K-HEALTH inAIR

K-HEALTHinAIR

Knowledge for improving indoor AIR quality and HEALTH

D1.2
REPORT ON MONITORING DATA (VERSION I)

Funded by the European Union

Project Title	Knowledge for improving indoor AIR quality and HEALTH
Project No	101057693
Contract start date	01/09/2022
Contract duration	48 Months

Document ID	K-HEALTHinAIR _D1.2_Report on monitoring data_Version I
Deliverable leader	CSIC
Due date	29/02/2024
Deliverable date	29/02/2024
Dissemination level	PUBLIC/ SENSITIVE

AUTHORS – CONTRIBUTORS

Name	Organization
Alicia Aguado / Jose Fermoso / Sandra Rodríguez	CARTIF
Benigno Sánchez / Alberto Rodríguez	CIEMAT
Josep Roca / Rubèn González / Isaac Cano / Alba Gómez	HCB / IDIBAPS
Amy van Grieken / Simon de Leede	ERASMUS MEDICAL CENTER
Henrik Kofoed Nielsen	UNIVERSITY OF AGDER
Johannes Dalheimer	H+M / i2M
Wojciech Hanke / Sławomir Brzeźnicki	NOFER
Adam Muszyński / Artur Badyda	WARSAW UNIVERSITY OF TECHNOLOGY
Hanns Monshammer / Alexandra Kristian	MEDICAL UNIVERSITY OF VIENNA

Funded by the European Union

PEER – REVIEWERS

Name	Organization
Carla Martins	UNIVERSIDADE NOVA DE LISBOA
César Mediavilla	ATOS

DOCUMENT HISTORY

Version	Date	Author/Organization	Modifications	Status
v1	28/11/2022	CARTIF		1st approach
v1.1	12/02/2024	HCB	PILOT 1	1st pilot ES
v1.2	12/02/2024	M+H	PILOT 4	1st pilot DE
v1.3	14/02/2024	NOFER	PILOT 5	1st pilot PL/AT
v1.4	14/02/2024	EMC	PILOT 2	1st pilot NL
v1.5	14/02/2024	UiA	PILOT 3	1st pilot NO
v2	19/02/2024	CARTIF		Final version
V3	26/02/2024	UNL / ATOS-EVIDEN	Revision	Final version
V4	28/02/2024	CARTIF / CSIC		Final version to be submitted

Disclaimer

The K-HEALTHinAIR Platform is in an embryonic phase and the graphics displays in this deliverable are subject to improvements and corrections in the future.

Copyright message

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

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)
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
GDPR	General Data Protection Regulation

Funded by
the European Union

HCB	Hospital Clinic Barcelona
HIMSS	Healthcare Information and Management Systems Society
HOM	Home (Scenario)
HOS	Hospital (Scenario)
HPLC	High-Performance Liquid Chromatography
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
LEC	Lecture hall (Scenario)
M+H	Mann+Hummel
MET	Metro station (Scenario)
MKT	Market (Scenario)
mMRC	Modified Medical Research Council
MUW	Medical University of Wien
NIO	Noffer Institute
NL	Netherlands (ISO 3166 country code)
NO	Norway (ISO 3166 country code)
NO_x	Nitrogen Oxides
O_3	Ozone
OAQ	Outdoor Air Quality
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
T	Temperature
TAI-12	Test of Adherence to Inhalers 12
tVOC	Total Volatile Organic Compound
UiA	University of Adger
VOC	Volatile Organic Compound
WHO	World Health Organization
WP	Work Package
WUT	Warsaw University Polytechnical

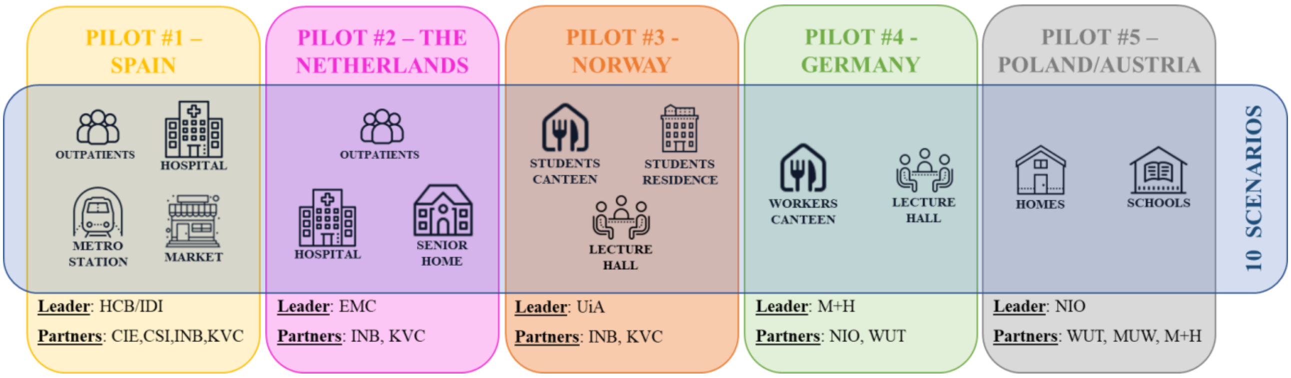
EXECUTIVE SUMMARY

K-HEALTHinAIR is an interdisciplinary research project that aims to increase knowledge about chemical and biological indoor air pollutants affecting human health, and to provide solutions for more accurate monitoring and improvement of indoor air quality.

The project will leverage on a novel artificial intelligence algorithm and advanced data analysis to identify the determinants, their sources, and the potential health risks of indoor air quality.

A rigorous research action based on data collected through real-life scenarios, public health surveillance, and particularly vulnerable groups such as high-risk outpatients, elderly people, pregnant women, and children, will investigate the holistic correlations between indoor air quality characterization and its harmful effects on health.

This deliverable is included in the framework of the WP1 'IAQ systematic analysis and monitoring for 9 relevant scenarios (5 pilot studies)'. Within this WP, knowledge on IAQ for 9 relevant European scenarios will be generated through the monitor of 5 pilot studies. This WP also covers the study of high-risk outpatients' daily life in 2 of the pilot studies (Spain and The Netherlands). So, this work with outpatients has been considered as an additional scenario because the project will study the IAQ in their daily life, mainly at home. Therefore, 10 scenarios (once outpatients are added as the 10^{th}) are relevant regarding coverture and impact.



In this deliverable, it is presented the summary of the monitoring data collected across five pilots and their respective scenarios through the next activities:

- Description of the results obtained so far in each pilot/scenario. Additionally, during February 2024, the first analysis of the information collected by each of the pilots has been conducted, showing an extract of the monitoring data collected by tools, sampling, questionnaires, additional data, etc.
- Since in most of the pilots and scenarios a year of monitoring was not completed, all delays encountered in each scenario/pilot has been explained meticulously. This explanation should include a breakdown of the causes of delays along with their respective updated timelines. However, the delay in the launch of monitoring campaigns has resulted in a lack of information for the entire sampling period initially planned for the first monitoring phase, from March 2023 to February 2024.

- Updated the chronogram for each pilot and scenario. This chronogram outlines the projected timeline for the completion of each stage, providing clarity on progress and anticipated milestones. The chronogram is more detailed in D1.7.

K-HEALTHinAIR Scenarios. Deployment state.

K-HEALTH	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

Dates in red are due to delays and pilots not completed.

The precise and continuous measurement of IAQ is essential for understanding and addressing challenges related to health and well-being in enclosed environments. To carry out this study effectively, K-HEALTHinAIR has leveraged IoT devices for continuous IAQ monitoring, incorporating a diverse array of selected parameters tailored to the project's requirements.

Deployed across all scenarios, these sensors form a crucial component of our comprehensive effort to conduct extensive and continuous measurements of air quality in real-time. They offer invaluable data on critical parameters such as temperature (T), relative humidity (RH), total volatile organic compound (tVOC) concentration, formaldehyde levels, and various particle sizes (PM_1, $PM_{2.5}$, PM_4 and PM_{10}).

These tools have universal communication system that ensures the monitoring device connectivity in any indoor space at any location, coupled with a dedicated cloud platform for data storage and analysis. The implementation of these sensors not only enables a thorough assessment of indoor air quality but also facilitates early identification of potential health risks, allowing for proactive implementation of corrective measures. Furthermore, the capability for continuous monitoring provides a dynamic insight into fluctuations in air quality, enabling an agile and adaptive response to changing conditions.

The sensors used to measure IAQ are as follows:

- INBIOT sensors (MICA – INBIOT: https://www.inbiot.es/productos/dispositivos-mica/mica). These sensors provide continuous monitoring of T, RH, CO_2, tVOC, formaldehyde, and PM (1, 2.5, 4, and 10 of particle size) → installed in P1, P2, P3 and P5.
- M+H sensors: These sensors offer continuous monitoring of T, RH, CO_2, tVOC, and PM (1, 2.5, and 10 of particle size) → installed in P4 and P5.
- IoT fabrikken: These sensors offer continuous monitoring of T, RH, CO_2, tVOC, sound, light and presence → installed in P3.

In addition to indoor sources, the study considers outdoor air quality (OAQ) within the influence zones of the project. This data integration aims to contextualize indoor air conditions within the broader environmental context.

- AerisWeather: (https://www.aerisweather.com/). OAQ data is reported using the AerisWeather platform, encompassing T, RH, and concentrations of key pollutants in the surrounding area. These pollutants include PM, NO_x, CO, and O_3 levels. With current breakthroughs in data fusion and machine learning, it can now be forecasted air quality globally with unprecedented accuracy. The platform allows the real-time view and forecasts up to 96 hours ahead with a hyperlocal resolution interpolated from a <15km grid to identify problem areas. AerisWeather platform leverages advanced, real-time modelling techniques using data fusion from air quality sensors, pollution emission sources, long-range dispersion models and machine learning and then through an API service data is provided for the locations selected to the K-HEALTHinAIR data platform → installed in P1, P2, P3, P4, P5.
- KUNAK AIR Lite: This is an air quality monitoring to measure VOC, NO_2, PM (1, 2.5, 10), T and RH. This local outdoor measurement station provides insights into the rates of indoor and outdoor pollutants in the indoor air, offering a comparative perspective → installed in P3.

For more details about dates and numbers of sensors installed, see D1.7. Coordination program for pilots (Version II) and Figure 3.

PILOT #1. BARCELONA (ES)

Pilot #1 in Barcelona (Spain) focuses on two primary areas of interest. Firstly, it examines the relationship between IAQ and health status by following up of high-risk outpatients with chronic obstructive pulmonary disease (COPD). Secondly, it characterizes three distinct indoor scenarios: The Hospital Clinic de Barcelona, a city market and a metro station, all in close proximity to HCB.

Despite significant delays due to ethical approval processes and a cyberattack at HCB, the study protocols for indoor scenarios were approved by mid-April 2023 and the final approval of the study protocols with patients was effective in November 2023. So, the pilot has adapted its protocols and contingency plans to ensure the achievement of project outcomes and finally progress has been made with IAQ sensor installation and data collection in hospital settings.

o The high-risk outpatients' scenario focuses on analysing the relationships between patients' home IAQ and health status with focus on acute health effects. The pilot follows up a cohort of 200 high-risk chronic respiratory patients (HOM01) for at least two full years (started in November 2023 and 95 recruited until February 2024). This cohort includes 40 patients (20% of the study group) diagnosed with severe asthma refractory to standard therapy, and up to 160 multimorbid patients (80%) with COPD, aiming to detect acute exacerbations and recommend preventive measures. This cohort will be completed by February-March 2024. It includes a) the collection of health-related data such as medical surveillance, including enhanced lung function testing, digital support using the Health Circuit platform, and predictive modelling for enhanced management of exacerbations; PROMS, PREMS and questionnaires; b) the continuous IAQ monitoring (MICA – INBIOT, 74 installed so far) of relevant parameters such as T, RH, CO_2, PM, VOCs and formaldehyde, in their homes (the indoor environment where they spend a mayor part of their lives); c) the sampling of the key health affecting agents such as PM, VOCs (including formaldehyde) and microbiome in some selected outpatients (not started yet).

Additionally, the pilot conducts an exhaustive one-year follow-up of 10 severe asthma patients (HOM02) to further analyze IAQ and exacerbations. In this scenario there is a more extensive medical follow-up compared to HOM01 and include a portable monitoring tool for all the patients. Due to the mentioned delays, it is essential to note that the sampling/monitoring campaign has yet to be initiated in this scenario which is expected to begin in March 2024.

o In the hospital scenario, HOS01, (initiated on June 2023), IAQ monitoring involves strategically: a) monitoring of the relevant parameters such as T, RH, CO_2, PM, VOCs and formaldehyde through the installation of 18 sensors (MICA – INBIOT) across 5 different areas: 1) common spaces and waiting rooms, 2) general hospitalization ward, 3) intensive care ward, 4) outpatient consultation facilities and 5) pathological anatomy labs, providing insights into IAQ dynamics and potential health implications; b) a sampling of VOCs, formaldehyde, radon, PM and microbiome; c) the collection of OAQ in the surrounding areas and d) the use of questionnaires with the staff (because in principle this is the population group spending more time inside these settings) is carried out to establish a comprehensive understanding of the specific components that may contribute to health concerns in the settings selected by K-HiA.

o The market scenario, MKT01, has been blocked until February 2024 due, mainly, to political issues but finally has been opened and monitoring will start in March 2024.

o The metro scenario, MET01, is proving to be the most challenging. Metro authorities have been somewhat hesitant to grant space for monitoring from the outset due to past issues with asbestos and it is still under negotiation transiently stop the process until May 2024.

Overall, the Barcelona pilot faces challenges but remains committed to its objectives of understanding IAQ-health relationships and proposing interventions to enhance indoor air quality and promote healthier environments.

PILOT #2. ROTTERDAM (NL)

Pilot #2 in Rotterdam (The Netherlands) focuses on two main areas: 1) the follow-up of high-risk outpatients, including those with COPD, and 2) the analysis of two significant indoor settings: hospital areas and senior homes' common areas. However, this pilot proposes a less holistic analysis and covers less parameters in comparison with P1.

Despite delays due to ethical approval processes and internal approvals, progress has been made with sensor installation and monitoring in both hospital and senior home environments. The IAQ monitoring has started on January 2024. The recruitment numbers are increasing steadily since the ethical committee has given their approval of an amendment of the original protocol and information letter. This amendment was necessary because, participant's data is being shared among partners (ATOS, INBIOT and IDIBAPS). To cover the sharing a personal data a Joint Controllers Agreement (JCA) has been drafted. Recruitment delays can be attributed to the JCA being drafted and has not been finalized yet.

The work with the settings, hospital, senior home and outpatients, is focused on massive monitoring of the relevant parameters such as T, RH, CO_2, PM, VOCs and formaldehyde (MICA – INBIOT sensors), sampling of VOCs (including formaldehyde) in the IAQ, collection of OAQ in the surrounding areas and use of questionnaires with the staff.

Funded by the European Union

o For the high-risk outpatients, 50 high-risk outpatients living in their homes (HOM01) and 60 elderly residents (HOM02), will be study to analyse the relationships between patient's home IAQ and health status with focus on mental health and QoL. All these outpatients have one or more chronic conditions such as frailty, COPD, bronchiectasis, asthma, cardiovascular disorders, or type II diabetes mellitus. It will include the collection of health-related data such as a) medical surveillance, b) PROMS, c) questionnaires and d) the continuous monitoring of relevant parameters such as T, RH, CO_2, PM, VOCs and formaldehyde through MICA – INBIOT sensors. Recruitment process is still under development due to different delays attributed to the drafting and finalization of a Joint Controllers Agreement (JCA) for sharing participant data among project partners.

o The building for the setting of the hospital is the Erasmus University Medical Centre (HOS01). Locations in the hospital for a) installing the IAQ sensors are strategically placed in the Pulmonary Inpatient Clinic (which has 7 MICA – INBIOT sensor installed in December 2023) and Outpatient Clinic of the Pulmonary Department (massive IAQ monitoring started in September with 3 MICA – INBIOT devices and was later extended to 4). Also, this setting will include b) the sampling of VOCs, c) the collection of OAQ in the surrounding areas and d) the use of questionnaires with the staff. Delays of this scenario can be attributed to waiting times for ethical approval, discussions with authorized personal started to get permission to place and install IAQ sensors, and bureaucratic procedures within the senior management hierarchy. Hospital setting is partially deployed (monitoring tools have been installed but participants are still being recruited)

o The general area of the senior homes contains most often a seating area with tables and some senior homes have an activity room attached or otherwise nearby (RET01, RET02, RET03, RET04). Monitoring in senior homes encounters delays due to internal approval processes within the housing corporation and technical challenges related to Wi-Fi router replacements. Despite these obstacles, one common area in a senior housing building undergoes continuous IAQ monitoring.

PILOT #3. GRIMSTAD (NO)

Pilot #3 in Grimstad (Norway) focuses both on the analysis of the IAQ and on the evaluation of the impact of wood as indoor building materials on health. It covers the approach with three main settings, 1) canteens areas, 2) students' residences and 3) lecture halls.

Both canteen and lecture hall are deployed since late 2023 but the students' residence is still ongoing due to the difficulties of recruitment process of the students due to the lack of interest even when some incentives have been proposed.

o In the canteens, monitoring of IAQ is carried out at University of Agder (UiA) (CAN01) and Fagskolen i Agder (CAN02), facing initial challenges in Wi-Fi access and data collection. a) The installation of 10 MICA – INBIOT sensors is carried out to the analysis of the IAQ massive monitoring of the relevant parameters such as T, RH, CO_2, PM, VOCs, formaldehyde, light and noise. b) Questionnaires development and approval processes were coordinated with relevant authorities and was approved with the recruitment of 9 participants from the staff. c) Sampling of VOCs including formaldehyde is still under preparation and will be deployed in 2024-2025. The monitoring of CAN02 with a lot of wooden surfaces compared to CAN01 with nearly no wooden surfaces implies the possibility for comparison of the impact of wood surfaces on IAQ.

o The IAQ in student residences includes a) the monitoring of 20 student's bedsits and single room apartments (RES01, RES02, RES03, RES04, RES05, RES06, RES07, RES08) in Jon Lilletuns vei and Tønnevoldsgate, is scrutinized due to high occupancy and potential sources of indoor pollutants. Nine IoT fabrikken and 20 inBiot monitors are going to be installed in single-room apartments and bedsits across eight buildings, providing insights into IAQ variations based on building age and HVAC systems, when 20 students accept installation of monitors in their home. Sampling of VOCs is still under preparation and will be deployed in 2024-2025 like the questionnaires.

o IAQ characterization in lecture halls at UiA campus Grimstad, Jon Lilletuns vei 9, involves monitoring indoor air conditions in two different halls, one inaugurated in 2010 (LEC01) and the other constructed in 1982 and renovated in 2010 (LEC02). Sensors capture IAQ data to reflect students' daily activities. Sampling of VOCs is still under preparation and will be deployed in 2024-2025. The participants have not got any questionnaires yet due to delayed recruitment. which will be finalized in March 2024. The aim is to recruit 50 students.

PILOT #4. LUDWIGSBURG (DE)

Pilot #4 in Ludwigsburg (Germany) encompasses the analysis of two significant indoor settings: two canteen areas and a lecture hall. It is focused on the identification of the determinants in these settings and to identify the best conditions for the canteen customers.

The installation of sensors began in March 2023 in both scenarios, with some delays due to cyber security concerns during the integration of Kaiterra Sensedge Mini devices to the local Wi-Fi network and due to structural requirements, necessitating custom wooden constructions. Despite these minor problems, devices were successfully integrated into the network. Collaborative efforts were made to develop tailored questionnaires, although challenges arose regarding GDPR compliance and the canteen team's willingness to participate. Despite successful monitoring of indoor air quality parameters and chemical sampling events, issues with participant identification disrupted the seamless integration of questionnaire within the RedCAP system, prompting the development of a tailored contingency plan. Challenges persist regarding the distribution of surveys to students, prompting the development of a contingency plan focused on increasing student engagement through various strategies.

o In the canteen scenario (Ludwigsburg Canteen (CAN01) and Ludwigsburg Bistro (CAN02)), a) the monitoring of the relevant parameters such as T, RH, CO_2, PM and VOCs is carried out through the implementation of KAITERRA sensors, also b) the sampling of the key health affecting agents: PM, VOCs (including formaldehyde) and microbiome in the IAQ, c) the collection of OAQ in the surrounding areas and d) the use of questionnaires with the staff and other specific for customers, its configuration has been adapted due to restrictions of the canteen authority.

o In the lecture hall scenario, at the Technical University of Munich (TUM) Campus Heilbronn (LEC01) a) the monitoring of the relevant parameters such as T, RH, CO_2, PM and VOCs is carried out through the implementation of KAITERRA sensors, also b) the sampling of the key health affecting agents: PM, VOCs (including formaldehyde) and microbiome in the IAQ has started, c) the collection of OAQ in the surrounding areas and d) the use of questionnaires with the students.

Overall, Germany pilot aims to deeply characterize indoor air quality in canteen areas and a lecture hall, facilitating the identification of potential determinants of indoor air pollution on health status and the proposal of preventive actions. Despite challenges, the pilot demonstrates significant progress in understanding indoor environmental quality and its implications for health.

PILOT #5. LODZ, WARSAW / WIEN (PL/AT)

Pilot #5 in Lodz, Warsaw and Wien (Poland and Austria) encompasses the analysis of two significant indoor settings: homes and schools. Home setting selected in this pilot is different from the one considered with outpatients in Barcelona and in Rotterdam. These pilot studies are focused on searching for the determinants in homes with different systems for cooking and heating and in newly constructed houses, and to assess IAQ parameters in schools where children spend a considerable amount of time.

Homes recruitment of participants started in late March 2023 and concluded in December 2023. Schools' recruitment in secondary schools was completed in Lodz in January-February 2024 and is ongoing in Warsaw.

In the <u>home</u> scenario (PL/AT-HOM01 - PL/AT-HOM05) 28 houses with various heating systems, including solid fuels, natural gas, oil, electric energy, or renewable sources are recruited in Austria and 30 houses with different heating systems are recruited in Poland. The study aims to identify key compounds or parameters within indoor air that may affect human health, through a) a massive monitoring with KAITERRA sensors, monitoring the relevant parameters such as T, RH, CO_2, PM and VOCs; b) sampling of the key health affecting agents such as PM, VOCs (including formaldehyde), PAHs and microbiome; c) the collection of OAQ in the surrounding areas, d) the use of questionnaires and e) includes biological monitoring by urine samples to evaluate the presence of PAHs metabolites in homes with solid fuels used for heating. This scenario is fully deployed since August 2023.

o In the <u>school</u> scenario (PL/AT-SCH01 – PL/AT-SCHxx) 3 schools with 2 or 3 classes each and 22 schools with a total of 53 classrooms and 400 children are recruited. The study aims to identify key compounds or parameters within indoor air that may affect human health, through a) a massive monitoring with KAITERRA and MICA – INBIOT sensors, monitoring the relevant parameters such as T, RH, CO_2, PM, VOCs and formaldehyde; b) sampling of the key health affecting agents such as PM, VOCs (including formaldehyde), PAHs and microbiome; c) the collection of OAQ in the surrounding areas and d) the use of questionnaires. This scenario is fully deployed since October 2023.

Overall, Poland/Austria pilot addresses the critical issue of IAQ in homes and schools, aiming to understand its impact on residents' health, especially vulnerable groups like children. By analysing various IAQ parameters and considering different heating systems, the pilot seeks to identify potential health risks and propose interventions to improve IAQ and overall well-being in residential and educational settings.

1 INTRODUCTION

The study of indoor air quality has become increasingly significant worldwide, given the paramount importance of health and well-being in enclosed environments. In a world where the majority of our time is spent indoors, the quality of the air we breathe profoundly impacts our health, productivity, and overall quality of life.

As an initial consideration, K-HEALTHinAIR proposes an approach considering two complementary approaches to identify health determinants of Indoor Air Environments:

- Follow up of individuals, especially high-risk outpatients (Pilots #1 & #2).
- Study of nine different settings / scenarios (Distributed among Pilots #1 to #5).

On one side, two pilot studies dedicated to high-risk outpatients to mainly study the occurrence, impact, determinants, and sources of acute events possibly affecting these individuals. On the other side, different settings relevant at European level and where Indoor Air Quality (IAQ) can affect a significant number of people or vulnerable populations, have been identified and will be analyzed through the pilot studies.

K-HEALTHinAIR defines setting as a representative indoor environment in Europe, and scenario as the actions performed to assess the IAQ in a specific setting. In some way, the work with outpatients is also considered as an additional scenario because the Project will study the IAQ in their daily life, mainly at home. The ten scenarios (once outpatients are added as the 10th) are relevant regarding coverture and impact, both for the number of people potentially affected and for the nature of the target groups to protect (vulnerable populations such as high-risk outpatients, children or pregnant women). From now on, the main characteristics for each setting and the planned configuration to launch the data collection will be reviewed. Additionally, target groups, and how to evaluate the health effects on them, will be initially defined for each scenario.

This document aims to collect the first version of the monitoring data in pilots in the first step at M18. Five different pilots in six countries (#1: Spain, #2: the Netherlands, #3: Norway, #4: Germany, #5: Poland and Austria) will be developed to cover ten different scenarios (outpatient's home, hospital, metro station, market, senior home, canteens, student's residence, lecture hall, schools, and homes) (Figure 1).

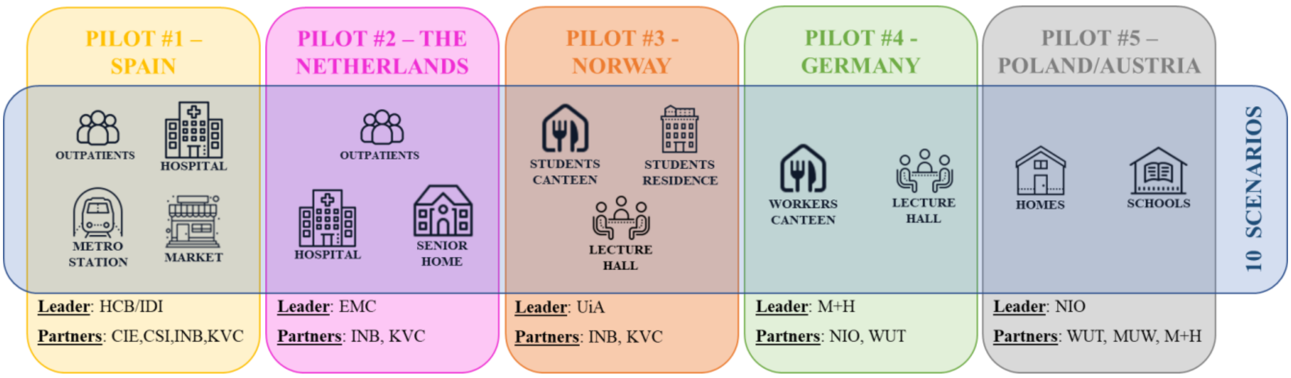


Figure 1. Pilots/scenarios selected in K-HiA project.

Funded by the European Union

Each pilot study has two, three or four scenarios/settings to study. Figure 1 shows the pilots and selected scenarios/settings for them. It is to note that only two pilots imply the recruitment and follow-up of high-risk outpatients (Pilot 1 and Pilot 2). Each pilot study and its scenarios/settings included, has its own configuration and data sources.

Figure 3 shows the initial configuration of the pilot studies including target groups, sampling locations, parameters to be covered by the monitoring tools and other information describing the relevance of the scenarios. In this table, dates have been updated with real values by the end of February 2024.

Figure 2 shows a summary of the main data sources for each scenario and the responsible partner. All these data will be widely described in the sections below.

Figure 2. Main data sources in the pilot studies and the responsible partner.

K-HEALTHinAIR Relevant Scenarios										
K-HEALTH inAIR	OUTPATIENTS	HOSPITAL	METRO STATION	MARKET	SENIOR HOME	CANTEEN	STUDENTS RESIDENCE	LECTURE HALL	HOME	SCHOOL
Medical surveillance	IDI/HCB/ EMC	IDI/HCB/ EMC	-	-	EMC	-	-	-	-	-
Biological monitoring (PAHs urine metabolites)	-	-	-	-	-	-	-	-	NIO	-
VOCs & Chemicals	CIE	CIE	CIE	CIE	-	WUT	CIE/UiA	WUT/NIO	-	WUT/NIO /MUW
PMs	-	CIE	CIE	CIE	-	WUT	-	-	WUT	WUT
Microbiome	CSI-1	CSI-1	CSI-1	CSI-1	-	WUT	-	WUT	-	WUT
Radon	-	CIE	CIE	-	-	-	-	-	NIO	-
Data Public health	IDI/HCB/ EMC	IDI/HCB/ EMC	IDI/HCB	IDI/HCB	EMC	M+H / UiA	UiA	M+H / i2M	NIO	NIO
Massive monitoring	INB	INB	INB	INB	INB	M+H / INB / UiA	INB / UiA	M+H / i2M	M+H / i2M	M+H / i2M
Mental health and QoL	IDI/HCB/ KVC	IDI/HCB/ KVC	IDI/HCB/ KVC	IDI/HCB/ KVC	EMC/KVC	UiA/KVC	UiA/KVC	WUT/NIO	WUT/NIO	WUT/NIO
PROMS / PREMS	IDI/HCB/ KVC	IDI/HCB/ KVC	IDI/HCB/ KVC	IDI/HCB/ KVC	EMC/KVC	-	-	-	-	-
Other data	All	All	All	All	All	All	All	All	All	All

VOC has been updated in the table because MUW team join the task by sampling VOC and formaldehyde in Austrian schools.

Radon has been updated in the table because, while the project gets the approval for sampling in the metro, hospital settings was analyzed.

Funded by the European Union

Figure 3. Configuration of the planned studies.

	#1: BARCELONA				#2: ROTTERDAM			#3: GRIMSTAD			#4: BADEN-WURTEMBERG		#5: LODZ, WARSAW, VIENNA	
K-HEALTH inAIR	OUTPATIENTS	HOSPITAL	METRO STATION	MARKET	OUTPATIENTS	HOSPITAL	SENIOR HOME	STUDENTS CANTEEN	STUDENTS RESIDENCE	LECTURE HALL	WORKERS CANTEEN	LECTURE HALL	HOME	SCHOOL
Additional Medical surveillance	210 High-risk outpatients	--	--	--	50 High-risk outpatients	--	60 elderly residents	--	--	--	--	--	Biological monitoring for dwelers	--
Vulnerable group	High-risk outpatients	To be identify	To be identify	To be identify	High-risk outpatients	To be identify	Elderly people	To be identify	To be identify	To be identify	To be identify	To be identify	Reprod. aged women, seniors with respir. Prob.	Children 7-17 years old
Workers	--	Medical staff	Staff	Merchants	--	--	--	Kitchener, waiters	Students	Students	Kitchener, waiters	--	--	Teachers
Sampling period	Nov23-Feb26	Jun23-Feb26	May24-Feb26	Mar24-Feb26	Mar24-Feb26	Oct23-Feb26	Mar24-Feb26	Nov23-Feb26	Mar24-Feb26	Oct23-Feb26	Apr23-Feb26	Jun23-Feb26	Jul23-Feb26	Jun23-Feb26
Sampling locations	Outpatient's home	4sites: Hall,ward, intensive care wards, outp. onsult	3sites: ticket offices, corridor, platform	2sites: basement, first floor	Outpatient's home	First 3floors of outpatients clinics	General space of the senior home	6+4 sites / 2canteens	20 bedrooms	2	8 sites / 2 canteens	2 sites / 2 lecture hall	31 Poland+ 28 Austria Living room	22 Poland + 3 Austria schools 3sits/school
Massive continuous monitoring INB, M+H	200 () units T, RH, tVOC, CH_3O, PM & CO_2 sensors	18 units T, RH, tVOC, CH_3O, PM & CO_2 sensors	9 units T, RH, tVOC, CH_3O, PM & CO_2 sensors	6 units T, RH, tVOC, CH_3O, PM & CO_2 sensors	50 (10) units T, RH, tVOC, CH_3O, PM & CO_2 sensors	11 units T, RH, tVOC, CH_3O, PM & CO_2 sensors	60 (1) units T, RH, tVOC, CH_3O, PM & CO_2 sensors	10 units T, RH, tVOC, CH_3O, PM & CO_2 sensors	20 (0) units T, RH, tVOC, CH_3O, PM & CO_2 sensors	2 units T, RH, tVOC, CH_3O, PM & CO_2 sensors	8 units T, RH, tVOC, CH_3O, PM & CO_2 sensors	5 units T, RH, tVOC, CH_3O, PM & CO_2 sensors	59 units T, RH, tVOC, CH3O, PM & CO_2 sensors	78 units T, RH, tVOC, CH3O, PM & CO_2 sensors
Workers / People involved	200	~200 / 10,000	~10 / 6,000	~65 / 3,000	50	~150 / 8,000	50 / 300	50 / 3,500	20 / 500	20 / 500	20 / 500	-- / 100	64	~560 / 5,000
PLAN OF INTERVENTION after determinant identification	Awareness, behavioral change	Awareness, Control measures	Identifying sources, Optimiz. air renovation	Sources removal, optimiz. air renovation and HVAC	Awareness, Control measures	Awareness, behavioral change	Sources removal, optimiz. air renovation and HVAC	Sources removal, optimiz. air renovation and HVAC	Sources removal, optimiz. air renovation and HVAC	Sources removal, optimiz. air renovation and HVAC	Sources removal, optimiz. air renovation and HVAC	Sources removal, optimiz. air renovation and HVAC	User awareness, behavioral change and tech. solute.	Awareness, education, democr. air renovation solutions

Dates in red are due to delays and pilots not completed.

2 BARCELONA PILOT #1 (ES)

Pilot #1 ES addresses two well-defined areas of interest.

- Firstly, the analysis of the relationships between indoor air quality (IAQ) and health status.
- The second focus of the pilot is the characterisation of three different indoor scenarios: i) the Hospital Clinic de Barcelona (HCB: HOS01), ii) a city market (Ninot: MKT01), and iii) a metro station (Clinic: MET01), both close to the HCB.

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.

Table 1. Launching dates of the information sources for the Barcelona Pilot.

	HOSPITAL	METRO STATION	MARKET	OUTPATIENTS
VOCs & Chemicals	Jun '23	-[3]	Mar '24[4]	Jan'24[5]
PMs	Jun '23	-	Mar '24	Mar'24[6]
Microbiome	Sep '23[1]	-	Mar '24	Mar'24
Radon	Jun '23	-	--	--
Data Public health	Jan'19[2]	-	Jan'19	Jan '19
Massive monitoring	Jun '23	-	Mar '24	Nov '23
Questionnaires	Mar'24[1]	-	Mar '24	Nov '23

PILOT COORDINATOR:

IDIBAPS / BARCELONA CLINIC HOSPITAL

OBJECTIVES:

Pilot study focused on the identification of IAQ determinants of unhealthy events in high-risk outpatients and the characterization of the IAQ in four different scenarios: HOSPITAL, METRO STATION, MARKET, outpatient's HOME.

LOCATIONS:

· High-Risk Outpatients from the Integrated Healthcare District of Barcelona-Esquerra (AISBE)

· Hospital Clinic of Barcelona

C. de Villarroel, 170, 08036 Barcelona

· Ninot Market of Barcelona

C. de Mallorca, 133, 08036 Barcelona

· Hospital Clínic Metro Station

Hospital Clinic, 08036 Barcelona

VOCs: Volatile Organic Compounds; PMs: particles; Data Public Health: registry data from the Catalan Health Surveillance System (CHSS); Massive monitoring: Continuous monitoring of indoor air quality (IAQ); Questionnaires: Standardized questionnaires administered to the patients and professionals. Patients' data capturing with digital support not depicted in the table, see reference[1].

[1] – Microbiome: Bimonthly measurements. Metagenomics results will be available late February '24. Not reported in D1.2.

[2] – Data Public Health: Obtained from the Catalonian Health Surveillance System (CHSS). Data for the professionals in the different scenarios and for the patients will be reported since January 2019 to the end of the follow-up. Information not reported in the current deliverable. See text for further description.

[3] – Metro station: Study delayed due to lack of permit of the authority. Contingency plan described in the text.

[4] – Market: The permit to initiate the study was obtained by mid-February 2024. Logistics currently active.

[5] – Data sampling of VOCs at homes were initiated in January 2024. See text for further description.

[6] – Data collection of PMs and microbiome at homes will be initiated in March 2024. See text for further description.

STUDIES PERIODS

Hospital: Jun 2023 – March 2026.

Market: Mar 2024 – March 2026.

Metro: On hold (next update May 2024) and ending in March 2026.

OUTPATIENTS: Protocol 1 (200). November 2023 – March 2026. The recruitment of participants was on late November 2023. The follow-up will last until February 2026.

OUTPATIENTS: Protocol 2 (10). March 2024 – February 2025. The recruitment of participants will be initiated in March 2024.

To analyse the relationships between IAQ and health status, the pilot follows up a cohort of 200 high-risk chronic respiratory patients (HOM01) for at least two full years. The cohort includes 40 patients (20% of the study group) with a diagnosis of severe asthma refractory to standard therapy (REF) [1], and up to 160 multimorbid patients (80%) with a diagnosis of chronic obstructive pulmonary disease (COPD) [2] who are allocated close to the tip of the regional risk stratification pyramid (above percentile 80) [3]. The characteristics of the study protocol are described in detail in a manuscript [4] to be submitted for publication in the BMJ Open by the end of the current month, also included as an Annex to the deliverable 1.7 "Coordination program for pilots M18". The protocol consists of different actions for early detection of acute episodes of exacerbation in these patients that, besides analysing the relationships between IAQ and deleterious health events, aims to generate recommendations for preventing emergency room consultations and unplanned hospital admissions in high-risk chronic patients.

Briefly, four specific studies are undertaken: i) Enhanced Lung Function Testing using oscillometry as a novel tool [5], ii) Continuous monitoring of IAQ as planned in the project, iii) Digital support with an Adaptive Case Management approach using the Health Circuit platform (https://www.healthcircuit.es/), and iv) Predictive modelling for enhanced management of exacerbations.

Each component has specificities in design, set-up, data analysis and expected results, as reported in [4] and Annex to D7.1.

Moreover, the pilot will further analyse the relationships between IAQ and acute episodes of exacerbations with an exhaustive one-year follow-up of 10 severe asthma patients (HOM02).

Incidences with a negative impact on the project's workplan

The essential traits of Pilot #1, the Barcelona pilot, including both outpatients' studies (HOM01 and HOM02), as well as the characterisation of the three relevant indoor settings: hospital scenario (HOS01), metro station scenario (MET01), and market scenario (MKT01), are depicted in Table 1 and also includes information on the current timeline of the pilot. As described in Table 1, the development of the pilot has suffered a significant delay due to two relevant incidences with synergistic effects of the project timetable: i) Ethical Committee's approval, and ii) Cyberattack at HCB that have triggered the design and execution of a contingency plan, as described below.

Ethical Committee approval – An overall description of the project, including a high-level description of the Barcelona pilot, was submitted (late June 2022) to the Ethical Committee for Human Research at HCB (CEIm) before the kick-off meeting (late September 2022). However, the full detailed description of the study protocols following the guidelines established by the CEIm was not ready for submission until early November 2022.

The submission was structured in four differentiated components: i) a general description of the project, ii) Cohort of 200 patients (HOM01), iii) Cohort of an exhaustive study of 10 COPD patients (HOMO2), and iv) Protocols for the three indoor settings: hospital (HOS01), market (MKT01), and metro station (MET01). The protocols for the three indoor settings were finally approved by mid-April 2023. However, the CEIm still raised significant concerns on three specific issues: i) Recruitment strategies, ii) Amount of information requested from the patients, and iii) Use of the One Beat watch (sensors) for capturing physiological data from the patients. All of them were solved after some interactions with the CEIm, such that the final approval of the study protocols with patients was released by early July 2023. The CEIm at HCB meets regularly every fifteen days. However, the complexities of the study protocols with patients and the highly negative impact of the cyberattack generated long, unexpected delays in the entire process.

Moreover, an additional limiting factor was the approval of the project by a second Ethical Committee (Fundació Gol i Gorina) responsible for research studies carried out with primary care providers: CAPSBE and Institut Catalan of Health in the project. In this case, the approval process was relatively short because the reports of the CEIm were accepted without further changes. Still, the permission to access the electronic clinical records by the research members with contracts at FCRB-IDIBAPS generated a short additional delay until the patients' recruitment process was effective in November 2023, as indicated in Table 1.

Impact of the cyberattack – On the 5th of March 2023, the HCB had a severe cyberattack with a huge impact on the clinical activity of the hospital, not to mention the research area. The HCB was under the tight control of the regional government of Catalonia from early March to late May 2023. The following factors explain the impact of the event: i) Severity of the attack, ii) the high level of digitalization (HIMSS highest degree), and iii) the complexities of the interactions of the hospital with different institutions (University of Barcelona, Primary Care providers, Single-public payer, IDIBAPS and associated research centres, etc.). Until mid-May, the clinical activity was based on paper, and all administrative processes suffered significant delays. Since late spring, a stepwise process of normalization of the clinical activity has been in place, but the research activities suffered negative impacts during the entire year. As expected, the security protocols became very rigid and strict during the recovery process.

Other issues – As mentioned, the approval of the protocols for characterization of the three indoor scenarios was obtained in mid-April 2023. Due to the cyberattack, monitoring at HCB could not begin until mid-June 2023, as indicated in Table 1. The current version of D1.2 reports sequential reliable data obtained during the second semester of 2023, but optimal communication of the hospital sensors will not be achieved until February 2024.

Specific issues emerged limiting the deployment of the study in the metro and marked primarily explained by local political factors (May and July elections). The arrangements with the market have been in place since February 2024, such that regular measurements will be initiated during March, as indicated in Table 1.

The arrangements with the metro authorities for the protocol deployment progressed slowly but positively during the last six months until the 26th of January 2024, when the metro authority indicated by mail the need to stop the process due to potential problems with the Labor Unions. After a careful analysis with the Spanish partners, it has been concluded that we should keep productive interactions with the Metro authority looking for a transient stop of the deployment until May 2024. Meanwhile, a contingency plan is being elaborated.

As depicted in Table 1, delays in the microbiome measurements due to already solved technical issues and in administering the questionnaires to a sample of professionals at the hospital. Both aspects will be fully overcome this March 2024 without significantly impacting the project's outcomes.

Contingency plan and project's calendar

Since late 2022, several relevant modifications have been introduced in the Barcelona pilot to ensure the expected project outcomes. The incidences described above further endorsed the initial changes in the protocols submitted to the CEIm, as well as the contingency plans elaborated for both the patients' study protocols and the analyses of the indoor scenarios described below:

Follow-up of the cohort (HOM01): Two major modifications of the proposal approved have been:

i) The introduction of patients' home monitoring with the MICA-INBIOT sensors, and

ii) the strategies in place for early detection of exacerbations described in the Annex to D1.7 (manuscript ready for submission for publication to BMJ Open).

Both modifications are significant in analysing the relationships between IAQ and health status/detection of determinants. Moreover, they will provide ancillary outcomes such as better characterization and management of acute episodes with a potentially high positive impact on the use of healthcare resources. Despite the current delay in the data collection, the characteristics of the final study protocols represent a major improvement. In the current calendar of the Table 1, the cohort recruitment will be completed at the end of March 2024, so a follow-up period of 24-30 months will be done instead of the 36 months initially planned. Intermediate analyses every six months are planned to identify determinants, explore causalities, and generate preventive actions within the project's lifetime. We believe the current work plan fully overcomes the potential limiting effects of shortening the follow-up period.

An exhaustive study of patients (HOM02): Three relevant changes have been introduced in the protocol.

i) Firstly, severe asthma patients were decided as the target candidates instead of COPD, as planned. The change has been adopted because asthma patients show more likelihood of acute episodes associated with poor IAQ, while COPD patients have marked heterogeneities resulting in poor comparability among studies, as acknowledged by recent publications [6],

[7]. Moreover, asthma patients have an active lifestyle and better skills and age using digital tools than COPD patients.

ii) The second relevant factor is the introduction of portable MICA-INBIOT sensors, which allow for a better understanding of the relationships between IAQ and health.

iii) Finally, a third novelty is the introduction of sensors able to detect oxidants (NO_x), which are critical determinants of respiratory tract inflammation with well-proven synergistic effects with other pollutants. The timeline of the project will ensure a full-year follow-up as planned. The current calendar for the HOMO2 study is from the 1st of April 2024 to the 30th of March 2025.

Characterization of indoor settings: The measurements carried out at HCB are progressing adequately, and minor issues like microbiome measurement and administration of questionnaires to selected volunteers will be undertaken in March 2024 without relevant impacts on the analysis of the site. As indicated, the market will be initiated in March 2024 with positive perspectives regarding the expected outcomes. Finally, the metro scenario shows uncertainties that will be fully solved by Spring 2024. If the collaboration with the metro's authority in Barcelona does not progress as expected, alternative scenarios are being explored and activated in May, if necessary. The analysis of the results of each of the three scenarios after a one-year follow-up (Table 1) will determine further measurement plans.

2.1 Hospital scenario (ES-HOS01)

Indoor air quality in hospitals is a critical factor influencing both patient well-being and staff productivity. Maintaining high air quality is essential to create a healing environment, prevent the spread of infections, and ensure the safety of patients with compromised immune systems. Factors such as ventilation systems, air filtration, and pollutant levels play a pivotal role in determining the overall indoor air quality.

The primary objective of this study is to identify and delineate the key compounds or parameters, the determinants, within indoor air that have the potential to impact human health within the complex array of contaminants present in any enclosed environment. By scrutinizing factors such as particulate matter, volatile organic compounds (VOCs), humidity levels, and microbial content, it is aimed to establish a comprehensive understanding of the specific components that may contribute to health concerns in the settings selected by K-HiA. This focused analysis will pave the way for targeted interventions and strategies to enhance air quality, promoting a healthier environment for both patients and healthcare professionals.

2.1.1 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 IAQ 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).

The installed sensors (MICA – INBIOT: https://www.inbiot.es/productos/dispositivos-mica/mica) provide continuous monitoring of T, RH, tVOC, formaldehyde concentration and PM concentration (1, 2.5, 4 and 10 of particle size).

Table 2 summarizes the average values and distributions of monitored parameters and outlines the maximum peaks observed over six months from July to December 23. It also contrasts the observed results with the legal limits stipulated by current legislation. The results displayed in Table 2 consistently demonstrate the conformity of all monitored parameters within the ranges recommended by the regulatory bodies, a part of the TVOCs that exhibit both mean and average levels above the threshold.

Table 2. Average values and distributions of monitored parameters over six months (Jul-Dec 2023) in the hospital (ES-HOS-01-001 to ES-HOS-01-005). Legal exposure limits extracted from: WHO.

Parameter	Mean (SD)	Median (IQR)	Max	Limits
Temperature (°C)	24.72 (2.21)	25 (23.5 - 26)	33.7	-
Relative Humidity (%)	53.01 (9.48)	55 (46 - 60)	78	-
CO_2 (ppm)	535.93 (155.93)	484 (423 - 599)	2,398	900 (ppm) – 1h
Formaldehyde (µg/m^3)	25.86 (138.36)	14 (3 - 31)	6,214	60 (µg/m^3) – 8h
TVOC (ppb)	4,765.03 (8,840.72)	1,681 (546 - 4,627.75)	60,000	600 (µg/m^3) – 8h Aprox. 130 ppb
PM_1 (µg/m^3)	3.71 (8.12)	2 (1 - 5)	784	-
$PM_{2.5}$ (µg/m^3)	4.06 (10.08)	2 (1 - 5)	852	5 (µg/m^3) - Annual
PM_4 (µg/m^3)	4.19 (11.52)	3 (1 - 5)	998	-
PM_{10} (µg/m^3)	4.26 (12.19)	3 (1 - 5)	1,085	15 (µg/m^3) - Annual

The time series data generated from continuous monitoring activities are systematically collected and presented on the project's dedicated platform. This platform offers a sophisticated interface with nuanced visualization dashboards, providing stakeholders comprehensive insights into the IAQ dynamics. Figure 4 shows a snapshot of the graphical view of the registers of INBIOT sensors installed in one of the areas of the hospital for one week.

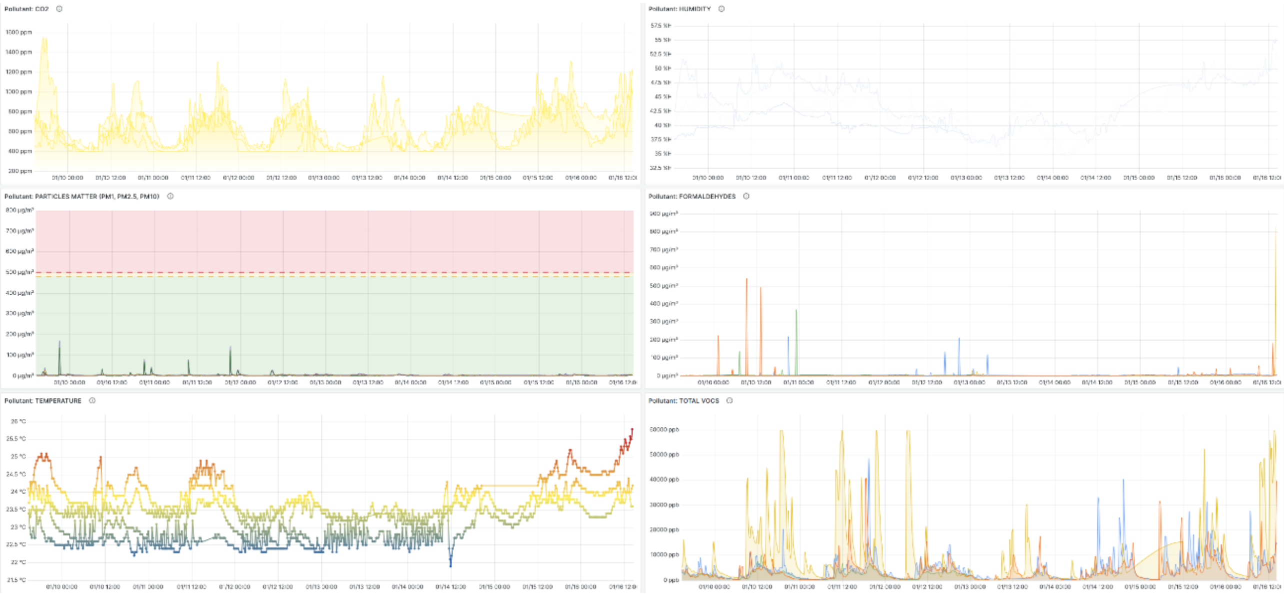


Figure 4. Snapshot of the graphical view of the registers of INBIOT sensors installed in one of the areas of the hospital in Barcelona (generated with K-HEALTHinAIR platform).

2.1.2 OAQ modelled data from AerisWeather

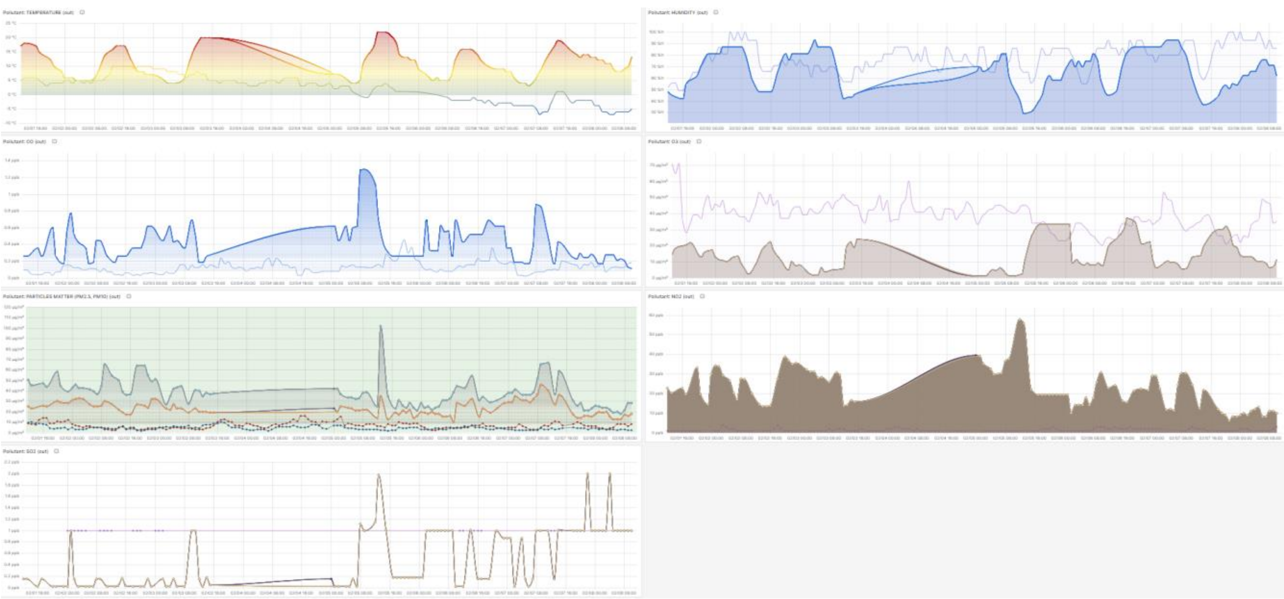


Figure 5. Snapshot graphical evolution of the outdoor air quality parameters included in the study in Barcelona (T, RH, CO, O_3, PM and NO_X concentrations) (generated with K-HEALTHinAIR platform).

OAQ data is reported by utilizing the AerisWeather (https://www.aerisweather.com/) platform, encompassing T, RH, and concentrations of key pollutants in the surrounding area. These pollutants include PM, NO_x, CO, and O_3. Incorporating OAQ data into the analysis aims to contextualize indoor air conditions within the broader environmental framework.

The time series data generated from OAQ are systematically collected and presented on the project's dedicated platform. Figure 5 shows a snapshot of the graphical view of the OAQ registers over time.

2.1.3 VOCs sampling

The VOCs sampling was initiated in June 2023, involving the collection of two consecutive samples and two duplicates from a representative point within each hospital area. Utilizing the Gilian pump model GilAir Plus, an airflow of 200 cc/min was regulated, extracting air from the environment for 1 hour. To facilitate sampling, stainless-steel tubes containing Tenax were connected at the pump's entrance. Following these active and passive sampling procedures on Tenax, the captured compounds underwent analysis via thermal desorption coupled with gas chromatography and mass detection.

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: acetonitrile, methyl bromide (bromomethane), 1,3-butadiene, chlorobenzene, methyl chloroform (1,1,1-trichloroethane), benzyl chloride, ethyl chloride (chloroethane), methylene chloride (dichloromethane), methyl chloride (Chloromethane), cresols/Cresylic acid (isomers and mixture), 1,4-dichlorobenzene(p), 1,3-dichloropropene, ethylene dichloride (1,2-dichloroethane), ethylidene dichloride (1,1-dichloroethane), hexachlorobutadiene, hexachlorocyclopentadiene, hexachloroethane, hexamethylene-1,6-diisocyanate, lindane (all isomers), methyl methacrylate, 1,1,2,2-tetrachloroethane, carbon tetrachloride, 1,2,4-trichlorobenzene, and 1,1,2-trichloroethane.

Table 3 presents the mean, standard deviation, median, interquartile range, minimum, and maximum concentrations of various VOCs measured in indoor and outdoor environments of the hospital. It also includes the corresponding limits for each compound. The number of pollutants considered indoor is 47, while the number of pollutants considered outdoor is 28. Indoor concentrations generally exceed outdoor levels, with chloroform exhibiting the highest indoor mean concentration of 4,068.54 $\mu g/m^3$ compared to 3,587.5 $\mu g/m^3$ outdoors. Cyclopentane, ethylene glycol butyl ether, and m-xylene & p-xylene also show notable indoor concentrations. Conversely, certain compounds like n-undecane and 3-ethyltoluene have higher outdoor levels. The analysis reveals that the average and median concentrations of all assessed compounds are below their respective thresholds. However, it is noted that a few observations exceed the specified limits for chloroform.

The compounds found indoors but not outdoors include Ethylene glycol butyl ether, m-Xylene y p-xylene, n-hexane, Bromodichloromethane, n-heptane, n-octane, 2,2,4-trimethylpentane, nonanal, trichloroethylene, benzene, camphor, alpha-limonene, undecanoic acid, butylacetate, benzaldehyde, 1,2,3 trimethylbenzene, n-tridecane, 3-ethyltoluene, 3-heptanone, cumene, n-decane, tetrachloroethylene, n-dodecane, n-propylbenzene, 2-butanone oxime, acetophenone, n-undecane, isobornylacetate, mesitylene, 1,2,4 trimethylbenzene, p-cymene, n-nonane, 1-butanol, 1-pentadecene, diisobutylphthalate, 2-butoxyethylacetate, n-butylbenzene, 4-ethyl-m-xylene, and naphthalene. Conversely, the compound propylene dichloride (1,2-dichloropropane) and hexanal are found outdoors but not indoors.

Funded by the European Union

Table 3. Average values and distributions of sampled compounds concentrations over seven months (Jun – Dec 2023) in the hospital. Legal exposure limits extracted from: VLA-ED INSS 2022.

Compound	Mean (SD)	Median (IQR)	Min	Max	Limits
Indoor (µg/m^3)					
Chloroform	4,068.54 (5,078.71)	1,410.61 (202.93-7,635.98)	0	19,795.64	10,000
Cyclopentane	207.38 (299.41)	61.43 (2.87-341.87)	0	2,171.40	1,745,000
Ethylene glycol butyl ether	62.95 (113.68)	17.88 (0-97.09)	0	678.38	98,000
m-Xylene and p-Xylene	49.15 (89.2)	7.05 (4.71-13.43)	2	401.02	221,000
o-Xylene	50.08 (90.8)	6.66 (4.99-11.93)	1.37	397.24	221,000
n-Hexane	57.76 (72.59)	24.54 (5.83-96.59)	0	297.07	72,000
nonanal	61.67 (57.32)	41.91 (15.17-90.59)	0	231.59	-
Bromodichloromethane	17.51 (40.7)	0 (0-1.35)	0	215.81	1,075,000
Ethylbenzene	33.22 (58.02)	4.17 (2.36-15.72)	0	208.91	441,000
Toluene	16.77 (20.17)	13.07 (8.73-18.38)	4	186.27	192,000
n-Heptane	22.52 (26.5)	11.77 (3.87-32.46)	0	151.29	2,085,000
n-Octane	12.11 (25.7)	0.58 (0-7.1)	0	112.88	1,420,000
2-ethyl-1-hexanol	21.94 (30.48)	6.29 (0-40.9)	0	103.91	5,400
Decamethylcyclopentasiloxane	9.57 (13.64)	3.49 (0-17.43)	0	85.77	-
2,2,4-Trimethylpentane	10.69 (19.14)	0 (0-15.33)	0	83.29	1,420,000
Trichloroethylene	5.76 (12.31)	0 (0-5.48)	0	67.92	54,700
1-Methoxy-2-propylacetate	1.85 (6.73)	0.11 (0-0.97)	0	59.61	28,000
Benzene	9.83 (13.52)	2.28 (0.75-16.55)	0	53.71	3,250
Camphor	13.81 (13.2)	10.69 (3.05-20.73)	0	53.03	13,000
Hexanal	3.58 (7.4)	1.34 (0-4.78)	0	52.04	-
alpha-limonene	8.2 (7.66)	6.63 (2.79-10.3)	0	35.4	86,000
Undecanoic Acid	4.27 (10.61)	0 (0-0)	0	31.8	-
Butylacetate	3.97 (3.58)	3.32 (2.2-5)	0	31.14	241,000
benzaldehyde	3.65 (4.74)	1.57 (0-6.93)	0	17.7	-
1,2,3 Trimethylbenzene	2.13 (2.34)	1.48 (0.69-2.94)	0	12.14	100,000
n-Tridecane	4.43 (3.11)	5.73 (0-6.2)	0	11.24	-
3-EthylToluene	1.72 (2.05)	0.91 (0.29-2.72)	0	10.85	100,000
3-heptanone	0.95 (1.92)	0 (0-0)	0	10.35	95,000
Cumene	1.01 (1.88)	0.16 (0-0.98)	0	8.01	50,000
n-Decane	0.74 (1.11)	0.34 (0-1.01)	0	7.24	-
Tetrachloroethylene	0.31 (1.16)	0 (0-0)	0	7.21	138,000
n-Dodecane	2.4 (2.25)	3.6 (0-4.24)	0	6.51	-
n-Propylbenzene	0.86 (1.43)	0.25 (0-0.91)	0	6.48	-
2-Butanone Oxime	0.84 (2.09)	0 (0-0)	0	6.28	50,000

Compound	Mean (SD)	Median (IQR)	Min	Max	Limits
acetophenone	0.36 (1.07)	0 (0-0)	0	6.19	50,000
n-Undecane	1.3 (1.02)	1.28 (0.79-1.65)	0	5.8	-
Isobornylacetate	1.23 (1.45)	0.71 (0.05-1.82)	0	5.63	-
Mesitylene	0.7 (1.08)	0.27 (0-0.9)	0	5.03	100,000
1,2,4 Trimethylbenzene	1.38 (0.64)	1.27 (0.91-1.71)	0.26	3.72	168,000
p-Cymene	0.7 (0.72)	0.41 (0.17-1.18)	0	3.22	113,000
alpha-pinene	0.2 (0.53)	0 (0-0.01)	0	2.83	1,065,000
n-nonane	0.52 (0.62)	0.25 (0-0.81)	0	2.72	98,000
1-Butanol	0.06 (0.31)	0 (0-0)	0	1.77	61,000
1-Pentadecene	0.02 (0.14)	0 (0-0)	0	1.13	13,000
Diisobutylphthalate	0.05 (0.17)	0 (0-0)	0	1	-
2-Butoxyethylacetate	0.21 (0.38)	0 (0-0)	0	0.91	-
n-Butylbenzene	0.07 (0.21)	0 (0-0)	0	0.71	-
4-Ethyl-m-Xylene	0.09 (0.2)	0 (0-0)	0	0.56	221,000
Naphthalene	0.09 (0.15)	0 (0-0.18)	0	0.52	53,000
Outdoor (µg/m³)					
Chloroform	3,587.5 (5,887.76)	513.34 (0-4,180.94)	0	17,124.06	10,000
Cyclopentane	366.24 (407.48)	182.84 (30.44-669.74)	1.37	1,679.32	1,745,000
n-Hexane	80.32 (102.65)	15.52 (2.02-228.08)	0	249.28	72,000
Bromodichloromethane	32.51 (52.59)	0 (0-106.64)	0	129.44	1,075,000
n-Heptane	25.34 (31.81)	5.11 (2.11-69.74)	0.85	78.56	2,085,000
n-Octane	20.57 (31.55)	0 (0-63.36)	0	77.42	1,420,000
2,2,4-Trimethylpentane	20.07 (28.4)	0 (0-61.61)	0	68.29	1,420,000
nonanal	14.91 (12.43)	10.07 (8.91-18.31)	0	53.17	-
Trichloroethylene	14.14 (21.27)	0 (0-44.4)	0	51.53	54,700
Benzene	13.61 (17.66)	1.22 (0.75-39.07)	0.26	42.6	3,250
acetophenone	3.92 (7.31)	0.15 (0-4.29)	0	28	50,000
benzaldehyde	8.64 (8.59)	8.08 (0-15.77)	0	23.26	-
Toluene	8.82 (6.45)	5.47 (4.6-8.92)	4.03	22.7	192,000
Ethylbenzene	5.91 (6.3)	2.79 (1.21-13.26)	0.39	16.97	441,000
o-Xylene	6.92 (4.92)	5.35 (2.71-12.28)	1.09	14.75	221,000
m-Xylene y p-Xylene	5.24 (4.02)	3.74 (1.95-9.94)	0.56	11.88	221,000
Butylacetate	2.96 (2.82)	2.1 (1.59-3.12)	0	11.65	241,000
2-ethyl-1-hexanol	2.38 (3.86)	0 (0-6.89)	0	9.33	5,400
Camphor	2.3 (2.8)	1.1 (0-4.76)	0	7.73	13,000
n-Tridecane	0.97 (2.11)	0 (0-0)	0	5.44	-
n-Dodecane	1.84 (1.62)	3.11 (0-3.21)	0	3.42	-

Compound	Mean (SD)	Median (IQR)	Min	Max	Limits
n-Propylbenzene	0.73 (1.16)	0.07 (0-1.1)	0	3.02	-
Tetrachloroethylene	0.29 (0.85)	0 (0-0)	0	2.98	138,000
3-EthylToluene	0.7 (1)	0.19 (0-1)	0	2.95	100,000
1,2,3 Trimethylbenzene	0.9 (0.79)	0.73 (0.38-1.25)	0	2.84	100,000
Cumene	0.42 (0.9)	0 (0-0.08)	0	2.84	50,000
Propylene dichloride (1,2-Dichloropropane)	0.29 (0.84)	0 (0-0)	0	2.68	-
Mesitylene	0.45 (0.75)	0.04 (0-0.57)	-0.23	1.89	100,000
n-Undecane	0.58 (0.7)	0 (0-1.28)	0	1.7	50,000
Hexanal	0.47 (0.52)	0.37 (0-0.8)	0	1.61	-
1,2,4 Trimethylbenzene	0.61 (0.36)	0.52 (0.41-0.85)	0.08	1.47	100,000
n-Butylbenzene	0.12 (0.3)	0 (0-0)	0	1.09	-
n-nonane	0.23 (0.28)	0.08 (0-0.39)	0	0.8	1,065,000
alpha-pinene	0.02 (0.11)	0 (0-0)	0	0.6	113,000
p-Cymene	0.15 (0.17)	0.09 (0.01-0.25)	0.01	0.55	50,000
4-Ethyl-m-Xylene	0.3 (0.27)	0.53 (0-0.53)	0	0.53	221,000
1-Methoxy-2-propylacetate	0.04 (0.11)	0 (0-0)	0	0.49	28,000
Isobornylacetate	0.03 (0.1)	0 (0-0)	0	0.48	-
alpha-limonene	0.06 (0.11)	0 (0-0.04)	0	0.37	168,000
Naphthalene	0.08 (0.08)	0.09 (0-0.14)	0	0.27	53,000
n-Decane	0.03 (0.07)	0 (0-0)	0	0.26	-

2.1.4 Formaldehyde sampling

Collecting aldehydes and ketones, particularly formaldehyde, from indoor air was performed monthly (starting June 2023). The sampling involved the utilisation of a Gilian 800i pump and DNPH cartridges, with each location requiring a duration of 3 hours. DNPH tubes, exposed to the ambient air, captured the compounds by generating stable derivatives, subsequently subjected to analysis via High-Performance Liquid Chromatography (HPLC) in the laboratory.

Table 4 resents average values and distributions of sampled compound concentrations measured in indoor and outdoor air in μg/m^3. The compounds 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 potentially elevated indoor air pollutant levels. 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.

Funded by the European Union

Table 4. Average values and distributions of sampled compounds concentrations over eight months (Jun 2023 - Jan 2024) in the hospital (ES-HOS-01-001 to ES-HOS-01-005) and outdoors (ES-HOS-01-000). Legal exposure limits extracted from: VLA-ED INSS 2022 if available, otherwise VLA-EC INSS 2022 (*).

Compound	Mean (SD)	Median (IQR)	Min	Max	Limits
Indoor (µg/m³)					
2-Butanone	0.02 (0.12)	0 (0-0)	0	0.71	600,000
Acetaldehyde	27.67 (39.4)	12.68 (8.1-25.99)	2.67	211.24	46,000*
Acetone	486.8 (869.77)	39.42 (14.85-87.16)	3.61	2461.35	1,210,000
Benzaldehyde	0.79 (3)	0 (0-0)	0	16.23	-
Butyraldehyde	2.41 (3.49)	0 (0-6.48)	0	8.23	-
Crotonaldehyde	1.65 (1.11)	1.75 (1-2.42)	0	3.69	870*
Formaldehyde	48.62 (72.86)	11.43 (4.66-32.38)	1.89	217.33	370
Hexaldehyde	0.62 (1.22)	0 (0-0)	0	4.38	-
m-Tolualdehyde	0.32 (1.9)	0 (0-0)	0	11.39	-
Methacroleyne	2.15 (1.87)	2.08 (0-2.84)	0	8.64	-
Propynaldehyde	0.55 (0.79)	0 (0-1.2)	0	2.27	46,000
Valeraldehyde	0.8 (2.12)	0 (0-0)	0	9.83	179,000
Outdoor (µg/m³)					
2-Butanone	0 (0)	0 (0-0)	0	0	600,000
Acetaldehyde	6.28 (1.68)	6.49 (4.97-7.08)	4.27	9.08	46,000*
Acetone	23.55 (11.66)	20.77 (16.66-27.44)	10.04	45.83	1,210,000
Benzaldehyde	0 (0)	0 (0-0)	0	0	-
Butyraldehyde	0 (0)	0 (0-0)	0	0	-
Crotonaldehyde	2 (1.79)	2.15 (0.52-3.12)	0	4.57	870*
Formaldehyde	4.73 (1.35)	4.3 (3.91-5.57)	2.94	6.92	370
Hexaldehyde	1.13 (2.99)	0 (0-0)	0	7.92	-
m-Tolualdehyde	2.96 (5.19)	0 (0-4.14)	0	12.41	-
Methacroleyne	1.49 (1.04)	2.09 (0.87-2.13)	0	2.36	-
Propynaldehyde	0.23 (0.62)	0 (0-0)	0	1.63	46,000
Valeraldehyde	0 (0)	0 (0-0)	0	0	179,000

2.1.5 Radon sampling

Radon measurements were conducted using radon-specific passive detectors. After the test period, the detectors were returned to a laboratory for analysis, and the average radon concentration is calculated based on the marks left on the plastic. The analysis was performed in different locations distributed across a single waiting room in the hospital's basement (Jul 2023). The results in Table 5 indicate low radon concentrations, suggesting that further replicates are unnecessary.

Table 5. Results of the radon sampling conducted in the basement of the hospital in July 2023.

Location	Days	Exposure CRn (Bq/m^3)	Radon concentration UCRn (Bq/m^3)
Sample 1	36	93	10
Sample 2	36	105	11
Sample 3	36	109	12

2.1.6 PM sampling

Sampling PM was performed monthly (starting June 2023) with the portable device Fluke 985. Table 6 presents average values and distributions of sampled PM concentrations measured in indoor and outdoor air in particles/m^3, including various particle size categories ranging from $PM_{0.3}$ to PM_{10}. The data reveals substantial differences between indoor and outdoor particle concentrations across different size categories, with higher mean and median values generally observed outdoors than indoors.

Table 6. Average values and distributions of sampled PM concentrations over eight months (Jun 2023 - Jan 2024) in the hospital (ES-HOS-01-001 to ES-HOS-01-005) and outdoors (ES-HOS-01-000). Legal exposure limits extracted from: N.A.

Particle size	Mean (SD)	Median (IQR)	Min	Max	Limits
Indoor (particles/m^3)					
$PM_{0.3}$	37,321,943.66 (29,132,381.19)	34,914,689 (17,974,876-54,351,324)	257,768	116,211,511	-
$PM_{0.5}$	4,231,524.64 (4,525,514.04)	2,803,743 (1,791,331-4,903,266)	74,293	21,495,974	-
PM_1	917,337.57 (1,412,994.05)	432,662 (267,708-811,052)	31,002	7,654,519	-
PM_2	30,865.51 (33,487.31)	17,620 (11,158-30,579)	6,497	147,881	-
PM_5	606,477.56 (1,148,244.3)	313,065 (210,982-558,810)	32,274	6,959,745	-
PM_{10}	57,893.91 (70,914.33)	34,181 (21,186-45,445)	6,850	300,141	-
Outdoor (particles/m^3)					
$PM_{0.3}$	52,728,813.56 (24,936,841.88)	56,786,194 (42,282,504-65,921,540)	10,477,754	83,002,471	-
$PM_{0.5}$	5,185,443.15 (3,189,671.66)	4,588,100 (3,012,553-6,679,590)	1,405,932	11,308,686	-
PM_1	1,217,505.3 (1,143,530.62)	753,672 (625,088-1,199,294)	464,406	3,893,926	-
PM_2	54,405.01 (29,287.81)	59,569 (33,263-75,847)	12,217	88,064	-
PM_5	885,999.29 (372,605.49)	864,442 (637,359-1,008,863)	416,525	1,626,765	-
PM_{10}	114,927.61 (43,626.04)	101,483 (81,674-159,975)	64,971	167,796	20,000

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 and 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.

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

Baseline indoor pollutant levels: The preliminary analysis indicates that basal concentrations of indoor pollutants in the hospital setting are low.

Compliance with air quality standards: The basal concentrations fall within the non-harmful ranges set by regulatory bodies, suggesting overall good indoor air quality compliance.

Elevated VOC levels: However elevated monitored values of TVOCs have been identified found exceeding the recommended parameters. Whereas the exhaustive VOCs analysis revealed that in exception of few chloroform measures, all the values are far below the recommended thresholds.

Importance of cross-validation: Cross validating the sensors measurements through empirical on-field measurements is mandatory. In this regard using consensual units to calculate PM and assessing TVOCs is crucial.

Investigation of chloroform levels: High concentrations of chloroform have been identified, systematically and across sampling points, this deserves further investigation to identify the main source of chloroform or evaluate if it is a sample contamination.

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

IAQ in the homes of patients is a crucial aspect influencing the well-being of individuals and the overall environment within residential settings. The quality of indoor air plays a pivotal role in ensuring a healthy living space and minimizing potential health risks for residents. Factors such as ventilation, air filtration systems, and the presence of pollutants contribute significantly to the overall indoor air quality of homes.

This study aims to address and elucidate the key compounds or parameters within indoor air that may impact human health in the diverse array of contaminants found in residential environments. By examining factors like particulate matter, volatile organic compounds (VOCs), humidity levels, and microbial content, the objective is to establish a comprehensive understanding of specific components that could pose health concerns in the context of residential spaces. This focused analysis will pave the way for targeted interventions and strategies to improve air quality, fostering a healthier living environment for residents.

So, high-risk outpatients (HOM01) scenario is focused on analysing the relationships between patients' home IAQ and their health status, especially on acute health effects. The number of outpatients analysed will be 200.

2.2.1 Cohort recruitment

Recruitment and characterization of the candidates – Recruiting, characterizing candidates, and establishing care and follow-up plans entail an initial telephone call and a 3-visit process overseen by a nurse case manager at the patients' residences. This process comprises:

Visit 0 (telephone – 15 min): Initial telephone contact to screen inclusion/exclusion criteria and schedule the first home-based visit.

Visit 1 (home-based – up to 60 min): Detailed explanation of the study protocol, consent form signature, installation and configuration of sensors (home-based IAQ sensor and wrist sensor), and app setup. Instructions for using the chat and sensors are provided, and baseline characterization is conducted by administering K-HiA questionnaires.

Visit 2 (home-based - up to 60 min): Review and reinforce Visit 1 content, complete the remaining K-HiA questionnaires for baseline characterization, and assess pulmonary capacity through FS and FOT measurements.

Visit 3 (home-based - up to 60 min): Clinical assessment, development of a clinical support plan to be shared with the primary care physician and/or specialist, and patient education for self-management.

The baseline evaluation and follow-up of the participants includes a careful assessment of their digital literacy such that the study protocol considers the following three modalities of patients' participation in terms of technological support, namely: i) phone-based only, ii) phone-based and passive use of the Beat One watch sensor, and iii) digital support for patients and health professionals provided by the Health Circuit platform. The modality of participation will modulate the availability of data. Each of these categories involves a different interaction modality with the nurse case manager, who will be the interface between the patient and the corresponding primary care physician (for all patients) and/or specialist (only for severe asthma patients).

Recruitment faced delays during January due to a flu outbreak but is expected to regain momentum, with completion anticipated by March-April 2024. The calculations displayed in the subsequent sections consider only the 62 patients recruited until the 31st of January of 2024.

Table 7. Baseline characteristics of the recruited patients. The AMG is a summary measure of morbidity that considers a weighted sum of all chronic and relevant acute conditions. The AMG categories are defined according to percentile thresholds for the distribution of the AMG index across the entire population of Catalonia: Tier 3 [P80-P95), Tier 4 [P95-P99), Tier 5 ≥ P99.

Particle size	Mean (SD)
Progress; n/200 (%)	95/200 (47.5%)
Age; mean (SD)	69.35 (7.65)
Male/Female; n (%)	41 (43.2%) / 54 (56.8%)
AMG; mean (SD)	24.15 (10.77)
AMG; category 3/4/5; n (%)	59 (61.7%) / 33 (35%) / 3 (3.3%)
Diagnosis - COPD; n (%)	65 (68.4%)
Diagnosis - Severe Asthma; n (%)	30 (31.6%)

2.2.2 IAQ Massive monitoring INBIOT sensors

Ensuring ideal IAQ within residential environments is pivotal for fostering well-being and public health, particularly for vulnerable groups such as high-risk respiratory patients. This information is particularly relevant for implementing IAQ monitoring in the homes of 200 high-risk respiratory outpatients. Utilizing desktop Wi-Fi-enabled MICA devices allows for seamless integration into home environments.

Table 8 provides an overview of the average values and distributions of monitored parameters over two months from December 2023 to January 2024, along with the maximum peaks observed. Additionally, it compares the observed results with the legal limits established by current legislation. The data presented in Table 8 consistently shows that all monitored parameters remain within the legal ranges, indicating compliance with regulatory standards.

A comprehensive and detailed comparative assessment of the monitored parameters across the different dwellings is presented in the subsequent sections.

Table 8. Average values and distributions of monitored parameters over two months (Dec 2023 -Jan 2024) in patients' homes. Legal exposure limits extracted from: WHO.

Parameter	Mean (SD)	Median (IQR)	Max	Limits
Temperature (°C)	20.6 (2.01)	20.5 (19.2-22)	30.6	-
Relative Humidity (%)	46.97 (6.43)	47 (42-52)	74	-
CO_2 (ppm)	767.46 (433.53)	634 (482-896)	6,770	900 (ppm) – 1h
Formaldehyde (µg/m³)	29.83 (24.99)	26 (10-44)	889	60 (µg/m³) – 8h
TVOC (ppb)	6,401.08 (11,733.38)	1,821 (583-5,998)	60,000	600 (µg/m³) – 8h. Aprox. 130 ppb
PM_1 (µg/m³)	39.83 (107.12)	7 (4-22)	2,309	-
$PM_{2.5}$ (µg/m³)	43.96 (121.86)	8 (4-24)	2,619	5 (µg/m³) - Annual
PM_4 (µg/m³)	45.79 (129.93)	8 (4-24)	2,784	-
PM_{10} (µg/m³)	46.6 (133.55)	8 (4-25)	2,858	15 (µg/m³) - Annual

2.2.3 OAQ modelled data from AerisWeather

OAQ data are reported by utilizing the AerisWeather (https://www.aerisweather.com/) platform, encompassing temperature, relative humidity, and concentrations of key pollutants in the surrounding area. These pollutants include PM, NO_x, CO, and O_3. Incorporating OAQ data into the analysis aims to contextualize indoor air conditions within the broader environmental framework.

The time series data generated from OAQ are systematically collected and presented on the project's dedicated platform. Figure 6 shows a snapshot of the graphical view of the OAQ registers over time.

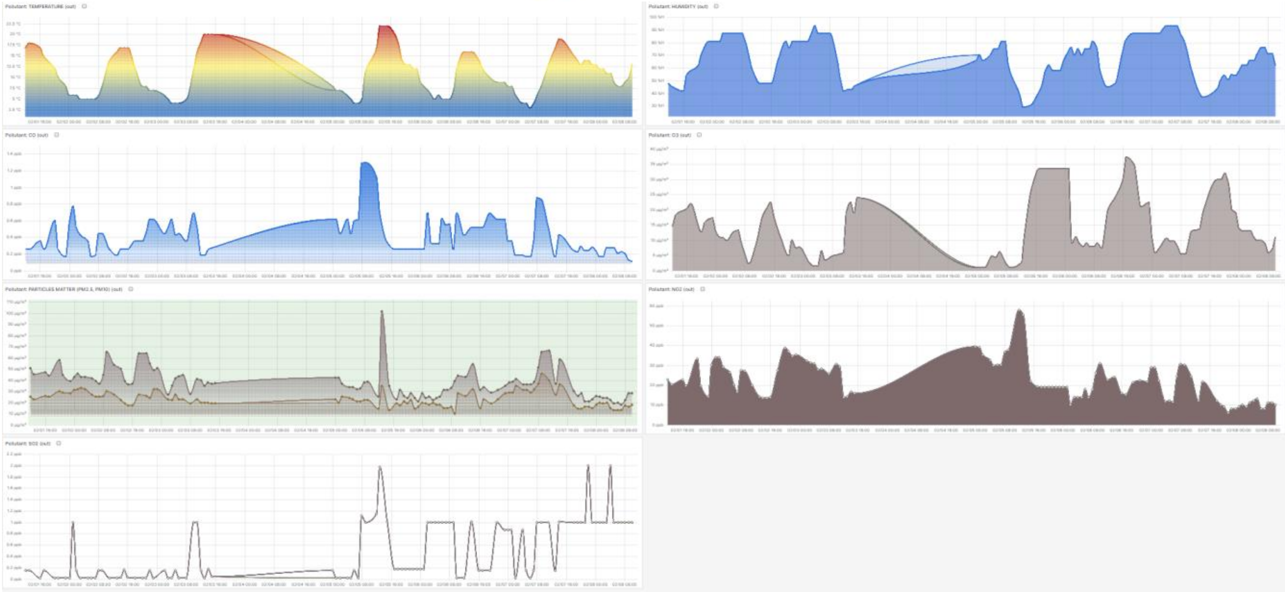


Figure 6. Snapshot graphical evolution of the outdoor air quality parameters included in the study in Barcelona (T, RH, CO, O_3, PM and NO_X concentrations) (generated with K-HEALTHinAIR platform).

2.2.4 Questionnaires

Table 9 provides a comprehensive overview of the questionnaires administered in the cohort of 200 outpatients. The intention behind these questionnaires is to gather robust data, ensuring the successful progression of the study while aligning with its specific objectives.

The questionnaires have been meticulously designed to minimize respondent fatigue while maximizing data quality and relevance. The results from these questionnaires will be pivotal in shaping the subsequent phases of the research in Barcelona. They will be instrumental in determining the efficacy and future scalability of the pilot project.

*Table 9. Summary table of the administered questionnaires. *Patients with asthma. ** Patients with COPD.*

Questionnaire	Follow up of 200 outpatients (Asthma/COPD)
Sociodemographic	Baseline
Observational Checklist	Baseline
Time spent in the scenario	Baseline / Every 6 months
PARIS Survey	Baseline / Every 6 months
ICHOM Adult Set	Baseline / Every 6 months
Asthma Control Test (ACT)	Baseline / Every 6 months *
Test of Adherence to Inhalers 12 (TAI-12)	Baseline / Every 6 months
Mini Asthma Quality of Life Questionnaire (mini AQLQ)	Baseline / Every 6 months *
Sino-Nasal Outcome Test (SNOT-22)	Baseline / Every 6 months*
COPD Assessment Test (CAT)	Baseline / Every 6 months**
Modified Medical Research Council (mMRC) Dyspnea scale	Baseline / Every 6 months

Table 10 provides a detailed analysis of respiratory health questionnaires, with variations in participant numbers and scores obtained.

Table 10. Baseline characterization of the patient self-reported health outcomes using standardized questionnaires.

Questionnaire	n	Mean (SD)	Median (IQR)	Min -Max
ICHOM Adult Set				
PROMIS 10 – Physical Health Score	14	11.8 (2.2)	11.5 (9.3 – 12.8)	8 - 16
PROMIS 10 – Mental Health Score	14	12.4 (2.6)	12.5 (10.5 – 14)	8 - 17
WHO-DAS-12	13	8.2 (10.4)	4 (2 – 6)	0 - 33
WHO 5	14	46.3 (21.1)	52 (29 – 63)	8 - 72
Asthma Control Test (ACT)	19	16.0 (5.1)	17.0 (13.0 – 19.5)	5 - 25
Test of Adherence to Inhalers 12 (TAI-12)	12	48.6 (3.8)	50 (50 -50)	37 - 50
Mini Asthma Quality of Life Questionnaire (mini AQLQ)	16	66.3 (19.9)	72 (54.3 – 78.5)	20 - 97
Sino-Nasal Outcome Test (SNOT-22)	15	48.3 (19.3)	42 (34 – 63)	22 - 93
COPD Assessment Test (CAT)	20	14.1 (6.9)	13.5 (7.8 – 19.0)	6 - 28
Modified Medical Research Council (mMRC) Dyspnea scale	49	1.2 (1.2)	1 (0 –2)	0-4

In the ICHOM Adult Set, 14 individuals provided data for the PROMIS 10 questionnaires, yielding an average of 11.8 (SD 2.2) for physical health and 12.4 (SD 2.6) for mental health, suggesting moderately good health states within ranges of 8-16 and 8-17, respectively. For the WHO-DAS-12 completed by 13 individuals, the mean was 8.2 (SD 10.4), with a range of 0-33, while the WHO 5, based on responses from 14 individuals, indicated psychological well-being with a mean of 46.3 (SD 21.1) and a range of 8-72. Participants in the study demonstrated moderately good physical and mental health, as indicated by the PROMIS 10 and WHO 5 questionnaires, with scores within ranges considered indicative of satisfactory well-being.

The Asthma Control Test (ACT), with responses from 19 individuals, had an average of 16.0 (SD 5.1), within a score range of 5 to 25, reflecting variability in asthma control among participants, suggesting the need for tailored management strategies to improve control for some individuals.

Adherence to inhaler treatment, measured by the TAI-10 and completed by 12 individuals, showed notable adherence with a high average of 48.6 (SD 3.8), within a score range of 37-50, approaching the questionnaire's maximum score of 50 and significantly above the minimum possible score of 10, indicating good compliance with prescribed medication regimens.

Quality of life related to asthma, assessed through the Mini Asthma Quality of Life Questionnaire (Mini AQLQ) by 16 individuals, had an average of 66.3 (SD 19.9) within a range of 20-97. The scores ranging from relatively low to high, suggesting differing levels of impact of asthma on daily life activities.

The Sino-Nasal Outcome Test (SNOT-22), measuring nasal and paranasal symptom severity, had responses from 15 individuals with an average score of 48.3, a standard deviation of 19.3, and a score range of 22 to 93, indicating a moderate impact on participants' quality of life due to their symptoms.

The CAT, completed by 20 participants, yielded an average of 14.1 points, with scores ranging from 6 to 28, indicating a mild to moderate impact of COPD on participants on average. The mMRC scale, with data from 49 participants, showed an average of 1.2 with a standard deviation of 1.2 and a response range of 0 to 4, reflecting mild to moderate impact on patients' breathlessness, indicating the presence of symptoms that may affect daily functioning but not to a disabling extent for most individuals.

Notably, most patients did not experience the highest levels of respiratory difficulty, indicated by a score of 4 on the Modified Medical Research Council (mMRC) Dyspnea scale. The mMRC scale, with data from 49 patients, is a self-assessment tool that measures the degree of breathlessness in daily activities using a scale from 0 to 4. The sample mean was 1.2, with a standard deviation of 1.2, reflecting variability in breathlessness experience among individuals. Results ranged from 0 – no respiratory difficulty – to 5 – severe breathlessness preventing physical activity. The fact that the maximum score reported by patients did not reach the upper limit of the scale indicates that most experience a level of breathlessness that does not become disabling in daily life. However, it does not impede the performance of a preliminary characterization of the monitored environments.

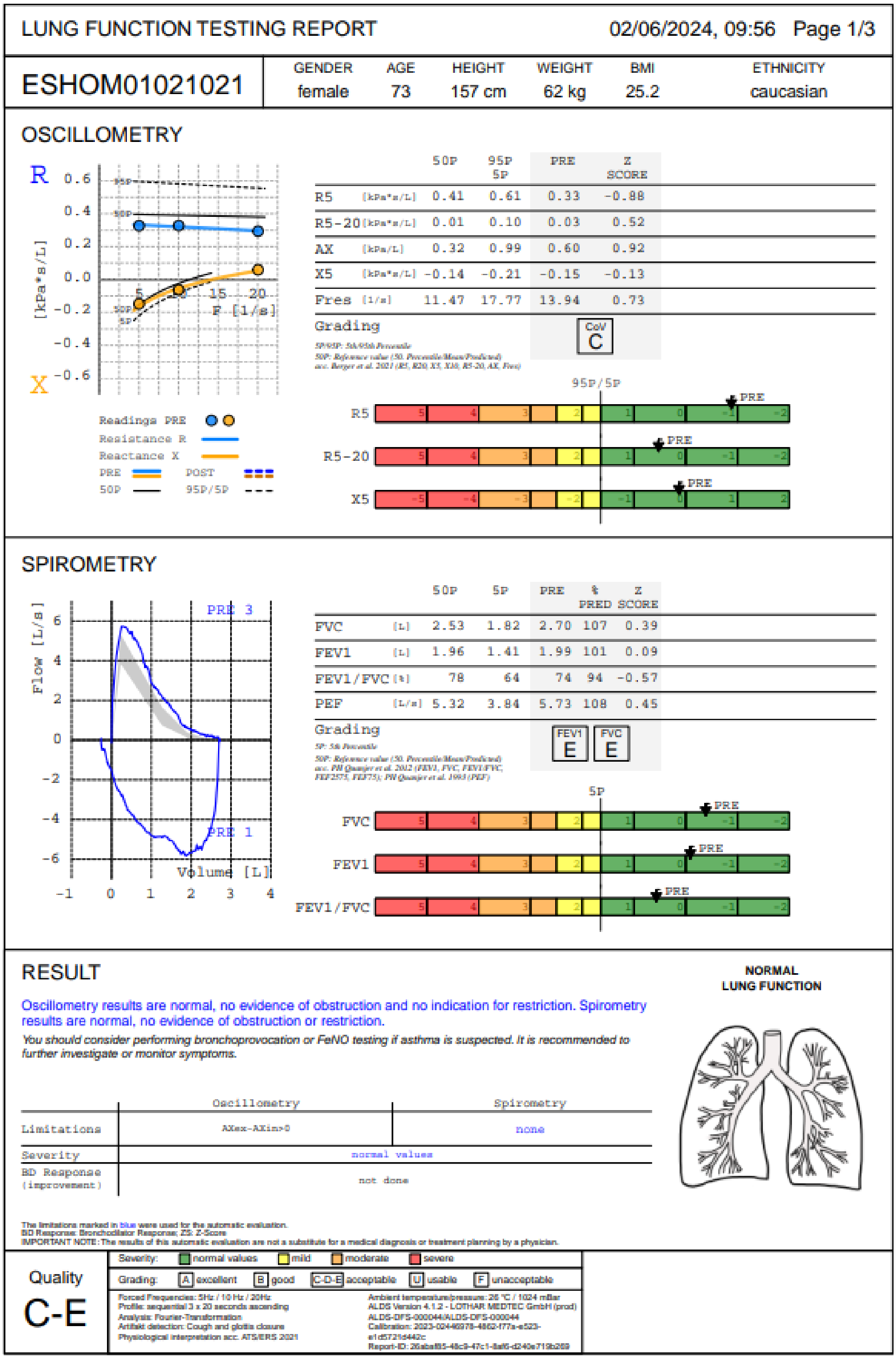
2.2.5 Patients Health data

Once the cohort is fully recruited, the patient's medical history will be extensively collected, drawing from various sources, including population registries and extracts from primary care and hospital medical records. Data gathering will encompass several key aspects. Firstly, information regarding the utilization of healthcare resources encompassing number of encounters with healthcare professionals at different levels, including primary care visits, outpatient care visits, mental health ambulatory visits, emergency room visits, day hospital visits, intermediate care admissions, hospital admissions, and admissions in mental health centers. Additionally, total healthcare expenditure will be recorded to provide insights into resource allocation and healthcare utilization patterns. Furthermore, detailed records of disease diagnoses and medications prescribed will be documented to facilitate a comprehensive understanding of patient's health profiles. Finally, clinical procedures undergone by patients, during hospital admissions, length of stay in the ICU (if applicable), lab tests performed, and various outpatient visits will also be meticulously documented. Lastly, assessments related to frailty, including functional and social aspects, will be included to provide a holistic view of patients' health status and needs. This comprehensive data collection approach will enable robust analysis and evaluation of the cohort's healthcare utilization, disease burden, and overall health outcomes.

2.2.6 Lung function assessments

On the other hand, the assessment of pulmonary capacity through Forced Oscillation Technique (FOT) and Forced Spirometry (FS) measurements follows a different schedule. These assessments will occur upon entry into the study and every six months after that. Utilizing the Ambulatory Lung Diagnosis System (ALDS) manufactured by Lothar-Medtech equipment (https://alds.health/), these measurements provide crucial insights into lung function. The pulmonary assessment is scheduled for the second home visit, limiting the availability of records when writing this deliverable. In Figure 7, an example of the outcome of the lung function assessment is presented, showcasing data such as Forced Vital Capacity

(FVC), Forced Expiratory Volume in one second (FEV1), FEV1/FVC ratio for FS assessments, resistance (R5 and R5-20), reactance (X), and Resonance frequency for the FOT.



LUNG FUNCTION TESTING REPORT 02/06/2024, 09:56 Page 1/3

ESHOM01021021	GENDER	AGE	HEIGHT	WEIGHT	BMI	ETHNICITY
	female	73	157 cm	62 kg	25.2	caucasian

OSCILLOMETRY

		50P	95P 5P	PRE	Z SCORE
R5	[kPa*s/L]	0.41	0.61	0.33	-0.88
R5-20	[kPa*s/L]	0.01	0.10	0.03	0.52
AX	[kPa/L]	0.32	0.99	0.60	0.92
X5	[kPa*s/L]	-0.14	-0.21	-0.15	-0.13
Fres	[1/s]	11.47	17.77	13.94	0.73
Grading				CoV C	

5P/95P: 5th/95th Percentile
50P: Reference value (50. Percentile/Mean/Predicted)
acc. Berger et al. 2021 (R5, R20, X5, X10, R5-20, AX, Fres)

SPIROMETRY

		50P	5P	PRE	% PRED	Z SCORE
FVC	[L]	2.53	1.82	2.70	107	0.39
FEV1	[L]	1.96	1.41	1.99	101	0.09
FEV1/FVC	[%]	78	64	74	94	-0.57
PEF	[L/s]	5.32	3.84	5.73	108	0.45
Grading				FEV1 E	FVC E	

5P: 5th Percentile
50P: Reference value (50. Percentile/Mean/Predicted)
acc. PH Quanjer et al. 2012 (FEV1, FVC, FEV1/FVC, FEF2575, FEF75); PH Quanjer et al. 1993 (PEF)

RESULT

NORMAL LUNG FUNCTION

Oscillometry results are normal, no evidence of obstruction and no indication for restriction. Spirometry results are normal, no evidence of obstruction or restriction.

You should consider performing bronchoprovocation or FeNO testing if asthma is suspected. It is recommended to further investigate or monitor symptoms.

	Oscillometry	Spirometry
Limitations	AXex-AXin>0	none
Severity	normal values	
BD Response (improvement)	not done	

The limitations marked in blue were used for the automatic evaluation.
BD Response: Bronchodilator Response; ZS: Z-Score
IMPORTANT NOTE: The results of this automatic evaluation are not a substitute for a medical diagnosis or treatment planning by a physician.

Quality C-E

Severity: normal values, mild, moderate, severe
Grading: A excellent, B good, C-D-E acceptable, U usable, F unacceptable

Forced Frequencies: 5Hz / 10 Hz / 20Hz
Profile: sequential 3 x 20 seconds ascending
Analysis: Fourier-Transformation
Artifakt detection: Cough and glottis closure
Physiological interpretation acc. ATS/ERS 2021
Ambient temperature/pressure: 26 °C / 1024 mBar
ALDS Version 4.1.2 - LOTHAR MEDTEC GmbH (prod)
ALDS-DFS-000044/ALDS-DFS-000044
Calibration: 2023-02446978-4862-f77a-e523-e1d5721d442c
Report-ID: 26aba f85-48c9-47c1-8af6-d240e719b269

Figure 7. Example of a results sheet of a pulmonary assessment through FS and FOT measurements using the ALDS of Lothar-MedTech.

2.2.7 Watch wearable

All patients participating in the study under the modalities that include digital support are utilizing the Beat One watch (https://beat-one.com/producto/la-salud-en-tu-mano/). Specifically, in the modalities involving phone-based use and passive monitoring with the Beat One watch sensor, as well as in the modalities involving digital support provided by the Health Circuit platform, continuous monitoring of steps walked, and heart rate will be conducted through the Beat One watch. Additionally, heart rate variability, stress level, and sleep structure will be calculated from continuously monitoring heart rate data. Moreover, pulse oximetry, arterial pressure, and body temperature can be measured by the Beat One watch upon request by the nurse case manager.

Figure 8 illustrates an exemplary visualization of the data acquired through the sensor. Specifically, it depicts the temporal fluctuations of heart rate values collected every 15 minutes from a randomly selected patient participating in the study.

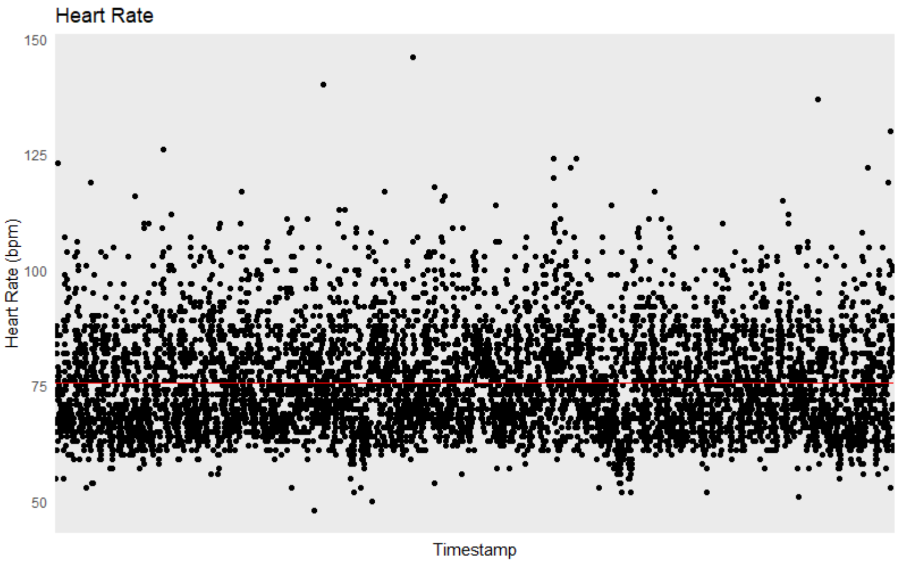


Figure 8. Visualization of the temporal fluctuations of heart rate values (bpm) collected every 15 minutes using the Beat One sensor. The redline displays the average heart rate value (bpm) over the monitored period.

2.2.8 Conclusions

Varied profiles of indoor pollutants: Observations reveal varied profiles of indoor pollutants across households, with smoking habit emerging as a primary driver for indoor PM pollution.

Identification of primary pollutant sources: Further research is necessary to pinpoint the primary sources of formaldehyde and the elevated TVOCs observed in indoor environments.

Correlation analysis with clinical data: Correlation analysis between IAQ and clinical data in outpatients is crucial for extending the relevance of the analyses beyond the comparison with stablished threshold and facilitating the identification of IAQ health determinants and informing *in vivo / in vitro* studies design.

Importance of cross-validation: Cross-validating the sensor measurements through empirical on-field measurements planned for the HOM-02 scenario is paramount.

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

Due to the above-mentioned delays, it is essential to note that the sampling/monitoring campaign has yet to be initiated in this scenario. As per the calendar presented at the beginning of this section (Table 1), the sampling/monitoring activity is expected to begin in March 2024. Therefore, no results are displayed in this issue of this Deliverable 1.2.

From March, the relationships between patients' home IAQ and their health status will be analysed, focusing on acute health effects in high-risk patients with CODP (HOM02). In this scenario there is a more extensive medical follow-up compared to ES-HOM01. The number of participants will be 10 outpatients.

2.3.1 Portable monitoring tool

Additional Information on the utilization of portable monitoring tools is described in the Deliverable 3.1.

2.4 Metro station scenario (ES-MET01)

Due to the above-mentioned reasons, 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 presented at the beginning of this section (Table 1), the sampling/monitoring activity in transient stop until May 2024. Therefore, no results are displayed in this issue of this Deliverable 1.2.

2.5 Market scenario (ES-MKT01)

Due to the above-mentioned delays, it is essential to note that the sampling/monitoring campaign has yet to be initiated in this scenario. As per the calendar presented at the beginning of this section (Table 1), the sampling/monitoring activity is expected to begin in March 2024. Therefore, no results are displayed in this issue of this Deliverable 1.2.

3 ROTTERDAM PILOT #2 (NL)

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 outpatients with COPD and 2) analysis of 2 relevant settings, hospital areas and a senior home (common areas).

The work with the outpatients (50 high-risk outpatients and 60 elderly residents) is focused on analysing the relationships between patient's home IAQ and health status with attention on acute health effects. It includes a) the collection of health-related data such as medical surveillance, PROMS and questionnaires and b) the monitoring of relevant parameters such as T, RH, CO_2, PM, VOCs and formaldehyde.

The work with the settings, hospital and senior home, is focused on a) monitoring of the relevant 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 use of questionnaires with the staff (because in principle this is the population group spending more time inside these settings).

Table 11. Launching dates of the information sources for the Rotterdam Pilot.

	HOSPITAL	SENIOR HOME
VOCs & Chemicals	Pending, second half of 2024	Pending, second half of 2024
Data Public health	31-05-2023	31-05-2023
Massive monitoring	In September 2023 massive monitoring started at EMC. Recruitment of high-risk outpatients from 09-01-2024	In October 2023 massive monitoring started in general areas of senior homes. Recruitment of high-risk outpatients from 09-01-2024
Mental health and QoL	Recruitment start 09-01-2024	Recruitment start on 09-10-2024
PROMS	Recruitment start 09-01-2024	Recruitment start on 09-01-2024
Observational checklist	Recruitment start 09-01-2024	Recruitment start on 09-01-2024
Questionnaires	Recruitment start 09-01-2024	Recruitment start on 09-01-2024

PILOT COORDINATOR:

ERASMUS UNIVERSITY MEDICAL CENTER

OBJECTIVES:

Pilot study focused on the identification of determinants for high-risk outpatients and also in two different scenarios: HOSPITAL and SENIOR HOME.

LOCATIONS:

· High-Risk Outpatients from the delta area of Rotterdam- Rijnmond.

· IAQ monitoring in homes of high-risk outpatients, in selected sites in the hospital and in general spaces of senior housing buildings.

· Erasmus University Medical Center:

Doctor Molewaterplein 40, 3015 GD Rotterdam

In short:

· 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)

The building for the setting in this scenario is the Erasmus University Medical Centre. Locations in the hospital that are targeted for installing the IAQ sensors is the Pulmonary Inpatient and Outpatient department.

Mass IAQ monitoring in the outpatient clinic of the pulmonary department started in September with three MICA devices and was later extended to four. Mass monitoring at the inpatient pulmonary department.

The inpatient clinic of the pulmonary department has at present three IAQ sensors devices of which four extra have been installed December 2023.

Delays can be attributed to waiting times for ethical approval (EA), the first EA submission was not approved, so in April 2023 a second version was submitted. After the ethical approval, discussions with authorized personal started in order to get permission to place and install IAQ sensors. Secondly, delays were due to the need for explanation, discussion and approval to install sensors from several layers of senior management. Moreover, wall-mounted installation of sensors requires additional requests and approvals.

3.1.1 IAQ Massive monitoring INBIOT sensors

INBIOT sensors provide continuous monitoring of temperature, relative humidity, tVOC, formaldehyde concentration and PM concentration (1, 2.5, 4 and 10 of particle size). Next, Figure 9, Figure 10, Figure 11 and Figure 12 display a snapshot of the dashboard of the platform during a whole week, showing T, RH, CO_2, formaldehyde, TVOC, PM_1, $PM_{2.5}$ and PM_{10}.

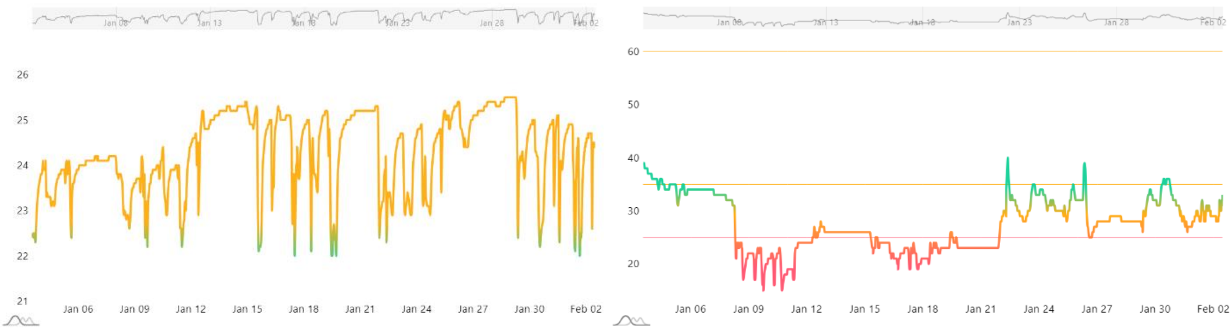


Figure 9. Snapshot of the graphical view of temperature, °C, (left) and relative humidity, %, (right) registers of INBIOT sensors installed in one of the areas of the hospital in Rotterdam.

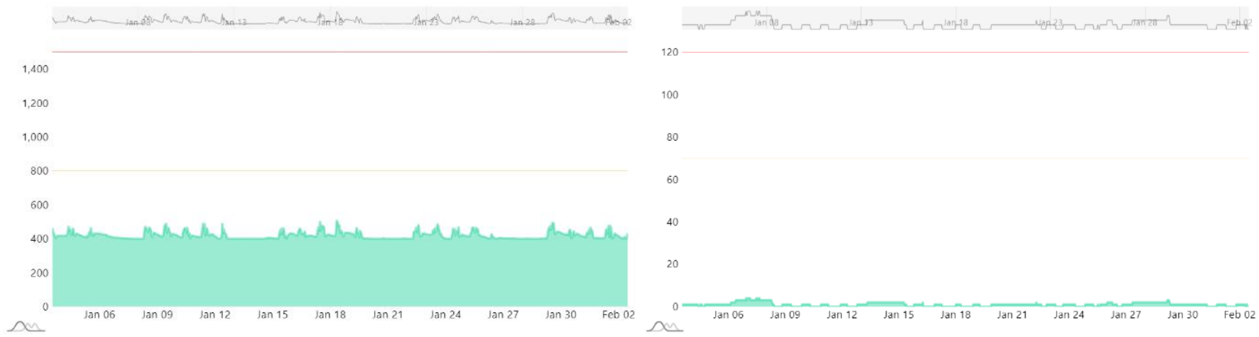


Figure 10. Snapshot of the graphical view of CO_2, ppm, (left) and formaldehyde, $\mu m/m^3$, (right) registers of INBIOT sensors installed in one of the areas of the hospital in Rotterdam.

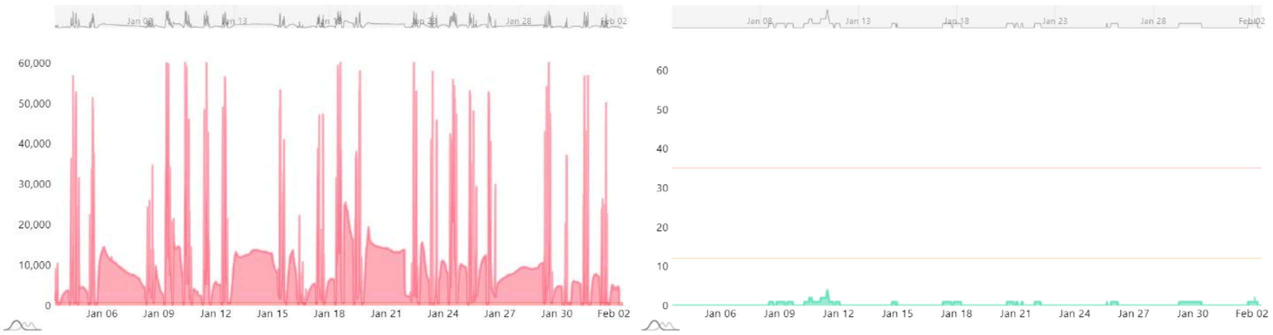


Figure 11. Snapshot of the graphical view of TVOC, ppb, (left) and PM_1, $\mu m/m^3$, (right) registers of INBIOT sensors installed in one of the areas of the hospital in Rotterdam.

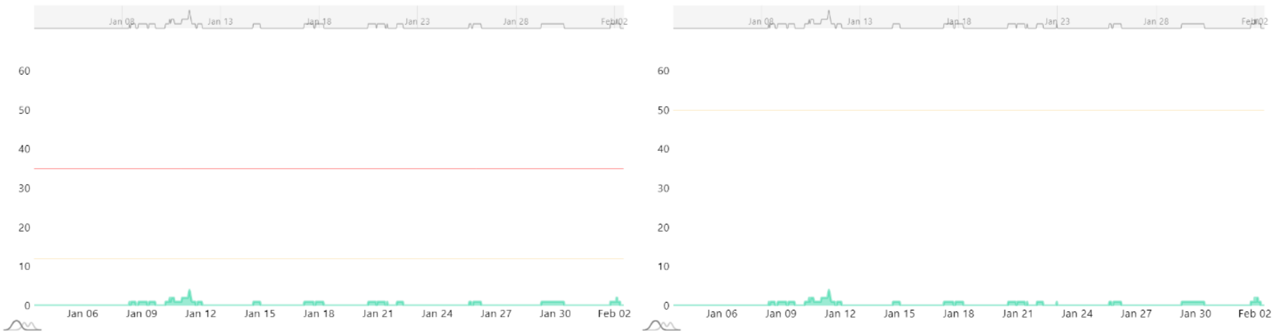


Figure 12. Snapshot of the graphical view of $PM_{2.5}$, $\mu m/m^3$, (left) and PM_{10}, $\mu m/m^3$, (right) registers of INBIOT sensors installed in one of the areas of the hospital in Rotterdam.

3.1.2 OAQ modelled data from AerisWeather

Although this data is being recorded, access to it is still unavailable due to permits that have not yet been signed.

3.1.3 VOCs sampling

The VOC sampling has not yet taken place but will take place in the second half of 2024.

3.1.4 Questionnaires

The baseline questionnaire has been distributed on paper because the JCA has not been signed yet and until that is the case the questionnaires cannot be distributed to the participants using REDCap.

Funded by the European Union

3.1.5 Conclusions

To summarize, the massive monitoring has started in the pulmonary department of EMC, but the VOCs sampling has not yet begun.

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

The general area of the senior homes contains usually a seating area with tables and some senior homes have an activity room attached or otherwise nearby. One common area is being monitored in one senior housing building until now. Delays are due to ethical approval and internal approval process within the housing corporation itself. The reasons for having only one area is because the housing corporation was replacing Wi-Fi routers in common area's or switching to different Internet providers.

3.2.1 IAQ Massive monitoring INBIOT sensors

As mentioned earlier, INBIOT sensors provide continuous monitoring of T, RH, tVOC, formaldehyde concentration and PM concentration (1, 2.5, 4 and 10 of particle size). Next, Figure 13, Figure 14, Figure 15, Figure 16 display a snapshot of the dashboard of the platform during a whole week, showing T, RH, CO_2, formaldehyde, TVOC, PM_1, $PM_{2.5}$ and PM_{10}.

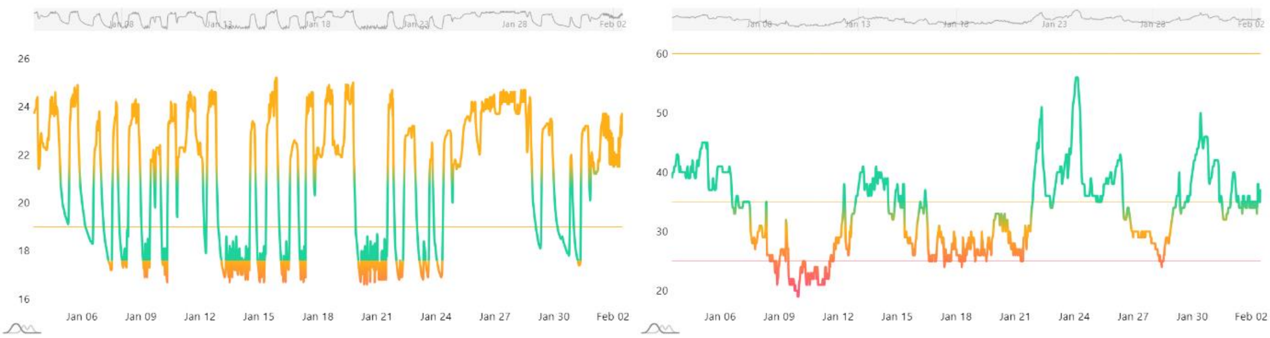


Figure 13. Snapshot of the graphical view of temperature, ºC, (left) and relative humidity, %, (right) registers of INBIOT sensors installed in the senior home in Rotterdam.

Figure 14. Snapshot of the graphical view of CO_2, ppm, (left) and formaldehyde, $\mu m/m^3$, (right) registers of INBIOT sensors installed in the senior home in Rotterdam.

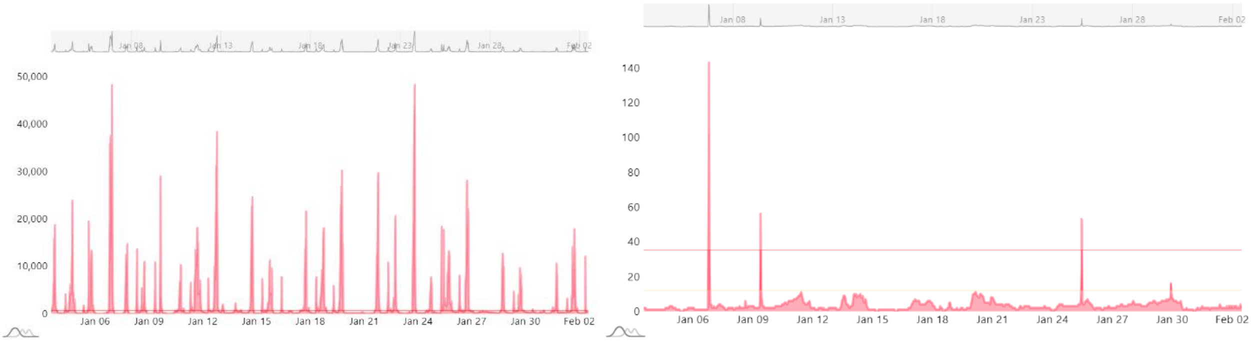


Figure 15. Snapshot of the graphical view of TVOC, ppb, (left) and PM_1, $\mu m/m^3$, (right) registers of INBIOT sensors installed in the senior home in Rotterdam.

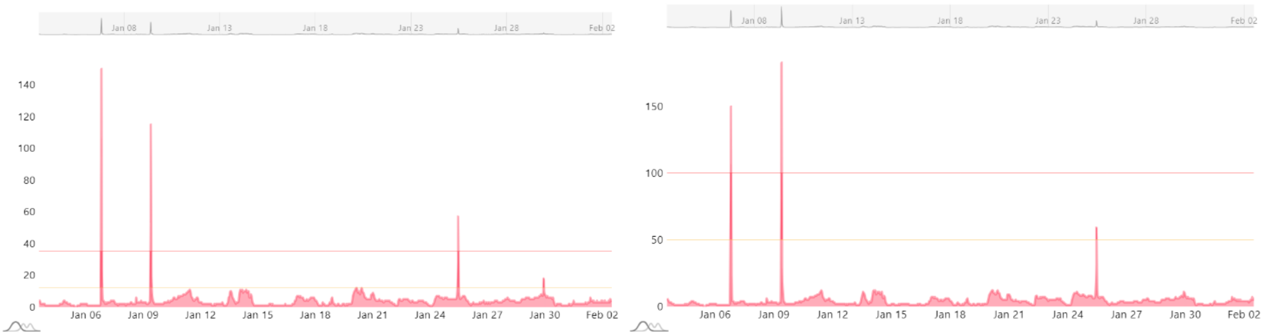


Figure 16. Snapshot of the graphical view of $PM_{2.5}$, $\mu m/m^3$, (left) and PM_{10}, $\mu m/m^3$, (right) registers of INBIOT sensors installed in the senior home in Rotterdam.

3.2.2 OAQ modelled data from AerisWeather

See Section 3.1.2 because the outdoor air is the same.

3.2.3 VOCs sampling

The VOC sampling has not yet taken place but will take place in the second half of 2024.

3.2.4 Questionnaires

The baseline questionnaire has been distributed on paper because the JCA has not been signed yet and until that is the case the questionnaires cannot be distributed to the participants using REDCap.

3.2.5 Conclusions

In conclusion, more effort must be made to install INBIOT sensors in the general areas of the retirement home after management has finalized their Wi-Fi availability. Talks with management have to be finalized to conduct PM and VOC sampling.

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

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

The IAQ monitoring has started as of January 2024. The recruitment numbers are increasing steadily sins the ethical committee has given their approval of an amendment of the original protocol and information letter. This amendment was necessary because, participant's data is being shared among partners (ATOS, INBIOT and IDIBAPS).

To cover the sharing a personal data a JCA has been drafted. Recruitment delays can be attributed to the JCA being drafted and has not been finalized yet.

D1.7 includes the recruitment process and plan to increase the visibility of the Rotterdam pilot study, thereby reaching more eligible participants.

3.3.1 IAQ Massive monitoring INBIOT sensors

Results of the IAQ sensors have not been aggregated yet and can therefore not be shown yet.

3.3.2 OAQ modelled data from AerisWeather

See Section 3.1.2 because the outdoor air is the same.

3.3.3 Portable monitoring tool

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

3.3.4 Questionnaires

The baseline questionnaires have been distributed to the first 11 (N=11) participants. The results have not been digitalized yet, therefore no graphs or other descriptive results can be shown. The baseline questionnaire has been distributed on paper because the JCA has not been signed yet and until that is the case the questionnaires cannot be distributed to the participants using REDCap.

3.3.5 Conclusions

To conclude, full focus will be on achieving the goal of including 110 participants in the pilot study. Later in 2024, 10 suitable participants will have been selected to implement the portable monitoring tool.

4 NORWAY PILOT #3 (NO)

Pilot #3 NO covers:

· The analysis of the IAQ and the evaluation of the impact of wood as indoor building material on health.

· Analysis of three relevant indoor settings located close to each other in Grimstad: canteen (UiA: CAN01, Fagskolen i Agder: 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) Jon Lilletuns vei and Tønnevoldsgate, 2 lecture hall at UiA campus Grimstad (LEC01 and LEC02).

· In addition, 50 students from UiA living in the students' residence but without IAQ monitoring will respond on questionnaires connected to the lecture hall scenario.

Table 12. Launching dates of the information sources for the Norway Pilot.

<table>
<tr><th></th><th>CANTEEN</th><th>STUDENTS RESIDENCE</th><th>LECTURE HALL</th><td rowspan="10"><u>PILOT COORDINATOR</u>:
UNIVERSITY OF AGDER

<u>OBJECTIVES</u>:
Pilot study focused on the identification of determinants in three different scenarios: CANTEEN, STUDENTS' RESIDENCE & LECTURE HALL and to study the impact of wood as indoor building materials on health.

<u>LOCATIONS</u>:
· Student canteen, UiA campus, Grimstad.
· Student canteen, Fagskolen i Agder, Grimstad.
· Student's residence, SiA, Grimstad.
· Lecture halls, UiA campus Grimstad.</td></tr>
<tr><td>VOCs & Chemicals</td><td colspan="3">April or September 2024[1]</td></tr>
<tr><td>Data Public health</td><td colspan="3">Pending[2]</td></tr>
<tr><td>Massive monitoring</td><td>18.10.2023
24.11.2023</td><td>Pending[1]</td><td>18.10.2023</td></tr>
<tr><td>Mental health and QoL</td><td colspan="3">Pending[1]</td></tr>
<tr><td>Sick building syndrome</td><td colspan="3">Pending[1]</td></tr>
<tr><td>Sleep and IAQ perception</td><td colspan="3">Pending[1]</td></tr>
<tr><td>Outdoor pollutants</td><td colspan="3">30.08.2023</td></tr>
<tr><td>Questionnaires</td><td colspan="3">Pending[1]</td></tr>
<tr><td>Other data</td><td colspan="3">Immediate processing</td></tr>
</table>

Pending[1] – late permission form the authority and reluctant respondents.

STUDIES PERIODS

Canteen: Autumn 2023 – March 2026. The launched of this scenario was done with the installation of the monitoring tools (18/10/2023 in the UiA's Canteen and 24/11/2023 in the Fagskolen I Agder's Canteen).

Residence: Feb 2024 – March 2026. The launched of this scenario will be done with the installation of the monitoring tools in the residence halls and the students' rooms, when 20 students accept installation of monitors in their home.

Lecture hall: October 2023 – March 2026. The launched of this scenario was done with the installation of the 2 monitoring tools (18/10/2023).

Funded by the European Union

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

The installation of monitors in the canteens took place after an initial testing in the climate lab at UiA. The location, power and Wi-Fi connections were discussed with building owners JB Ugland (University of Agder) and Agder county (Fagskolen i Agder). Especially access permission to the wi-fi was challenging to get. When the necessary clarifications were made, the installation was prompt executed. The data collection started immediately but after a software update (28th November), 2 out of 6 monitors at UiA and 1 out of 4 at Fagskolen did not give data. After several restarts by switch off and on fuses, only one at Fagskolen i Agder is missing today.

The development of the questionnaires was carried out with assistance from KVLOCE and discussions with the other pilots, especially the most similar one, the German. The complete set of questionnaires was necessary together with knowledge to the final selected method of data handling and treatment. After several rounds, the information letter for participants, questionnaires and protection of personal data were approved by SIKT (Norwegian Agency for Shared Services in Education and Research) (6th November 2023). The complete group of 8 canteen staff at UiA signed letter of consent the 27th November 2023 and the only available staff at Fagskolen signed at 31st January 2024. The maximum number in the canteen scenario is achieved with 9 staff. RedCAP is not started due to the delay in the recruitment of students.

The impact of wood as indoor building material on health is mainly covered by a K-HEALTHinAIR PhD project: Wood Surfaces and Their Influence on Indoor Air Quality and Health in Care Centres. However, the monitoring of CAN02 (Fagskolen i Agder) with a lot of wooden surfaces compared to CAN01 (UiA) with nearly no wooden surfaces imply the possibility for comparison of monitoring data.

4.1.1 IAQ Massive monitoring INBIOT sensors

INBIOT sensors provide continuous monitoring of T, RH, tVOC, formaldehyde concentration and PM concentration (1, 2.5, 4 and 10 of particle size). Next, Figure 17 shows a snapshot of the dashboard of the platform during 24 hours.

Figure 17. Snapshot of the graphical view of the registers of INBIOT sensors installed in canteens in Grimstad (generated with K-HEALTHinAIR platform).

4.1.2 IAQ Massive monitoring IoT fabrikken sensors

9 IoT fabrikken monitors have been installed with battery and SIM card measure T, RH, CO_2, TVOC, sound, light, presence. Figure 18 shows the sound measured in the combustion lab on a day with demonstration for 30 pupils. More graphs are shown in the residence hall paragraph as the IoT monitors will be used there from the beginning.

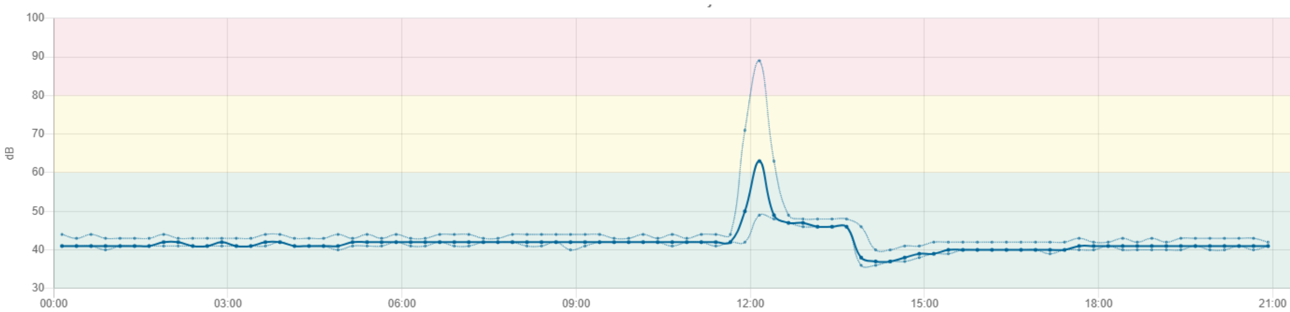


Figure 18. Snapshot of the graphical view of sound measured with IoT monitor 15th February 2024 in the UiA combustion in Grimstad (generated with IoT platform: roomalyzer.com).

4.1.3 OAQ modelled data from AerisWeather

In addition to “indoor” sources of information, another crucial aspect characterizing indoor air quality in the project involves considering the quality of outdoor air in the project's influence zones. Leveraging the AerisWeather platform, it modelled and reported data on temperature, relative humidity, and the concentrations of key pollutants in the area. This includes PM, NO_x, CO, and O_3 levels (Figure 19). By incorporating OAQ data into the analysis, it is aimed to contextualize indoor air conditions within the broader environmental context, providing a more holistic understanding of the factors influencing the air quality in the studied indoor environments.

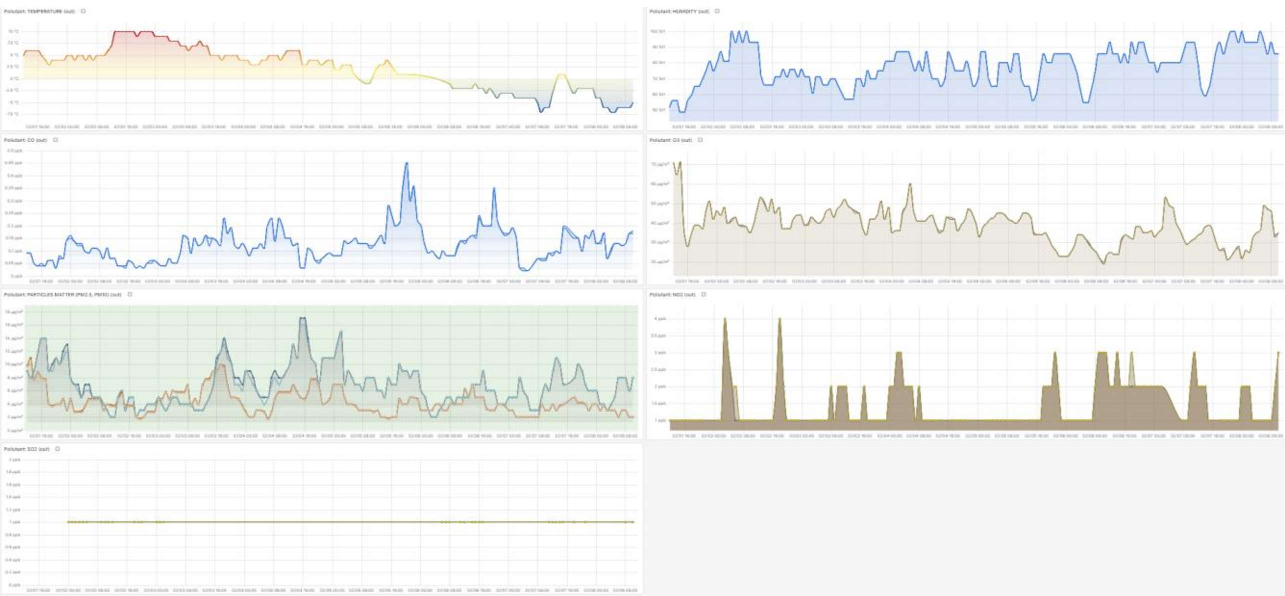


Figure 19. Snapshot graphical evolution of the outdoor air quality parameters included in the study in Grimstad (T, RH, CO, O_3, PM and NO_X concentrations) (generated with K-HEALTHinAIR platform).

Data from the locally outdoor air quality measurement station since it was put into service are shown in Table 13. The values show the outdoor air in Grimstad has low levels of pollution for the listed components.

Table 13. Outdoor pollution and temperature since 31st August 2023.

Parameter	Average	Maximum	Minimum
PM 2.5 [µg/m³]	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

For comparison, it is compared the data with the closest official governmental outdoor measurement station Bjørdalssletta, Kristiansand 40 km drive from Grimstad. This comparison is shown in Table 14, which shows the particle pollution in Grimstad is very low compared to Kristiansand, while the NO_2 level are more similar.

Table 14. 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). The precision of $PM_{2.5}$ measurement is ±5% & 5 µg/m³ for INBIOT.

Parameter	$PM_{2.5}$ (1h) [g/m³]		NO_2 (1h) [g/m³]	
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	-	-

The values for the pollutants VOC and formaldehyde are shown in Table 15 which shows clearly that the dominating source to VOC pollution has to be found indoor, where the values are quite even and more than hundred times the outdoor concentration. In general, the levels of VOC are lower at Fagskolen i Agder. This is most probably due to the operation of the ventilation. Fagskolen has constant normal ventilation Monday-Friday, and low ventilation during the weekend. UiA has normal ventilation level during workhours, and low-level evening and nights at workdays, and in the complete weekend. This will change the picture and means the students are exposed to lower levels of pollution in realty (see Table 16).

*Table 15. Measured values of VOC and formaldehyde 8th January 2023 – 28th January 2024. All data are from INBIOT monitors (*Outdoor: Only measurements from the last complete week 22-28 January).*

Parameter	VOC [ppb]		Formaldehyde [g/m³]	
Indoor	Average	Max	Average	Max
Canteen				
UiA 01 (Column glass)	387	28 – 14,901	3	0 - 24
UiA 04 (dividing half wall)	471	5 – 10,013	3	0 - 23
Fagskolen 01 (big area)	343	0 - 865	19	0 - 71
Fagskolen 02 (niche)	295	4 - 854	3	0 - 30
Lecture room				
UiA 01 (new)	702	7 - 3,049	2	1 - 18
UiA 02 (old)	454	8 - 9,441	1	0 - 6
Outdoor UiA	2*	0-6*	-	-

Table 16 shows the two pollutants have both substantial lower levels and maximum when the lecture rooms are occupied, compared to evening, nights, and weekends. The level of formaldehyde is in general very low while VOC sometimes are very high.

Table 16. Measured values in the complete three weeks 24/7, compared to workhours 8-16 five days a week for the same period 8 – 28 January 2024.

Parameter	VOC [ppb]				Formaldehyde [g/m³]			
Indoor	Average		Max		Average		Max	
Lecture rooms	24/7	WH	24/7	WH	24/7	WH	24/7	WH
UiA 01 (new)	702	209	3049	1274	2	1	18	10
UiA 02 (old)	454	241	9441	4206	1	0	6	1

In Table 17, the measured levels of CO_2 indicate a relatively high air exchange rate. The relative humidity level around 24% RH is very low and could be reflected in the questionnaires for students related to sick building syndrome, etc.

Table 17. Lecture rooms. Measured values for humidity and CO_2 in the complete three weeks 24/7, compared to workhours 8-16 five days a week for the same period 8th – 28th January 2024.

Parameter	Relative Humidity [%]				CO_2 [ppm]			
Indoor	Average		Max		Average		Max	
Lecture rooms	24/7	WH	24/7	WH	24/7	WH	24/7	WH
UiA 01 (new)	24.5	23.4	36	36	444	493	2267	841
UiA 02 (old)	26.0	24.9	41	37	442	485	982	982

4.1.4 OAQ Massive with Kunak AIR Lite

An air quality monitoring station was installed locally at UiA in August 2023 to measure VOC, NO_2, PM (1, 2.5, 10 μm), temperature and humidity. This local outdoor measurement station gives knowledge about the rate of indoor and outdoor pollutants in the indoor air. The closest measurement station is located next to the main highway in Kristiansand with a population of 66,576 (statistics Norway 2023) compared to 14,400 in Grimstad (Store norske leksikon). Figure 20 shows the development of temperature, $PM_{2.5}$, and VOC since the measurement station was put into service.

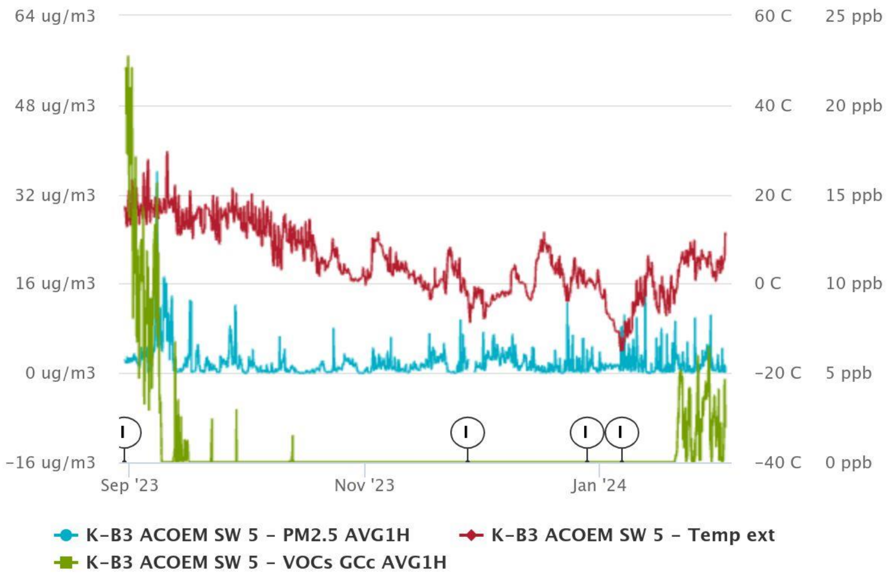


Figure 20. Graphical evolution of some of the outdoor air quality parameters measured locally at UiA in Grimstad including T, $PM_{2.5}$ and VOC concentrations with the Kunak AIR Lite station.

4.1.5 VOCs sampling

Pump (GilAir-Plus STP), test tubes (Tenax) and standard flow cell (Gilibrator-2) were in stock in 13rd December 2023. The sampling is pending due to the recruitment of students from residence halls is not finished. The sampling in all Norway scenarios should take place at the same time.

A manual for the sampling in Grimstad procedure was received from CIEMAT in April 2023.

4.1.6 Formaldehyde sampling

Pump (Gilian 800i), test tubes (DNPH) and standard flow cell (Gilibrator-2) were in stock 13rd December 2023. The sampling is pending due the recruitment of students from residence halls is not finished. The sampling in all Norway scenarios should take place the same time.

A manual for the sampling in Grimstad procedure was received from CIEMAT April 2023.

4.1.7 Questionnaires

The canteen staff will get the following questions including time in the scenario:

- QoL: EQ-5D-5L.
- Mental health: PHQ-9 normal version.

- Sick building syndrome: Headache, Dry eyes, running nose, Itching, and difficulties in concentration.
- Perception of IAQ: Kitchen, canteen and coffee shop.
- Sleep quality.

The participants have not got any questions yet due to delayed recruitment at Fagskolen i Agder and coordination with student's questionnaire.

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

Indoor air quality in the student's residence is a crucial aspect influencing the well-being of individuals and the overall environment within residential settings. The quality of indoor air plays a pivotal role in ensuring a healthy living space and minimizing potential health risks for residents. This scenario is relevant due to the high occupancy (single room apartments and bedsits) and a variety of potential sources for indoor pollutants. The scenario extensively monitors both indoor and outdoor air quality and through questionnaires uncover health effects among students in the project lifetime. Together with monitors in canteen and lecture halls a significant amount of the pollutants to which students are exposed to are mapped.

9 IoT fabrikken and 20 INBIOT monitors are going to be installed in single room bedsits and apartments belonging to The Student Association in Agder, SiA Housing and Student Service. The INBIOT and IoT fabrikken monitors have so far been tested in the climate laboratory at UiA.

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. These buildings have different age, with separate heating, HVAC systems. 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.

4.2.1 IAQ Massive monitoring INBIOT sensors

The mounting of the sensors is pending due to delayed recruitment of students (letter of consent for the questionnaire). As of 16st February 2024, 22 students have accepted the questionnaire and 13 of them also the monitors.

4.2.2 IAQ Massive monitoring IoT fabrikken sensors

The IoT fabrikken sensors provides continuous monitoring of T, RH, CO_2, TVOC, sound, light, and presence (Figure 21). They are not installed for the same reasons as INBIOT above.

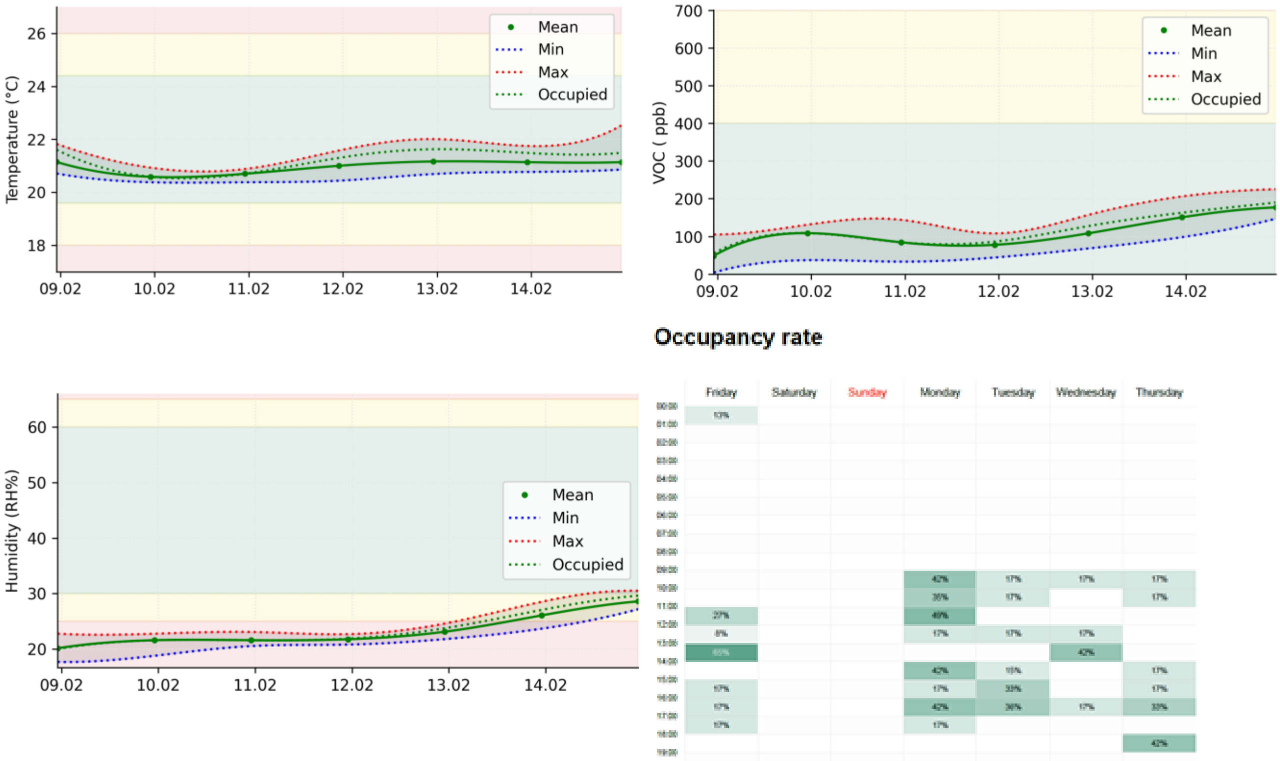


Figure 21. Graphical evolution of some of the indoor air quality parameters measured with IoT monitors for one week in February 2024 in an office at UiA in Grimstad (generated with IoT platform: roomalyzer.com).

See Section 4.1.3 above.

4.2.3 OAQ Massive with Kunak AIR Lite sensor

The air quality monitoring station was installed locally at UiA in August 2023 to measure VOC, NO_2, PM (1, 2.5, 10 μm), T and RH, see 4.1.4. An example of measurements from the Kunak platform is shown in Figure 22.

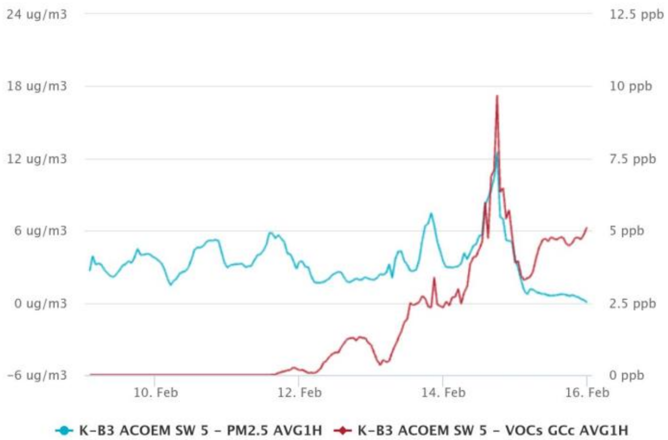


Figure 22. Graphical evolution of some of hourly average for $PM_{2.5}$ and VOC measured 9th – 16th February 2024 with the Kunak AIR Lite station in Grimstad.

4.2.4 VOCs sampling

The sampling is pending due to the recruitment of students from residence halls is not finished.

A manual for the sampling in Grimstad procedure was received from CIEMAT in April 2023.

4.2.5 Formaldehyde sampling

The sampling is pending due the recruitment of students from residence halls is not finished.

A manual for the sampling in Grimstad procedure was received from CIEMAT in April 2023.

4.2.6 Questionnaires

The residence hall students with monitors will get the following questions including time in the scenario:

- QoL: EQ-5D-Y.
- Mental health: PHQ-9 adapted version for young people.
- Sick building syndrome: Headache, Dry eyes, running nose, Itching, and difficulties in concentration.
- Perception of IAQ: Home.
- Sleep quality (Noise is one of the options as reason for poor sleep quality).

The participants have not got any questions yet due to delayed recruitment. This will be finalized in February 2024.

4.3 Lecture hall scenario (NO-LEC01)

Characterize deeply IAQ in the lecture hall of UiA Jon Lilletuns vei 9 (LEC01 and LEC02). The lecture halls are located in two different part LEC01 is from 2010 and LEC02 is from 1982 and renovated in 2010.

In order to cover 24 hours per day of student's life, sensors are placed in the most used lecture rooms by the students from the residence halls.

4.3.1 IAQ Massive monitoring INBIOT sensors

Figure 23. Snapshot of the graphical view of the registers of INBIOT sensors installed in one of the areas of lecture halls in Grimstad (generated with K-HEALTHinAIR platform).

INBIOT sensors provide continuous monitoring of T, RH, tVOC, formaldehyde concentration and PM (1, 2.5, 4 and 10 of particle size). Next, Figure 23 shows a snapshot of the dashboard of the platform during 24 hours.

4.3.2 IAQ Massive monitoring IoT fabrikken sensors

The IoT monitors were used in residence halls from the beginning.

4.3.3 OAQ modelled data from AerisWeather

See Section 4.1.3 above.

4.3.4 OAQ Massive with Kunak AIR Lite sensor

See Sections 4.1.4 and 4.2.4.

4.3.5 VOCs sampling

The sampling is pending due to the recruitment of students from residence halls is not finished. The sampling in all Norway scenarios should take place the same time.

A manual for the sampling in Grimstad procedure was received from CIEMAT April 2023.

4.3.6 Formaldehyde sampling

The sampling is pending due to the recruitment of students from residence halls is not finished. The sampling in all Norway scenarios should take place the same time.

A manual for the sampling in Grimstad procedure was received from CIEMAT in April 2023.

4.3.7 Questionnaires

The residence hall students without monitors will get the following questions including time in the scenario lecture halls:

- QoL: EQ-5D-Y.
- Mental health: PHQ-9 adapted version for young people.
- Sick building syndrome: Headache, Dry eyes, running nose, Itching, and difficulties in concentration.
- Perception of IAQ: Home.
- Sleep quality (Noise is one of the options as reason for poor sleep quality).

The participants have not got any questions yet due to delayed recruitment. This will be finalized in February. The aim is to recruit 50 students for the lecture hall scenario.

4.4 Conclusions

The monitoring is running satisfactorily for outdoor air quality and indoor air quality in canteens and lecture halls.

The mounting of 20 monitors in the residence halls are lacking behind due to late approval of the data protection related to the questionnaires and recruitment of students. The actions carried out are to give a gift card and direct personal contact to potential respondents. This will hopefully also give 50 students for the questionnaire in the lecture hall scenario.

The recruitment of canteen staff is 100% of the present potential number of respondents.

Knowledge to the use of rooms and ventilation setting as especially VOC concentrations are very high when the rooms are not used.

The sampling with pumps of VOC's and formaldehyde will take place when the 20 students are recruited. The measurement procedure is described.

A deeper analysis of the monitor data is planned and includes a comparison of the data for OAQ from Kunak, AerisWeather and nearest governmental measurement station.

Funded by the European Union

5 GERMANY PILOT #4 (DE)

Pilot #4 DE covers:

- The analysis of two relevant indoor settings: 2 canteen areas scenario (Ludwigsburg Canteen (CAN01) and Ludwigsburg Bistro (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.

Table 18. Launching dates of the information sources for the Germany Pilot.

	CANTEEN	LECTURE HALL
VOCs & Chemicals	Jul 2023 & Jan 2024	
PMs	Jul 2023 & Jan 2024	
Microbiome	Jul 2023 & Jan 2024	
Massive monitoring	5th Apr 23	12th Jun 23
Sick building syndrome questionnaire	July 2023	Pending[1]
Subjective IAQ perception questionnaire	July 2023	Pending[1]
Other data (e.g. HVAC, air purifier)	June 2023	

PILOT COORDINATOR:
MANN + HUMMEL / i2M

OBJECTIVES:
Pilot study focused on the identification of determinants in two different scenarios: CANTEEN and LECTURE HALL.

LOCATIONS:
· Workers canteen at MANN+HUMMEL GmbH, Ludwigsburg, Germany.
· Lecture Halls at TUM Campus Heilbronn, Germany.

Pending[1] – Recruitment of students not successful and acceptance of questionnaire.

STUDIES PERIODS

Canteen: April 2023 – February 2026. The launched of this scenario was done with the installation of the monitoring tools (05/04/23).

Lecture hall: June 2023 – February 2026. The launched of this scenario was done with the installation of the monitoring tools (12/06/23).

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

In consultation with MANN+HUMMEL's IT department and the real estate team, the installation of sensors commenced in March 2023 as part of our indoor air quality monitoring initiative. While the installation progressed, minor delays were encountered during the onboarding process of the Kaiterra Sensedge Mini devices to the local Wi-Fi network, primarily due to cyber security concerns. These challenges were promptly addressed through collaboration with relevant stakeholders to ensure a secure and seamless integration.

Furthermore, the development of questionnaires, a critical component of our data collection strategy, was undertaken in collaboration with KVELOCE and other pilot locations. This collaborative effort aimed to tailor the questionnaires to the specific needs of our monitoring initiative. However, significant challenges emerged during this process, particularly concerning the willingness of the canteen team to agree with the questionnaires and ensuring GDPR compliance.

To navigate these challenges effectively, extensive collaboration took place with MANN+HUMMEL's Corporate Data Protection Officer, ensuring that all aspects of the questionnaire development and distribution adhered to GDPR regulations. Additionally, in order to secure participation from the canteen team, adjustments were made to the questionnaire content. Specifically, the original mental health and well-being questionnaires were substituted with inquiries focused on "sick-building syndrome" (SBS), aligning with the interests and concerns of the canteen team.

Throughout the continuous monitoring period, which began on April 5th, 2023, a thorough assessment of indoor air quality parameters has been conducted, including temperature, relative humidity, CO_2 levels, $PM_{2.5}$ and PM_{10} concentrations, and tVOC. Additionally, chemical sampling events were carried out in July 2023 and January 2024 to analyse indoor pollutants such as particulate matter (PM), volatile organic compounds (VOCs), and microbiome composition, enhancing our understanding of indoor environmental quality.

Despite the overall success of the monitoring process, challenges arose regarding participant identification, impacting the distribution and analysis of questionnaires. Specifically, personnel in the canteen lost their participant IDs, hindering the matching of questionnaires within the RedCAP system. This issue disrupted the seamless integration of questionnaire responses with other monitored data, potentially affecting the accuracy and comprehensiveness of our analyses.

In response to these identification challenges, a tailored contingency plan was devised, involving additional meetings and the implementation of alternative solutions to safeguard participant IDs in accordance with GDPR regulations. However, the effectiveness of these measures remains to be fully evaluated during subsequent questionnaire distributions.

5.1.1 IAQ Massive monitoring M+H sensors

Indoor air quality in canteen is significant due to the elevated occupancy levels, particularly during lunchtime and breaks. There exists a considerable variability in noise and potential sources of VOCs and particles, stemming from activities like waste disposal, cooking, specialty coffee preparation, and the self-serving area, coupled with external air intake.

The primary objective of this study is to identify and delineate the key compounds or parameters, the determinants, within indoor air that have the potential to impact human health within the complex array of contaminants present in any enclosed environment. By scrutinizing factors such as PM, VOCs, humidity levels, and microbial content, it is aimed to establish a comprehensive understanding of the specific components that may contribute to health concerns in the settings selected by K-HEALTHinAIR. This focused analysis will pave the way for targeted interventions and strategies to enhance air quality, promoting a healthier environment for both patients and healthcare professionals.

M+H sensors provides continuous monitoring of temperature, relative humidity, tVOC and PM concentration (1, 2.5 and 10 of particle size). Next, Figure 24 shows a snapshot of the dashboard of the K-HiA platform during 24 hours.

Figure 24. Snapshot of the graphical view of the registers of M+H sensors installed in one of the areas of the canteen in Ludwigsburg (generated with K-HEALTHinAIR platform).

5.1.2 OAQ modelled data from AerisWeather

In addition to “indoor” sources of information, another crucial aspect characterizing indoor air quality in the K-HiA project involves considering the quality of outdoor air in the project's influence zones. Leveraging the AerisWeather platform, it is modelled and reported data on temperature, relative humidity, and the concentrations of key pollutants in the area. This includes PM, NO_x, CO, and O_3 levels. By incorporating outdoor air quality data into the analysis, it is aimed to contextualize indoor air conditions within the broader environmental context, providing a more holistic understanding of the factors influencing the air quality in the studied indoor environments. Figure 25 shows a snapshot of the graphical view of the OAQ registers over time in the K-HiA platform.

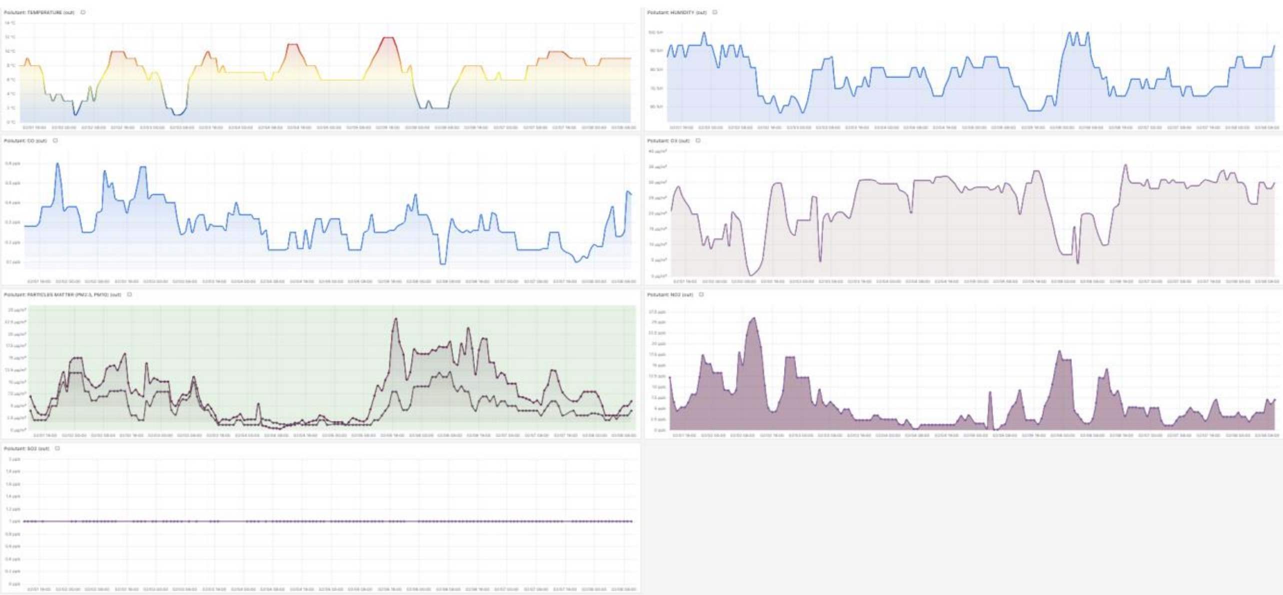


Figure 25. Snapshot graphical evolution of the OAQ parameters included in the study (T, RH, CO, O_3, PM and NO_X concentrations) in the canteen in Ludwigsburg (generated with K-HEALTHinAIR platform).

5.1.3 VOCs sampling

Indoor air samples for the determination of VOCs and aldehydes were collected in July 2023 and January 2024. Samples were collected using silica gel test 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), 2-butanone (2-BUT), methacrolein, butyraldehyde (BUTYR), benzaldehyde (BENZ), valeraldehyde (VALER), toluylaldehyde and hexaldehyde (HEX) were determined by the HPLC-UV method. The results of the analysis for the canteen scenario are presented in Figure 26.

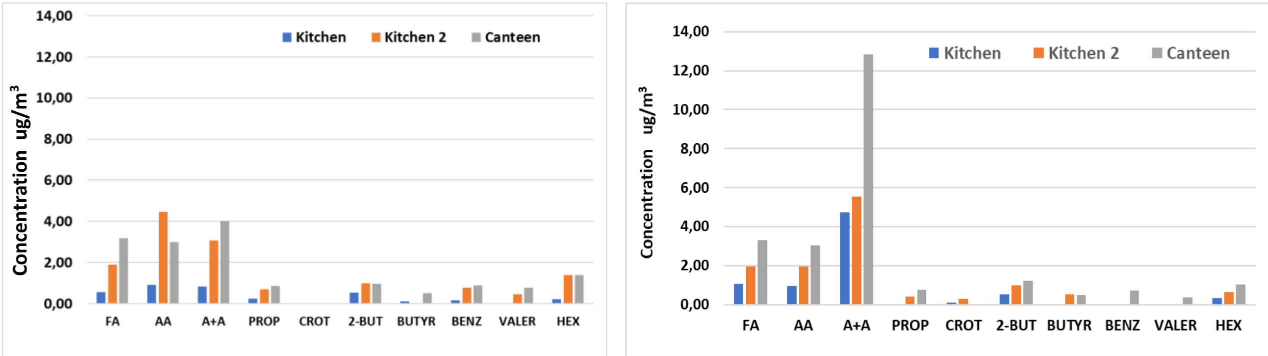


Figure 26. Concentration of FA, AA, A+A, PROP, CROT, 2-BUT, BUTYR, BENZ, VALER and HEX in indoor air samples collected in the canteen in Ludwigsburg. Left: July 2023. Right: January 2024.

5.1.4 PM sampling

The results of PAHs analyses for kitchen, canteen and bistro are presented in Figure 27. The results include only the first series of measurement, i.e. from July 2023. The samples from January 2024 are still in the process of assessment.

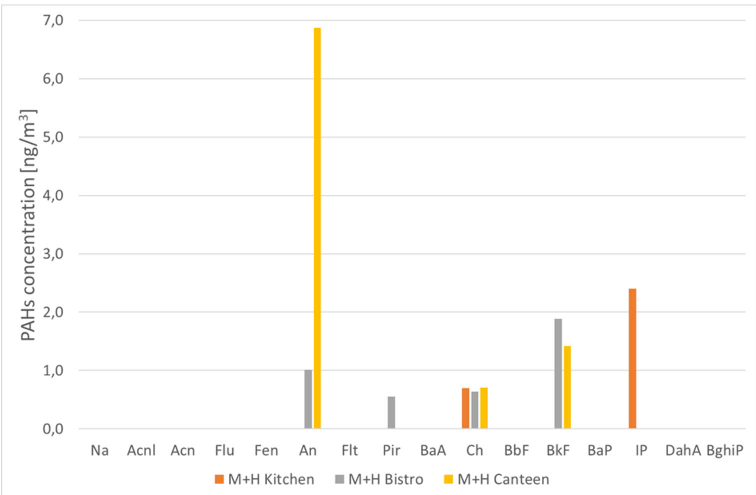


Figure 27. Concentrations of PM_4-bound PAHs in kitchen, canteen and bistro in MANN+HUMMEL headquarter in Ludwigsburg measured in July 2023.

Respirable particles (PM_4) samples were collected in kitchen, canteen and bistro in July 2023 and January 2024. GilAirPlus aspirators, produced by Gilian (USA) were used to collect the samples on quartz filters with a diameter of 25 mm. The PM_4 samples were then used for the assessment of polycyclic aromatic hydrocarbons (PAHs) concentrations using gas chromatograph with a flame ionization detector (FID). The following 16 standard PAHs were determined: naphthalene (Na), acenaphthylene (Acnl), acenaphthene (Acn), fluorene (Flu), phenantrene (Fen), anthracene (An), fluoranthene (Flt), pyrene (Pir), benzo(a)anthracene (BaA), chrysene (Ch), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), benzo(a)pyrene (BaP), indeno(1,2,3-cd)pyrene (IP), dibenzo(ah)anthracene (DahA), and benzo(ghi)perylene (BghiP).

The IAQ in canteen, kitchen and bistro 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 quantified at all (concentrations were below the limit of quantification). From the group of most hazardous PAHs, only indenopyrene was detected in kitchen, 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 a more extended period of analysis, far-reaching conclusions are expected to be drawn.

5.1.5 Microbiome sampling

Two techniques are used for sampling airborne microorganisms:

- A culture-dependent method using standard impactors: MAS-100 Eco® (Merck Millipore) and SAS Super IAQ (VWR®) microbial air samplers with subsequent incubation at relevant temperatures to grow bacteria and fungi (quantitative analysis),
- A culture-independent method using Coriolis micro samplers based on the impingement into sterile phosphate buffer saline and subsequent amplicon metagenomic sequencing to examine airborne microbial community structure (qualitative analysis).

To examine the effect of outdoor temperature on dominant airborne microorganisms in indoor air, microbiome sampling is carried out in 2 seasons:

- cold (heating) season (late autumn/winter),
- hot season (late spring/summer).

In order to limit the negative impact of high variability in the number of microorganisms in the air on the final result, 10 replicates are collected at each point using impactors, according to the protocol presented in Annex 1 of D1.1 Coordination program for pilots. Results are presented in tables showing mean, minimum (min) and maximum (max) values, standard deviation (SD) and standard error (SE) (see Figure 28 for details). Then average values for different sampling points are then analysed and compared using descriptive statistics and graphs (Figure 29).

Figure 28 below shows a snapshot of the datasheet containing results obtained by the culture-dependent method for area 002 in canteen 02 on June the 13th, 2023: 10 replicates for bacteria and fungi with descriptive statistics: mean, minimum (min) and maximum (max) values, standard deviation (SD) and standard error (SE).

	bacteria 37°C				moulds 20°C			
replicate	sampling time	sample volume [dm^3]	CFU	CFU/m^3	sampling time	sample volume [dm^3]	CFU	CFU/m^3
1	12:15	25	5	200	12:15	25	6	240
2	12:14	25	4	160	12:14	25	5	200
3	12:13	25	15	600	12:10	50	8	160
4	12:12	25	5	200	12:09	50	8	160
5	12:11	50	10	200	12:08	50	19	380
6	12:08	50	10	200	12:07	50	11	220
7	12:06	50	5	100	12:02	250	72	288
8	12:05	50	14	280	11:59	250	79	316
9	11:56	250	52	208	11:53	250	77	308
10	11:45	250	51	204	11:45	250	57	228
n				10				10
min				100				160
max				600				380
mean				235				250
SD				136				72
SE				43				23

Figure 28. Snapshot of the datasheet with results obtained by the culture-dependent method for area 002 in canteen 02 in Ludwigsburg on June the 13th, 2023, starting sampling time 11:45 (file DECAN02002MCC2023-06-13-1145). 10 replicates for bacteria and fungi are shown with descriptive statistics: mean, minimum (min) and maximum (max) values, standard deviation (SD) and standard error (SE).

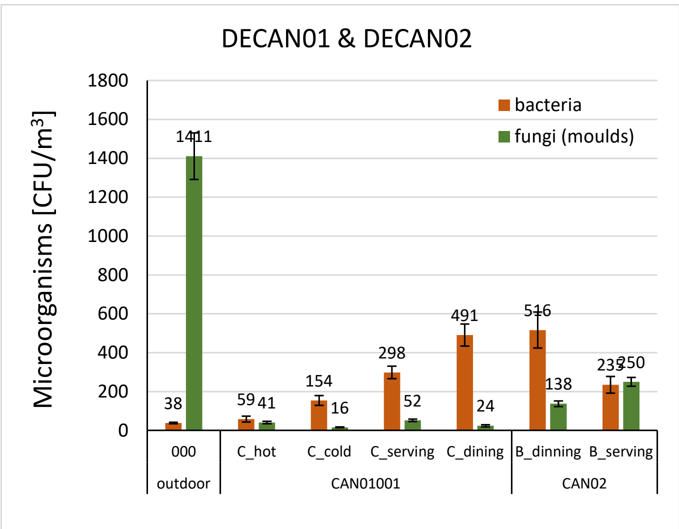


Figure 29. Example of chart comparing level of microbial contamination in outdoor and indoor air in the canteens in Ludwigsburg (various areas in CAN01 and CAN02). Results obtained by the culture-dependent method on June the 13th, 2023. 10 replicates were used to calculate mean values, error bars show standard error (SE).

However, it is essential to note that the samples collected by the impingement method are currently undergoing the sequencing process at an external laboratory. The sequencing step is a crucial phase in obtaining comprehensive microbiome data, and while it is ongoing, the complete assessment of biological pollutants is yet to be finalized.

5.1.6 Questionnaires

The questionnaire (Figure 30) was designed to encompass an assessment for symptoms associated with sick building syndrome (SBS). As part of a cohort study involving 10-12 kitchen staff members, participants were provided with paper questionnaires, each containing a unique ID for accessibility purposes. Subsequently, the responses were manually transcribed into the REDCap database for further analysis and integration with other monitored data sets.

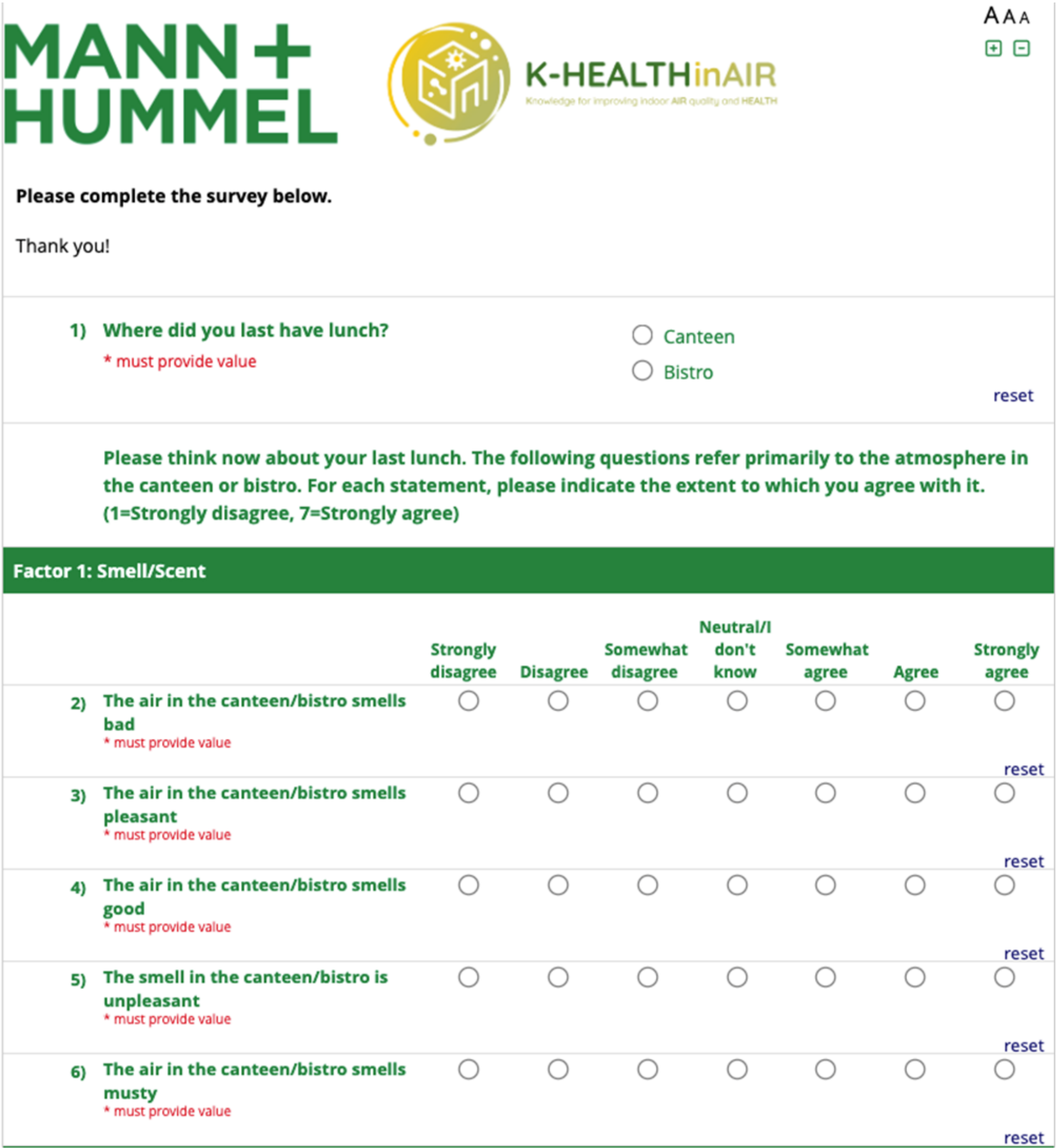
Matrix group: symptoms

Past and current diseases or symptoms - Did you have any of the following symptoms in the last week?

	Yes, often (every day)	Yes, sometimes	No, never	If yes, do you belive this is attributable to your work environment? - Yes	If yes, do you belive this is attributable to your work environment? - No	If yes, do you belive this is attributable to your work environment? - I don't know
Variable: fatigue **Fatigue**	☐	☐	☐	☐	☐	☐
Variable: headache **Headaches**	☐	☐	☐	☐	☐	☐
Variable: nausea **Nausea/Dizziness**	☐	☐	☐	☐	☐	☐
Variable: concentration **Difficulty concentrating**	☐	☐	☐	☐	☐	☐
Variable: itchy_eyes **Itching, burning, or irritation of the eyes**	☐	☐	☐	☐	☐	☐
Variable: running_nose **Irritated, congested, or runny nose**	☐	☐	☐	☐	☐	☐
Variable: dry_throat **Hoarse, dry throat**	☐	☐	☐	☐	☐	☐
Variable: cough **Coughing**	☐	☐	☐	☐	☐	☐
Variable: facial_skin **Dry or reddened facial skin**	☐	☐	☐	☐	☐	☐
Variable: itchy_ears **Flaky/itchy scalp or ears**	☐	☐	☐	☐	☐	☐
Variable: dry_skin **Dry hands, itching, reddened skin**	☐	☐	☐	☐	☐	☐

Figure 30. Snapshot of questionnaire for canteen staff in Ludwigsburg.

The survey (Figure 31), crafted in collaboration with the University of St. Gallen, was designed to assess subjective perceptions of air quality, considering various influencing factors. Employing contemporary digital methods, the survey was distributed through accessible means such as links or QR codes. Notably, it was made available to participants during an internal fair hosted at the MANN+HUMMEL headquarters, ensuring widespread engagement and data collection.


MANN+HUMMEL

K-HEALTHinAIR

Knowledge for improving indoor AIR quality and HEALTH

AAA

Please complete the survey below.

Thank you!

1) Where did you last have lunch?
* must provide value

- Canteen
- Bistro

reset

Please think now about your last lunch. The following questions refer primarily to the atmosphere in the canteen or bistro. For each statement, please indicate the extent to which you agree with it. (1=Strongly disagree, 7=Strongly agree)

Factor 1: Smell/Scent

	Strongly disagree	Disagree	Somewhat disagree	Neutral/I don't know	Somewhat agree	Agree	Strongly agree
2) The air in the canteen/bistro smells bad * must provide value	○	○	○	○	○	○	○
3) The air in the canteen/bistro smells pleasant * must provide value	○	○	○	○	○	○	○
4) The air in the canteen/bistro smells good * must provide value	○	○	○	○	○	○	○
5) The smell in the canteen/bistro is unpleasant * must provide value	○	○	○	○	○	○	○
6) The air in the canteen/bistro smells musty * must provide value	○	○	○	○	○	○	○

reset

Figure 31. Snapshot of survey for canteen visitors in Ludwigsburg.

5.1.7 Conclusions

The monitoring campaign is proceeding smoothly, with the main risk being potential network errors. To mitigate this risk, notifications to prompt timely resolution have been implemented. The adaptation of questionnaires has been successful, and no foreseeable risks are anticipated if participant IDs are remembered. Analysis of chemical sampling data regarding VOCs, PM, and microbiome has not revealed any concerning indications. Further analysis will be conducted to determine appropriate steps for implementing improvement measures.

5.2 Lecture hall scenario (DE-LEC01)

The installation of air quality monitoring devices presented unexpected difficulties, especially within the lecture halls of the newly constructed Bildungscampus in Heilbronn. Due to the specific structural requirements of the facility, implementing the desired wall installation for the devices demanded a bespoke wooden construction, skilfully crafted by a contracted carpenter. Coordination challenges arose due to the availability of all stakeholders, leading to delays in the process. However, with invaluable support from the IT department, the devices were efficiently onboarded to the local network, guaranteeing their seamless integration.

The monitoring initiative commenced on June 12th, 2023, aiming to evaluate indoor air quality parameters crucial for maintaining a healthy environment. These analyses provided valuable insights into indoor air quality dynamics, encompassing parameters such as temperature, relative humidity, CO_2 levels, $PM_{2.5}$ and PM_{10} concentrations, and TVOC.

Additionally, chemical sampling events were carried out in July 2023 and January 2024 to analyse indoor pollutants such as PM, VOCs, and microbiome composition. These efforts served to enhance our understanding of indoor environmental quality, shedding light on the composition and potential sources of indoor pollutants within the monitored environment.

Despite encountering minor connectivity issues in July leading to a slight data loss, our monitoring operations have largely proceeded smoothly, facilitating the collection of robust indoor air quality data. However, a notable deviation from our original plan pertains to the distribution of surveys, which has yet to be executed due to difficulties accessing students. Recognizing the pivotal role of student participation, a contingency plan has been developed aimed at directly engaging students. This plan may include strategies such as increasing our presence during lectures and hiring selected working students from the university. The effectiveness of these strategies will be assessed in subsequent phases of our monitoring process.

Characterize deeply IAQ in a lecture hall (LEC01) at TUM Campus Heilbronn. Number of participants: students may complete questionnaires anonymously, but there will be no individual monitoring; only aggregated data will be collected.

5.2.1 IAQ Massive monitoring M+H sensors

As mentioned earlier, M+H sensors provides continuous monitoring of T, RH, tVOC, formaldehyde concentration and PM concentration (1, 2.5, 4 and 10 of particle size). Next, Figure 32 shows a snapshot of the dashboard of the platform during a whole week.

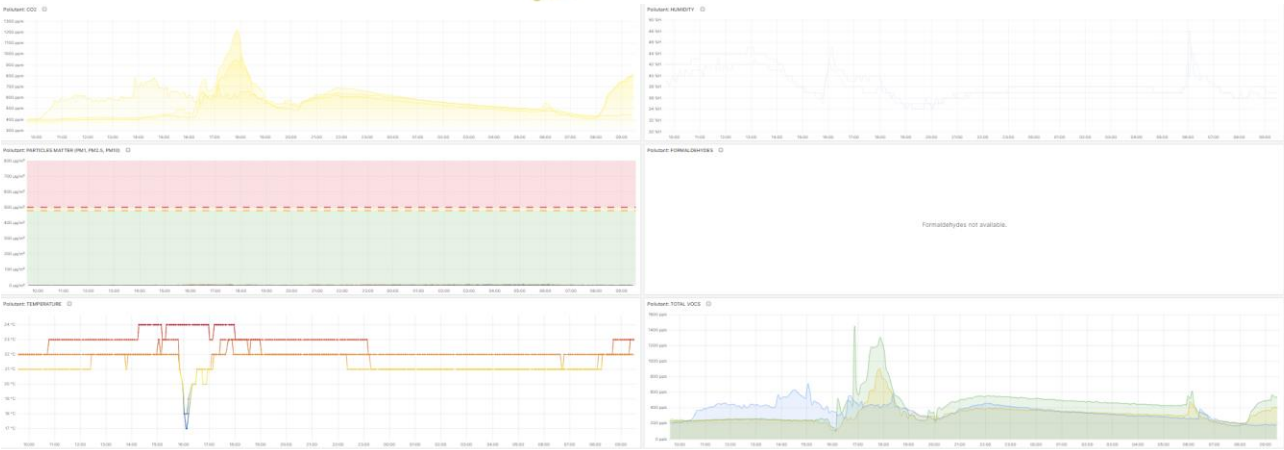


Figure 32. Snapshot of the graphical view of the registers of M+H sensors installed in one of the areas of lecture hall in Heilbronn (generated with K-HEALTHinAIR platform).

5.2.2 OAQ modelled data from AerisWeather

As previously stated, outdoor pollution influences indoor pollution. Figure 33 displays a screenshot of the platform dashboard featuring the parameters of temperature, humidity, CO, O_3, PM and NO_x.

Figure 33. Snapshot graphical evolution of the outdoor air quality parameters included in the study in Heilbronn (T, RH, CO, O_3, PM and NO_X concentrations) (generated with K-HEALTHinAIR platform).

5.2.3 VOCs sampling

Indoor air samples for the determination of VOCs and aldehydes 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.

Results of HPLC analysis performed for lecture hall scenario during summer and winter session are presented in Figure 34.

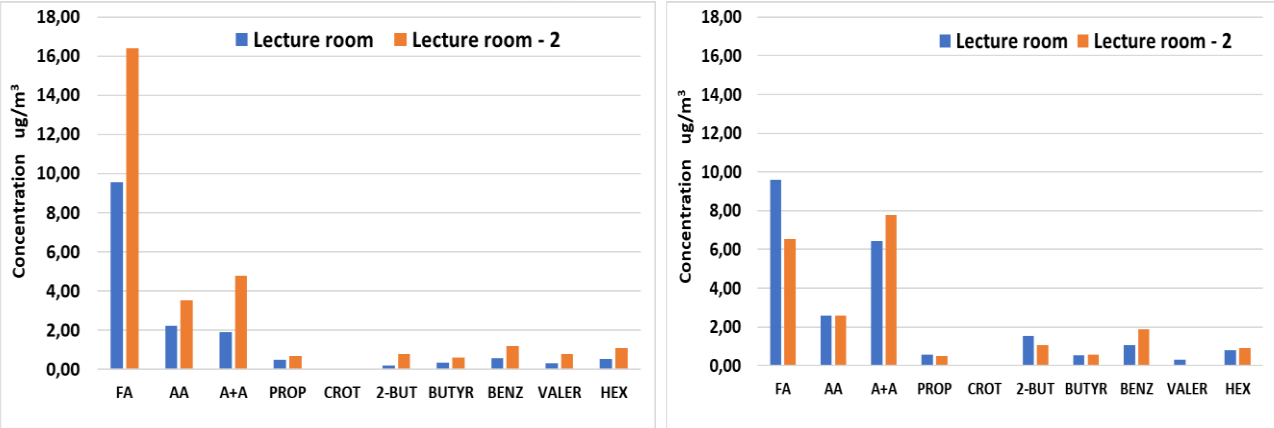


Figure 34. Concentration of FA, AA, A+A, PROP, CROT, 2-BUT, BUTYR, BENZ, VALER and HEX in indoor air samples collected in the lecture hall in Heilbronn. Left: July 2023. Right: January 2024.

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 35 presents the results of PAHs analyses in the lecture halls.

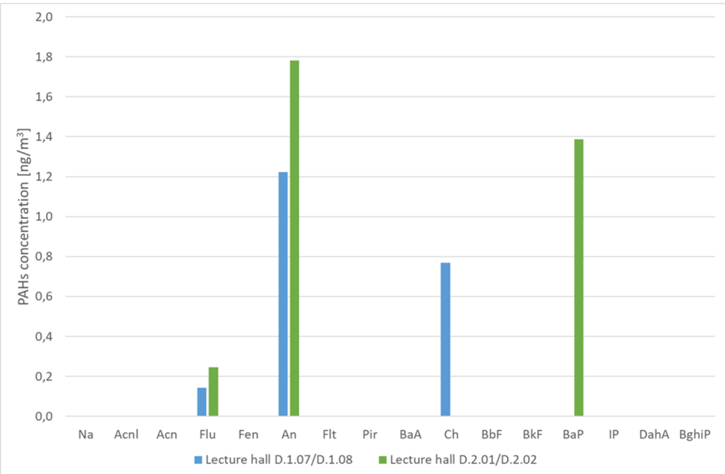


Figure 35. Concentrations of PM4-bound PAHs in 2 lecture halls located in the university buildings in TUM Campus Heilbronn measured in July 2023.

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

Figure 36 shows a snapshot of the datasheet containing results obtained by the culture-dependent method for area 003 in lecture hall 01 on June the 13th, 2023: 10 replicates for bacteria and fungi are presented, the mean values for different sampling points are then analysed and compared using descriptive statistics and graphs (Figure 37).

	bacteria 37°C				moulds 20°C			
replicate	sampling time	sample volume [dm³]	CFU	CFU/m³	sampling time	sample volume [dm³]	CFU	CFU/m³
1	14:09	25	16	640	14:08	25	25	1000
2	14:09	25	12	480	14:07	25	34	1360
3	14:08	25	17	680	14:07	50	39	780
4	14:07	25	5	200	14:06	50	31	620
5	14:07	50	28	560	14:05	50	43	860
6	14:06	50	18	360	14:04	50	35	700
7	14:05	50	26	520	14:01	250	175	700
8	14:04	50	19	380	14:01	250	178	712
9	13:56	250	226	904	13:59	250	158	632
10	13:56	250	141	564	13:59	250	201	804
n				10				10
min				200				620
max				904				1360
mean				529				817
SD				194				222
SE				61				70

Figure 36. Snapshot of the datasheet with results obtained by the culture-dependent method for area 003 in lecture hall 01 in Heilbronn on June the 13th, 2023, starting sampling time 13:56 (file DELEC01003MCC2023-06-13-1356): 10 replicates for bacteria and fungi are shown with descriptive statistics: mean, minimum (min) and maximum (max) values, standard deviation (SD) and standard error (SE).

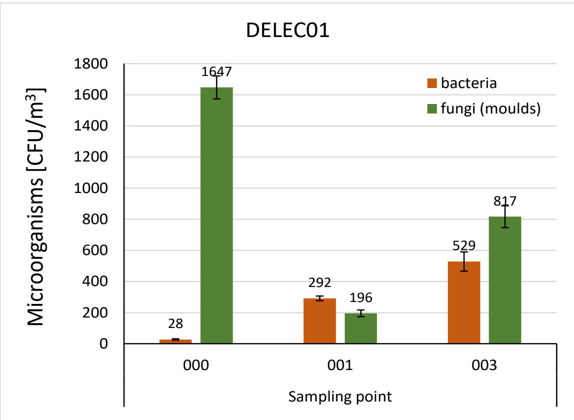


Figure 37. Example of chart comparing level of microbial contamination in outdoor and indoor air (lecture hall, various areas in LEC01 in Heilbronn). Results obtained by the culture-dependent method on June the 13th, 2023. 10 replicates were used to calculate mean values, error bars show standard error (SE).

As it has already been mentioned above, the samples collected by the impingement method are currently undergoing the sequencing process and the complete assessment of biological pollutants is yet to be finalized.

5.2.6 Questionnaires

The project initially targeted students as the primary target group. However, it was recognized that monitoring students throughout the entire project duration was not feasible. This challenge was compounded by the limited exposure time of students in the two targeted lecture halls, potentially as low as two hours per week, making it difficult to establish correlations between environmental factors and health impacts. To address these constraints, the research team transitioned from personal questionnaires to survey-based assessments. Currently, 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

The data collection process is proceeding without major issues, although network errors remain a potential risk. Efforts to minimize this risk include implementing notifications for prompt resolution. Meanwhile, adaptation of the questionnaires is underway, with plans for testing among a select group of pilot students. Evaluation of this testing phase will inform the broader rollout of the adapted questionnaires. Analysis of available chemical sampling data, including VOCs, PM, and microbiome, has not raised any red flags. Further examination of the data will guide the identification and implementation of improvement measures.

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

Pilot #5 PL/AT covers:

· Analysis of two relevant indoor settings: homes (HOM01-HOM05) and schools (SCH01-SCH22).

· 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.

Table 19. Launching dates of the information sources for the Poland/Austria Pilot.

	HOME PL	HOME AT	SCHOOL PL	SCHOOL AT	PILOT COORDINATOR: NOFER INSTITUTE OBJECTIVES: Pilot study focused on the identification of determinants in two different scenarios: HOME and SCHOOL. LOCATIONS: · Lodz. · Warsaw and surrounding area. · Vienna and surrounding area.
Biological monitoring – urine PAHs metabolites	Not started, the first round is planned for November 2024	Not planned	Not planned	Not planned	
VOCs & Chemicals	January 2024	February 2024	January 2024	January 2024	
PMs / PAHs	June 2023 and December 2023	June 2024	January 2024	Not planned	
Microbiome	May 2023	June 2024	Not planned	Not planned	
Radon	The measurements will start in April 2024	Not planned	The measurements will start in April 2024	Not planned	
Massive monitoring	March 2023	October 2023	July 2023	March 2023	
Spirometry and questionnaires schools in Austria	November 2024	January 2024	February 2024	Not planned	
Mental health and QoL	17th January 2024	February 2024	April 2024	March 2023	

Funded by the European Union

STUDIES PERIODS

Homes: July 2023 – February 2026. Recruitment of participants was initiated on late March 2023 and completed in December 2023. The follow-up will last until February 2026.

Schools: June 2023 – February 2026. The recruitment of participants in secondary schools was finalized in Lodz in January-February 2024 and is under way in Warsaw.

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

Indoor air quality in HOMES is a crucial aspect influencing the well-being of individuals and the overall environment within residential settings. The quality of indoor air plays a pivotal role in ensuring a healthy living space and minimizing potential health risks for residents. Factors such as ventilation, air filtration systems, and the presence of pollutants contribute significantly to the overall indoor air quality of homes.

This study aims to address and elucidate the key compounds or parameters within indoor air that may impact human health in the diverse array of contaminants found in residential environments. By examining factors like particulate matter, volatile organic compounds (VOCs), humidity levels, and microbial content, the objective is to establish a comprehensive understanding of specific components that could pose health concerns in the context of residential spaces. This focused analysis will pave the way for targeted interventions and strategies to improve air quality, fostering a healthier living environment for residents.

Also, 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.

- Number of participants in AT: 28 houses with different heating system (one or more participants per home, different locations in Austria): 10 heated using other solid fuels, 11 heated with natural gas and oil and 7 heated using electric energy or renewable energy sources.
- Number of participants in PL: 31 houses with different heating systems (one participant per home, in Warsaw region and Lodz): 8 houses heated using other solid fuels, 10 houses heated using natural gas and oil and 13 houses heated using electric energy or renewable energy sources.

6.1.1 IAQ Massive monitoring M+H sensors

M+H sensors provides continuous monitoring of T, RH, tVOC and PM concentration (1, 2.5 and 10 of particle size). Next, Figure 38 shows a snapshot of the dashboard of the graphical view during 24 hours of the registers of M+H sensors installed in the homes.

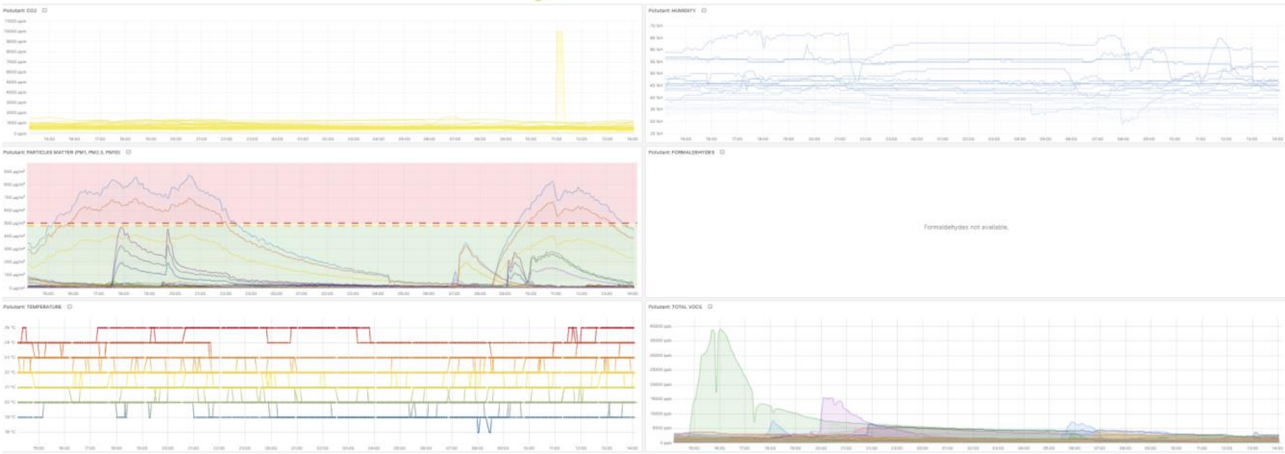


Figure 38. Snapshot of the graphical view of the registers of M+H sensors installed in Austrian's homes (generated with K-HEALTHinAIR platform).

6.1.2 OAQ modelled data from AerisWeather

In addition to "indoor" sources of information, another crucial aspect characterizing indoor air quality in the project involves considering the quality of outdoor air in the project's influence zones. Leveraging the AerisWeather platform, it is modelled and reported data on temperature, relative humidity, and the concentrations of key pollutants in the area. This includes PM, NO_x, CO, and O_3 levels. By incorporating outdoor air quality data into the analysis, it is aimed to contextualize indoor air conditions within the broader environmental context, providing a more holistic understanding of the factors influencing the air quality in the studied indoor environments.

Figure 39 shows the data of the OAQ in Poland and Figure 40 in Austria.

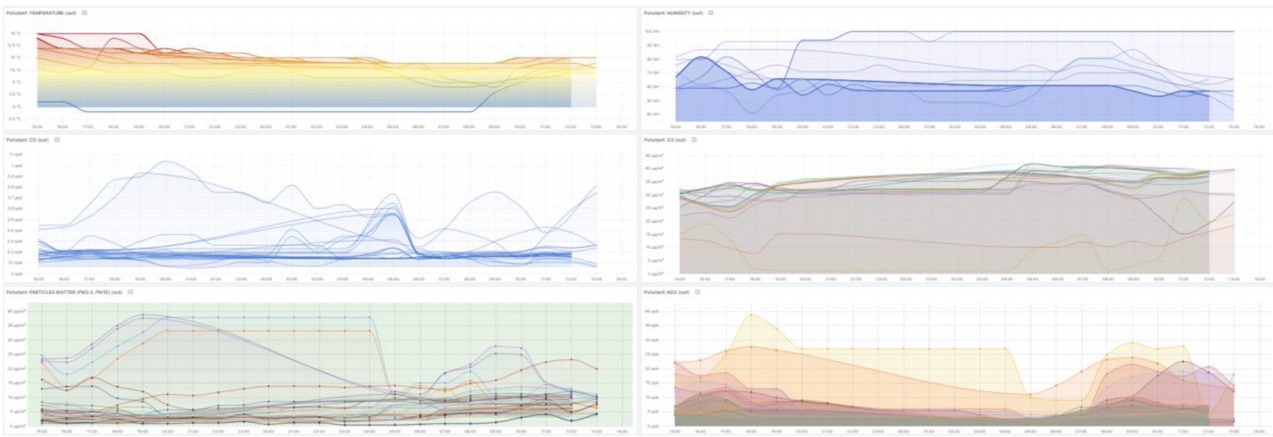


Figure 39. Snapshot graphical evolution of the OAQ parameters included in the study in Poland (T, RH, CO, O_3, PM and NO_X concentrations) (generated with K-HEALTHinAIR platform).

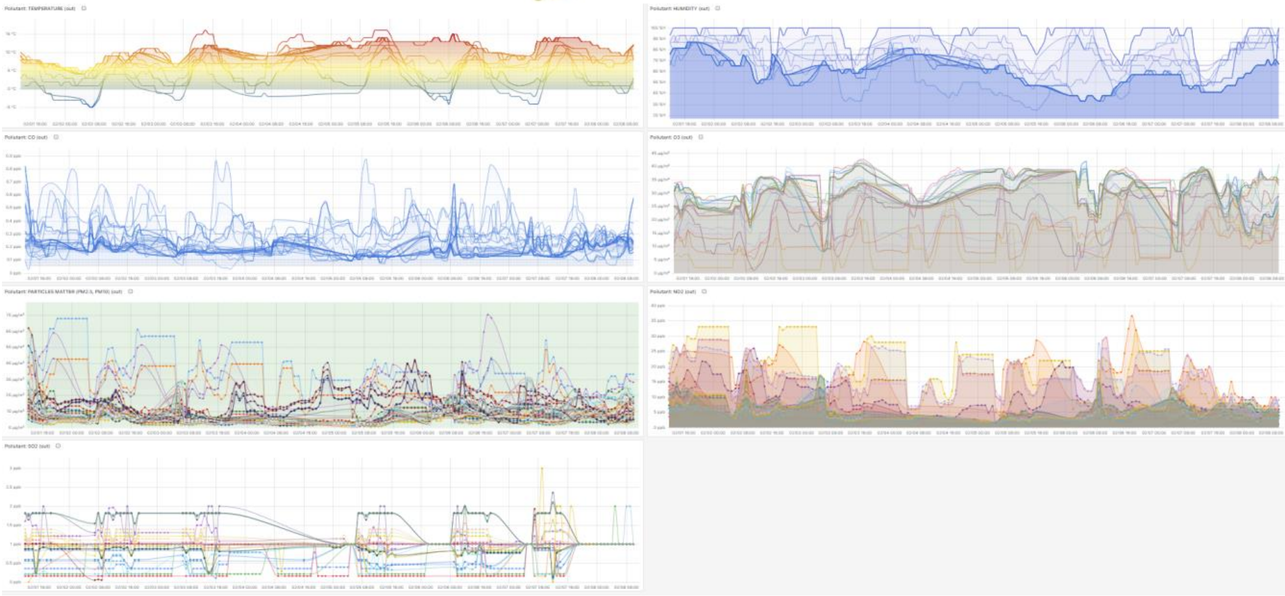


Figure 40. Snapshot graphical evolution of the OAQ parameters included in the study in Austria (T, RH, CO, O_3, PM and NO_X concentrations) (generated with K-HEALTHinAIR platform).

6.1.3 Radon sampling

Radon samplings will be conducted in the spring and summer of 2024,

6.1.4 PAH sampling

Respirable particles (PM_4) samples were collected in selected homes (according to the heating source) in January 2024. It was the first sampling campaign in homes in Poland and it encompassed 11 homes heated using various sources.

GilAirPlus aspirators, produced by Gilian (USA) were used to collect the samples on quartz filters with a diameter of 25 mm. The PM_4 samples were then used for the assessment of polycyclic aromatic hydrocarbons (PAHs) concentrations using gas chromatograph with a flame ionization detector (FID). The following 16 standard PAHs were determined: naphthalene (Na), acenaphthylene (Acnl), acenaphthene (Acn), fluorene (Flu), phenantrene (Fen), anthracene (An), fluoranthene (Flt), pyrene (Pir), benzo(a)anthracene (BaA), chrysene (Ch), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), benzo(a)pyrene (BaP), indeno(1,2,3-cd)pyrene (IP), dibenzo(ah)anthracene (DahA), and benzo(ghi)perylene (BghiP).

The samples collected in January 2024 are still in the process of assessment and the results of the chromatographic analyses will updated as soon as possible.

6.1.5 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, a 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 behaviour, new furniture, among other). 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 has been finalized in December 2023, so far, the questionnaires were not administered to the home residents. The scope of the planned to collect information is similar to that collected in Austria's homes.

6.1.6 Urine samplings for PAHs metabolites

As the recruitment of homes both in Poland and Austria has been just recently finalized, the urine sampling for PAHs has not been started yet. The first session in Poland is planned for November 2024.

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.

As coal-heated homes are not possible to locate and recruit, the ones heated by other solids have been successfully identified.

The PM samplings were done in Poland in January 2024 and it is not planned in Austria.

VOCS measurements were performed in Austria in January 2024.

Radon measurements are delayed however will be started in April 2024.

The questionnaires were collected in Austria and in Poland they will be collected in April 2024.

6.2 SCHOOLS scenario (PL/AT-SCH01 – PL/AT-SCHxx)

SCHOOLS scenario holds importance given the substantial amount of time children spend in these settings. This situation is particularly compelling owing to the vulnerability of children as a demographic group, compounded by the high occupancy rates in classrooms. Children can be exposed to various levels of bacteria and moulds in indoor air, sometimes extremely high, depending on the occupancy, their behaviour, ventilation conditions (air exchange rate), and a season (predominance of bacteria or fungi). Additionally, potential sources of contaminants, such as school materials, formaldehyde, insufficient ventilation, cleaning products, noise, VOCs, PM, CO_2, T, and stress, contribute to the intricacies of this matter.

- Schools studied in AT: 3 schools with 2 or 3 classes each and with 40, 43 and 76 children per class.
- Schools studied in PL: 22 schools with 53 classrooms in total and with 400 children in total.

6.2.1 IAQ Massive monitoring M+H sensors

Figure 41 shows a snapshot of the dashboard of the platform during 24 hours in Poland.

Funded by the European Union

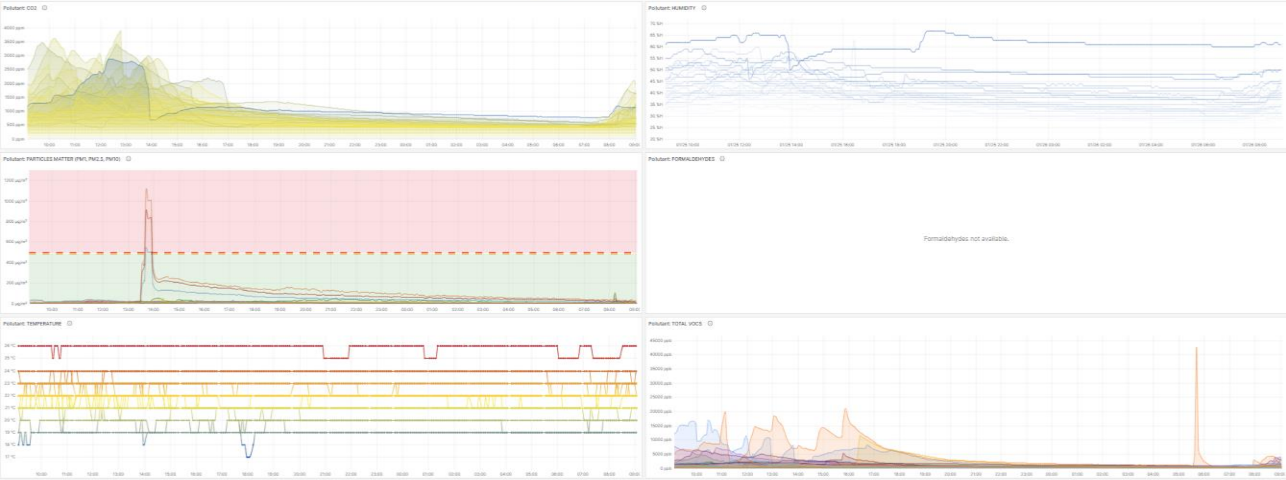


Figure 41. Snapshot of the graphical view of the registers of M+H sensors installed in Polish's schools (generated with K-HEALTHinAIR platform).

6.2.2 OAQ modelled data from AerisWeather

See Section 6.1.2.

6.2.3 VOCs sampling

Indoor air samples for aldehydes and VOCs measurements were collected in 6 secondary schools in Lodz area. Three of the studied schools were located in the city center, two near streets with heavy traffic, and one in an area with low traffic. Sampling session was conducted in November 2023 (heating season) and samples were taken in the same places where M&H and INBIOT sensors were installed.

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), 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 um, 2.1x150 mm. A mixture of acetonitrile and water was used as the mobile phase (gradient elution). Results of performed analysis are Figure 42, Figure 43 and Figure 44.

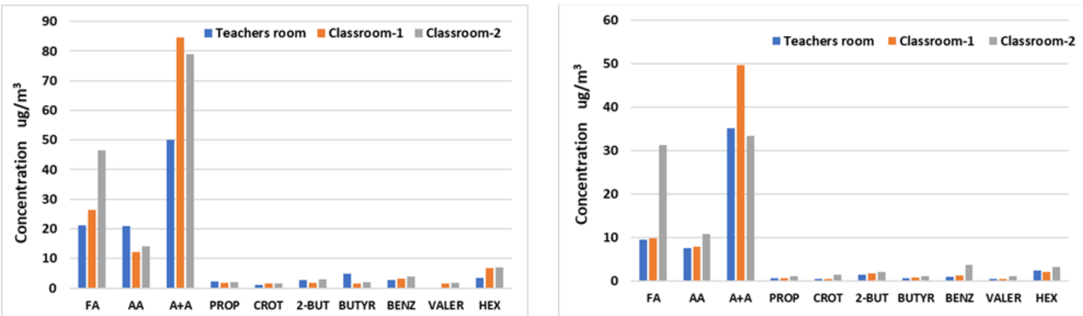


Figure 42. Concentration of FA, AA, A+A, PROP, CROT, 2-BUT, BUTYR, BENZ, VALER and HEX in indoor air samples collected in schools in Poland in November 2023. Left: School #1 (city center). Left: School #2 (city center).

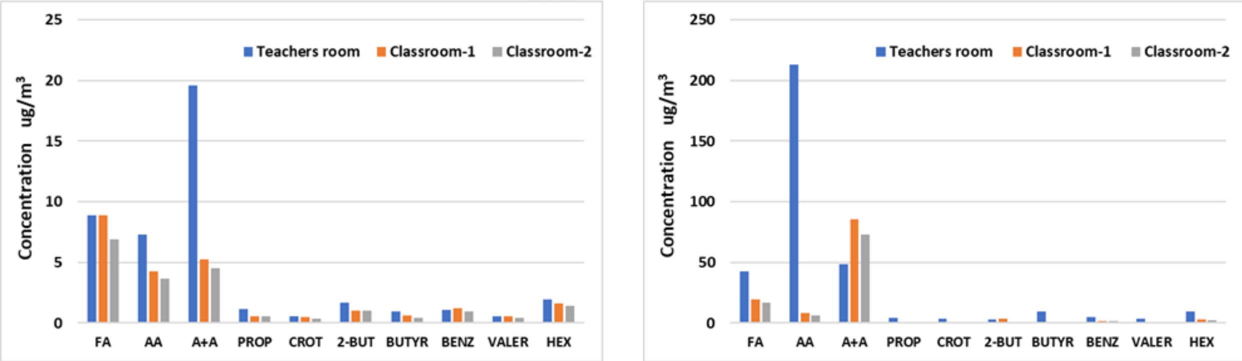


Figure 43. Concentration of FA, AA, A+A, PROP, CROT, 2-BUT, BUTYR, BENZ, VALER and HEX in indoor air samples collected in schools in Poland in November 2023. Left: School #3 (city center). Left: School #4 (heavy traffic area).

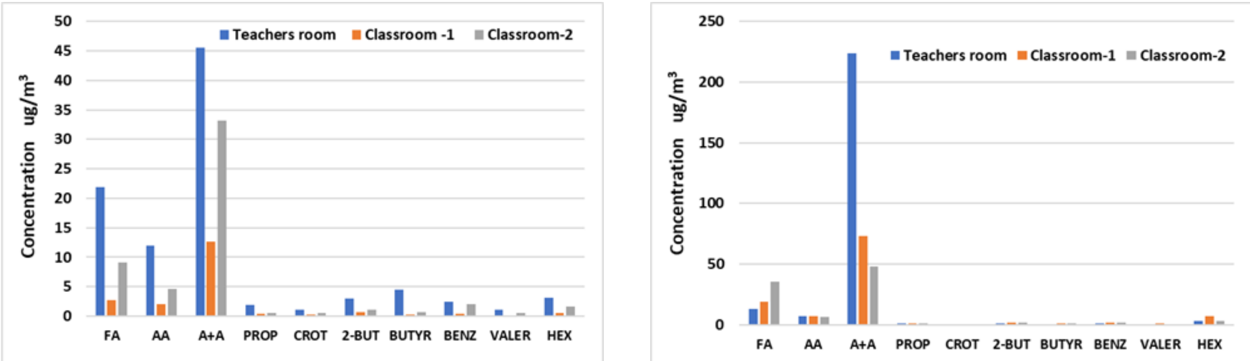


Figure 44. Concentration of FA, AA, A+A, PROP, CROT, 2-BUT, BUTYR, BENZ, VALER and HEX in indoor air samples collected in schools in Poland in November 2023. Left: School #5 (heavy traffic area). Left: School #6 (area without traffic).

6.2.5 PAH sampling

PM4 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.

Figure 45, Figure 46 and Figure 47 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.

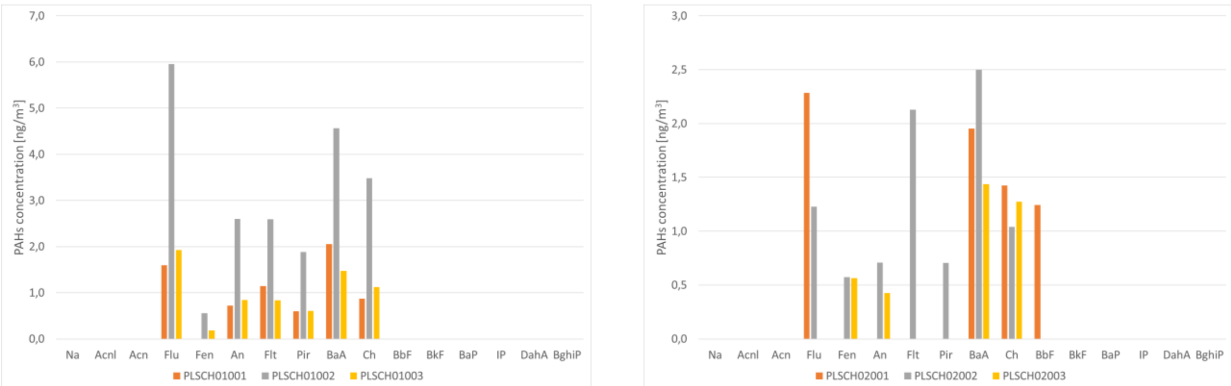


Figure 45. Concentrations of PM_4-bound PAHs measured in July 2023 in 3 classrooms of schools in Poland. Left: PLSCH001 located in the vicinity of Warsaw. Right: PLSCH002 located in the vicinity of Warsaw.

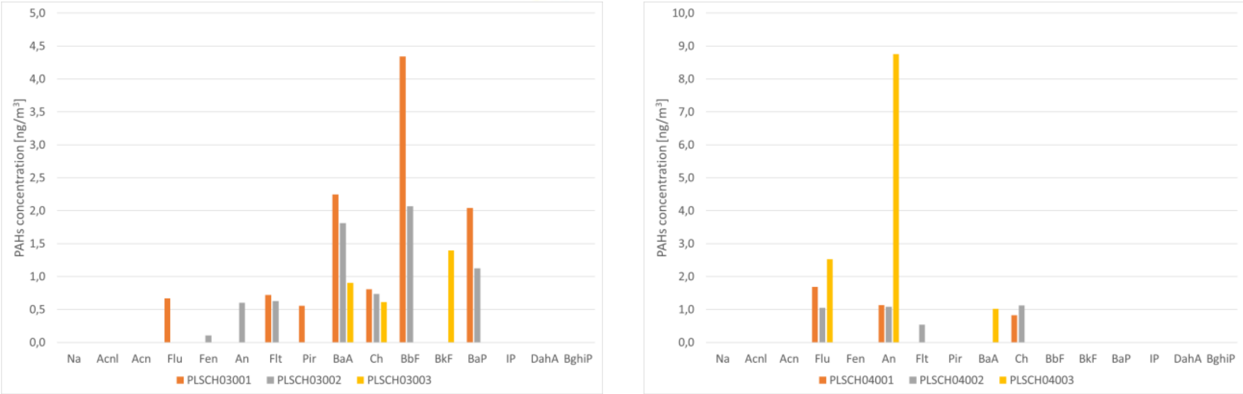


Figure 46. Concentrations of PM_4-bound PAHs measured in July 2023 in 3 classrooms of schools in Poland. Left: PLSCH003 located in the vicinity of Warsaw. Right: PLSCH004 located in Warsaw.

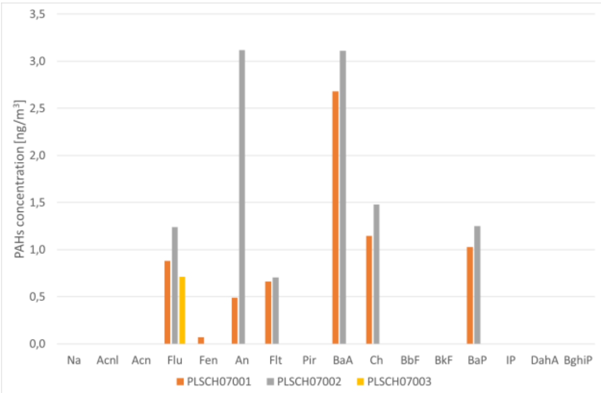


Figure 47. Concentrations of PM_4-bound PAHs measured in July 2023 in 3 classrooms of schools PLSCH007 located in Warsaw.

In general, the indoor air quality in classrooms of the schools involved in the sampling campaign 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, 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 is 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.

6.2.6 Microbiome sampling

Two techniques are used for sampling airborne microorganisms:

- A culture-dependent method using standard impactors: MAS-100 Eco® (Merck Millipore) and SAS Super IAQ (VWR®) microbial air samplers with subsequent incubation at relevant temperatures to grow bacteria and fungi (quantitative analysis),
- A culture-independent method using *Coriolis micro* samplers based on the impingement into sterile phosphate buffer saline and subsequent amplicon metagenomic sequencing to examine airborne microbial community structure (qualitative analysis).

To examine the effect of outdoor temperature on dominant airborne microorganisms in indoor air, microbiome sampling is carried out in 2 seasons:

- cold (heating) season (late autumn/winter),
- hot season (late spring/summer).

In order to limit the negative impact of high variability in the number of microorganisms in the air on the final result, 10 replicates are collected at each point using impactors, according to the protocol presented in Annex 1 of D1.1 Coordination program for pilots. Results are presented in tables showing mean, minimum (min) and maximum (max) values, standard deviation (SD) and standard error (SE) (see Figure 48 for details). Then average values for different sampling points are then analysed and compared using descriptive statistics and graphs (Figure 49).

	bacteria 37°C				moulds 20°C			
replicate	sampling time	sample volume [dm^3]	CFU	CFU/m^3	sampling time	sample volume [dm^3]	CFU	CFU/m^3
1	12:45	50	186	3720	12:45	25	4	160
2	12:44	50	167	3340	12:44	25	5	200
3	12:44	50	212	4240	12:43	50	20	400
4	12:43	50	206	4120	12:43	50	17	340
5	12:42	25	101	4040	12:40	50	13	260
6	12:42	25	134	5360	12:40	50	11	220
7	12:41	25	98	3920	12:36	250	60	240
8	12:41	25	126	5040	12:36	250	44	176
9	12:33	250	612	2448	12:33	250	53	212
10	12:30	250	588	2352	12:30	250	52	208
n				10				10
min				2352				160
max				5360				400
mean				3858				242
SD				969				75
SE				306				24

Figure 48. Snapshot of the datasheet with results obtained by the culture-dependent method for area 004 in school 01 in Poland on May the 29th, 2023, starting sampling time 12:30 (file PLSCH01004MCC2023-05-29-1230). 10 replicates for bacteria and fungi with descriptive statistics: mean, minimum (min) and maximum (max) values, standard deviation (SD) and standard error (SE).

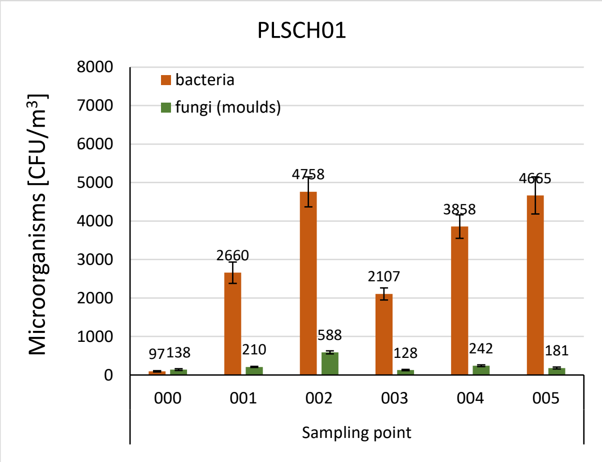


Figure 49. Example of chart comparing level of microbial contamination in outdoor and indoor air in school in Poland (various areas in SCH01). Results obtained by the culture-dependent method on May the 29th. 10 replicates were used to calculate mean values, error bars show standard error (SE).

However, it is essential to note that the samples collected by the impingement method are currently undergoing the sequencing process at an external laboratory. The sequencing step is a crucial phase in obtaining comprehensive microbiome data, and while it is ongoing, the complete assessment of biological pollutants is yet to be finalized.

6.2.7 Questionnaires

Questionnaire survey – secondary schools Lodz.

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. 71 students (31%) responded to Part A after two reminders.

6.2.8 Conclusions

The recruitment of schools was very successful. In Poland 22 schools were recruited, and in Austria 3 schools. In each school, at least three sensors were installed.

VOCs were measured in November 2023 in Poland and in February 2024 in Austria.

Microbiome sampling was performed in Poland and it is planned for June 2024 in Austria.

PM sampling was performed in Poland in June 2023 and December 2023 and it is planned for June 2024 in Austria.

Radon measurement will carry out in Poland in April 2024.

The questionnaire survey started in Poland in January 2024 and it is planned for the end of February 2024 in Austria.

7 CONCLUSIONS

Next, it is summarized the status, development and preliminary results of the monitoring data collected in the five pilots and their respective scenarios.

The 5 pilot studies have different approaches and all of them configure the WP1 and the main data collection actions proposed for K-HEALTHinAIR.

Pilot #1 Barcelona is the more holistic pilot configured within K-HEALTHinAIR. It covers the two approaches proposed by K-HiA: Follow up of high-risk outpatients with COPD and analysis of 3 relevant settings, hospital areas, metro station and a market.

The hospital scenario has been fully launched in June 2023, the market scenario is expected to be launched in March 2024 and the metro scenario will be updated in May 2024. About the outpatients, its recruitment has started in November 2023 but it is not finished, and the other outpatients with higher monitoring will be initiated in March 2024.

The preliminary analysis indicates that basal concentrations of indoor pollutants in the hospital setting are low. The basal concentrations fall within the non-harmful ranges set by regulatory bodies, suggesting overall good indoor air quality compliance. However elevated monitored values of TVOCs have been identified found exceeding the recommended parameters. Whereas the exhaustive VOCs analysis revealed that in exception of few chloroform measures, all the values are far below the recommended thresholds. Also, high concentrations of chloroform have been identified, systematically and across sampling points, this deserves further investigation to identify the main source of chloroform or evaluate if it is a sample contamination.

About the outpatients, observations reveal varied profiles of indoor pollutants across households, with smoking habit emerging as a primary driver for indoor PM pollution. Correlation analysis between IAQ and clinical data in outpatients is crucial for extending the relevance of the analyses beyond the comparison with established threshold, and facilitating the identification of IAQ health determinants and informing in vivo /in vitro studies design. Cross-validating the sensor measurements through empirical on-field measurements planned for the HOM02 scenario is paramount.

Pilot #2 Rotterdam is the second pilot working with outpatients in K-HiA. It also covers the two approaches proposed by the project: Follow up of high-risk outpatients with COPD and the analysis of 2 relevant settings, hospital areas and a senior home (common areas).

Continuous monitoring has started yet in the hospital. However, some delays launching the process due to waiting times for ethical approval (EA) occurred. VOC sampling has not yet begun (scheduled second half of 2024).

Additional efforts are needed to install InBiot sensors in the common areas of the senior home once management has finalized Wi-Fi availability. Only one common area is monitored in one senior home building. Delays acuminated because of ethical approval and internal approval process within the housing corporation itself. The reason for have only one area is because the housing corporation was replacing Wi-Fi routers in common area's or switching to different Internet providers. VOC sampling has not yet begun (scheduled second half of 2024).

The recruitment number of outpatients are increasing steadily since the ethical committee has given their approval of an amendment of the original protocol and information letter. This amendment was necessary because, participant's data is being shared among partners (ATOS, InBiot and IDIBAPS). Recruitment delays can be attributed to the JCA being drafted and has not been finalized yet.

Pilot #3 Norway is a pilot that will be focused both on the analysis of the IAQ and on the evaluation of the impact of wood as indoor building materials on health. It covers the approach with 3 relevant settings, canteen areas, students' residence and lecture hall.

The monitoring operations are proceeding satisfactorily, encompassing both outdoor and indoor air quality assessments in canteens and lecture halls. However, the installation of 20 monitors in the students' residence is lagging due to delayed approval of data protection related to questionnaires and student recruitment. Efforts such as offering gift cards and direct personal contact are underway to attract potential respondents, aiming to secure 50 students for the questionnaire in the lecture hall scenario. Instead, the recruitment of canteen staff has reached 100% of the potential respondents.

Sampling of VOCs and formaldehyde will be started upon recruitment of the 20 students, with a detailed measurement procedure in place.

A deeper analysis of the monitor data is planned, including a comparison with OAQ data from Kunak, AerisWeather, and the nearest governmental measurement station.

Pilot #4 Germany. It covers the approach with the analysis of 2 relevant settings, canteen and lecture hall. It is focused on the identification of the determinants in these settings and also to identify the best conditions for the canteen customers.

Both scenarios have been fully launched, in April 2023 the canteen and in June 2023 the lecture hall.

Overall, the monitoring campaigns in both the canteens and lecture halls are progressing smoothly with some potential risks, primarily related to network errors. To address this, notifications have been implemented to ensure timely resolution of any issues. The adaptation of questionnaires has been successful in canteens, and there are no foreseeable risks regarding participant IDs. In the lecture halls, adaptation of questionnaires is underway with plans for testing among a select group of pilot students. Analysis of chemical sampling data, including VOCs, PM, and microbiome, has not shown any concerning indications. However, further analysis is planned to determine appropriate improvement measures. Further examination of the data will guide the identification and implementation of improvement measures as the monitoring progresses.

Pilot #5 Poland / Austria is a pilot configured within K-HiA. It covers the approach of analyzing 2 relevant settings, home and schools. Home setting selected in this pilot is different from the one considered with outpatients in Barcelona and in Rotterdam. This pilot studies are focused on searching for the determinants in homes with different systems for cooking and heating and in newly constructed houses.

Recruitment of participants in homes was completed. 28 houses in Austria with different heating system (one or more participants per home, different locations in Austria): 10 heated

Funded by
the European Union

using other solid fuels, 11 heated with natural gas and oil and 7 heated using electric energy or renewable energy sources. 30 houses with different heating systems (one participant per home, in Warsaw region and Lodz): 8 houses heated using other solid fuels, 10 houses heated using natural gas and oil and 12 houses heated using electric energy or renewable energy sources.

The recruitment of participants in secondary schools was finalized in Lodz in January-February 2024 and is under way in Warsaw. 3 schools with 2 or 3 classes each and with 40, 43 and 76 children per school are recruited in Austria and 22 schools with 53 classrooms in total and with 400 children in total in Poland.

8 REFERENCES

[1] Holguin F et al. Management of severe asthma: ERS/ATS guideline. Eur. Respir. J 2020; 55: 1900588[https://doi.org/ 10.1183/13993003.00588-2019]

[2] Agustí A et al. Global Initiative for COPD 2023 Report: GOLD Executive Summary. Eur Respir J. 2023 Apr 1;61(4):2300239. doi: 10.1183/13993003.00239-2023. PMID: 36858443; PMCID: PMC10066569

[3] Monterde D, Vela E, Clèries M. Adjusted morbidity groups: A new multiple morbidity measurement of use in Primary Care. Aten primaria. 2016 Dec 1;48(10):674–82

[4] Gomez A et al. Protocol for the Enhanced Management of Multimorbid Patients with Chronic Obstructive Pulmonary Diseases: Role of Indoor Air Quality. BMJ Open 2024 (submitted)

[5] Veneroni C et al. Diagnostic Potential of Oscillometry: A Population-based Approach. https://doi.org/101164/rccm202306-0975OC. doi:10.1164/RCCM.202306-0975OC

[6] Wouters EFM, Breyer MK, Breyer-Kohansal R, Hartl S. COPD Diagnosis: Time for Disruption. J Clin Med. 2021 Oct 11;10(20):4660. doi: 10.3390/jcm10204660. PMID: 34682780; PMCID: PMC8539379

[7] Celli B et al. Definition and Nomenclature of Chronic Obstructive Pulmonary Disease: Time for Its Revision. Am J Respir Crit Care Med. 2022 Dec 1;206(11):1317-1325. doi: 10.1164/rccm.202204-0671PP. PMID: 35914087; PMCID: PMC9746870

[8] Urban PM2.5 Atlas, Air Quality in European Cities, Page 132, 2023 Report. https://publications.jrc.ec.europa.eu/repository/handle/JRC134950