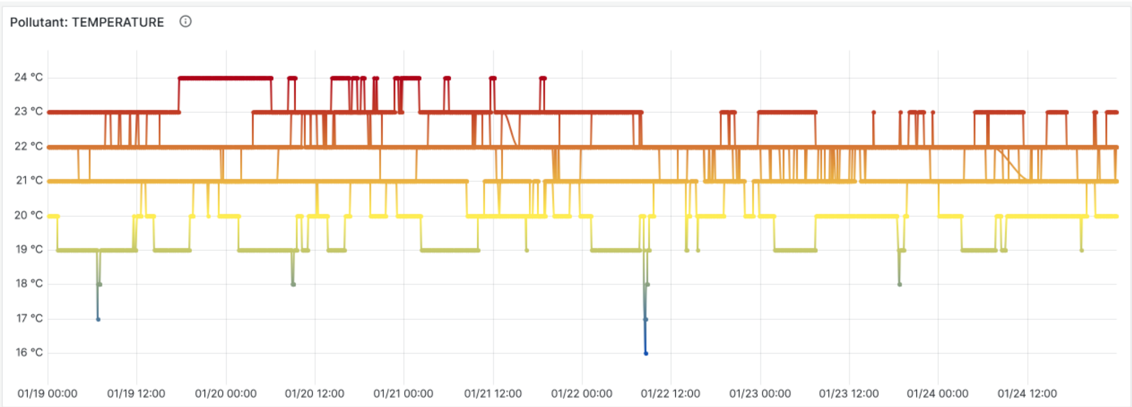

Figure 117. Snapshot of the graphical view of the T data (℃) collected of M+H sensors in the home's locations (as a whole) with electricity for the heating system (generated with K-HEALTHinAIR platform).

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6.1.1.2 Relative humidity

Figure 118, Figure 119 and Figure 120 present the evaluation of relative humidity across the three types of studied homes. The homes with natural gas and electricity have a higher humidity (30-60%) and the homes with solid fuels have a lower humidity (between 25-45%). In this report, only several days of the sampling period have been graphed to facilitate understanding of the figure. However, similar relationships between house types can be found throughout the entire period. Nevertheless, a more in-depth study will be conducted once the necessary functionalities of the platform are available and a longer period of time has been monitored.

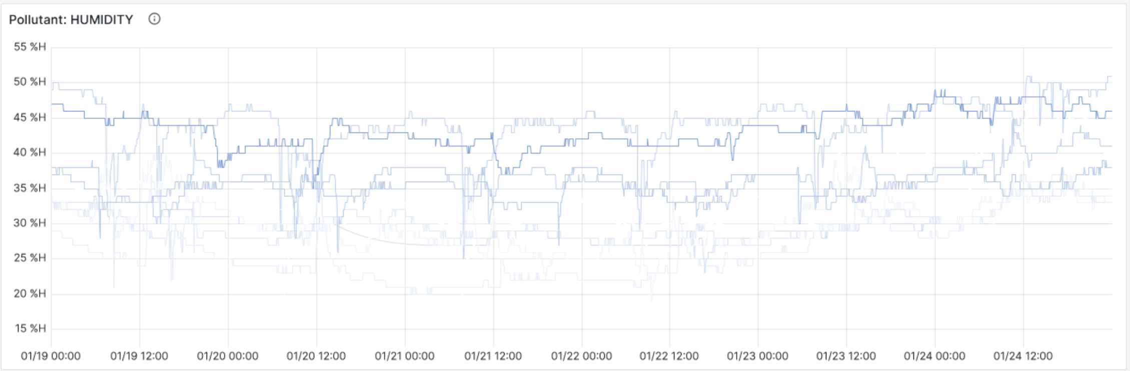

Figure 118. Snapshot of the graphical view of the RH concentration data collected of M+H sensors in the home's locations (as a whole) with solid fuels (generated with K-HEALTHinAIR platform).

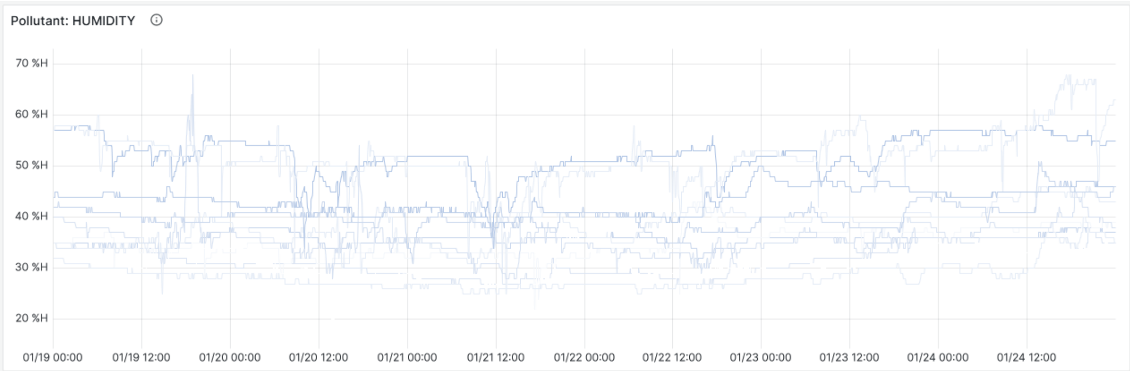

Figure 119. Snapshot of the graphical view of the RH concentration data collected of M+H sensors in the home's locations (as a whole) with natural gas and oil (generated with K-HEALTHinAIR platform).

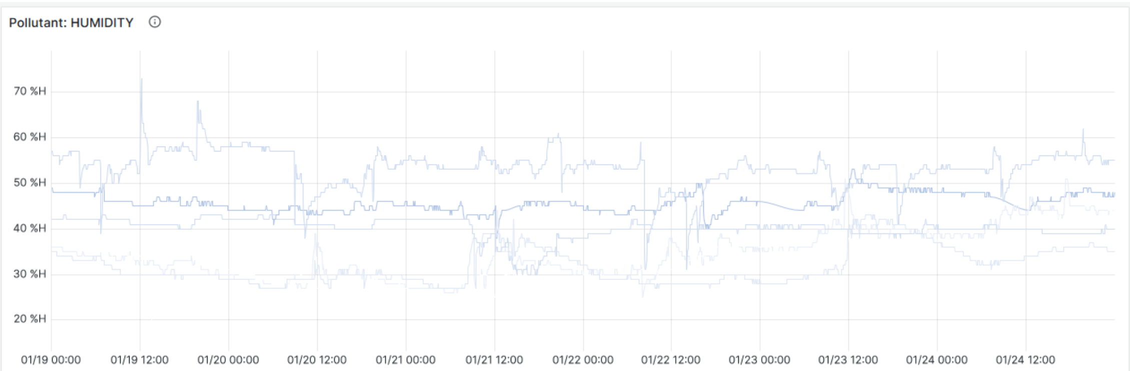

Figure 120. Snapshot of the graphical view of the RH data collected of M+H sensors in the home's locations (as a whole) with electricity for the heating system (generated with K-HEALTHinAIR platform).

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6.1.1.3 CO_2

A study of the evolution of CO_2 levels is carried out to evaluate the level of ventilation in the corresponding house. At this stage, a detailed analysis is not intended because there is not enough seasonal variation available for it. Nevertheless, a more in-depth study will be conducted once the necessary functionalities of the platform are available and a longer period of time has been monitored. However, initial comparisons can be presented between the three types of houses enrolled in the study: biomass heating, gas, or electricity. However, in this regard, examining the overall ventilation patterns and comparing them with PM concentration as the primary parameter of indoor pollution seems to be an interesting study.

As an example, the records for groups of houses are shown in Figure 121, Figure 122 and Figure 123 for several days. In relation to ventilation behaviors in the different houses, no significant differences are observed in the preliminary analysis conducted. Although there are variations in concentrations, and perhaps the lowest values are recorded in houses with electric heating, no levels above normal are found in any group of houses or in any particular house, at least at this stage. Elevated CO_2 concentrations can indicate both ventilation issues. This prompts further exploration to identify and address the underlying cause.

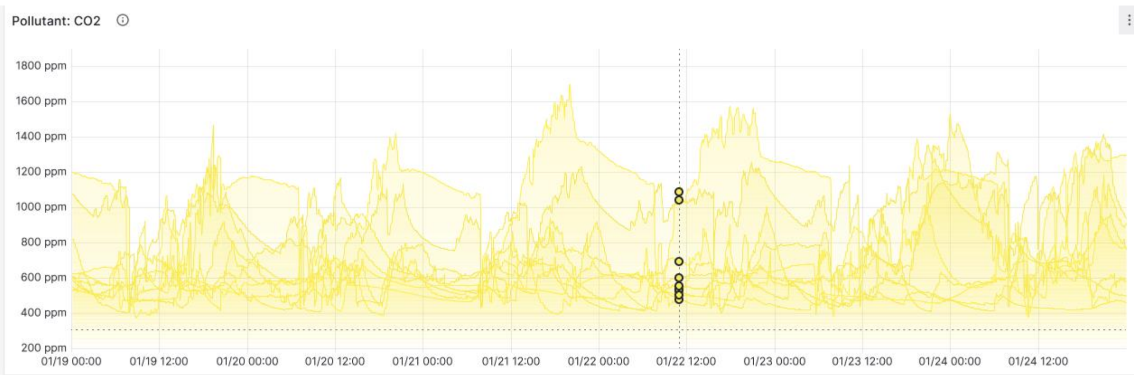

Figure 121. Snapshot of the graphical view of the CO_2 concentration (ppm) data collected of M+H sensors in the home's locations (as a whole) with solid fuels (generated with K-HEALTHinAIR platform).

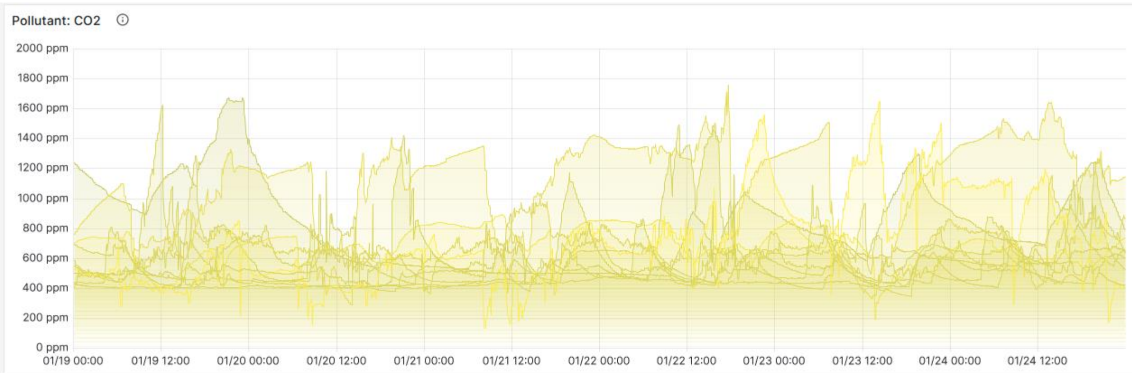

Figure 122. Snapshot of the graphical view of the CO_2 concentration (ppm) data collected of M+H sensors in the home's locations (as a whole) with natural gas and oil (generated with K-HEALTHinAIR platform).

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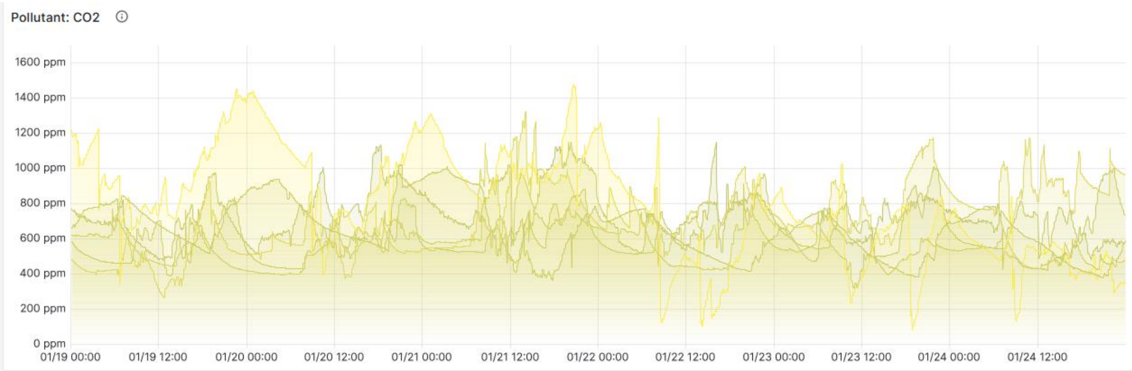

Figure 123. Snapshot of the graphical view of the CO_2 concentration (ppm) data collected of M+H sensors in the home's locations (as a whole) with electricity for the heating system (generated with K-HEALTHinAIR platform).

As mentioned earlier, CO_2 concentration is not typically considered a contaminant in indoor air quality assessments. However, it serves as a valuable indicator of ventilation levels and can also correlate with other potential sources of contamination[34], such as aerosols expelled during respiration by individuals with communicable diseases. In the home scenario where cohabitation is prevalent, this aspect may not be as relevant in terms of pollution but remains useful as an indicator of ventilation patterns. Monitoring CO_2 levels provides insights into indoor air circulation and ventilation efficiency, aiding in maintaining a healthy indoor environment regardless of specific contaminant sources or the influence of the outdoor pollution. This parameter will also be used to assess whether possible high levels of pollutants may be due to accumulation from poor ventilation or if the sources of these pollutants indoors are significant.

In the context of homes, studies consulted during the literature review (D2.1) have identified occupancy as the main source of CO_2 exposure, with the number of individuals directly influencing indoor CO_2 levels. Additionally, fireplaces, cooking and combustion processes have been recognized as significant contributors to indoor CO_2 release, underscoring their impact on indoor air quality. Furthermore, the ventilation conditions and type of ventilation system has been identified as a major determinant of CO_2 levels, alongside factors such as house type, room volume, building's characteristics (e.g., location, insulation, structure), environmental parameters, and seasonal variations.

6.1.1.4 TVOC

Figure 124, Figure 125, and Figure 126 presents an overview of the assessment of tVOC concentrations across the specified three types of homes. In general, the houses don't exceed the established limit levels (except for some where isolated peaks of 60,000 ppb are observed). Overall, the three types of houses have similar levels, and conclusions cannot be drawn at the moment.

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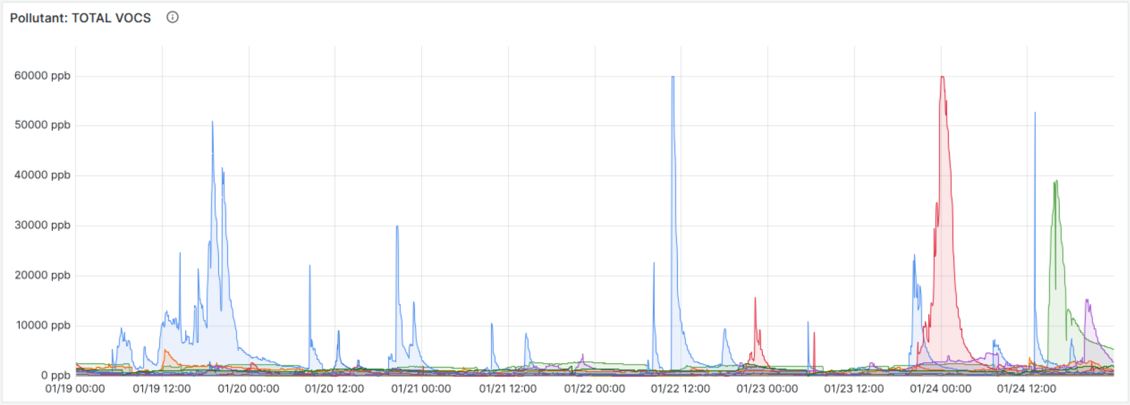

Figure 124. Snapshot of the graphical view of the tVOC concentration (ppb) data collected of M+H sensors in the home's locations (as a whole) with solid fuels (generated with K-HEALTHinAIR platform).

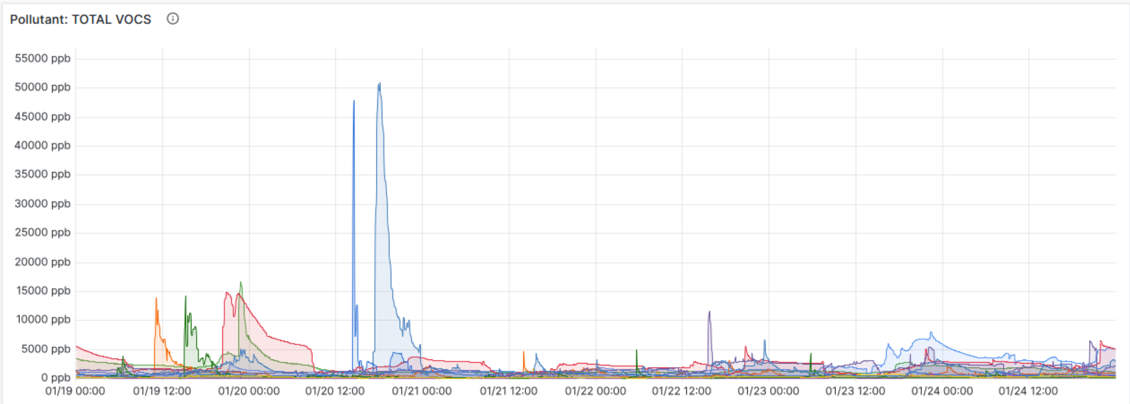

Figure 125. Snapshot of the graphical view of the tVOC concentration (ppb) data collected of M+H sensors in the home's locations (as a whole) with natural gas and oil (generated with K-HEALTHinAIR platform).

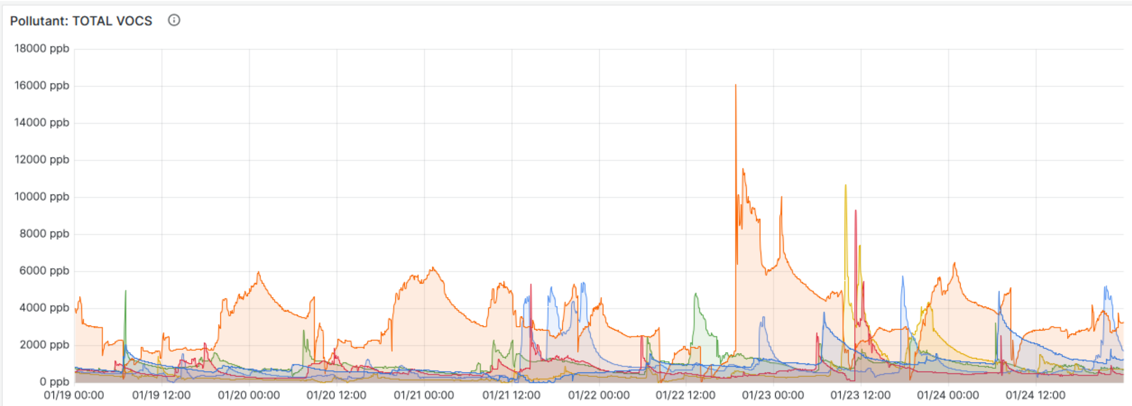

Figure 126. Snapshot of the graphical view of the tVOC concentration (ppb) data collected of M+H sensors in the home's locations (as a whole) with electricity for the heating system (generated with K-HEALTHinAIR platform).

During literature review (D2.1), it was found that in homes the most relevant indoor sources of VOCs identified were furniture, combustion, occupancy, cleaning products and consumer products. Other sources identified were smoking, paints and coatings, textiles, candles, renovation work and construction. Outdoor sources are also major contributors for indoor levels of VOCs. Ventilation was, by far, the most frequently identified determinant factor as, depending

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on the frequency and type, it can either help dispel indoor produced VOCs or allow penetration from outdoor sources. House location was also a frequently identified determinant factor, as outdoor environment is an important source. The age of the furniture, number of occupants, heating systems, frequency of both cleaning and use of cleaning products were also recognized as determinant factors.

6.1.1.5 PM

Firstly, it should be noted that the platform includes PM_1, $PM_{2.5}$, and PM_{10} parameters, so each location generates three fairly similar graphs. For the next platform update, only $PM_{2.5}$ will be included to make the visualization and analysis of information more convenient.

In relation to particle concentration profiles (Figure 127, Figure 128 and Figure 129), very high peaks are found in all types of houses, including those with electric heating. It is true that there is great variability among houses, with some having levels that are not too high and without notable peaks, while others experience frequent peaks (probably smokers' houses). It should be noted that this is an initial analysis, and more monitoring time, including other seasons of the year, is needed in combination with the sampling campaigns results to draw relevant conclusions. However, the peaks reached and the sustained concentration values seem to be outside the recommended limits.

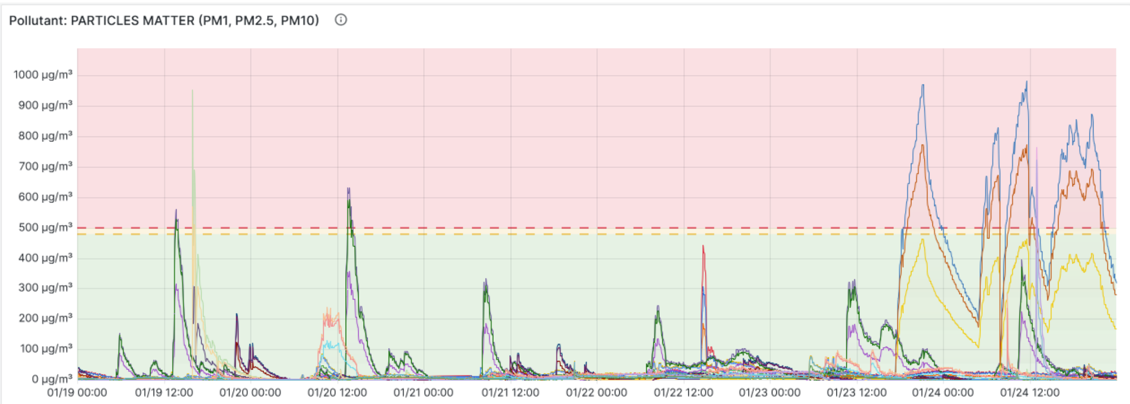

Figure 127. Snapshot of the graphical view of the PM data (μg/m³) collected of M+H sensors in the home's locations (as a whole) with solid fuels (generated with K-HEALTHinAIR platform).

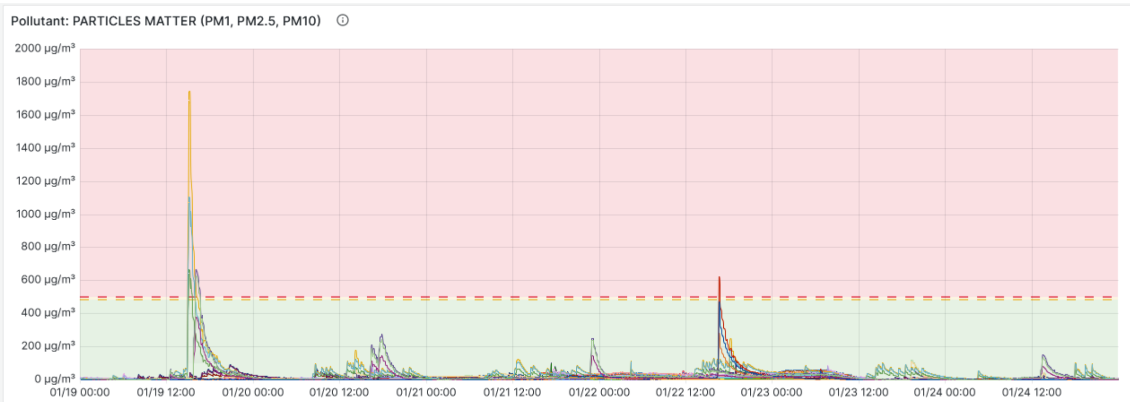

Figure 128. Snapshot of the graphical view of the PM data (μg/m³) collected of M+H sensors in the home's locations (as a whole) with natural gas (generated with K-HEALTHinAIR platform).

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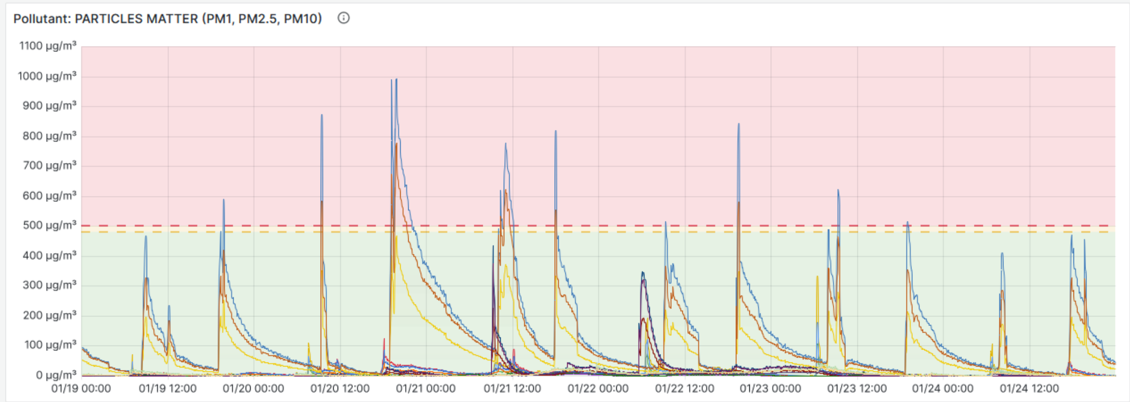

Figure 129. Snapshot of the graphical view of the PM data ($\mu g/m^3$) collected of M+H sensors in the home's locations (as a whole) with electricity for the heating system (generated with K-HEALTHinAIR platform).

However, something that has caught our attention is that the values recorded in some households are abnormally high. A round of inquiries will be conducted with the homeowners to study the possible causes after a preliminary time considered as baseline situation.

As reference levels, the values suggested by WHO for OAQ in its latest update in 2021 have been considered for $PM_{2.5}$ and PM_{10}. These values, set at 15 and 45 $\mu g/m^3$ respectively, represent the average concentrations not to be exceeded over a 24-hour period. It seems that the values are not exceeded, but when the platform allows, the number of exceedances of the aforementioned values will be studied, and the degree of influence this may have on the values recorded inside the building will be examined.

On the other hand, from the literature review developed in the framework of WP2 (D2.1), it is highlighted that most of the studies detected the presence of particulate matter sized 10 µm and 2.5 µm. Additionally, four studies quantified the presence of 0.1 µm particles (ultrafine particles), while one study identified the presence of 1.0 µm particles and another study reported the presence of particles sized 0.25 µm, 0.25-2.5 µm and 2.5-10 µm. The main sources identified for indoor levels of PM_{10}, $PM_{2.5}$, $PM_{1.0}$, $PM_{0.25}$ and $PM_{0.1}$ were cooking and smoking. Moreover, the outdoor environment and traffic emissions were recognized as contributing factors for PM_{10}, $PM_{2.5}$, $PM_{1.0}$, along with the burning of candles or incense. Other sources of indoor PM_{10} and $PM_{2.5}$ include combustion processes, organic sources like skin fragments, hair, dandruff, indoor plants and pets, as well as resuspension from human movement and cleaning practices such as sweeping. Ventilation continues to emerge as a critical factor in determining indoor levels of particles across all sizes. Various factors of pollutants' presence related to building characteristics, including building orientation, floor level, location, room volume and house type (apartment, single or multi-family house) were identified. The heating system was also found to impact particulate matter levels, along with the number of occupants present in the indoor environment. This aspect will be deeply studied within this scenario.

6.1.2 OAQ modelled data from AerisWeather

The records of outdoor air quality, along with T and RH values, allow for the examination of the influence that exterior pollution may have on indoor air quality. Among the parameters monitored outdoors, only the concentrations of $PM_{2.5}$ and PM_{10}, as well as T and RH, coincide with those monitored indoors. This correlation enables a comparative analysis between IAQ and

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OAQ, shedding light on the potential impact of external pollution sources on the indoor environment of the homes. By evaluating these shared parameters, it can be better understood how outdoor conditions affect indoor air quality and implement appropriate measures to mitigate any adverse effects.

As shown in D1.2, information regarding outdoor air quality has been collected on the platform since the start of monitoring. However, functionalities of the platform that enable the analysis of this information and, more importantly, facilitate clear comparisons between indoor and outdoor environments to identify potential correlations are still being developed.

The analysis of OAQ information around homes will begin by evaluating the overall profiles for the period from September 2023 to January 2024.

6.1.2.1 Temperature

The temperature spans from -20 °C to 32 °C, exhibiting notable fluctuations between the maximum and minimum values in certain instances (Figure 130).

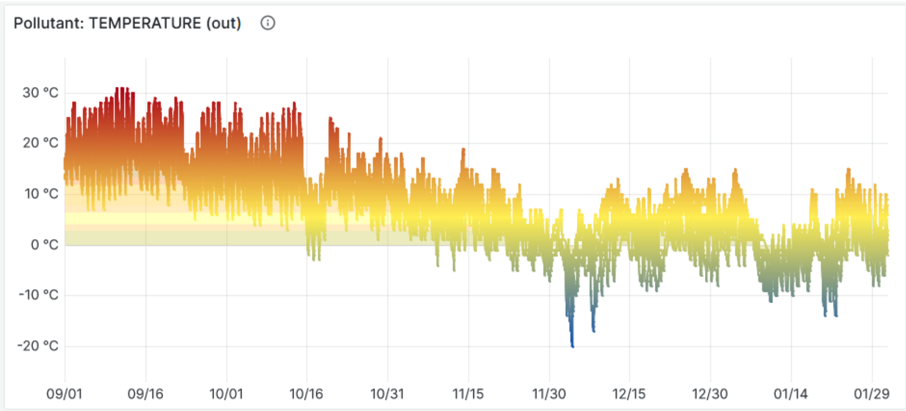

Figure 130. Outdoor temperature data (°C) provided by Aerisweather platform in the home's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.1.2.2 Humidity

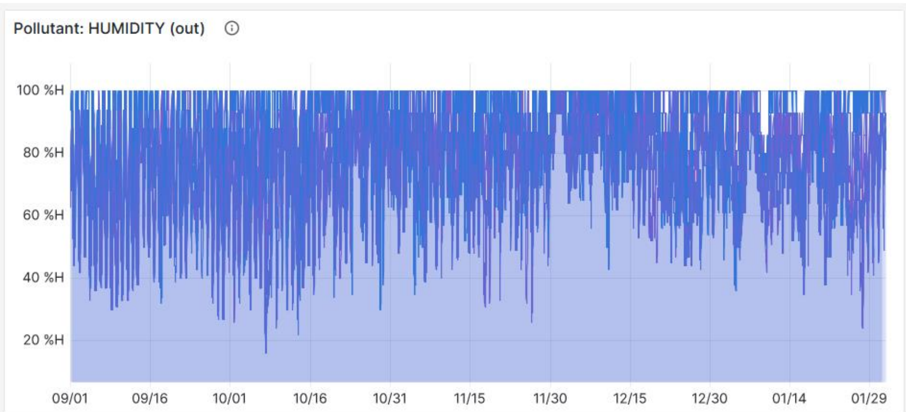

Figure 131. Outdoor relative humidity data (%) provided by Aerisweather platform in the home's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

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On the other hand, relative humidity remains generally high, around 60%, although in some areas, humidity levels drop to as low as 20%. There is a zone with particularly high humidity, consistently hovering around 100% (Figure 131).

6.1.2.3 CO

Regarding CO, the levels are above 0.5 ppb, with occasional higher peaks but lower than 1.5 ppb (Figure 132). These values are far from the limits established by European legislation (Directive 2008/50/EC of the European Parliament and of the Council, dated 21 May 2008), which states that average values over 8 hours outdoors should not exceed 10 μg/m^3 (equivalent to 8 ppb).

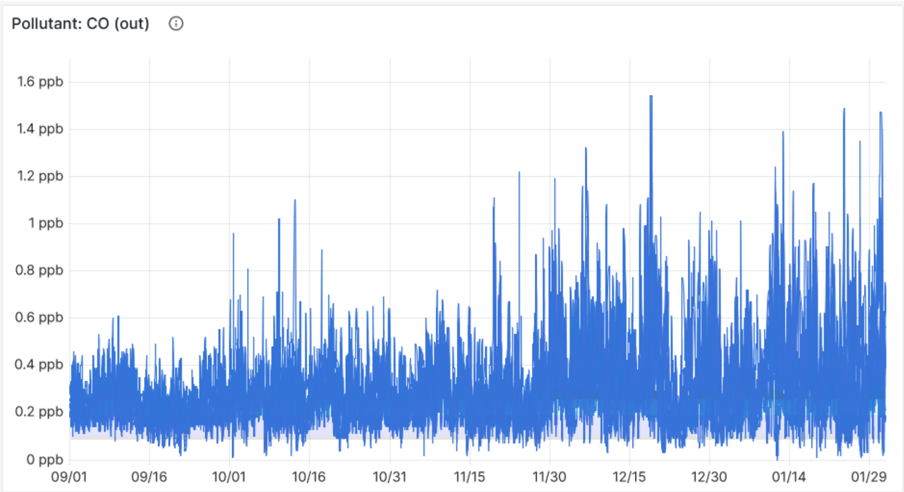

Figure 132. Outdoor CO concentration (ppb) data provided by Aerisweather platform in the home's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.1.2.4 O_3

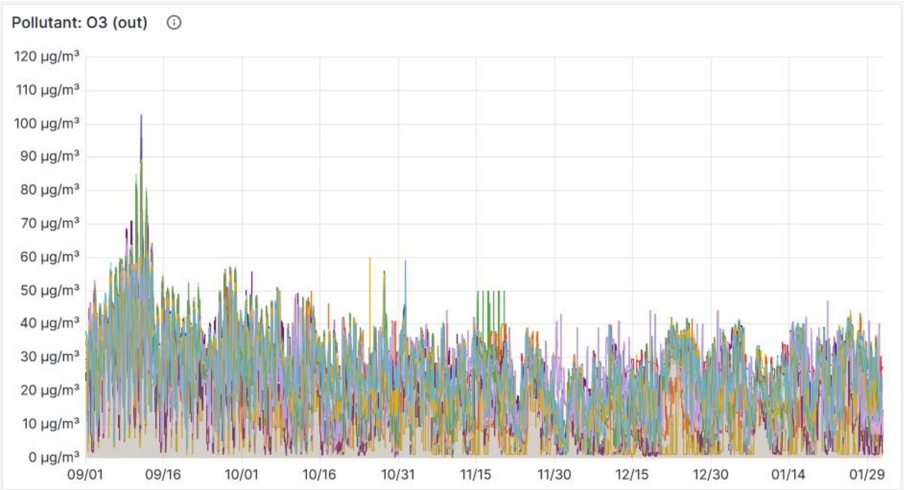

Figure 133. Outdoor O_3 concentration (μg/m^3) data provided by Aerisweather platform in the home's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

On the other hand, O_3 levels are higher, ranging between 0 µg/m^3 and generally 40 µg/m^3, with some higher peaks in summer time reaching 100 µg/m^3 (Figure 133). WHO recommends not exceeding an average value of 60 µg/m^3 over six months and not exceeding 100 µg/m^3 as an

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average value over 8 hours. During this period, these values have not been exceeded. However, it would be necessary to verify if the 8-hour limit is not exceeded at any time, as these values are high.

6.1.2.5 PM

As additional information, a report from the Urban $PM_{2.5}$ Atlas, Air Quality in European Cities is presented for the city of Wien in Figure 134.

The report from the Urban $PM_{2.5}$ Atlas, Air Quality in European Cities[20], sheds light on the major sources of particles in the outdoor environment of the city of Wien. One notable observation is that residential activities significantly outweigh other sources, indicating that daily household routines contribute substantially to particle emissions in urban air. Following behind, transportation, industry, and agriculture are identified as having a comparable impact on air quality. This suggests that a variety of human activities, spanning from vehicular emissions to industrial processes and agricultural practices, collectively contribute to the particle pollution observed in Wien's outdoor air. Understanding the relative contributions of these sources is crucial for developing effective strategies to mitigate air pollution and improve overall air quality in urban areas like Wien and beyond.

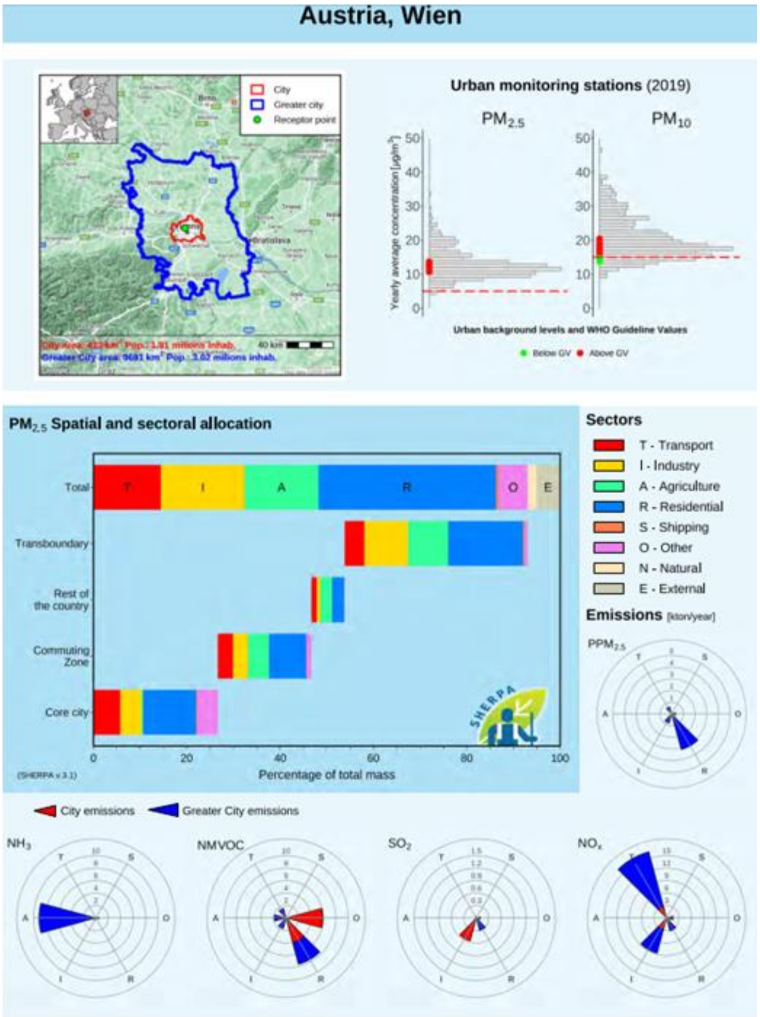

Figure 134. $PM_{2.5}$ pollution in Vienna (Austria). Urban $PM_{2.5}$ Atlas, Air Quality in European Cities, 2023 Report p. 138[20].

On the other hand, regarding PM, the levels increase throughout the period, from nearly 0 µg/m³ and reaching usually around 50 µg/m³. There are some moments with peaks overpassing 100 µg/m³ (Figure 135). This is relevant as these values exceed the limits recommended by WHO (5 µg/m³ annual average and 15 µg/m³ average over 24 hours, see Table 2), which are the most stringent, but they are also close to those set by European legislation (Directive 2008/50/EC of the European Parliament and of the Council, of 21 May 2008, on ambient air quality and cleaner air for Europe) for $PM_{2.5}$ at 25 µg/m³ as an average of 24 hours. Additionally, these particles can be a source of contamination in indoor environments, making it relevant to address.

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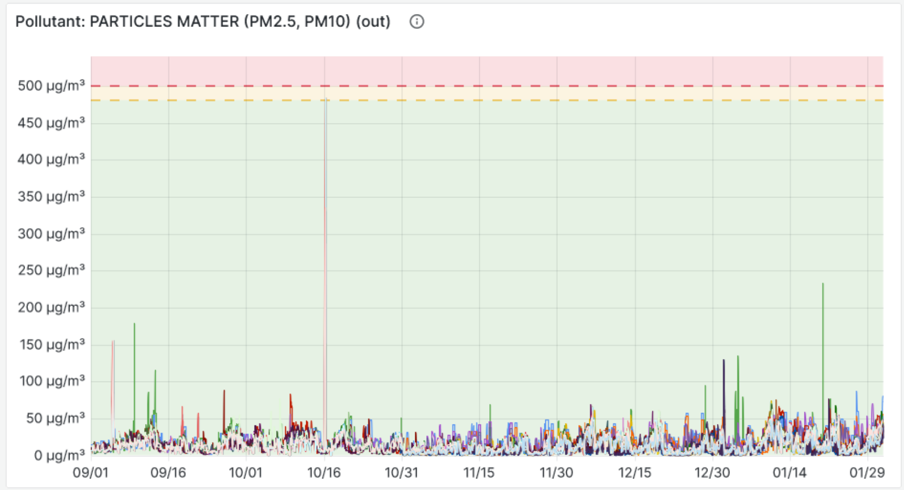

Figure 135. Outdoor PM concentration data provided by Aerisweather platform in the home's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.1.2.6 NO_2

Concerning NO_2, the Figure 136 illustrates the concentration profile observed in Vienna from September 2023 to January 2024. Notably, there are discernible daily fluctuations in concentration, typical of urban environments. At the onset of the day, there is a prominent peak attributed to the initial rush hour traffic, gradually diminishing until the subsequent evening peak, albeit usually of lesser intensity. Weekends generally exhibit lower values, reflecting reduced traffic activity. The average concentration hovers around 15 ppb, with distinct spikes reaching up to 40 ppb.

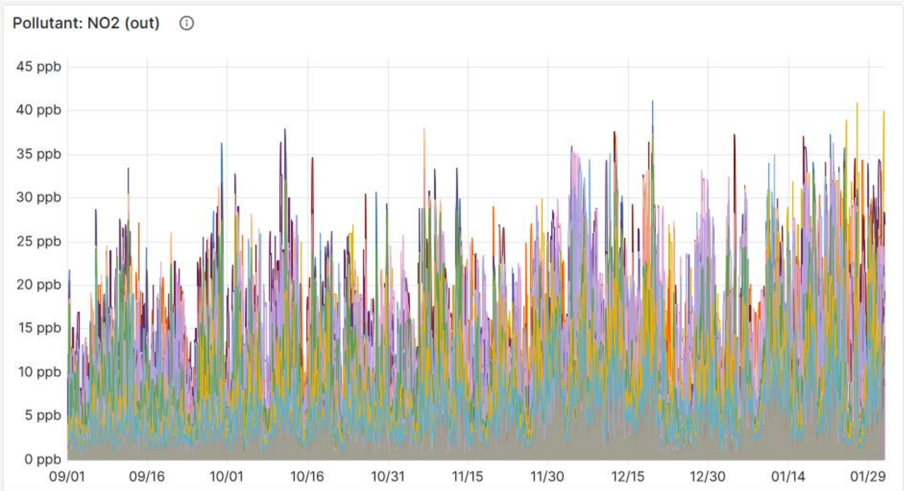

Figure 136. Outdoor NO_2 concentration (ppb) data provided by Aerisweather platform in the home's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.1.2.7 SO_2

In the case of Poland and Austria, the concentration of SO_2 has been added to the study. In the other pilot studies, it was not considered necessary because ambient concentrations of this compound are usually lower, but here it will be evaluated because it may be relevant due to the

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type of fuels used. However, as can be observed in the Figure 137, the recorded values are not very high.

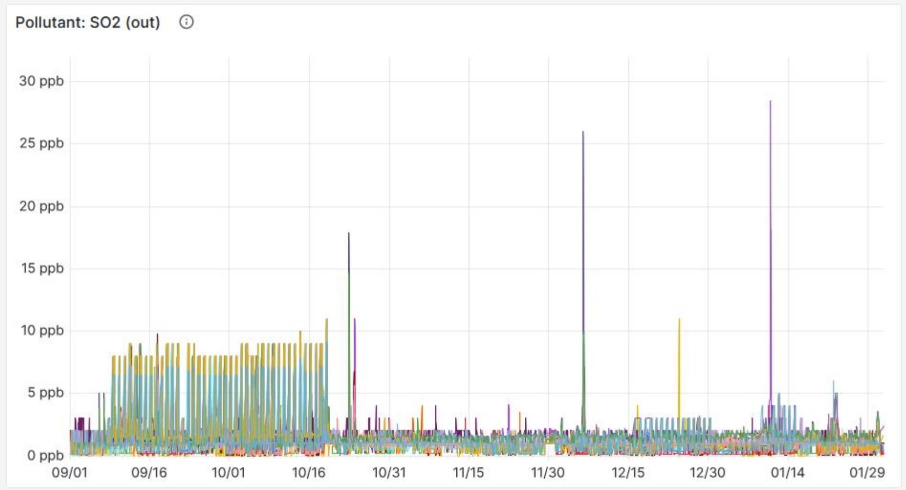

Figure 137. Outdoor SO_2 concentration (ppb) data provided by Aerisweather platform in the home's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.1.2.8 Comparison indoors versus outdoors

Indeed, differences between indoor and outdoor temperatures can provide valuable insights into the energy needs of buildings and help understand ventilation behaviors, among other studies[35,36]. Discrepancies in temperature levels between indoor and outdoor environments can indicate the effectiveness of insulation, heating, and cooling systems within buildings. Moreover, studying these variations can offer valuable information about occupants' ventilation practices and behaviors, which are essential factors influencing IAQ and overall comfort levels. As an example, Figure 138 illustrates temperature profiles both indoors and outdoors. As evident, particularly during the winter season, noticeable temperature differences exist. In principle, these differences may lead individuals to ventilate their homes less to conserve heating energy.

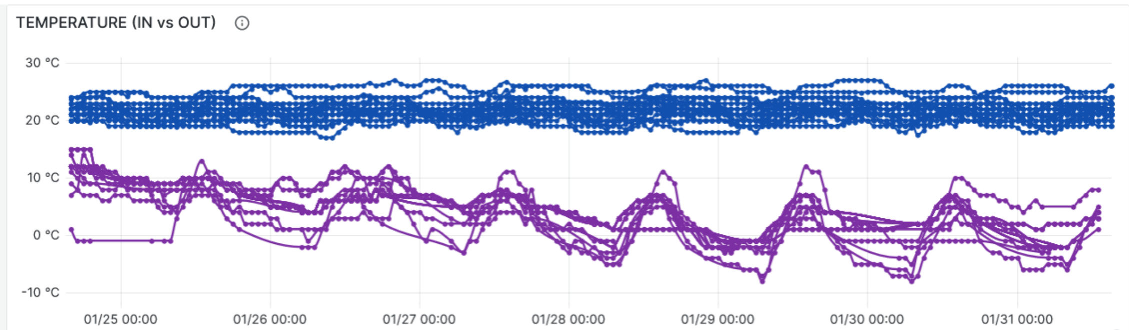

Figure 138. Evolution of temperature outdoors and indoors in the home's locations (as a whole) between 25/01/2024 and 31/01/2024 (generated with K-HEALTHinAIR platform).

Regarding the concentration of $PM_{2.5}$ and PM_{10}, the initial findings indicate that indoor levels are significantly higher than outdoor levels. Additionally, larger variations are observed throughout the day (Figure 139).

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Analyzing the $PM_{2.5}$ and PM_{10} profiles outdoors during the cold season (for example, as shown in the Figure 140 covering the period from 1/11/23 to 30/1/24), it is evident that outdoor values rarely exceeded 100 µg/m^3. However, indoors, these values are frequently surpassed by a significant margin in some homes. This phenomenon is being studied within the framework of WP3, specifically in the framework of the sensor validation activity, which has recently started.

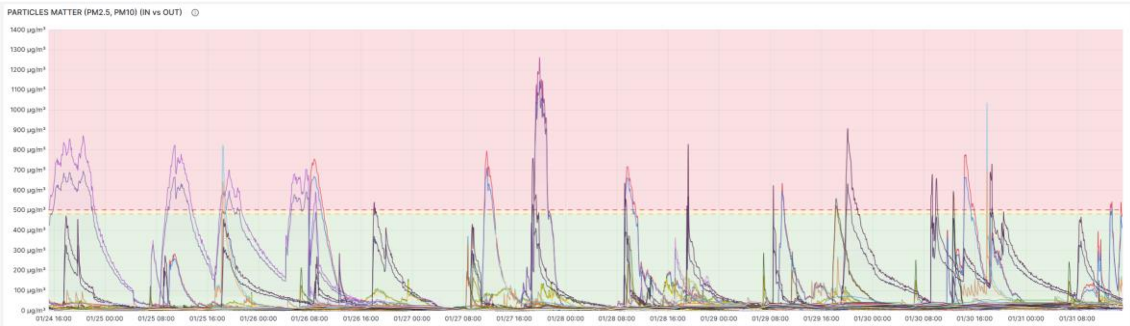

Figure 139. Evolution of PM outdoors and indoors in the home's locations (as a whole) between 25/01/2024 and 31/01/2024 (generated with K-HEALTHinAIR platform).

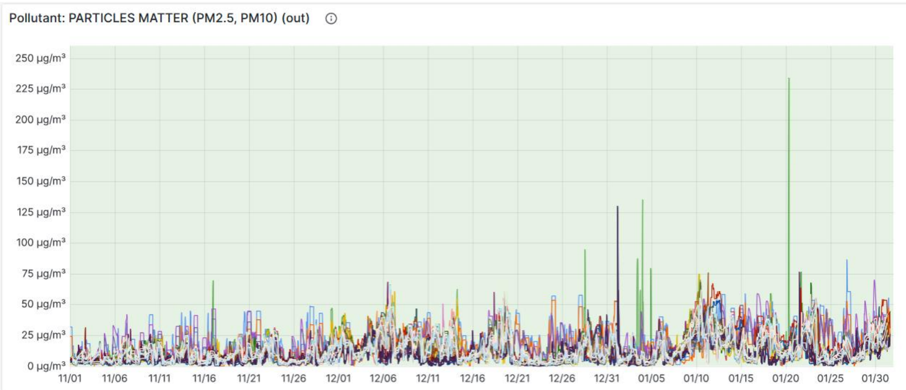

Figure 140. Evolution of PM outdoors and indoors in the home's locations (as a whole) between 11/01/24 and 30/01/24 (generated with K-HEALTHinAIR platform).

6.1.3 VOCs sampling

VOCS sampling were performed in Austria and Poland but the results are not ready.

6.1.4 Formaldehyde sampling

Formaldehyde sampling are not started yet.

6.1.5 PM/PAHs sampling

The first PM sampling for PAHs concentrations assessment in Poland was completed in January 2024, but the results are not ready yet. The raw data from the analysis of the collected samples was provided on February 27th, 2024, but there is not enough time to complete the analyses of this data. The first results show that most samples collected at homes contain all or almost all of the analyzed 16 PAHs, but their concentrations vary. Most samples also contain PAHs that are particularly harmful to health (e.g. BaP, IP, DahA and BghiP) due to their high biological activity. The comparison with summer sampling results will be possible after the summer campaign which is planned to be completed in May-July 2024.

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PM sampling in homes in Austria is not planned at the moment.

6.1.6 Questionnaires

In Austria, during the recruitment process, a comprehensive baseline questionnaire with standardized questions was used as a baseline. It is composed by socio-demographic data, time spent/activity in the scenario, and questionnaires to measure QoL and mental health. During the follow-up period, continuous health reporting will be monthly performed. In this continuous reporting, only QoL (EQ-5D-5L) and mental health (PHQ-9) will be considered, together with time spent/activity in the scenario. It also includes other questions (e.g. health symptoms, cleaning behavior, new furniture, among others). The monthly online survey of participants starts in February 2024 (until then, questionnaires in Austria were filled out monthly offline).

In Poland, as the recruitment of homes was finalized in December 2023, so far, the questionnaires were not administered to the home residents. The scope of the plan to collect information is similar to that collected in Austria's homes.

6.1.7 Conclusions

The recruitment of homes in Poland and Austria was very successful. The total number reached is 28 in Austria and 31 in Poland. In each of these homes, at least one IAQ sensor was installed.

Heterogeneous profiles of indoor pollutants:

1. Observations reveal varied profiles of indoor pollutants across households but also big differences among dwellings.
2. No mayor differences have been found until now among the three categories of houses considered until now. A deeper analysis with powerful data analysis tools is needed.
3. Further research is necessary to pinpoint the primary sources of formaldehyde and VOCs in indoor environments.

Outdoor data pending to be studied to provide individual conclusions.

Potential benefits of preventive strategies:

1. Elevated pollution exposure in certain dwellings associated with unhealthy habits and type of heating systems suggests the potential benefits of preventive strategies.

PM/PAHs sampling:

1. The results of PM samples collected for the assessment of PAHs in homes in Poland are currently very preliminary. It is not possible to compare them with the results from the summer period, because measurements in the summer season are planned for mid-2024.
2. Nevertheless, comparison of the results with the summer measurement campaign conducted in Polish schools allows to conclude that samples collected in winter are characterized by the presence of a larger number of the analysed 16 PAHs, as well as that they also contain the most harmful compounds (5- and 6-ring), which were either

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not found in samples from schools taken in the summer or occurred sporadically and in low concentrations.

3. These preliminary results may prove that relatively high concentrations of PAH pollutants inside houses may be caused by the inflow of polluted outdoor air or the generation of PAHs directly inside the building where, for example, solid fuels are used for heating purposes. A more detailed analysis of the results will allow determining the possible sources of these pollutants.
4. The results will also be compared with the outcomes from the following campaigns which are planned to be completed in the next 2 non-heating and 2 heating seasons.

6.2 Schools scenario (PL/AT-SCH01 – PL/AT-SCH22)

IAQ in relevant environments with high presence of vulnerable groups such as schools' institutions and its relationship with acute health events is a critical issue.

Indoor environment in schools is a public concern. According to recent studies, children aged between 3 and 14 spend 90% of the day indoors both in winter and summer[37–41].

Indoor air pollution in schools is characterized by large variability in pollutants' concentration among different indoor environments and may also vary within a specific environment as a function of location and time. The scope of these variations, depends on factors such as the emission characteristics of the sources, the occupants' behaviour and the microclimatic and ventilation conditions[42]. Conditions commonly found in schools, can have adverse effects on the air quality and therefore on occupant's health. In particular, it was highlighted that the location, the age and air-tightness of school buildings, the room design, the ventilation rate, the building and furnishing materials, and outdoor pollution play an important role in the indoor pollutants' concentrations.

There is a lack of available reference values for most of the pollutants monitored in indoor environments. A good step in this direction is established by WHO in 2010, an indoor air quality guideline for short- and long-term exposures to formaldehyde[43].

The most common pollutants found in schools and childcare facilities are the following: PM, VOCs, formaldehyde and carbonyl compounds, other inorganic gases: and NO_x, CO, SO_2, CO_2 and O_3.

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Table 12. Description of the schools participating in the project.

	Austria		Poland	
	Primary school	Secondary school	Primary school	Secondary school
Recruited school	1	2	7	15
N° classrooms	Vienna: 4	Graz: 3 Judenburg: 3	Warsaw (23 classrooms in total)	Lodz (30 classrooms in total)
N° participating pupils	Vienna: 76	Graz: 40 Judenburg: 43	Warsaw 150	Lodz 200
Spirometry	Yes	-	Yes (2 schools)	-
N° of monitoring tools	4	6	23	45
Questionnaire	-	Baseline Monthly follow-ups	Baseline Monthly follow-ups	Baseline Monthly follow-ups
Microbiome sampling	-	Yes	Yes	
PM sampling	-	Yes	Yes	
VOCs + FA sampling	Yes	Yes	Yes	Yes

Due to the lack of sufficient information to conduct an in-depth analysis at this point, as mentioned earlier, a series of simple considerations and analyses will be made with the information available at present.

The hypothesis supporting this research are the following:

Hypothesis H1: The health risk assessment. Exposure to poor indoor air quality in residential settings may contribute to the exacerbation of respiratory symptoms in high-risk respiratory outpatients. This exacerbation can lead to a decline in pulmonary function and potentially result in avoidable visits to the emergency department, hospitalizations, or in extreme cases, mortality.

Hypothesis H2: Exposure to pollutants and allergens present in indoor air can induce inflammation and irritation in the respiratory system. This can result in reduced lung function, decreased oxygen delivery to the body, and alterations in heart rate variability.

Hypothesis H3: Exposure to poor IAQ can be linked to reduced QoL, compromised mental health, heightened loneliness, increased disease prevalence and comorbidities, greater medication usage, and the emergence of IAQ-related symptoms.

Hypothesis H4: A multidimensional approach considering different health determinants, such as health history, IAQ and OAQ exposure parameters, biological signals, PROMS, and periodic assessments of pulmonary function may enhance the prediction of exacerbations of pulmonary disease. This would facilitate early detection and treatment of exacerbations, eventually reducing ERV and hospitalizations.

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6.2.1 IAQ Massive monitoring M+H and INBIOT sensors

In relation to the school scenario, the following series of profiles are provided to assess the occupancy levels, ventilation habits, and potential determinants that may affect air quality.

In the analysis of these parameters, it's important to consider that this data represents a month within the cold season, with very low outdoor temperatures. Under these conditions, it's understandable that, considering the energy-efficient designs of school buildings, there may be a relaxation of good ventilation practices.

- Indoor environment in schools is a public concern. According to recent studies, children aged between 3 and 14 spend 90% of the day indoors both in winter and summer.
- 3 schools in Austria and 22 schools in Poland have been recruited with, at the starting point of the study, more than 500 students involved.

6.2.1.1 Temperature

The profile of temperature indicate that the recorded values are within normal ranges, although occasionally they may exceed the recommended intervals (Figure 141).

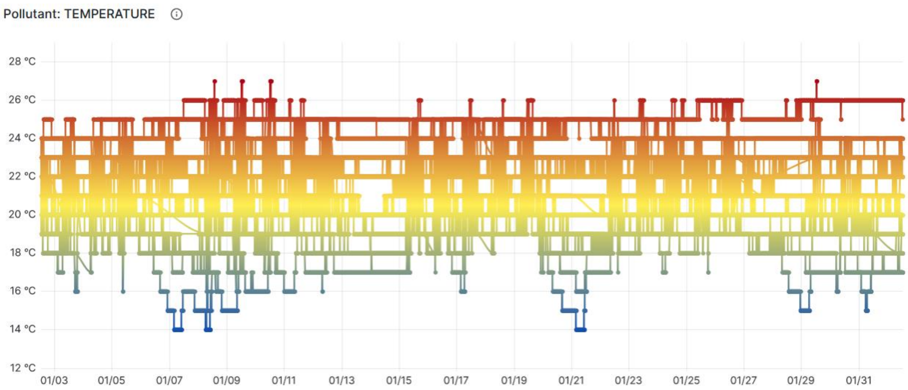

Figure 141. Snapshot of the graphical view of the T (°C) data collected of M+H sensors in the school's locations (as a whole) with solid fuels (generated with K-HEALTHinAIR platform).

6.2.1.2 Relative humidity

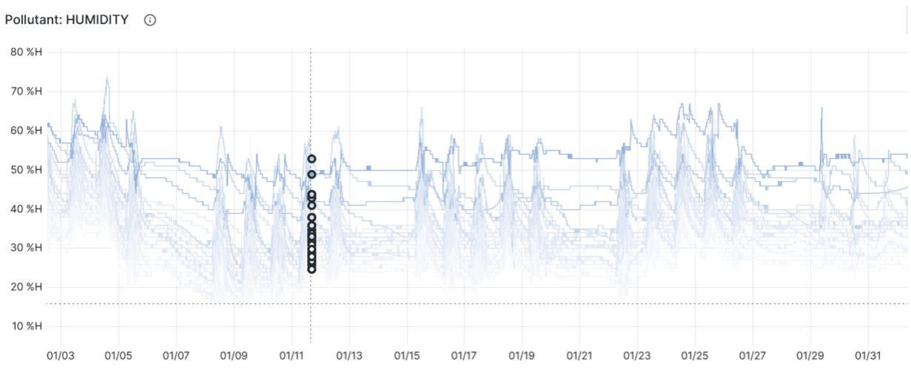

Figure 142. Snapshot of the graphical view of the relative humidity (%) data collected of M+H sensors in the school's locations (as a whole) with solid fuels in January 2024 (generated with K-HEALTHinAIR platform).

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The profiles of humidity of the Figure 142 indicate that the recorded values are within normal ranges. However, the noteworthy observation is the disparity in readings among different schools. Assuming an appropriate range is between 40% and 60%, many schools remain below these recommended values for extended periods.

6.2.1.3 CO_2

The levels of CO_2 concentration indicate that ventilation is not occurring during class times. The levels observed in almost all schools, ranging between 1,000 and 2,000 ppm, suggest that windows are not being opened at any point during the morning. Additionally, it's worth noting that in some schools, the concentration of students further contributes to levels (between 2,000 and 4,000 ppm) that could potentially impact the cognitive ability of the students.

These levels fall within the range of other similar studies in schools. In the SINPHONIE[44] project, for example, the range was between 269 and 4,960, Meanwhile, in the InAirQ[45] project, the levels were slightly lower, ranging between 767 and 2,328. In other schools in Poland[46], the levels ranged between 500 and 3,500.

In the Figure 143, it can be observed the profiles of CO_2, making it easy to identify periods of school activity. Additionally, it can be seen that at the end of the school day, the decrease in concentration is slow, indicating a missed opportunity for ventilation, which would be advisable.

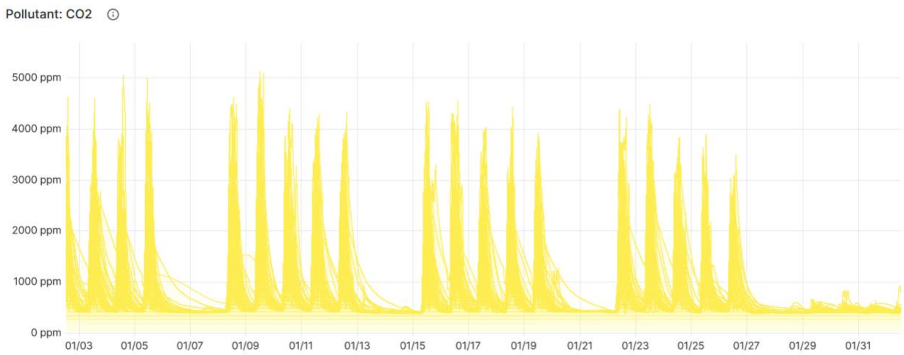

Figure 143. Snapshot of the graphical view of the CO_2 concentration (ppm) data collected of M+H sensors in the school's locations (as a whole) with solid fuels in January 2024 (generated with K-HEALTHinAIR platform).

Most of the studies consulted in the literature review (D2.1) identified occupancy as the main source of exposure, with the number of persons being a determinant for the indoor levels of CO_2. The outdoor environment was also identified as a source, highlighting the influence of outdoor air on indoor air quality. Regarding other determinants, the type of ventilation, room volume, building maintenance, classroom orientation, physical activities, were also considered important factors with an influence of CO_2 levels indoors.

6.2.1.4 TVOC

In relation to VOCs (Figure 144), there is greater variability among different schools. In schools with higher values, the peaks observed seem to be "parallel" to those of carbon dioxide. Further analysis will be necessary as more data is collected, but these peaks appear to be associated with the presence of people.

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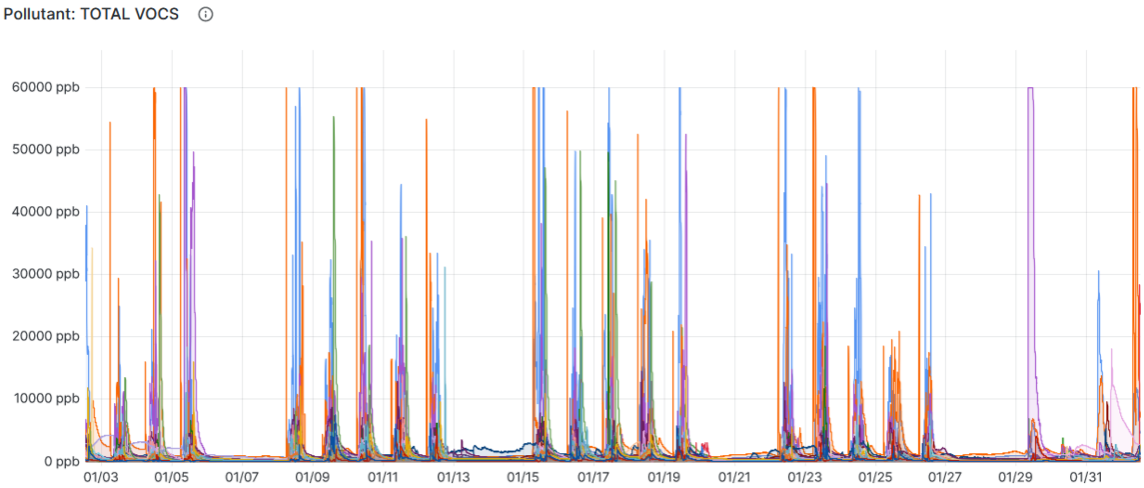

Figure 144. Snapshot of the graphical view of the tVOCs concentration (ppb) data collected of M+H sensors in the school's locations (as a whole) with solid fuels in January 2024 (generated with K-HEALTHinAIR platform).

The most relevant sources identified for VOCs' presence in schools during the literature review are the cleaning products and materials used for students' activities (e.g., crafts, paints, glues). Furniture, floor, and textiles were also recognized as possible sources of VOCs. The contribution of outdoor sources was also identified. Several factors were identified as determinants of VOCs levels indoors, with ventilation conditions being one of the most frequent.

However, there were several studies (D2.1) with some VOCs quantified in schools for which it was not possible to identify the main sources (hexanal, propionaldehyde, acetaldehyde) which emphasizes the need for further research dedicated to understanding the presence of these compounds indoors.

6.2.1.5 PM

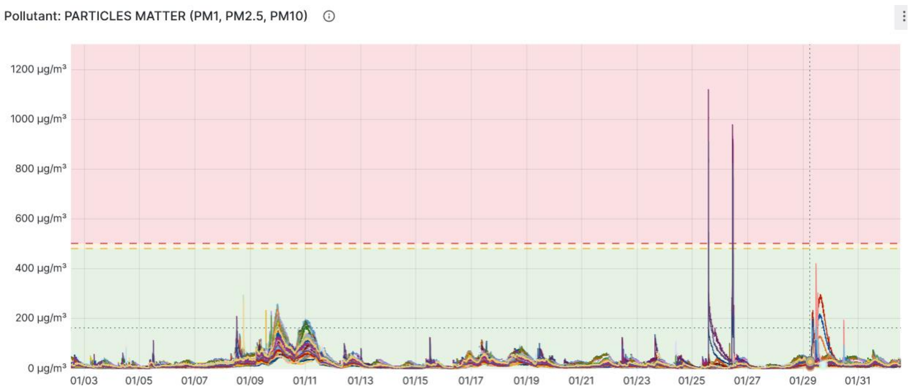

Figure 145. Snapshot of the graphical view of the PM concentration (µg/m³) data collected of M+H sensors in the school's locations (as a whole) with solid fuels in January 2024 (generated with K-HEALTHinAIR platform).

Regarding particle concentration, the Figure 145 shows the concentration profile recorded during January 2024. As evident, there are some significant peaks, but generally, the values remain within a controlled range. As mentioned earlier, a pending task is to conduct a sensor validation exercise in controlled real-life environments. However, there is indeed a school that has recorded relatively high particle values. Nevertheless, if these values are not consistent over time, they may not be of significant concern.

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This exercise is currently being planned, and as the initial step the evaluation of data recorded during the in-situ samplings conducted in various scenarios will be done.

Most of the studies consulted during the literature review (D2.1) assessed the presence of particulate matter (PM) 10 µm and 2.5 µm, although three studies quantified 1.0 µm particles and seven studies quantified 0.1 µm particles (ultrafine particles) as well. The outdoor environment (outdoor values will be commented below), mainly air pollution (schools located in intense traffic zones), was identified as contributor for indoor levels of PM_{10}, $PM_{2.5}$, $PM_{1.0}$ and $PM_{0.1}$. The presence of students in the school rooms was also a source of contamination as well as the number of people was pointed out as a determinant. This is also related to the moments of students' activities, movements within the rooms and cleaning at the end of the day, emphasized in several studies to contribute to higher indoor levels of particulate matter. A very characteristic aspect of school settings is the use of chalk, and this was pointed out in several studies as a source of indoor PM (PM_{10}, $PM_{2.5}$, $PM_{1.0}$ and $PM_{0.1}$). Following the pattern of other indoor pollutants, ventilation plays a significant role in the levels of indoor particles, being identified as a determinant for all particles size. Several aspects related to the building characteristics were also identified as potential determinants: the floor level, the construction materials (walls, windows), type of playground, room orientation (influenced also by outdoor air pollution levels). An important contribution was the study that assessed the differences of indoor levels of particulate matter between schools where students wear socks and schools where students kept their shoes inside. This study proved that there is a significant difference in levels of PM_{10} indoors and schools where students wear socks presented lower levels. This information is relevant for the development of future mitigation measures.

6.2.2 OAQ modelled data from AerisWeather

The analysis of OAQ information, including T and RH, helps contextualize indoor records.

6.2.2.1 Temperature

For instance, the temperature profile in January illustrates temperatures fluctuating between 8 °C (occasional peaks) and a minimum of -15 °C (Figure 146). The outdoor temperatures have generally been quite cold, leading to high heating demands. In this context, the use of heating systems increases atmospheric pollutants, especially particles[47].

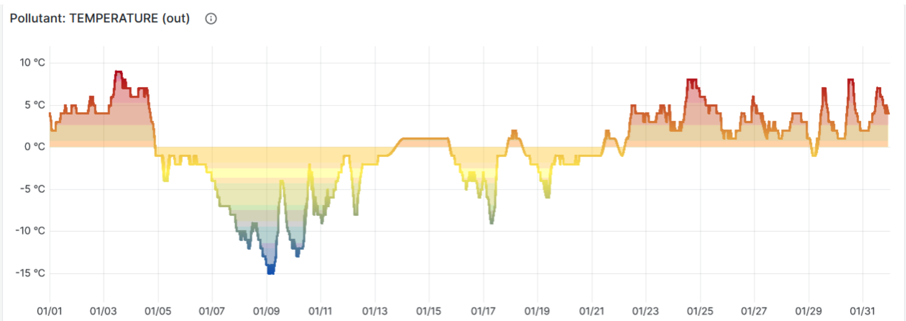

Figure 146. Outdoor temperature (°C) data provided by Aerisweather platform in the school's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.2.2.2 Relative humidity

The profiles for January for the rest of parameters are shown below. Regarding the concentrations of RH (Figure 147), CO (Figure 148), O_3 (Figure 149), PM (Figure 150), NO_2 (Figure 151), and SO_2 (Figure 152). As observed, all parameters exhibit peaks indicating episodes where recommended values were exceeded. Particularly noteworthy is an episode between January 7th and 13th when T were exceptionally low, resulting in increased values for all these parameters except O_3.

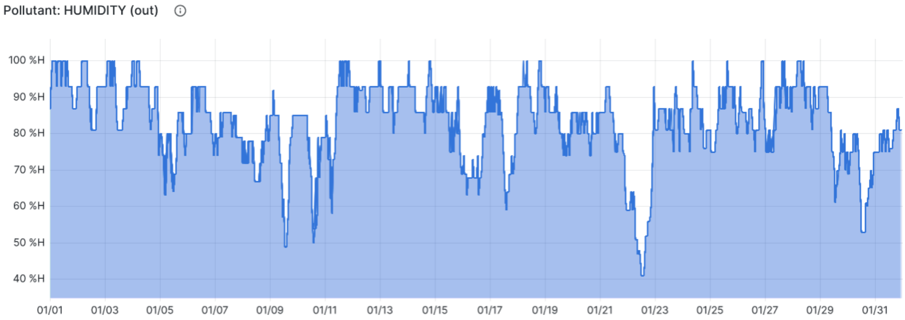

Figure 147. Outdoor relative humidity (%) data provided by Aerisweather platform in the school's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.2.2.3 CO

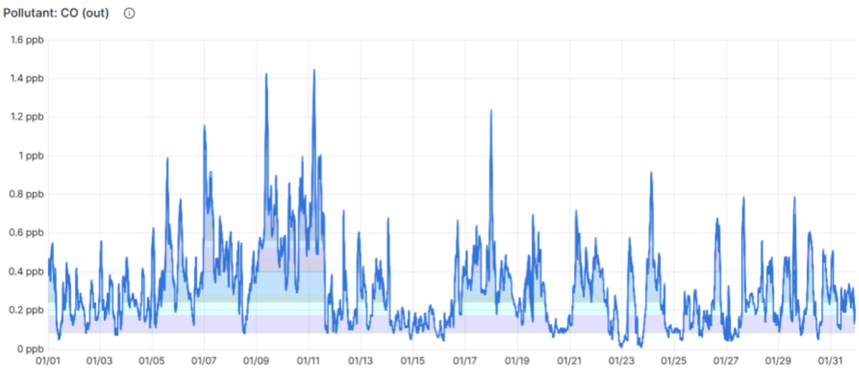

Figure 148. Outdoor CO concentration (ppb) data provided by Aerisweather platform in the school's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.2.2.4 O_3

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Figure 149. Outdoor O_3 concentration ($\mu g/m^3$) data provided by Aerisweather platform in the school's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.2.2.5 PM

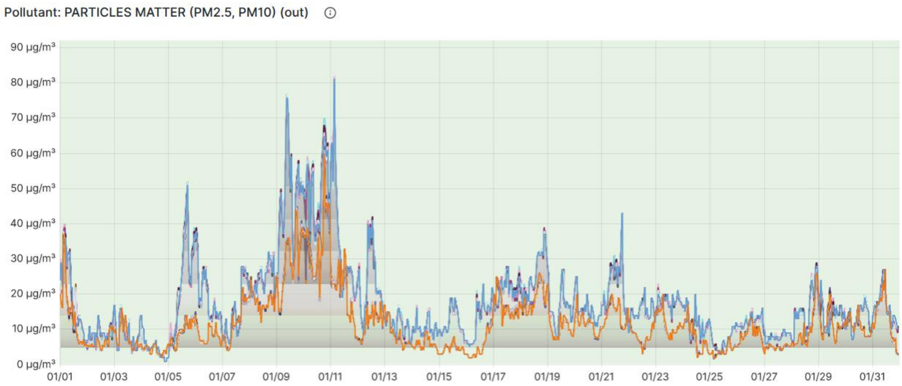

Figure 150. Outdoor PM concentration ($\mu g/m^3$) data provided by Aerisweather platform in the school's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.2.2.6 NO_2

The average concentration hovers around 15 ppb, with several peaks reaching up to 25 ppb. Within this period, this parameter does not present a relevant concern but it will be evaluated thought a longer period in order to value if seasonality can affect this conclusion (Figure 151).

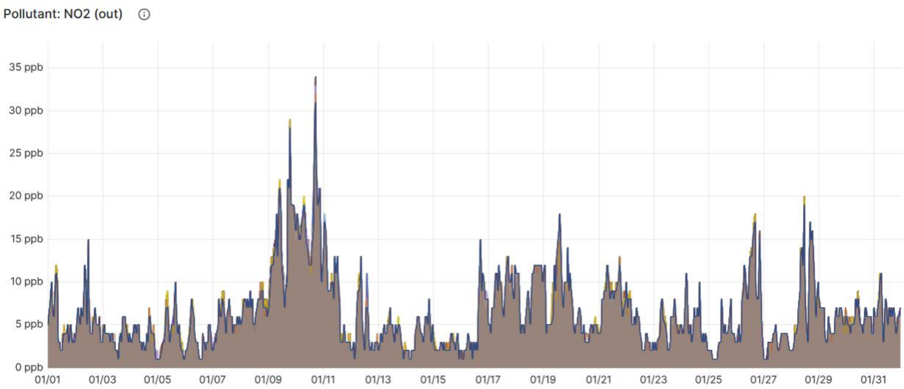

Figure 151. Outdoor NO_2 concentration (ppb) data provided by Aerisweather platform in the school's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

6.2.2.7 SO_2

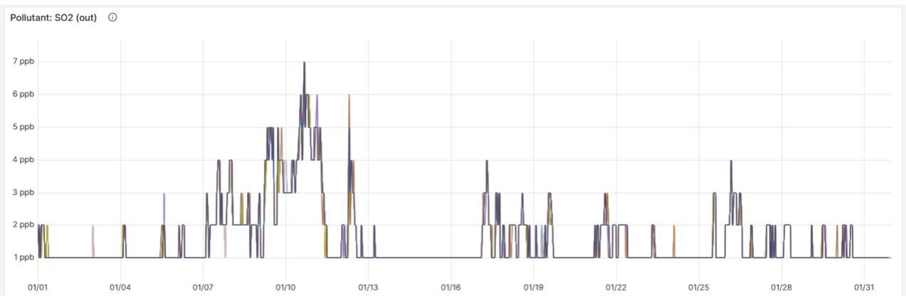

Figure 152. Outdoor SO_2 concentration (ppb) data provided by Aerisweather platform in the school's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

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The report from the Urban $PM_{2.5}$ Atlas, Air Quality in European Cities[20], sheds light on the major sources of particles in the outdoor environment of the Polish cities of Warsaw and Lodz (Figure 153). One notable observation is that residential activities significantly outweigh other sources, indicating that daily household routines contribute substantially to particle emissions in urban air. Following behind, transportation, industry, and agriculture are identified as having a comparable impact on air quality.

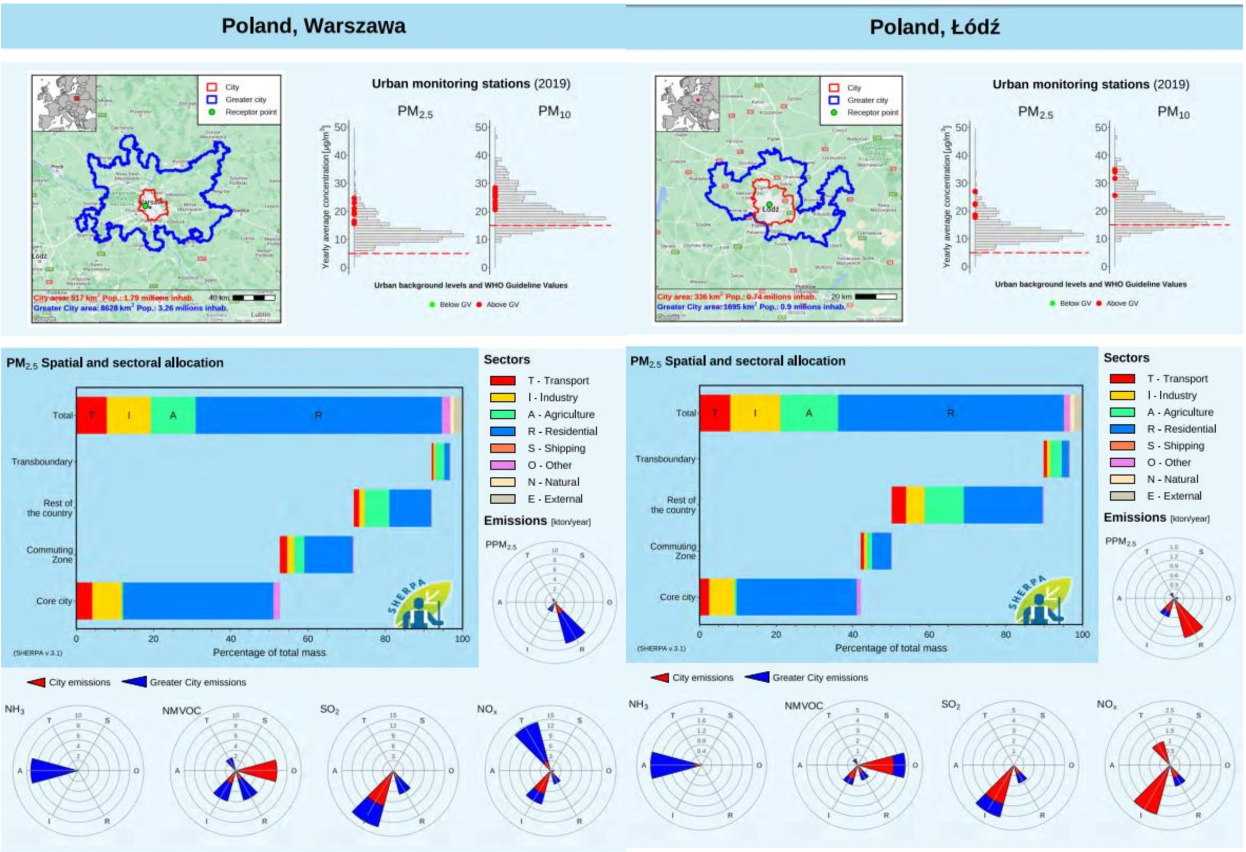

Figure 153. $PM_{2.5}$ pollution in Warsaw and Lodz (Poland). Urban $PM_{2.5}$ Atlas, Air Quality in European Cities, 2023 Report[20].

6.2.2.8 Comparison indoors versus outdoors

Figure 154 shows temperature records inside classrooms and outdoors. As evident, there is some variability among different schools.

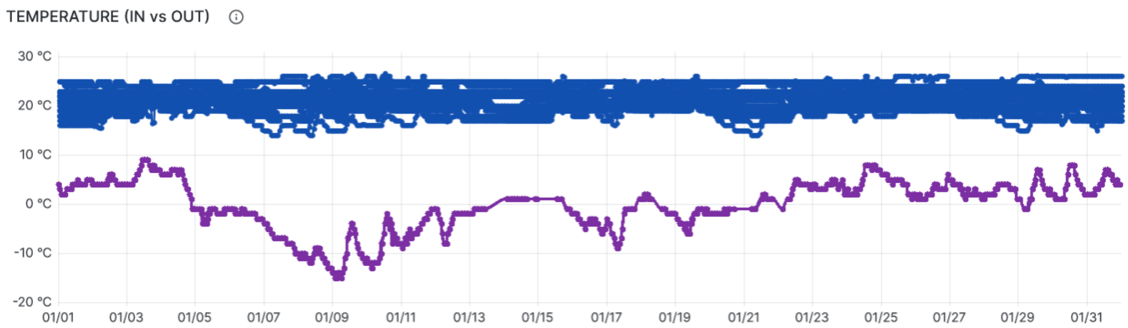

Figure 154. Evolution of temperature (°C) outdoors and indoors in the school's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

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Regarding relative humidity in Figure 155, there's a significant difference between indoor and outdoor levels at schools due to temperature effects.

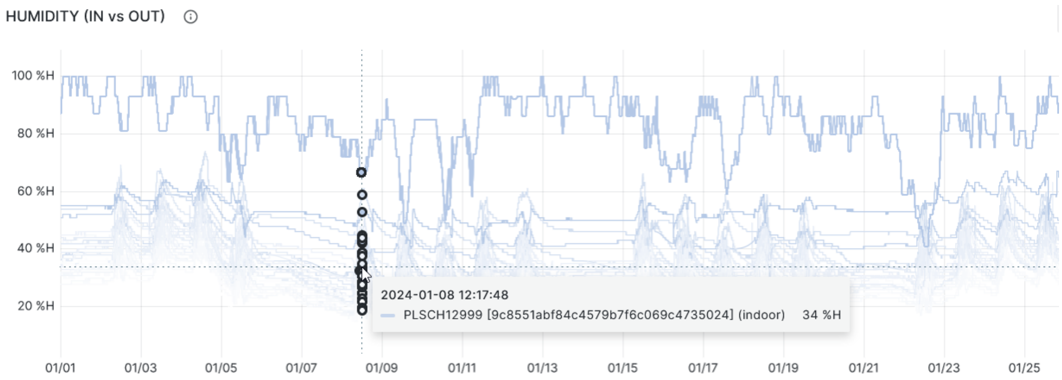

Figure 155. Evolution of RH (%) outdoors and indoors in the school's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

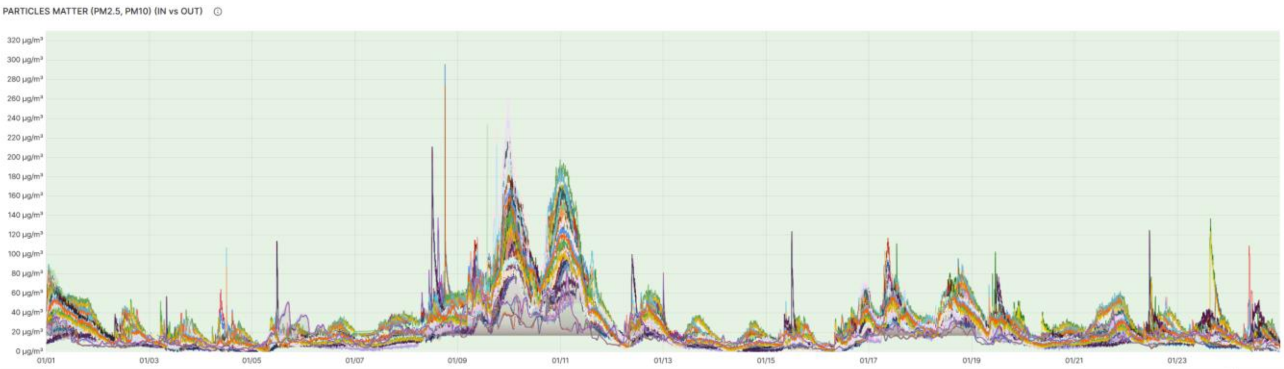

Figure 156. Evolution of PM concentration ($\mu g/m^3$) outdoors and indoors in the school's locations (as a whole) in January 2024 (generated with K-HEALTHinAIR platform).

As seen previously, significant variations exist in the concentrations of $PM_{2.5}$ and PM_{10} among different schools, as well as between indoor and outdoor environments. In the Figure 156, a certain correlation between both values seems to be apparent. When particle levels outdoors are higher, they generally also increase indoors, especially in some schools[48]. This observation, coupled with the fact that most schools do not have their own heating systems that could generate particles but rely on district heating networks, suggests a significant infiltration of particles from the outside. Furthermore, the fact that indoor values exceed that outdoors is a matter that will need to be evaluated within the framework of sensor validation in WP3. Data analysis will continue in the coming months as more data is collected.

6.2.3 VOCs sampling

A preliminary analysis of the collected information has not yet been possible because it has not been processed yet.

6.2.4 Formaldehyde sampling

Samples for aldehydes measurements were collected using silica gel tubes coated with 2,4-dinitrophenylhydrazine for 6 hours. The concentrations of 13 aldehydes (formaldehyde (FA), acetaldehyde (AA), acetone (A), acrolein (A), propionaldehyde (PROP), crotonaldehyde (CROT),

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2-butanone (2-BUT), methacrolein, butyraldehyde (BUTYR), benzaldehyde (BENZ), valeraldehyde (VALER), tolualdehyde and hexaldehyde (HEX)) were determined by the HPLC-UV method using the Acquity Arc UHPLC system (Waters) and Cortecs C18 analytical column 2.7 μm, 2.1x150 mm. A mixture of acetonitrile and water was used as the mobile phase (gradient elution). Results of performed analysis are presented in Figure 157, Figure 158 and Figure 159.

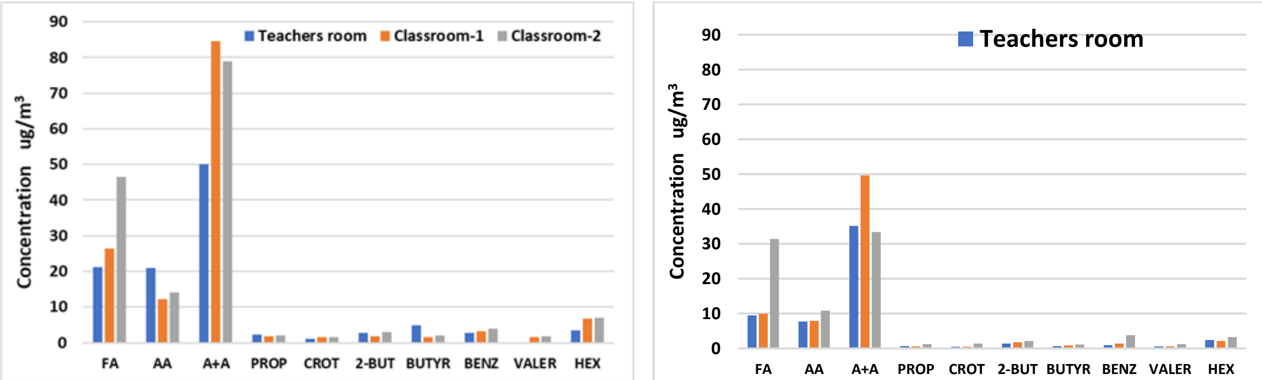

Figure 157. Concentration of FA, AA, A+A, PROP, CROT, 2-BUT, BUTYR, BENZ, VALER and HEX in indoor air samples collected in schools in November 2023. Left: School #1 (city center). Right: School #2 (city center).

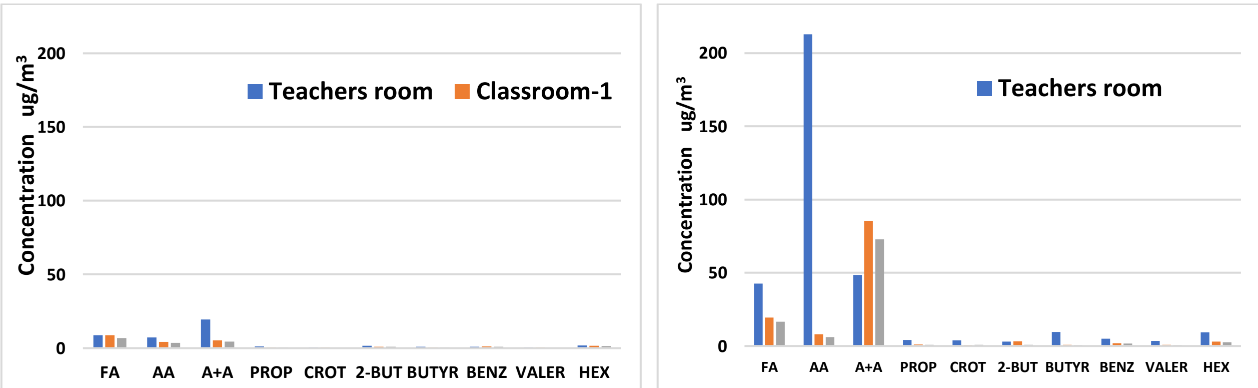

Figure 158. Concentration of FA, AA, A+A, PROP, CROT, 2-BUT, BUTYR, BENZ, VALER and HEX in indoor air samples collected in schools in November 2023. Left: School #3 (city center). Right: School #4 (heavy traffic area).

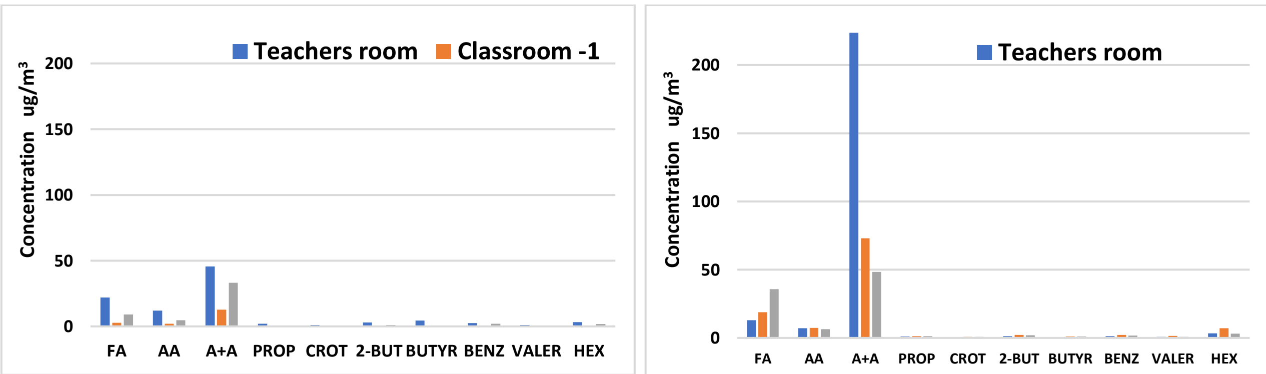

Figure 159. Concentration of FA, AA, A+A, PROP, CROT, 2-BUT, BUTYR, BENZ, VALER and HEX in indoor air samples collected in schools in November 2023. Left: School #5 (heavy traffic area). Right: School #6 (area without traffic).

Results of initial studies (determination of aldehydes in indoor air samples) conducted in secondary schools located in Lodz shows that main health risk is associated with presence of

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four compounds: formaldehyde, acetaldehyde, acetone and acrolein. The sum of the concentrations of these four compounds in all cases, regardless of school location, exceeds 80% of the sum of the concentrations of all determined aldehydes. We have found, that average sum of concentrations of all aldehydes were higher in the air of teacher's rooms than in classrooms (150,1 $\mu g/m^3$ vs. 85,7 $\mu g/m^3$). In our opinion these findings may be explain by smaller volume of teacher's rooms, and their better outfit (newer furniture, walls coverings, etc.).

It should be mentioned that in any case, concentration of formaldehyde does not exceed Polish maximum admissible concentration for IAQ (50 $\mu g/m^3$ - 24 h average). The next sampling session is planned for May – June 2024 (summer season) which will give material for comparisons similar to those made for kitchen or lecture hall scenarios (German Pilot).

6.2.5 PM/PAHs sampling

PM_4 sampling for PAHs assessment in schools was conducted in a similar scenario and the same methods as for homes. The first sampling campaign has been finished in July 2023 (non-heating season) and the second one in December 2023 (heating season). The samples from December 2023 are still being assessed in the laboratory, however some initial, raw data were delivered on February 27th, 2024. Nevertheless, it was not possible to finalize the analyses of these data and prepare appropriate graphs.

Figure 160, Figure 161 and Figure 162 the results of PAHs analyses in 5 schools (PLSCH001-PLSCH004 and PLSCH007) which were included in the first sampling campaign. In each school sampling was completed in 3 classrooms.

In general, the IAQ in classrooms of the schools involved in the sampling campaign in the summer season seems to be acceptable. Especially the concentrations of most hazardous PAHs (e.g. BaP, IP, DahA, BghiP) were relatively low or the presence of these compounds was not detected at all (concentrations were below the limit of quantification).

It should be added, that the measurement campaign was carried out in the summer, when generally the concentrations of PM and PM-bound PAHs remain at quite low levels. It was expected that only a comparison with the results from the winter campaign, carried out during the heating season, will allow more far-reaching conclusions to be drawn. And the first results from the winter campaign (not analysed in details yet) show that in the PM_4 samples from many locations, most of the 16 analysed PAHs were identified and also most hazardous, biologically active, 5- and 6-ring PAHs, like BaP, IP, DahA and BghiP were identified (in some locations also in relatively high concentrations). More detailed analyses will be conducted after finalizing the laboratory analyses.

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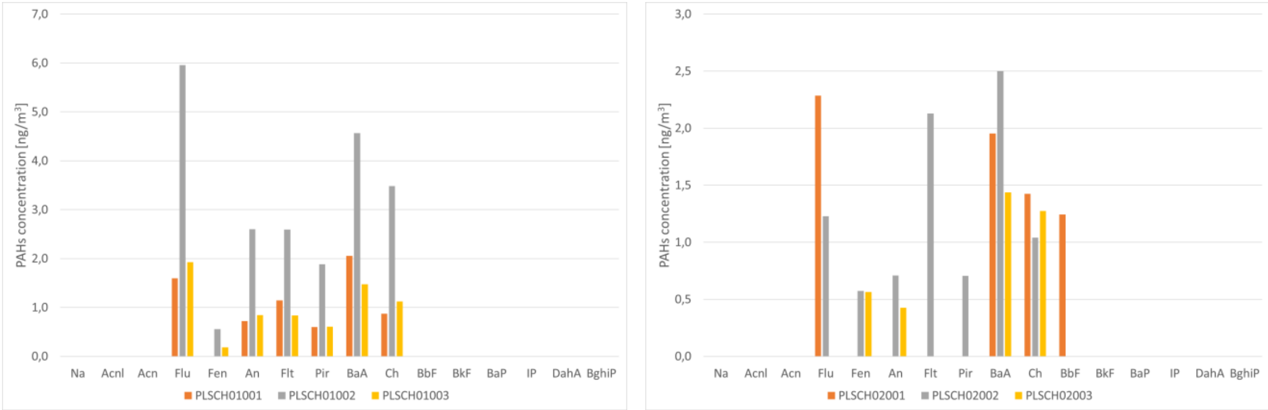

Figure 160. Concentrations of PM_4-bound PAHs measured in July 2023 in 3 classrooms of schools in Poland. Left: PLSCH001 located in the vicinity of Warsaw. Right: PLSCH002 located in the vicinity of Warsaw.

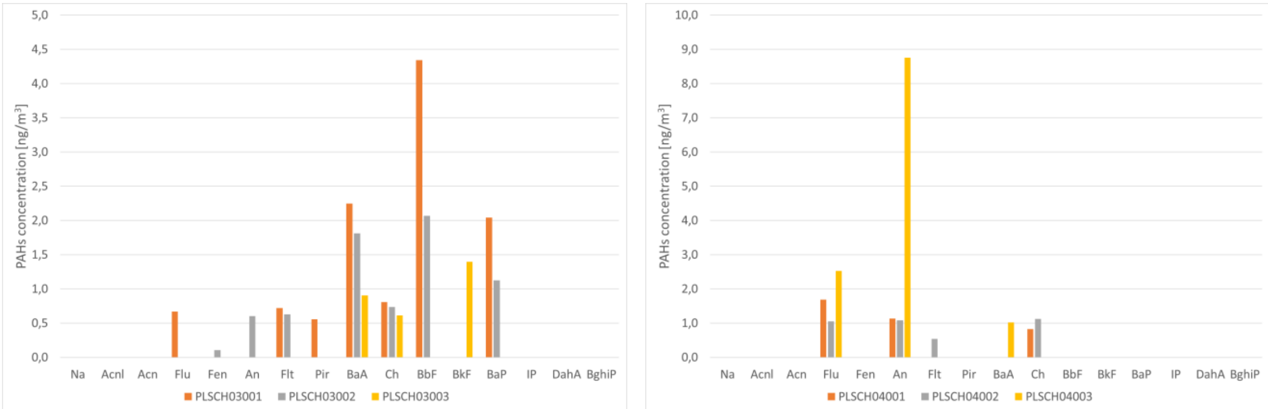

Figure 161. Concentrations of PM_4-bound PAHs measured in July 2023 in 3 classrooms of schools in Poland. Left: PLSCH003 located in the vicinity of Warsaw. Right: PLSCH004 located in Warsaw.

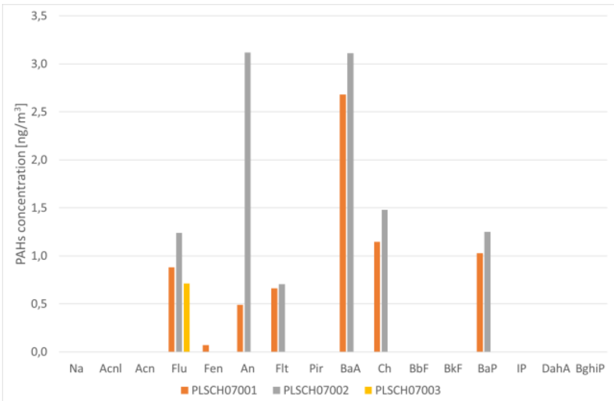

Figure 162. Concentrations of PM_4-bound PAHs measured in July 2023 in 3 classrooms of schools PLSCH007 located in Warsaw.

6.2.6 Microbiome sampling

Quantitative analysis of the microbiome results is conducted through descriptive statistics, which involve comparing mean values and considering standard errors. The research hypotheses outlined in D2.2 are evaluated by comparing the sampling results from multiple schools in Poland (following the schedule) and Austria (delayed due to school recruitment issues) during

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two periods: summer and winter. Additionally, data from scenarios DE-CAN and DE-LEC (Pilot 4) are also incorporated to enhance the comprehensiveness of the analyses.

Currently, only initial results from analyses conducted using culture-dependent methods have been obtained. Sequencing results will be available later due to the time-consuming nature of the procedures and the necessity to sequence all samples using uniform libraries. These preliminary findings confirm some of the hypotheses formulated in D.2.2.

1. Total number of microorganisms in indoor air depends on a season (predominance of fungi in summer).

The contrast in indoor microorganism concentrations between the two seasons is evident: bacteria levels significantly exceed those observed in summer during the winter months. Both in winter and summer, the levels are very low outdoors. This could indicate that lack of ventilation or heating are sources of bacteria indoors. On the other hand, for fungi, the concentration in summer is much higher than in winter. Additionally, the outdoor concentration in summer is very similar to the indoor concentration, with high levels in both cases, which could indicate that an external source is responsible for the fungi contamination (Figure 163).

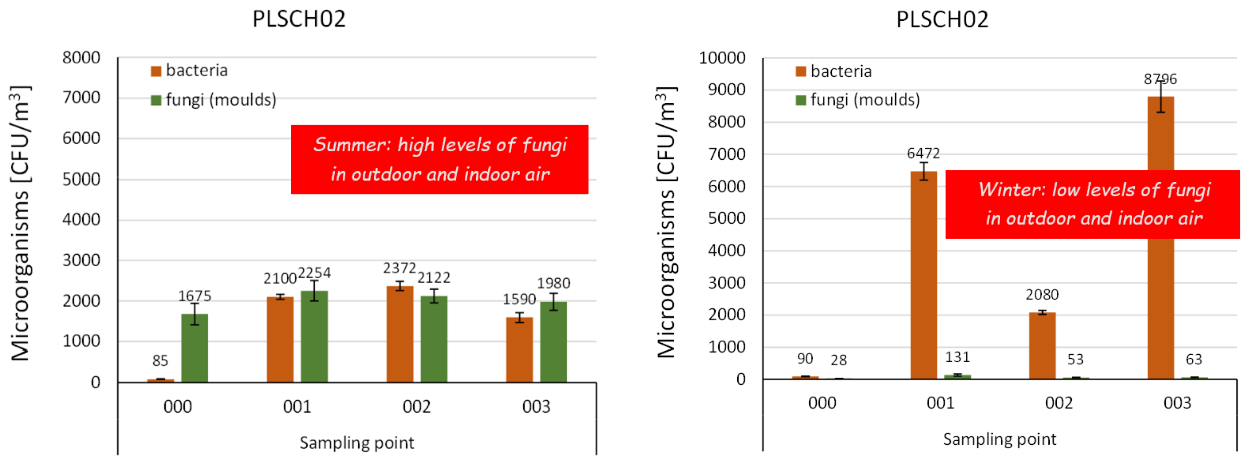

Figure 163. Comparison between 2 schools in Poland in summer and winter.

2. Total number of microorganisms in indoor air depends on occupants' behaviour and ventilation conditions.

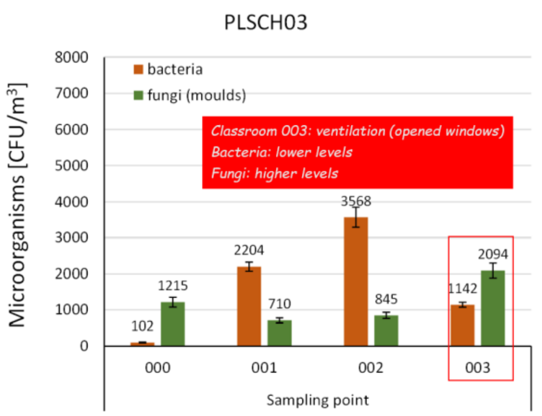

Figure 164. Microorganisms in different sampling points.

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3. Occupants in examined rooms are the main source of bacterial contamination of indoor air.

If it is compared the same classroom under the same conditions, but before and after a class, there is a difference in the concentration of bacteria due to variations in occupancy during this time.

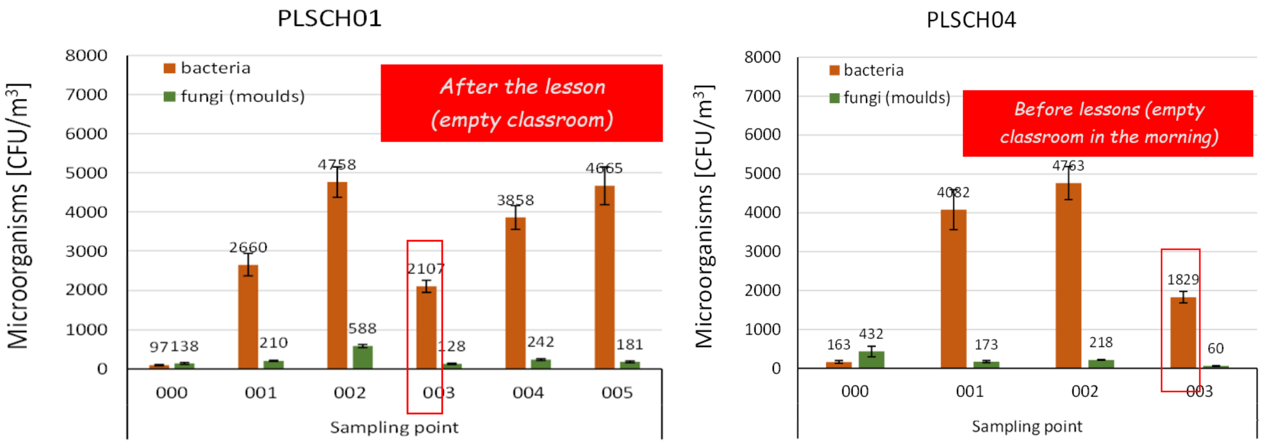

Figure 165. Comparison between 2 schools in Poland in winter.

4. Microbiological contamination of indoor air in schools/lecture halls is higher than in other public buildings.

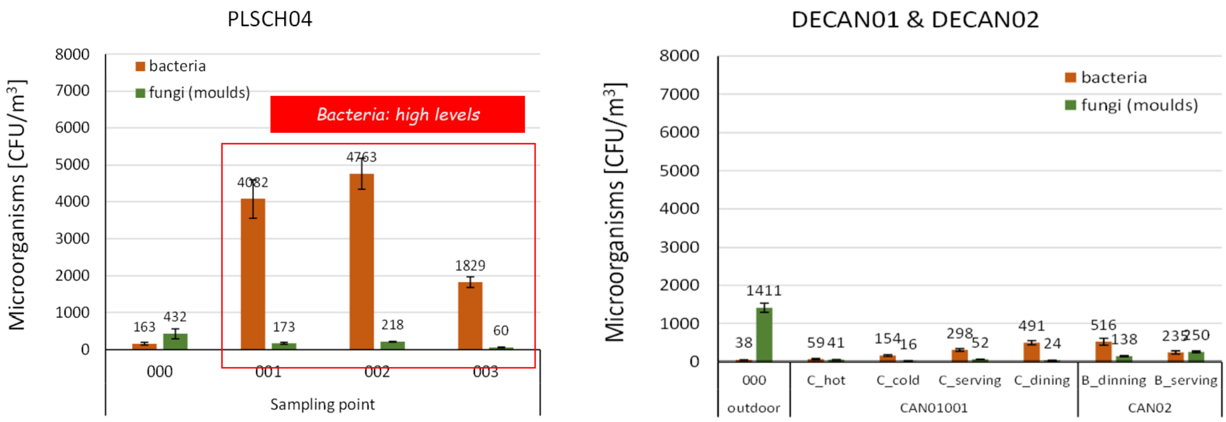

Figure 166. Comparison between the German canteens and a Polish school in summer season.

Other hypotheses:

- Geographical location shapes microbiome composition[49];
- Abundance of specific pathogenic microorganisms in indoor air is not correlated with the level of general microbial contamination;
- Exposure of children/students and canteen workers/customers to elevated concentrations of microorganisms in indoor air is associated with health problems and unspecific subtle symptoms (e.g. headache, fatigue, low productivity, coughing, sneezing, dizziness, nausea, irritation of the eye, nose, throat, and skin)[50].

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These hypotheses will be discussed after obtaining results of DNA sequencing and comparing with data in questionnaires.

6.2.7 Questionnaires

A series of meetings was organized to explain the questionnaire survey to headmasters, teachers, and students in all 15 schools in which the monitoring system was installed. As a result, 425 students expressed their interest in participating in the survey. However, after 3 weeks of intensive inquiries, 230 students (54%) provided their and parents' agreements.

The survey, using REDCAP, started on 17th January 2024. 71 students (31%) responded to Part A after two reminders.

In Austria the survey in secondary schools is planned for the end of February 2024.

6.2.8 Conclusions

The recruitment of schools was very successful; in Poland 22 schools were recruited, and in Austria 3. In each school, at least 3 sensors (INBIOT and M+H) were installed.

Basal concentrations of indoor pollutants:

1. CO_2 maximum levels in some schools indicate that improved ventilation patterns can be implemented.
2. TVOCs levels reach frequently very high values.
3. PM analysis should be carried out carefully later on because it appears as potential determinant from the literature review developed, prior results in PM sampling and the vulnerable group involved: children.

Time series analysis of VOCs:

1. Recurrent acute peaks of liberation of aldehydes and other VOCs have been identified through time series analysis.
2. Characterizing these outliers may contribute to identifying possible determinants and sources of IAQ health impacts.
3. Compounds such as formaldehyde, acetaldehyde, acetone and acrolein emerge as potential candidates for further investigation due to their elevated concentrations in comparison with other VOCs, as well as their well acknowledged deleterious health effects.

Outdoor data pending to be studied to provide individual conclusions.

PM/PAHs sampling:

1. The results of PM samples collected for the assessment of PAHs in schools in Poland were collected in two campaigns: the summer and the winter ones, however the results from the winter campaign are very initial.

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2. Comparison of the results from both campaigns conducted in Polish schools allows to conclude that samples collected in winter are characterized by the presence of a higher number of the 16 PAHs considered in the analyses, as well as that they also contain the most harmful compounds (5- and 6-ring), which were either not found in samples taken during summer campaign or occurred sporadically and in low concentrations. The presence of the most harmful compounds indicates health risks associated with breathing indoor air in winter.
3. However, due to the fact that all of the considered schools are heated from the district/municipal heating, it is very probable that high concentrations of PAHs inside the classrooms are rather be caused by the inflow of polluted ambient air. A more detailed analysis and comparison between the results from both campaigns will allow determining the possible sources of these pollutants.
4. The results will also be compared with the outcomes from the following campaigns which are planned to be completed in the next 2 non-heating and 2 heating seasons.

Microbiome analysis:

1. High level of bacterial contamination of indoor air indicates: i) low air exchange rate, ii) high occupancy of room.
2. High level of fungal contamination of air indicates: i) summer: immigration of fungi from outdoor air (low efficiency or no air filtration), ii) winter: mouldy building (internal source of fungal contamination).

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7 ROADMAP FOR THE NEXT PERIOD

The extensive scan analysis of the project, undertaken during the process of elaboration of the current document, clearly indicates that the activity of the consortium immediately after M18 should be executed in two consecutive phases.

The forthcoming four-month period: from M19 to M22, named as Consolidation Phase, must aim to achieve full maturity of the pilot sites and scenarios, whereas a subsequent second twelve-month period, from M23 to M34, named as Maturity Phase shall ensure a full year data collection in all pilot sites and scenarios.

Consolidation Phase (M19-M22)

The incoming period has been identified as a crucial step for ensuring a successful project development. The analysis done during the elaboration of D1.3 proposes specific KPI in the following three areas for the four-month period, from 1st March to 30th June 2024:

- Full deployment of all pilot sites and scenarios such that high-quality data collection at project level is ensured at the end of the period.
- Refinements of data management, fulfilling FAIR principles, are required to facilitate data analysis within scenarios and across pilot sites. In this regard, the following main challenges have been identified:
    - Homogeneity of the units expressing the levels of different pollutants within and across sites/scenarios
    - Analysis of comparability/equivalences among different types of equipment measuring the same pollutants. Also, specific efforts should be devoted assessing equivalences between continuous monitoring of IAQ and discrete measurements using gold standard procedures.
    - The influence of OAQ on IAQ measurements should be further analyzed to allow proper interpretation of indoor measurements.
- Critically assess initial decisions on citizens/patients' data capture to fulfil two complementary objectives: i) Adjust the amount of information collected to the real needs of the project aims, as advised by the GDPR (….) and indicated by the Ethical Committee for Human Research in Barcelona and Rotterdam, and ii) Increase applicability of planned measurement to real-world scenarios to facilitate future generalization, and confirmation, of the study results beyond the project lifetime.

Specific actions to cover all the aspects alluded to above should be identified and agreed during the 3rd consortium meeting to be held on 6th and 7th March in Ludwigsburg. As previously indicated, the elaboration, and further execution, of a credible work plan for the period has been identified as a critical step to ensure the success of the project.

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Maturity Phase (M23-M34) and subsequent project steps

We propose that this central project period addresses the following two core objectives. Firstly, completion of one full year data collection in all pilot sites and scenarios. The second objective, based on the results obtained throughout the entire period, shall be to fully redefine the granularities of the workplan for final fourteen-month phase of the project: from M35 to M48.

It is envisaged that by M23, the maturity of WP2 and WP4 achievements in terms of digital support for data analytics will facilitate continuous assessment of the results within and across pilots and scenarios such that both identification of determinants and hypothesis testing could be conceived as a building-blocks strategy allowing to shape, and initiate, the following three relevant areas for action during M35-M48 well before M30. Such areas are:

- Completion of *in vivo* and *in vitro* studies within the framework described in *D1.7 Coordination program for pilots (version II)*.
- Testing targeted preventive actions in selected scenarios, based on the identification of determinants during the Maturity phase.
- Refinement of clinical strategies aiming at preventing exacerbations associated to poor IAQ, as defined in Annex ("*Protocol for the Enhanced Management of Multimorbid Patients with Chronic Obstructive Pulmonary Diseases: Role of Indoor Air Quality*") to *D1.7 Coordination program for pilots (version II)*.

We strongly suggest considering the adoption of a PDSA (Plan-Do-Study-Act) methodology, equivalent to that described in Annex ("*Protocol for the Enhanced Management of Multimorbid Patients with Chronic Obstructive Pulmonary Diseases: Role of Indoor Air Quality*) to *D1.7 Coordination program for pilots (version II)* to foster the implementation of the work plan conceived for both Consolidation and Maturity phases of the project, as described above.

The key activity during the final semester, from M43 to M48, will be the formulation of recommendations for updated IAQ guidelines grounded on the results generated throughout the project lifetime.

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8 CONCLUSIONS

The content of the current document, *D1.3 Report on 1st Step: Scan Analysis,* is based on very preliminary results generated so far by the five pilot sites, encompassing ten different scenarios. It is of note, however, that the lessons learnt during the process of deployment of the different pilots, and the characteristics of the information collected, are already pointing toward well-defined directions that should lead toward a successful accomplishment of the expected outcomes within the project lifetime.

This document includes a descriptive analysis of the preliminary results and summary description of the lessons learnt from each pilot site and the different scenarios. Such initial results and lessons learnt from pilot's deployment are indicating future directions and but also needed corrections of the project work plan. Below are some initial conclusions and learnings from the preliminary analysis of the collected data. They are presented in a structured manner for each pilot. However, a common conclusion for this first analysis is that more data collection and analysis is needed for a comprehensive analysis.

Pilot 1: Hospital

- Basal concentrations of indoor pollutants in the hospital setting are generally low and comply with regulatory standards.
- Time series analysis reveals recurrent peaks of aldehydes and other VOCs, which may have health implications.
- Formaldehyde, acetone, and chloroform are identified as potential candidates for further investigation due to their elevated concentrations and known health effects.
- Delays in sequencing have hindered the microbiome analysis, which is crucial for understanding biological pollutants and cleaning dynamics within the hospital.

Pilot 1: Outpatients

- Heterogeneous profiles of indoor pollutants are observed across households, with smoking habit emerging as a primary driver for indoor PM pollution.
- Further research is needed to pinpoint primary sources of formaldehyde and VOCs in indoor environments.
- Elevated pollution exposure in certain dwellings associated with unhealthy habits suggests the potential benefits of preventive strategies.
- Correlation analysis between IAQ and clinical data in outpatients is crucial for identifying IAQ health determinants and enhancing precision in identifying exacerbations among respiratory patients.

Pilot 2: Hospital

- Overall, the IAQ parameters indicate relatively low indoor air pollutants concentration in the assessed hospital areas.

Pilot 3: Canteen & Lecture Hall

- Initial analysis indicates low basal concentrations of indoor pollutants, but further data collection is required.

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- The comparison of the preliminary modelled and measured values for pollution outdoor has shown the model overestimate the PM and underestimate the NO_2.

- PM is, regardless this, very low both indoor and outdoor.

Pilot 4: Canteen & Lecture Hall

- Basal concentrations of indoor pollutants are low, with recurrent peaks of formaldehyde and other VOCs identified.
- More data collection is needed for comprehensive analysis.
- Outdoor PM infiltration is observed, particularly in areas closer to the buildings' entrances.
- High levels of bacterial and fungal contamination suggest low air exchange rates and potential indoor pollution sources.

Pilot 5: Homes & Schools

- Varied profiles of indoor pollutants are observed across households and schools.
- Elevated pollution exposure in certain dwellings suggests the potential benefits of preventive strategies.
- PM/PAHs sampling reveals higher concentrations in winter, indicating potential health risks associated with breathing indoor air during colder seasons.
- High levels of bacterial and fungal contamination indicate low air exchange rates and potential sources of indoor pollution.

On the other hand, while acknowledging the early stage of deployment of the different pilots, the report indicates also the lessons learnt from each pilot and from the different scenarios. Moreover, the analysis carried out during the process of preparation of D1.3 has provided key hints to propose a structured roadmap to be debated during the incoming consortium meeting to be held on 6th and 7th March 2024. Such debate should generate a granular work plan for execution during the Consolidation (M19-M22) and Maturity (M23-M34) phases of the project.

The roadmap of core actions for the subsequent period of the project (M18 to M34), including the associated key performance indicators (KPI), is also proposed. The main purpose being to foster a productive debate during the incoming 3rd consortium meeting to be held in Ludwigsburg on 6th – 7th March 2024. The final outcomes should be the generation of an operative action plan for the period. The conclusions highlight the steps to be adopted aiming at mitigating acknowledged risk of the project.

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10 ANNEXES

10.1 IAQ Guidelines

As part of the work within this work package, and in collaboration with WP2 and WP3, a table will be set up to identify the recommended maximum levels for each of the parameters being analyzed. In this regard, the compilation of available information has begun, which is extensive, along with the selection of those to be applied in the project. Here, a preliminary approximation is presented based on an initial simple literature search. This table will be supplemented with information extracted from the literature review conducted in WP2 and will feed the information sources for the development of the IAQ index.

The table with the comprehensive information gathered in the conducted search has not been included here due to its length, and only the most important parameters considered and the references used to assess the most suitable levels are identified. Additionally, from the references, any identified 'dose-response' values, health effects, and studied population groups have been extracted. An excel file within the full information is uploaded in the document repository of the Project in the WP2 section.

The information is presented in three sections: outdoor air including a table with summary values from the WHO, indoor air, and occupational health data. In addition, it is interesting to consider that these are levels measured using established reference methods, and air quality monitors are not yet widely accepted as valid in this regard. During the project, efforts will be made to analyze the information provided by the sensors and to use these reference values.

Table 13. Gideline's levels for the key pollutants in the K-HEALTHinAIR Project (Preliminary

POLLUTANT	AVERAGING TIME	Preliminary K-HEALTHinAIR guideline level	References
$PM_{2.5}$ (µg/m³)	Annual	5	WHO
	24-hour	15	WHO
PM_{10} (µg/m³)	Annual	15	WHO
	24-hour	45	WHO
TVOC (µg/m³)	Annual	200 ug/m³	The Netherlands
	8-hour	600 ug/m³	Portugal
Formaldehyde (µg/m³)	30-minutes	100	WHO
	8-hour	60	Austria
CO_2 (ppm)	1-hour	900	Multiple*
Radon (Bq/m³)	value	100	WHO
O_3 (µg/m³) Outdoor	Peak season	60	WHO
	8-hour	100	WHO
NO_2 (µg/m³) Outdoor	Annual	10	WHO
	24-hour	25	WHO
	1-hour	200	WHO

* Still under discussion depending on the scenario.

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OUTDOOR POLLUTION

Pollutant	Reference	Institution/Entity	Outdoor Admissible levels (annual)
PM_{10}	DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe (https://eur-lex.europa.eu/eli/dir/2008/50/oj)	European Commission	- 50 µg/m3 more than 35 times in a year (24 hours) - 40 µg/m3 (annual average)
	WHO Global Air Quality Guidelines https://www.who.int/publications/i/item/9789240034228	World Health Organization	PM10: 20 µg/m3 (annual levels recommendations)
$PM_{2.5}$	National Ambient Air Quality Standards (NAAQS) for PM | US EPA	EPA	Primary annual average: 9.0 to 10.0 µg/m3 Secondary standards: 15.0 µg/m3 24-hour standards with 98th percentile forms and levels of 35 µg/m3) PM10 (24-hour standards with one-expected exceedance forms and levels of 150 µg/m3)
	DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe (https://eur-lex.europa.eu/eli/dir/2008/50/oj)	European Commission	25 µg/m3 (24 hours)
NO	https://wwwn.cdc.gov/TSP/MMG/MMGDetails.aspx?mmgid=394&toxid=69	Centre for Disease Control USA	OSHA standard for nitric oxide is 25 parts per million parts of air (PPM) averaged over an eight-hour work shift OR 30 milligrams of nitric oxide per cubic meter of air (mg/m3).
NO_2	Air Quality Guide for Nitrogen Dioxide, EPA-456/F-11-003 (airnow.gov)	Environmental protection agency	EPA set a 1-hour NO2 standard at the level of 100 parts per billion (ppb). The annual average NO2 standard of is 53 ppb.

NO_2	WHO Global Air Quality Guidelines https://www.who.int/publications/i/item/9789240034228	World Health Organization	10 ug/m3 (annual) 25 ug/m3 (24 hours) 200 ug/m3 (1 hour)
NO_2	Air quality directive (2008/EC/50) https://eur-lex.europa.eu/eli/dir/2008/50/oj	European Commission	40 ug/m3 (annual) 200 ug/m3 (1 hour)
Lead	https://eur-lex.europa.eu/legal-content/PT/TXT/PDF/?uri=CELEX:02008L0050-20150918&from=SV	European Commission	Annual average exposure limit: 0.5 µg/m³ (micrograms per cubic meter)
Sulphur dioxide	https://eur-lex.europa.eu/legal-content/PT/TXT/PDF/?uri=CELEX:02008L0050-20150918&from=SV	European Commission	125 ug/m3 (24 hours) (exceed no more than 3 times a year) 350 ug/m3 (annual) (exceed no more than 24 times a year)
CO	https://eur-lex.europa.eu/legal-content/PT/TXT/PDF/?uri=CELEX:02008L0050-20150918&from=SV	European Commission	10 mg/m3 (8 hours)

WHO Global Air Quality Guidelines - Outdoor pollutants recommedations (https://www.who.int/publications/i/item/9789240034228)

POLLUTANT	AVERAGING TIME	WHO 2021 AIR QUALITY GUIDELINE (CURRENT)	WHO 2005 AIR QUALITY GUIDELINE (OLD)	CHANGE
$PM_{2.5}$ (µg/m^3)	Annual	5	10	-50%
	24-hour	15	25	-40%
PM_{10} (µg/m^3)	Annual	15	20	-25%
	24-hour	45	50	-10%
O_3 (µg/m^3)	Peak season	60	N/A	Newly introduced
	8-hour	100	100	Unchanged
NO_2 (µg/m^3)	Annual	10	40	-75%
	24-hour	25	N/A	Newly introduced
	1-hour	200	200	Unchanged
SO_2 (µg/m^3)	24-hour	40	20	100%
	10-minute	500	500	Unchanged
CO (mg/m^3)	24-hour	4	N/A	Newly introduced
	8-hour	10	N/A	Newly introduced
	1-hour	35	N/A	Newly introduced
	15-minute	100	N/A	Newly introduced

INDOOR POLLUTION

Pollutant	Reference	Institution/Entity/Country	Indoor Admissible levels
PM_{10}	Indoor Air Quality Guidelines (IAQGs)	France	50 ug/m3 (24 hours) 20 ug/m3 (1 year) 75 ug/m3 (rapid action) 15 ug/m3 (long period)
	RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	50 ug/m3 (24 hours) 20 ug/m3 (1 year)
	INDOOR AIR QUALITY IN BELGIUM https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/hgr_8794_advice_iaq.pdf	Belgium (Flanders)	40 ug/m3 (24 hours)
		Finland	50 ug/m3
	Law 353-A/2013	Portugal	50 ug/m3 (8 hours)
		Norway	90 ug/m3 (8 hours)
		Lithuania	100 ug/m3
		Poland	90 ug/m3 (8 hours)

$PM_{2.5}$	Indoor Air Quality Guidelines (IAQGs)	France	25 ug/m3 (24 hours) 10 ug/m3 (1 year) 50 ug/m3 (rapid action) 10 ug/m3 (long period)
		Germany	25 ug/m3 (24 hours)
	RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	25 ug/m3 (24 hours) 10 ug/m3 (1 year)
	INDOOR AIR QUALITY IN BELGIUM https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/hgr_8794_advice_iaq.pdf	Belgium (Flanders)	15 ug/m3 (1 year)
	Law 353-A/2013	Portugal	25 ug/m3 (8 hours)
		Norway	40 ug/m3 (8 hours)
		Poland	40 ug/m3 (8 hours)
NO_2	WHO Guidelines for Indoor Air Quality: selected pollutants	World Health Organization	200 ug/m3 - 1-hour average 40 ug/m3 - annual average
	Air Quality Guide for Nitrogen Dioxide, EPA-456/F-11-003 (airnow.gov)	Environmental protection agency	1-hour NO2 standard - 100 ppb Annual average NO2 standard - 53 ppb

	Indoor Air Quality Guidelines (IAQGs)	France	200 ug/m3 - 1-hour average 40 ug/m3 - annual average
		Germany	350 ug/m3 (30 minutes) (danger threshold) 60 ug/m3 (7 days) (danger threshold)
	RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	200 ug/m3 - 1-hour average 40 ug/m3 - annual average
	Indoor Air Quality Guidelines for selected Volatile Organic Compounds (VOCs) in the UK https://assets.publishing.service.gov.uk/media/5d7a2912ed915d522e4164a5/VO__statement_Final_12092019_CS__1_.pdf	United Kingdom	300 ug/m3 - 1-hour average 40 ug/m3 - annual average
	INDOOR AIR QUALITY IN BELGIUM https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/hgr_8794_advice_iaq.pdf	Belgium (Flanders)	135 ug/m3 (1 hour) (guideline value) 200 ug/m3 (1 hour) (Intervention value)
		Norway	200 ug/m3 (1 hour) 100 ug/m3 (24 hours)
Total VOCs	RIVM report 609021044/2007 Health-based guideline values for the indoor environment	Netherlands	200 ug/m3 - 1 year

	https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf		
	INDOOR AIR QUALITY IN BELGIUM https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/hgr_8794_advice_iaq.pdf	Belgium (Flanders)	200 ug/m3
	Law 353-A/2013	Portugal	600 ug/m3 (8 hours)
		Norway	400 ug/m3
		Lithuania	600 ug/m3 (8 hours)
		Poland	400 ug/m3
Toluene	Indoor Air Quality Guidelines (IAQGs)	France	20000 ug/m3
		Germany	300 (1-14 days) - all day use 3000 (1-14 days) - danger threshold
	RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	200 ug/m3 - 1 year
	INDOOR AIR QUALITY IN BELGIUM https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/hgr_8794_advice_iaq.pdf	Belgium (Flanders)	260 ug/m3

		Austria	75 ug/m3 (1 hour)
	Law 353-A/2013	Portugal	250 ug/m3 (8 hours)
		Poland	200 ug/m3 (24 hours)
		Poland	250 ug/m3 (8 hours)
Benzene	WHO Guidelines for Indoor Air Quality: selected pollutants	World Health Organization	No safe level of exposure can be recommended. The risk of toxicity from inhaled benzene would be the same whether the exposure was indoors or outdoors. Thus, there is no reason that the guidelines for indoor air should differ from ambient air guidelines.
	Décret n° 2011-1727	France	30 ug/m3 (24 hours) 10 ug/m3 (1 year) 10 ug/m3 (rapid action) 2 ug/m3 (long period)
	RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	20 ug/m3
	Indoor Air Quality Guidelines for selected Volatile Organic Compounds (VOCs) in the UK https://assets.publishing.service.gov.uk/media/5d7a2912ed915d522e4164a5/VO__statement_Final_12092019_CS__1_.pdf	United Kingdom	5 ug/m3 (1 year)

	INDOOR AIR QUALITY IN BELGIUM https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/hgr_8794_advice_iaq.pdf	Belgium (Flanders)	<=2 ug/m3 (guideline value) 10 ug/m3 (intervention value)
	Law 353-A/2013	Portugal	5 ug/m3 (8 hours)
		Poland	10 ug/m3 (24 hours)
		Poland	20 ug/m3 (8 hours)
Ethylben-zene	Indoor Air Quality Guidelines (IAQGs)	France	22 mg/m3 (24 hours) 1.5 mg/m3 (1 year)
Formalde-hyde	WHO Guidelines for Indoor Air Quality: selected pollutants https://www.who.int/publications/i/item/9789289002134	World Health Organization	100 ug/m3 – 30-minute average (threshold should not be exceeded at any 30-minute interval during a day)
	Décret n° 2011-1727	France	50 ug/m3 (2 hours) 10 ug/m3 (1 year) 100 ug/m3 (rapid action) 10 ug/m3 (long period)
		Germany	120 ug/m3

RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	120 ug/m3 (30 minutes) 10 ug/m3 (1 year) 1.2 (long period)
Indoor Air Quality Guidelines for selected Volatile Organic Compounds (VOCs) in the UK https://assets.publishing.service.gov.uk/media/5d7a2912ed915d522e4164a5/VO__statement_Final_12092019_CS__1_.pdf	United Kingdom	100 ug/m3 (30 minutes)
INDOOR AIR QUALITY IN BELGIUM https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/hgr_8794_advice_iaq.pdf	Belgium (Flanders)	10 ug/m3 (30 minutes) (guideline value) 100 ug/m3 (30 minutes) (intervention value)
	Finland	50 ug/m3
	Austria	100 ug/m3 (30 minutes) 60 ug/m3 (24 hours)
Law 353-A/2013	Portugal	100 ug/m3 (8 hours)
	Norway	100 ug/m3 (30 minutes)
	Lithuania	100 ug/m3
	Poland	50 ug/m3 (24 hours)
	Poland	100 ug/m3 (8 hours)

Trichloro-ethylene	WHO Guidelines for Indoor Air Quality: selected pollutants https://www.who.int/publications/i/item/9789289002134	World Health Organization	No safe level of exposure can be recommended.
Trichloro-ethylene	Indoor Air Quality Guidelines (IAQGs)	France	800 ug/m3 (14 days/year) 10 ug/m3 (rapid action) 2 ug/m3 (reference value)
Trichloro-ethylene		Germany	1 ug/m3 (7 days)
Trichloro-ethylene	INDOOR AIR QUALITY IN BELGIUM https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/hgr_8794_advice_iaq.pdf	Belgium (Flanders)	200 ug/m3
Trichloro-ethylene	Law 353-A/2013	Portugal	25 ug/m3 (8 hours)
Trichloro-ethylene		Poland	150 ug/m3 (24 hours)
Trichloro-ethylene		Poland	200 ug/m3 (8 hours)
Tetrachlo-roethylene	WHO Guidelines for Indoor Air Quality: selected pollutants https://www.who.int/publications/i/item/9789289002134	World Health Organization	0.25 mg/m3 – annual average
	Indoor Air Quality Guidelines (IAQGs)	France	1380 ug/m3 (14 days/year) 250 ug/m3 (1 year)

			250 ug/m3 (long period) 250 ug/m3 (reference value)
		Germany	1 ug/m3 (7 days)
	RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	250 ug/m3
		Belgium (Flanders)	100 ug/m3
		Austria	250 ug/m3 (7 days)
	Law 353-A/2013	Portugal	250 ug/m3 (8 hours)
Naph-talene	WHO Guidelines for Indoor Air Quality: selected pollutants https://www.who.int/publications/i/item/9789289002134	World Health Organization	0.01 mg/m3 – annual average
	Indoor Air Quality Guidelines (IAQGs)	France	10 ug/m3 (1 year)
		Germany	20 ug/m3 (7 days) (all day use) 200 ug/m3 (7 days) (danger threshold)
	RIVM report 609021044/2007 Health-based guideline values for the indoor environment	Netherlands	25 ug/m3

	https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf		
		Poland	100 ug/m3 (24 hours)
		Poland	150 ug/m3 (8 hours)
Styrene		Germany	30 ug/m3 (7 days) (all day use) 300 ug/m3 (7 days) (danger threshold)
	RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	900 ug/m3
		Finland	1 ug/m3
		Austria	40 ug/m3 (7 days) 10 ug/m3 (10 hours)
		Poland	20 ug/m3 (24 hours)
			30 ug/m3 (8 hours)
Acetaldehyde	Indoor Air Quality Guidelines (IAQGs)	France	3 mg/m3 (1 hour) 0.16 mg/m3 (1 year)
Dichloromethane		Germany	200 ug/m3 (24 hours) (all day use) 2000 ug/m3 (24 hours) (danger threshold)

Dichloro-methane	RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	200 ug/m3 (1 year)
Radon	WHO Handbook on Indoor Radon: a public health perspective https://iris.who.int/bitstream/handle/10665/44149/9789241547673_eng.pdf?sequence=1	World Health Organization	WHO proposes a reference level of 100 Bq/m3 to minimize health hazards due to indoor radon exposure. However, if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq/m3 which represents approximately 10 mSv per year according to recent calculations by the International Commission on Radiation Protection.

CO_2	Belgian Law on Indoor Air Quality https://www.health.belgium.be/en/closer-legal-framework-indoor-air-quality The law aims to improve indoor air quality in all closed spaces accessible to the public, i.e. all places enclosed by doors or walls and fitted with a ceiling or floor that are not limited to the family sphere or purely to the professional sphere. In other words, your home and meeting rooms at the office, for example, are not affected by this law.	SANTE PUBLIQUE, SECURITE DE LA CHAINE ALIMENTAIRE ET ENVIRONNEMENT	Reference Level A: - the concentration of CO2 in a room is less than 900 ppm (which means that CO2 represents 0.09% of the volume of the air considered), or - the minimum ventilation and air purification flow rate is 40 m3 per hour per person, including at least 25 m3 per hour per person of ventilation with outside air. Reference Level B: -the concentration of CO2 in a room is less than 1,200 ppm (which means that CO2 represents 0.12% of the volume of the air considered), or - the minimum ventilation flow rate with outside air is 25 m3 per hour per person.
CO	WHO Guidelines for Indoor Air Quality: selected pollutants	World Health Organization	15 minutes – 100 mg/m3 1 hour – 35 mg/m3 (assuming light exercise and that such exposure levels do not occur more often than one per day) 8 hours – 10 mg/m3 (arithmetic mean concentration, light to moderate exercise) 24 hours – 7 mg/m3 (arithmetic mean concentration, assuming that the exposure occurs when the people are awake and alert but not exercising)

Indoor Air Quality Guidelines (IAQGs)	France	100 mg/m3 (15 minutes) 60 mg/m3 (30 minutes) 30 mg/m3 (1 hour) 10 mg/m3 (8 hours)
	Germany	1.5 mg/m3 (8 hours) - all day use 6 mg/m3 (30 minutes) - all day use 60 mg/m3 (30 minutes) - danger threshold 15 mg/m3 (8 hours) - danger threshold
RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	100 mg/m3 (15 minutes) 60 mg/m3 (30 minutes) 30 mg/m3 (1 hour) 10 mg/m3 (8 hours)
Indoor Air Quality Guidelines for selected Volatile Organic Compounds (VOCs) in the UK https://assets.publishing.service.gov.uk/media/5d7a2912ed915d522e4164a5/VO__statement_Final_12092019_CS__1_.pdf	United Kingdom	100 mg/m3 (15 minutes) 60 mg/m3 (30 minutes) 30 mg/m3 (1 hour) 10 mg/m3 (8 hours)
INDOOR AIR QUALITY IN BELGIUM https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/hgr_8794_advice_iaq.pdf	Belgium	5.7 mg/m3 (24 hours) (guideline value) 30 mg/m3 (1 hour) (intervention value)
	Finland	8 mg/m3
Law 353-A/2013	Portugal	10 mg/m3 (8 hours)

		Norway	25 mg/m3 (1 hour) 10 mg/m3 (8 hours)
		Lithuania	10 mg/m3
		Poland	25 mg/m3 (1 hour)
		Poland	10 mg/m3 (8 hours)
PAHs (B[a]P as marker)	WHO Guidelines for Indoor Air Quality: selected pollutants	World Health Organization	No threshold can be determined and all indoor exposures are considered relevant to health.
	RIVM report 609021044/2007 Health-based guideline values for the indoor environment https://www.rivm.nl/bibliotheek/rapporten/609021044.pdf	Netherlands	1.2 ng/m3
	Indoor Air Quality Guidelines for selected Volatile Organic Compounds (VOCs) in the UK https://assets.publishing.service.gov.uk/media/5d7a2912ed915d522e4164a5/VO__statement_Final_12092019_CS__1_.pdf	United Kingdom	0.25 ng/m3 (1 year)

Pollutant	Reference	Legislation (y/n)	Institution/Entity	Indoor Admissible levels
NO	0448.pdf (cdc.gov)	Yes	Centre for Disease Control USA	8h work shift - 25 ppm OR 30 mg/m3
NO	CDC - NIOSH Pocket Guide to Chemical Hazards - Nitric oxide	Yes	NIOSH USA	TWA 25 ppm (30 mg/m3)
NO	Microsoft Word - 1357.doc (nj.gov)	Yes	The American Conference of Governmental Industrial Hygienists	TLV - 25 ppm
Ethanol	https://nj.gov/health/eoh/rtkweb/documents/fs/0844.pdf	Yes	OSHA	TLV: 1000 ppm over an 8-hour work shift
Ethanol	https://nj.gov/health/eoh/rtkweb/documents/fs/0844.pdf	Yes	NIOSH	TLV: 1000 ppm over a 10-hour work shift
Ethanol	https://nj.gov/health/eoh/rtkweb/documents/fs/0844.pdf	Yes	ACGIH	TLV: 1000 ppm as a STEL (short term exposure limit)
Acetone	ACETONE | Occupational Safety and Health Administration (osha.gov)	Yes	OSHA	PEL-TWA 1000 ppm (2400mg/m3) 8-hour TWA
Acetone	ACETONE | Occupational Safety and Health Administration (osha.gov)	Yes	NIOSH	REL-TWA 250 ppm (590 mg/m^3) Up to 10-hour TWA
Acetone	ACETONE | Occupational Safety and Health Administration (osha.gov)	Yes	ACGIH	PEL-TWA 250 ppm 8-hour TWA--TLV-STEL 500 ppm
Acetone	0006.pdf (nj.gov)	Yes	IDLH	IDLH: 2500 ppm

Benzene	WHO Guidelines for Indoor Air Quality: selected pollutants	No	World Health Organization	No safe level of exposure can be recommended. The risk of toxicity from inhaled benzene would be the same whether the exposure was indoors or outdoors. Thus, there is no reason that the guidelines for indoor air should differ from ambient air guidelines.
Benzene	0197.pdf (nj.gov)	Yes	OSHA	1 ppm, 8-hr TWA 5 ppm, 15-min STEL
Benzene	0197.pdf (nj.gov)	Yes	NIOSH	0.1 ppm, 10-hr TWA 1 ppm, 15-min STEL
Benzene	0197.pdf (nj.gov)	Yes	ACGIH	0.5 ppm, 8-hr TWA 2.5 ppm, 15-min STEL
1,2-Dichlorobenzene	ICSC 1066 - 1,2-DICHLOROBENZENE (ilo.org)	Yes	ILO	TLV: 25 ppm as TWA 50 ppm as STEL A4 (not classifiable as a human carcinogen).
1,2-Dichlorobenzene	ICSC 1066 - 1,2-DICHLOROBENZENE (ilo.org)	Yes	EU-OEL	EU-OEL: 122 mg/m3, 20 ppm as TWA; 306 mg/m3, 50 ppm as STEL; (skin)
Formaldehyde	0946.pdf (nj.gov)	Yes	OSHA	0.75 ppm, 8-hr TWA 2 ppm, 15-min STEL
Formaldehyde	0946.pdf (nj.gov)	Yes	NIOSH	0.75 ppm, 8-hr TWA 2 ppm, 15-min STEL
Formaldehyde	0946.pdf (nj.gov)	Yes	ACGIH	0.75 ppm, 8-hr TWA 2 ppm, 15-min STEL
Formaldehyde	0946.pdf (nj.gov)	Yes	IDLH	20 ppm
Total VOC	Understanding VOC's and its effects on	Yes	WHO	0 to 400 ppb: This is the acceptable level of

	health | uHoo (getuhoo.com)			VOC indoors. You should not expect short-term effects such as irritation or discomfort.
Ozone	https://nj.gov/health/eoh/rtkweb/documents/fs/1451.pdf	Yes	OSHA	OSHA: The legal airborne permissible exposure limit (PEL) is 0.1 ppm averaged over an 8-hour workshift.
	https://nj.gov/health/eoh/rtkweb/documents/fs/1451.pdf	Yes	NIOSH	The recommended airborne exposure limit is 0.1 ppm, which should not be exceeded at any time
	https://nj.gov/health/eoh/rtkweb/documents/fs/1451.pdf	Yes	ACGIH	The recommended airborne exposure limits are for heavy work, 0.05 ppm; moderate work, 0.08 ppm; light work, 0.1 ppm; and workloads of less than 2 hours, 0.20 ppm; averaged over an 8-hour work shift.
Radon	RADON | Occupational Safety and Health Administration (osha.gov)	Yes	OSHA	OSHA radon exposure limit for adult employees is 100 pCi/L averaged over a 40-hour workweek.
Radon			NIOSH	NA
Radon			ACGIH	NA