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EDIAQI

Evidence Driven Indoor
Air Quality Improvement

Deliverable D3.1

Indoor Air Pollution Observation Toolkit

Work Package 3
SCIENCE
Version: Final

This project has received funding from the European Union's
Horizon Europe Framework Programme under grant agreement № 101057497.

Deliverable Overview

The toolkit contains all the selected scientific tools and methodologies that will be used during the project in real-time air pollution measurements visualised on EDIAQI project platform.

Additional Information

Type: DEM – Demonstrator, pilot, prototype

Dissemination Level: PU – Public

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Actual Submission Date: 30th of May 2024

Disclaimer

Document Revision History

Version	Date	Description	Partners
V0.1	29th of March 2024	1st draft of deliverable	TROPOS
V0.2	8th of April 2024	2nd draft of deliverable for WP3 member reviews	TROPOS
V0.3	19th of April 2024	3rd draft of deliverable for PI review	USEV & SCH
V0.4	29th of April 2024	Internal peer review version	USEV & SCH
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Statement of Originality

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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List of Terms and Abbreviations

Abbreviation	Description
APSS	Aerodynamic particle size spectrometer
ASE	Accelerated solvent extraction
BC	Black carbon
CO	Carbon monoxide
CO_2	Carbon dioxide
Device/LCS device	A unit composed of several sensors and other physical components
DNA	Deoxyribonucleic acid
EDIAQI	Evidence Driven Indoor Air Quality Improvement
EPA	Environment Protection Agency
FPA	Focal plane array
FTIR	Fourier transform infrared
GC-MS	Gas chromatography – mass spectrometry
IAP	Indoor air pollution
IAQ	Indoor air quality
IoT	Internet of things
LCS	Low-cost sensor
LDIR	Laser direct infrared
LIM	University of Leipzig, Institute of Meteorology
MPSS	Mobility particle size spectrometer
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NOx	Nitric oxide (NO and NO2, collectively)
O_3	Ozone
OPSS	Optical particle size spectrometer
PAH	Polycyclic aromatic hydrocarbons
PCR	Polymerase chain reaction
PM	Particulate matter
PNSD / PMSD	Particle number or mass size distribution
QR	Quick response
RH	Relative humidity
Sensor	A singular component capable of detecting a signal
Sensor parameters	Pollutants and parameters that can be measured by an LCS
SO_2	Sulfur dioxide
System set-up	A complete setup combining, mist- and fog-computing, IoT and Cloud system set up for IAQ monitoring

T	temperature
TD	Thermal desorption
TROPOS	Leibniz Institute for Tropospheric Research
TUG	Graz University of Technology
TVOC	Total volatile organic compounds
UFP	Ultrafine particles
UMOL	University of Molise
WCCAP	World Calibration Centre for Aerosol Physics
WSN	Wireless sensor network
WP	Work Package

Executive Summary

The main objective of this deliverable is to collect all the selected scientific tools and methodologies that are and will be used in EDIAQI and package it as a toolkit that can be used by the pilots and campaigns and future users. This document serves two purposes: (1) as a summarised collection of methodologies and (2) as an accompanying document describing the codes shared in an open access repository GitHub.

The Indoor Air Pollution Toolkit contains three main modules:

1. Sensor validation module

This module documents methods employed to validate the performance of the individual sensors based on U.S. Environment Protection Agency (EPA) guidelines from experiments to sensor data analysis. The descriptions of each experiment (laboratory and real-world scenarios) are presented as well as the statistical parameters used to evaluate the accuracy, precision, and sensitivities of the sensors. All the codes used are available in the GitHub folder to the pilots and campaigns (and users beyond EDIAQI) so that they may evaluate their sensors in the field.

2. Emerging pollutant measurement and analysis module

This module summarises all the methods used to measure and analyse emerging pollutants that are not measured by the LCS devices: microplastics, radon, VOCs, aldehydes, PAHs, microbiomes, ultrafine particles, and black carbon concentrations. Similarly, codes used to analyse these datasets are also available in the GitHub folder.

3. System architecture and visualisation module

This module provides all the methods employed in setting up an effective way to communicate indoor air quality to stakeholders through data visualisation. This involves a stakeholder map, summary table of best practices to visualise data to different stakeholders based on 20 years of research, and a communication system setup. Codes are also available in the GitHub folder.

This deliverable has been produced jointly by the WP3 team. No updates are planned for this deliverable, however, changes in minor aspects considered by the management team as improvements for the project will be considered and implemented as regular practices.

1. Introduction

Indoor air pollution (IAP) has gained a lot of traction not only within the scientific community but also with the public due to high relevance and better access to simpler ways of monitoring air quality indoors through low-cost sensors (LCS). In EDIAQI, a highly inter- and trans-disciplinary project with 8 pilots and campaigns, the research team employs a multitude of tools to better understand indoor air and raise awareness of our stakeholders. Here, the Indoor Air Pollution Observation Toolkit is presented, an output from WP3 (Figure 1), which is an ensemble of tools ranging from measurement of pollutant concentrations to data analysis and finally to local actor involvement and data visualisation. This toolkit will be used, not only as a collection, but as actual tools for the pilots and campaigns to use as they progress with their own experiments.

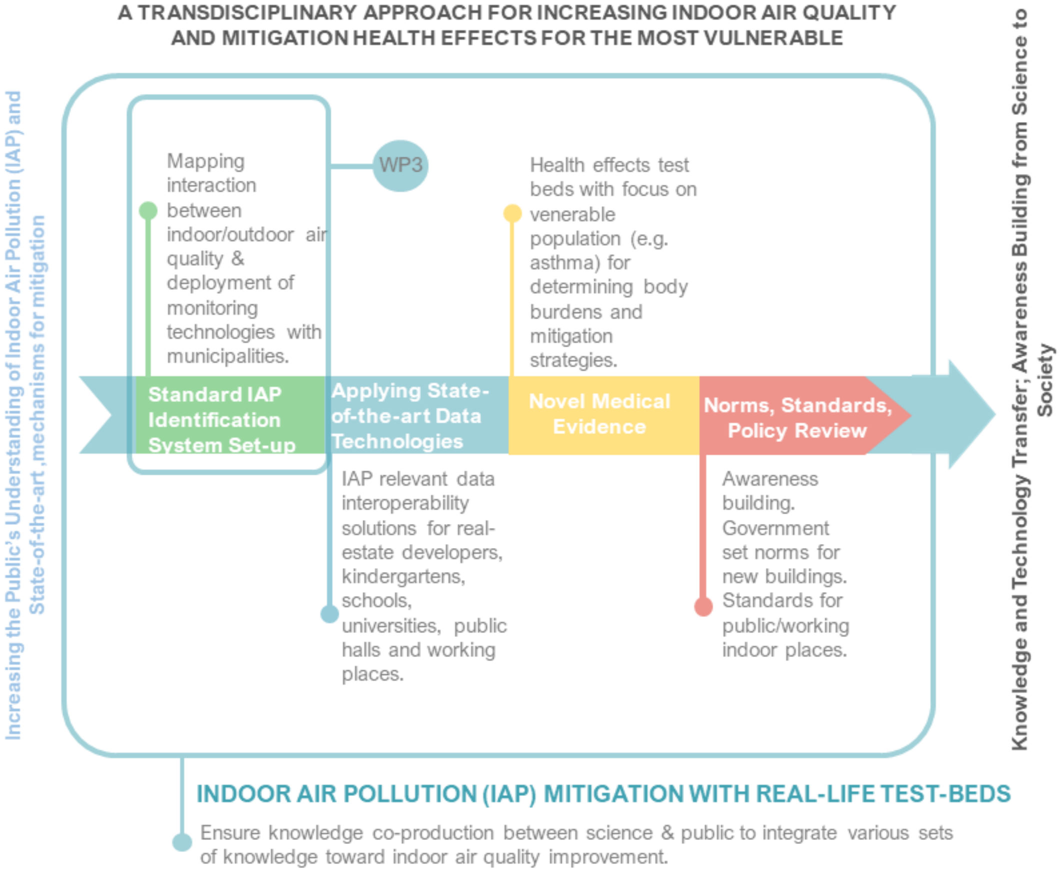

Figure 1 Role of WP3 in the overall concept of the EDIAQI project

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For readability, the authors would like to define the following terminologies and how they are used in this document:

- "**sensor**" – a singular component capable of detecting a signal;
- "**device**" or "**LCS device**" – a unit composed of multiple sensors and other physical components, the actual instrument;
- "**system set-up**" – a complete setup combining, mist- and fog-computing, IoT and Cloud system set up for IAQ monitoring.

1.1 Deliverable objective

The main objective of this deliverable is to document and make available all the scientific and statistical tools employed within EDIAQI and compile them into an "indoor air pollution observation toolkit" which can be accessed and used by others in the future. This document serves as the report of the demonstrator/prototype which is available in the open-source repository below.

1.2 Open-source repository

The following codes can be found in an open-access platform GitHub.

Table 1 List of available codes in the GitHub folder

File	File description	Author contact and affiliation
Eval_functions\Device_Evaluation	Functions to evaluate the performance of the sensors in terms of accuracy, precision, and sensitivity to T and RH	Dr. Sebastian Düsing duesing@tropos.de TROPOS
getDataFunctions	Functions needed to transform data from the different devices into a suitable format with harmonised headers	Dr. Sebastian Düsing duesing@tropos.de TROPOS
EDIAQ\data\chamber_lim\data	Chamber programme settings	Dr. Sebastian Düsing and Dr. Michael Schaefer (LIM) duesing@tropos.de TROPOS
\Eval_functions\template\template.R	Template for reporting sensor validation results	Dr. Sebastian Düsing duesing@tropos.de TROPOS
EDIAQI\scr\Microbiome\microbiome_bacteria.R	Template for analysis of bacterial sequencing data	Kristina Michl kristina.michl@tugraz.at

		TUG
EDIAQI\scr\Microbiome\ microbiome_fungi.R	Template for analysis of fungal sequencing data	Kristina Michl kristina.michl@tugraz.at TUG

2. Sensor Validation Module

This module contains the methods and tools used in T3.1.a Validation of LCS devices in laboratory and real-life settings. The LCS devices are from the project's sensor providers: LAS, WINGS (indoor and outdoor), and THINNECT or THIN and Table 2 shows the parameters each cover. These methods and tools are based on existing recommendations from Zimmerman (2022) with variations to adapt to the needs and limitations of the experiments.

Table 2 List of indoor air parameters measured by the sensor providers.

Parameter	LAS	WINGS Indoor	WINGS Outdoor	THIN v1	THIN v2
T	✓	✓	✓	✓	✓
RH	✓	✓	✓	✓	✓
Pressure	✓	✓	✓		
Noise			✓		
PM$_1$			✓		✓
PM$_{2.5}$	✓	✓	✓	✓	✓
PM$_{10}$	✓		✓		
CO		✓	✓		
CO$_2$	✓	✓	✓	✓	✓
NO			✓		
NO$_2$			✓		✓
SO$_2$			✓		
O$_3$	✓				
TVOC	✓	✓	✓	✓	✓
Aromatic VOC	✓				

2.1 Sensor validation experiments

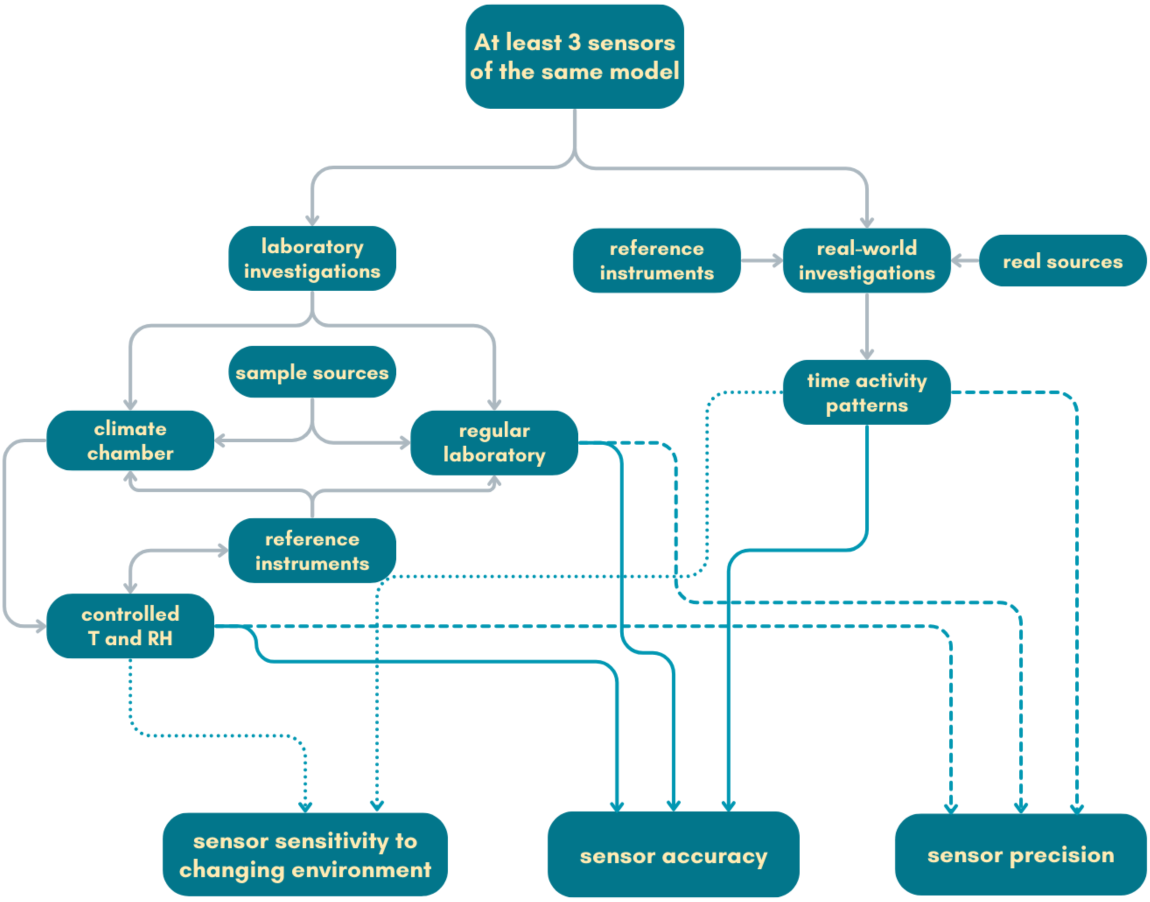

Figure 2 Schematic diagram of the methodology used to evaluate the performance of the low-cost sensors (adapted from Zimmerman (2022)).

Following the diagram in Figure 2, two categories of investigations were carried out: performance in controlled laboratory settings and real-world scenarios. However, due to experimental limitations, Figure 2 was expanded to 5 separate experiments to determine the three performance parameters: sensor sensitivity, accuracy, and precision. Table 3 summarises the list of experiments performed to evaluate the LCS while Table 4 lists the instrumentation used as reference.

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Table 3 List of sensor validation experiments

Experiment	Pollutant source	Accuracy	Precision	Sensitivity
A. Chamber experiments	Incense smoke, CO_2, Acetone	PM and CO_2, T and RH	All	T and RH
B. Regular laboratory	Arizona road dust CO_2	PM and CO_2	All	NA
C. Outdoor ambient experiments	Ambient outdoor air	PM, O_3, SO_2, NO, NOx, CO_2	All	NA
D. Semi-real-world setting: office	Ambient air, acetone, nebulised salt		All	NA
E. Real-world: classroom	Ambient air	PM, VOC, CO_2	All	NA

Table 4 List of reference instruments used

Pollutant	Instrument	Level	Experiments	Sensors	Location
PMx	MPSS+OPSS	Secondary	A, B, C, E	all	TROPOS & Vilnius
PM_{10}, $PM_{2.5}$	Sampling on filters: Sven Leckel LVS SEQ 47/50 Gravimetric analysis: Mettler TOLEDO MX5	Primary	C	WINGS	Zagreb
CO_2	Vaisala CO_2 Probe GMP343	Secondary	A, B, C, E	all	TROPOS
O_3	Thermoscientific ozone analyzer	Primary	C	all	TROPOS
	Horiba APOA 370 Ambient O3 monitor	Primary	C	WINGS	Zagreb
SO_2	Thermo Environmental Instruments Inc., SO_2 analyzer	Primary	C	all	TROPOS
	Horiba APSA 370 Ambient SO2 monitor	Primary	C	WINGS	Zagreb
NO, NOx	Horiba APNA 370 Ambient NOx monitor	Primary	C	All, WINGS	TROPOS, Zagreb
NOx	Horiba APNA 370 Ambient NOx monitor	Primary	C	All, WINGS	TROPOS, Zagreb
CO	Horiba APCA 370 Ambient CO monitor	Primary	C	WINGS	Zagreb

2.1.1 Laboratory experiments

A. Chamber experiments

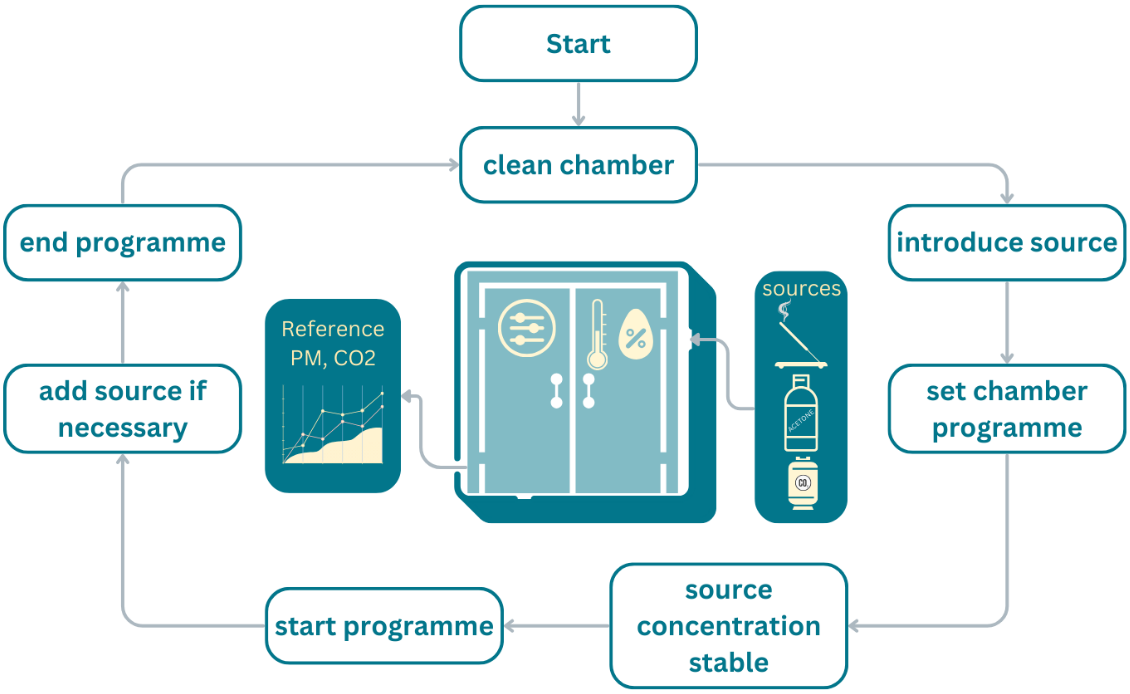

Figure 3 Diagram (left) and schematic (right) of chamber experiment processes.

From the recommendations of U.S. EPA, at least 3 LCS devices were acquired from each sensor partner. This experiment was done in the climate chamber of the Institute of Meteorology of the University of Leipzig (LIM) and the process is illustrated in Figure 3. This chamber has volume of 8 cm^3 with its own ventilation system, and 4 T and RH sensors by the side of the door opposite the vents. Most importantly, the T and RH inside the chamber can be controlled to investigate the sensitivity of sensors to changing conditions. The LCS devices were placed inside on top a metal table approximately 1 m away from the floor and walls of the chamber and around 1.5 m away from the ceiling. Due to limited space, the LCS devices were placed close to each other with care such that the exhaust of one doesn’t blow onto the sensor of another. The reference CO_2 sensor was placed inside the chamber as well. Through a sealable hole on the side of the chamber, a stainless-steel inlet was set up and connected to the PM proxy reference instruments outside the chamber, unaffected by the chamber conditions. The chamber's T and RH sensors served as reference measurements. Three sources of pollutants were introduced individually into the chamber to observe the response of the sensors: incense smoke for PM, and CO, acetone for VOC, and CO_2 gas. Before a new source is introduced, the chamber is flushed clean of pollutants (down to background levels). Once the concentration of the sources is stable, the chamber programme is started. The chamber was programmed in the following way:

1. Fixed T, variable RH
2. Fixed T, RH ramp
3. Fixed RH, variable T
4. Fixed RH, T ramp

The exact settings/programmes used in the chamber experiments are available in the GitHub folder.

B. Regular laboratory experiments

Incense smoke produces predominantly smaller particles. To investigate the response of the PM sensors to larger particles (PM_{10}), another experiment was conducted at the World Calibration Centre for Aerosol Physics (WCCAP). The LCS devices were placed in a clean room together with the reference instruments (MPSS and APSS). Arizona road dust and ammonium sulphate were nebulised individually in the room using SwisensAtomizer and a nebuliser, respectively.

2.1.2 Real-world experiments

C. Outdoor ambient experiments

At Zagreb, IMROH has two WINGS outdoor devices installed at two regular monitoring stations of the City of Zagreb (one at Ksaverska cesta and one at Peščenica station), which have reference measurements of PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NOx, O_3 at Ksaverska cesta, and PM_{10}, NO, NOx, and O_3 at Peščenica station. Reference measurements of PM_{10} and $PM_{2.5}$ are carried following the HRN EN 12341 standard: "Ambient air -- Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2.5}$ mass concentration of suspended particulate matter", while measurements of gases are following the HRN EN 14212:2012/ HRN EN 14212/AC:2014, HRN EN 14625:2012, HRN EN 14211:2012 and HRN EN 14626:2012 standards for SO_2, O_3, NO/NOx and CO, respectively. The Division of Environmental Hygiene of the Institute for Medical Research and Occupational Health is a testing laboratory accredited according to the HRN EN ISO/IEC 17025 standard by the

Croatian Accreditation Agency for these measurements (Accreditation Certificate number 1288).

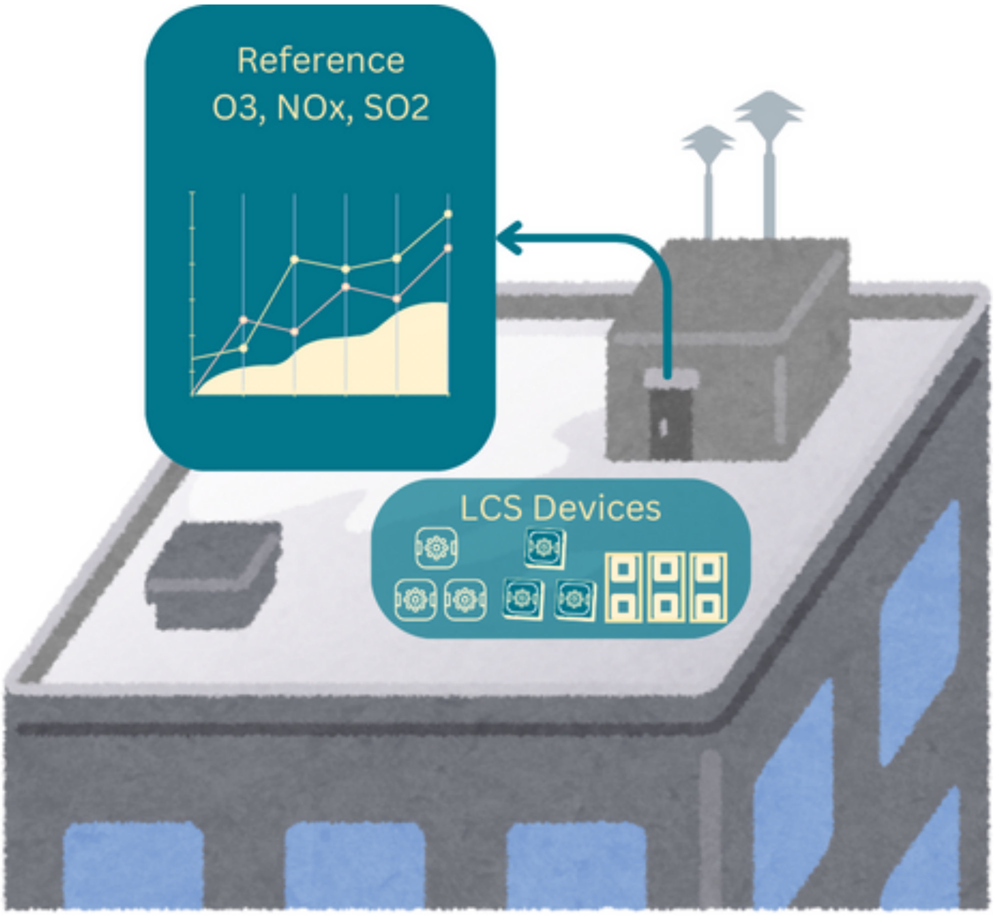

Figure 4 Schematic diagram of outdoor experiments at TROPOS.

At the TROPOS measurement station, the LCS devices were intercompared against the reference instruments measuring ambient concentrations of SO_2, O_3, NO, NOx, and NO_2 Figure 5. Since the LCS devices measure the parameters passively (no active pump), the devices were placed in a small chamber (to protect from the elements) with all holes opened and placed on the rooftop where the inlet of the reference instruments is sampling the air. Only the devices with SO_2, NOx, and O_3 sensors were included in this experiment: LAS, THIN, and WINGS outdoor devices.

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D. Semi-real-world experiment

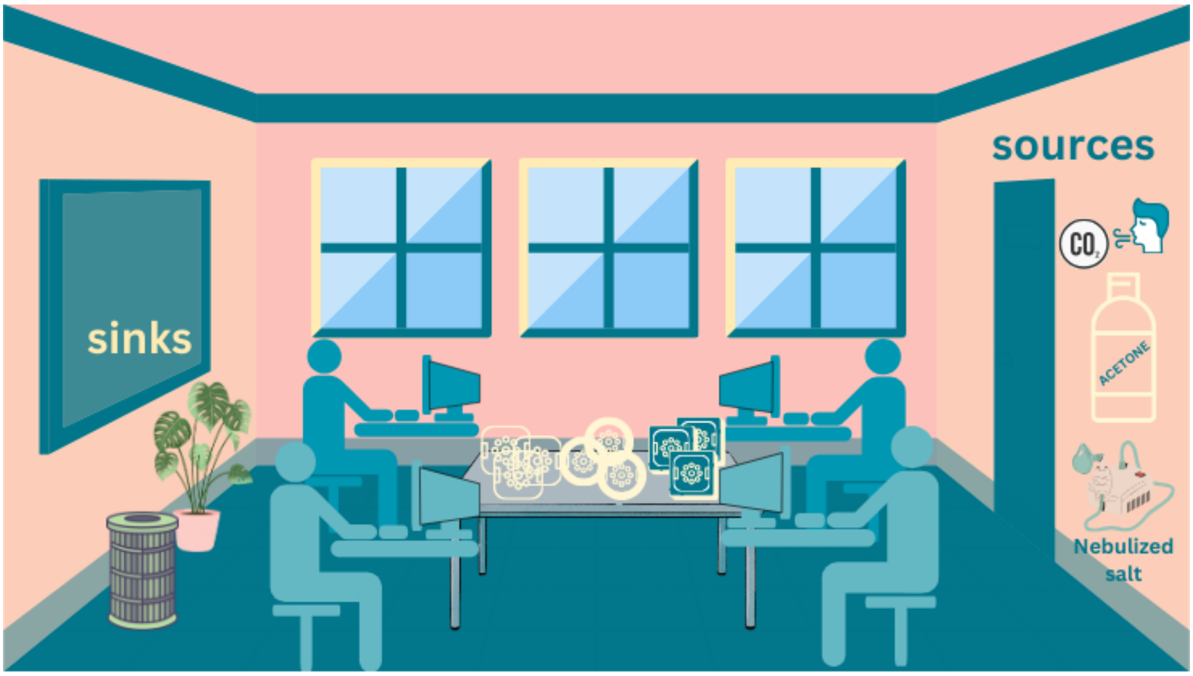

Figure 5 Schematic representation of a semi-real-world experiment in an active office using natural and artificial sources. The image is not the exact schematic of the room used.

The semi-real-world approach was conducted to investigate the performance of the LCS devices in an active indoor space influenced by natural sources and sinks with the addition of artificial sources. As illustrated in Figure 5 The LCS devices were placed on a table near the breathing height of sitting adults in the middle of an office regularly occupied by 1-4 scientists. One wall has 4 full windows that can be opened completely (only the two end windows were opened during this experiment) or slightly ajar and is facing south. The door is directly across the windows and is normally closed. The room has several potted plants and an air purifier. Reference instruments were not used here due to noise and space. The office users are the main source of CO_2. The room has natural ventilation (manually operated windows and doors), and the air purifier was only used in the context of the experiment. Pollutant sources were artificially introduced in the room. To test the VOC sensors, acetone poured in a saucer was left over the weekend when the room was empty. To test the PM sensors, saline solution was used in a nebuliser and introduced salt particles and water vapor into the room. In some experiments, the air purifier was used to compare the rate of decay of pollutant concentration against when it wasn't in use. Detailed time activity patterns of the dwellers (# of occupants, opening and closing of windows and doors, usage of air purifier, introduction of artificial sources) of the office were recorded by hand.

E. Real-world experiment

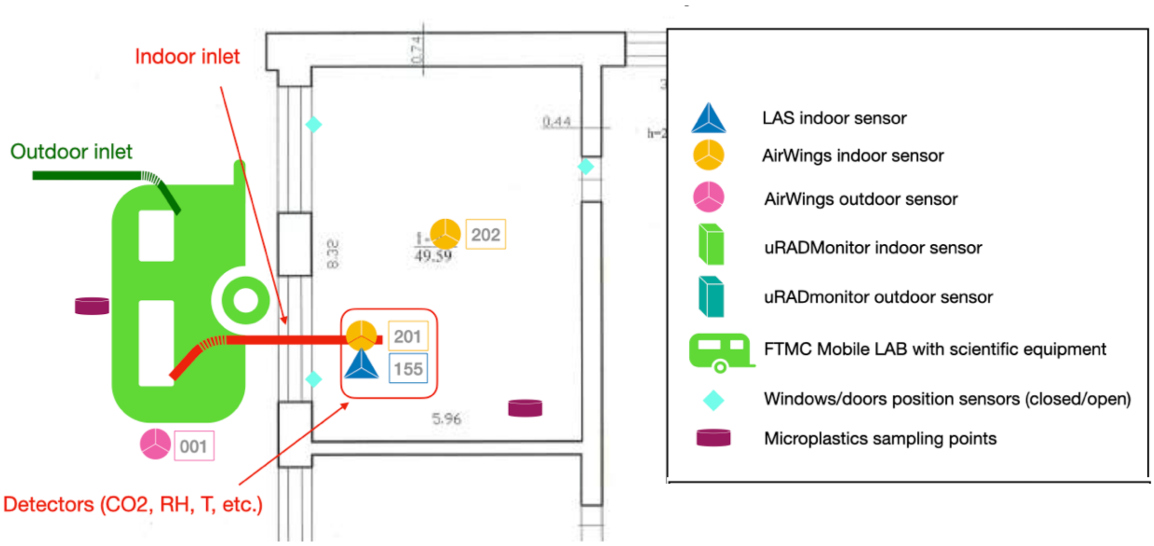

Figure 6 Schematic diagram of the field intercomparison setup between the sensors and the reference instruments installed in a classroom in the Vilnius campaign

This experiment was performed within the Vilnius campaign. All LCS devices were installed in an active classroom where the air is also monitored by proxy reference instrumentations placed in a trailer outside the classroom (Figure 6). This activity is part of C1: Evaluation of Low-cost sensors in WP4. Specifically, the real-world intercomparison is on-going as of the writing of this deliverable. Detailed information about this experiment will be provided in the deliverable C1.1. Briefly, for PM proxy reference, the trailer is equipped with two particle size spectrometers which when combined using appropriate assumptions, can provide high-time resolution values of PM that can be used as “proxy reference” to compare against PM values from the LCS devices – a preferred approach than comparing against the reference method (gravimetric) with low-time resolutions (hours or even days). The mobility particle size spectrometer (MPSS) provides particle number size distribution (PNSD) from 0.001 – 0.8 µm every 5 minutes. The optical particle size spectrometer (OPSS) or an aerodynamic size spectrometer (APSS) provide PNSD from 0.3 – 10 µm, and 0.5 – 20 µm, respectively. The combined PNSD can then be converted to a particle mass size distribution (PMSD) using an assumed particle density and then integrated to the appropriate cut-offs to obtain PM values at high time resolution. The operation of these instruments follows the World Meteorological Organization / Global Atmospheric Watch standards/guidelines:

- Use of conductive tubing and stainless-steel tubes were used to prevent further losses;
- Avoidance of bends in the inlet system and calculation of particle losses when bends are unpreventable;
- Conditioning of aerosol sample (<40% relative humidity) using a Nafion dryer.

2.2 Methods for sensor performance analysis

The performance of the sensors is evaluated with a variety of statistical metrics following the approach of Zimmerman (2022). The unit-to-unit variability (precision) and overall accuracy are evaluated for a set of sensors (3 of each). Additionally, the performance of individual devices is described. All the functions described here are available in the GitHub folder.

Accuracy

The **Pearson-coefficient of correlation (r)** is a measure of the correlation with a reference device and is estimated for each unit of a device type and is described in Equation 1,

$$r = \frac{\Sigma(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\Sigma(x_i - \bar{x})^2 \Sigma(y_i - \bar{y})^2}} \tag{1}$$

where x_i and $\bar{x}$ are the values of the reference measurements and mean of the reference, respectively, and y_i and $\bar{y}$ are the same values but for the sensor measurements.

The relationship between the reference and the sensor measurements were also evaluated using a **simple linear regression** assuming no uncertainties in the x-axis and is described in Equation 2

$$y = (a)x + (b) \tag{2}$$

where y is the sensor measurement, x is the reference, the a is the deviation between the two, and the b is the offset. The slope and intercept are estimated using the *lm* function from the *stats* package in R (R Core Team (2021)).

Additionally, **the root-mean-square error (RMSE)** and the **normalised root mean square error (NRMSE)** were used. RMSE is a measure of the difference between the reference and the observed values, and NRMSE is simply RMSE normalised with the mean of the true values. Equations 3 and 4 describe RMSE and NRMSE, respectively,

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)} \tag{3}$$

$$NRMSE = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)}}{\bar{x}} \times 100\% \tag{4}$$

where x is the reference value at given time i, N the number of observations and $\bar{x}$ is the overall mean reference value in that period.

Exemplary results of the CO_2 sensor performance are given in Table 5.

Table 5 Exemplary results of performance evaluation for the CO_2 sensors of three devices

Device ID	R^2	a	b (ppm)	RMSE (ppm)	NRMSE (%)	r
DUT1	0.992	0.946	210	77.5	3.00	0.996
DUT2	0.982	0.944	239	10.5	4.11	0.991
DUT3	0.988	0.939	52.1	114	4.43	0.994

Finally, the overall accuracy (ACC) of all the devices were calculated as follows:

$$ACC = \frac{\sqrt{\frac{1}{N \times D - 1}\sum_{d=1}^{D}\sum_{i=1}^{N}(y_{d,i} - \bar{y}_l)}}{\bar{\bar{x}}} \times 100\% \tag{5}$$

where N is the number of observations, D, the number of devices, i represents the i-th time interval within the measurement period, and $\bar{y}$ the mean of the devices in this interval.

Precision

The precision or unit-to-unit variability of the sensors where also evaluated.

The **coefficient of variation (CV)**, shows the extent of the variability of the measurements of the devices in relation to the mean of entire population, and is described in Equation 6 with similar terms as in Equation 5,

$$CV = \frac{\sqrt{\frac{1}{N \times D - 1}\sum_{d=1}^{D}\sum_{i=1}^{N}(y_{d,i} - \bar{y}_l)}}{\bar{\bar{y}}} \times 100\% \tag{6}$$

The precision and accuracy are expressed as percent and only data is considered with at least 3 data points per time interval.

Sensitivity

The cross-sensitivity against T and RH is tested for the chamber experiments for all measured parameters, but only for CO_2, VOC, and PM, the sensors were exposed to external sources. The sensitivity of the sensors was evaluated using a scatterplot with the reference and sensor values on the x and y axes, respectively, and in which the data pairs (reference-LCS) are color-coded according to the ambient RH or T with a scale ranging from 100 % to 0 % (10°C to 45°C) represented by a transition from red to blue with white representing 50 % RH (27.5°C).

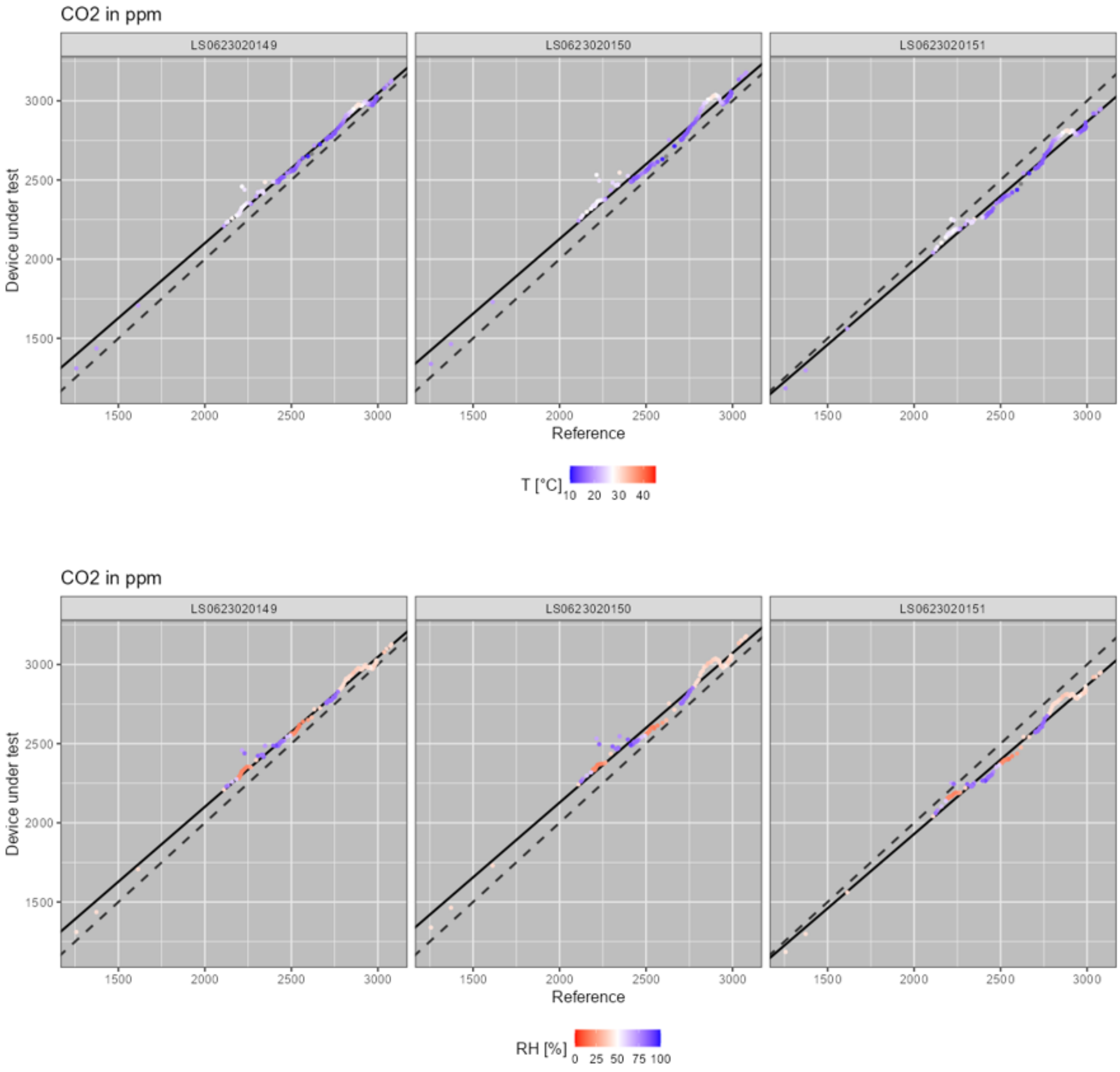

Figure 7 Exemplary results of the sensitivity of the CO_2 sensors to T and RH.

All of these were done under T3.1.a of WP3 which is also campaign 1 (C1) – “Evaluation of low-cost sensorics” under WP4 T4.2. The results of these activities will be presented in the campaign deliverables (C1.1, C1.2, and C1.3) under D4.2 – “A compendium of pilot reports and findings” by M32.

3. Indoor Air Pollutants Module

This module consists of all the methods and tools used in EDIAQI to investigate indoor air pollutants not measured by the any of LCS devices. These include chemical air pollutants, toxicological and biological contaminants, and emerging pollutants/parameters such as microplastics, radon, UFP, and BC which are covered by T3.1c and T3.1d and is spread over 6 pilots and campaigns and is summarised in Table 6.

3.1 Filter sampling protocols

The components of indoor air provide essential information to investigate which specific aspect (chemical composition, toxicology, microbiology) have an impact on human health. Unfortunately, this type of analysis does not exist in a "low-cost" form, especially online methods. Nevertheless, in EDIAQI, several methods were employed and are being developed to determine the composition of indoor air through offline analysis of gases and particulates collected on a filter. The following subsections describe each filter sampling method employed in EDIAQI.

3.1.1 Passive sampling with Radiello®

To determine concentrations of chemical pollutants, passive filter sampling was done using Radiello®. Although most extensively done in the Ferrara pilot, passive sampling is also/will be performed in the Zagreb, Estonia, Vilnius, and Seville pilots and campaigns. The Radiello is a certified instrument (EN 13528: 2002; EN 14662-4.5: 2005) composed of an open cylindrical filter which collects pollutants from air passively on its diffusive surface. As it is a passive sampler, it requires no loud pumps, power, and heavy equipment to operate making it suitable for indoor air monitoring. Radiellos are used in the Ferrara, Seville, Vilnius, and Tallinn pilots and campaigns specifically for determining concentrations of VOCs. The Zagreb pilot used an active sampler and is described in section 3.1.2. The Radiello is a low-cost way of sampling the air, but handling it requires care. Prior to installation, the Radiellos are stored in a refrigerator at a temperature of 7-8°C inside its packaging. The samplers are then carried in an appropriately sized thermal bag containing coolers to maintain the temperature. For sampling, they can be affixed on clothes or any other surfaces. In EDIAQI, the samplers were placed on walls at a height of between 1.5 and 1.8 meters and away from direct sunlight. When installing in outdoor settings, the samplers are placed at the same height and in an area protected from rain but well ventilated. Sampling usually lasts for 7 days and when done, the samplers are removed, resealed in a glass tube, labelled, and stored in a refrigerator at 7 - 8°C. For VOC analysis, the cartridges can be stored for a maximum of 6 months but for aldehydes only 60 days.

3.1.2 Active sampling

Active sampling is the method which requires pumps for sample collection and is suitable for airborne particulate matter as well as gaseous pollutants. It is performed by pumping air through a sampling media – a tube containing appropriate sorbent for gases, or a filter for particulate matter. Active sampling is performed in Zagreb. For active VOC sampling, the flow rate through the tube with sorbent should be in a range of a few millilitres per minute, while for PM sampling higher flow rates are required (3-5 L/min). Flow rates should be set and verified before sampling with a calibrator designed for this purpose. Devices for PM sampling is commercially available with an integrated pump and have impactor inlets for different filter diameters (e.g. 25 mm, 47 mm) and different fractions of particulate matter (PM_{10}, $PM_{2.5}$, PM_1). In Zagreb Pilot, active sampling is used for parallel collection of VOC and PM_1 in the indoor and ambient air. PM_1 fraction of particulate matter is collected on quartz filter continuously for seven days to collect a large enough sample for later PAH determination. VOC are collected on sorbent tubes for 50 minutes. This sampling time was selected due to high sensitivity of thermal desorption technique coupled with gas chromatography-mass spectrometry, which was later used for VOC analysis. The limitation of thermal desorption is that there is no possibility of dilution after sampling so longer exposure, even with 24-hour passive sampling, give samples which are out of the measuring range. In order to determine the representativeness of 50-min VOC active sampling, in selected households in parallel with active VOC sampling, passive Radiello samplers will be exposed over a week and will be analysed later by UMOL by method described by UMOL in section 3.2.2.

3.1.3 Dust collection

Dust samples are collected in households in Zagreb and surrounding places in Zagreb County, Croatia for two types of analysis. In each home, household members are requested to provide the contents of their vacuum cleaner bags and asked how long the content is in there. Also, all participants are asked to fill in a questionnaire regarding building characteristics (i.e. type of house; construction year; renovations at last five year; number of residents; type of household heating; type of cooker – gas or electric; area covered with carpets; number of padded furniture; number of curtains; number of electronic devices; number of windows). Collected dust samples are transported to the laboratory and after elimination of non-dust particles, samples are sifted twice through a 500 µm stainless steel mesh and then homogenised on a rotating mixer for 24 h (Jakovljević et al., 2022). All dust samples are stored in clean glass flask in a dark place at room temperature until analysis. The second type of analysis is the collection of dust samples from children's bedding using DUSTREAM® Collector vacuum cleaner filters that are placed on the vacuum cleaner nozzle for the analysis of bacterial and fungal composition. The samples are then stored at -20°C until DNA isolation to preserve genetic material and to eliminate mites.

3.1.4 Microplastics collection

The Ferrara and Zagreb pilots and the Vilnius campaign are investigating microplastics in the air. Below are the methods they used in collecting microplastics.

Vilnius campaign

A glass fibre filter (pore size, 1.6 µm, 47 mm, "Branchia") in a glass Petri dish and an empty pre-cleaned glass Petri dish are exposed to the indoor air to collect microplastic particles samples. The filters are placed at a height of about 70–75 cm above the ground, corresponding to the height of a student table.

The passive sampling method was also chosen for outdoor air samples. A glass container (height: 0.07m, collection area: 0.005675 m^2) was placed on a platform and used to collect microplastic particles. The duration of the passive sampling is one week (7 days). Duplicate samples are collected. The filters and glass containers are changed once a week for 12 months.

Zagreb Pilot

Microplastics particles will be collected in indoor air, in households, with the same method for passive sampling applied in the Vilnius campaign. A glass microfiber filter (Whatman GF/A, 47 mm) in a glass Petri dish and an empty pre-cleaned glass Petri dish will be exposed for one week (7 days) at a height of about 70–75 cm above the ground. Duplicate samples will be collected.

Ferrara Pilot

To standardise the sampling of microplastics, the Ferrara pilot will also use the same protocol used in the Vilnius and Zagreb pilots. Furthermore, UMOL's analytical chemistry group is constantly engaged in the research and development of innovative, eco-sustainable and low-cost methodologies to optimise sampling systems. The development of a microplastic sampling method based on a low volume sampler is under experimental evaluation. To date, no results in line with the standardised procedure are available. The new procedure will be added to the standard one as its functionality is developed and optimised during the project. For the Ferrara pilot, two samplings for microplastics will be carried out on all the sites, one in winter and one in summer respectively. The sampling will last 7 days and will be carried out in conjunction with the planned sampling of VOCs and aldehydes.

3.2 Analytical methods

This subchapter describes all the analytical methods used to determine the amounts of various pollutants from the particles collected on active and passive samplers.

Table 6 Summary table of analytical methods used to characterise pollutants collected through filter sampling

Parameter	Sampling method	Analytical method(s)	Pilot
VOC	Passive sampling using Radiello	Solvent desorption coupled with gas chromatography-mass spectrometry	**Ferrara, Seville, Estonia, and Vilnius**
VOC	Active sampling using sorbent tubes	Thermal desorption coupled with gas chromatography-mass spectrometry	**Zagreb pilot**
Aldehydes	Passive sampling using Radiello	High-performance liquid chromatography with a UV detector	**Ferrara, Seville, Estonia, and Vilnius**

This project has received funding from the European Union's
Horizon Europe Framework Programme under grant agreement № 101057497.

PAHs	Active sampling method	High-performance liquid chromatography with a fluorescence detector	**Zagreb pilot**
PM_1	Active sampling method	Gravimetrically	**Zagreb pilot**
Microplastics	Passive sampling method	Optical microscopy, µ-FTIR spectroscopy	**Vilnius campaign**
	Passive sampling method	Optical microscopy, µ-FTIR spectroscopy	**Ferrara pilot**
	Passive sampling method	Optical microscopy, µ-FTIR spectroscopy, LDIR spectroscopy	**Zagreb pilot**

3.2.1 PM_1 fraction of particulate matter

PM_1 mass concentrations were determined gravimetrically according to the EN 12341 standard. Before sampling, quartz filters were conditioned for 48 hours at relative air humidity 50±5 % and temperature 20±1 ˚C before first weighing and reweighing after the subsequent 24 h. The same procedure was applied after sampling. A microbalance Mettler TOLEDO MX5 with a resolution of 1 µg was used.

3.2.2 Volatile organic compounds (VOC)

In Zagreb pilot, VOCs were collected on conditioned tubes packed with a combination of porous polymer, graphitised carbon black, and carbonised molecular sieves (Markes, Llantrisant, United Kingdom). Tubes with samples were heated in thermal desorber up to 320 ˚C, and a helium flow was applied. For separation, DB-624 UI capillary GC column (6 % cyanopropyl/phenyl, 94 % polydimethylsiloxane, 60 m, 0.32 mm internal diameter, 1.80 µm film thickness, 60 m length, Agilent Technologies, Santa Clara, CA, USA) was used. For determination of VOCs thermal desorption coupled with gas chromatography/mass spectrometry (TD-GC/MS) instrument was used. The following 19 VOCs were determined: 2-methylpentane, methylene chloride, methylcyclopentane, Chloroform, 2-methylhexane, cyclohexane, benzene, heptane, trichlorethylene, methylcyclohexane, toluene, tetrachlorethylene, ethylbenzene, m-p-o xylene, styrene, 1,3,5-trimethylbenzene, 1,4-dichlorobenzene.

In the other pilots and campaigns, the cartridges from the Radiello samplers were analysed for VOCs using the following procedures:

The analytes from the cartridge were extracted through chemical desorption with solvent. Without removing the Radiello cartridges from the glass container, 2 mL of CS_2 and 100 µL of Internal Standard (I.S.) were introduced into the test tube. The I.S. is chosen such that its retention time falls in a clear area of the gas chromatogram. Compatibly with this need, 2-fluorotoluene was used. Only class A calibrated pipettes or dispensers are used. The glass tube containing the cartridge, the I.S. and the extraction solvent are sonicated for 30 minutes. The cartridge is then removed from the glass tube which was then discarded. Once sonification has been carried out, it is recommended to carry out the analysis in a very short time. Inject 1 µL of the solution directly to the GC-MS.

The instrument used for VOC analyses is a gas chromatograph combined with a mass spectrometry detection system (GC-MS). DB-VRX 122- 1564 capillary GC column (60 m length, 0.32 mm internal diameter, 1.40 µm film thickness, Agilent Technologies, Santa Clara, CA, USA) was used.

All quantifications are calculated by performing the Peak area / I.S. area ratio. The quantification of the analytes occurs by extrapolation from the respective calibration lines. The latter are previously optimized and constructed using scalar concentrations based on the detection and quantification limits of both the method and the instrument.

The following 17 VOCs were determined:

- Aliphatic: methylcyclopentane, cyclohexane, 2-methylpentane, heptane, 2-methylhexane
- Chlorinated: methylene chloride, chloroform, trichlorethylene, tetrachlorethylene, 1,4-dichlorobenzene
- Aromatic: benzene, toluene, ethylbenzene, o-xylene, m-p-xylene, styrene, 1,3,5-trimethylbenzene

3.2.3 Aldehydes

The sampling methods for aldehydes are like those described for VOC in section 3.1.1 The main difference is the cartridge used for this is a stainless-steel net cartridge filled with 2,4-dinitrophenylhydrazine (2,4-DNPH) coated Florisil®. The duration of optimal exposure varies with the expected concentration. Recommended exposure times are shown in Table 7.

Table 7 Recommended exposure times for passive sampling of aldehydes using specific Radiello

	External environment	Internal environment	Work environment	
			Average concentration	Peak concentration
Minimum	8 hours	8 hours	2 hours	15 minutes
Maximum	7 days	7 days	8 hours	1 hours

In relation to the high concentrations of formaldehyde, sampling between 8 and 12 hours is recommended.

The recovery of the analytes from the cartridge occurs by chemical desorption with solvent. Introduce 2 mL of HPLC grade acetonitrile into the tube containing the cartridge using a class A calibrated pipette. Shake occasionally for 30 min. Remove the cartridge and discard it. Filter the solution through a 0.45 µm acetonitrile-resistant filter and keep it tightly capped until analysis. The solution is stable for approximately 30 days, but immediate analysis is recommended. If analysis is deferred, store the solution at 4°C.

The instrument used for aldehyde analyses is a liquid chromatograph combined with a spectrophotometric detection system (HPLC-UV). A C18 reverse phase column is installed on the instrument with the following characteristics: 150 mm in length, 4.6 mm in diameter, 5 µm grain size of the support.

All analyses are carried out by injecting 25 µL of solution using an integrated autosampler according to the following elution gradient:

- solvent programmed: isocratic elution for 10 min. with acetonitrile/water 38:62 v/v, gradient in 10 min. to acetonitrile/water 75:25 v/v, inverse gradient in 5 min. to acetonitrile/water 38:62 v/ v.
- flow: 1.9 mL/min
- detector*:* set at a wavelength of 365 nm.

All quantifications are calculated by extrapolating from the respective calibration lines. The latter are previously optimised and constructed using scalar concentrations based on the detection and quantification limits of both the method and the instrument. The following 9 aldehydes were determined: formaldehyde, acetaldehyde, propanal, acrolein butanal, pentanal, hexanal, glutaraldehyde, benzaldehyde.

3.2.4 Polycyclic aromatic hydrocarbons (PAH)

Weekly PM_1 samples collected on quartz filters were extracted in an ultrasonic bath with a solvent mixture of toluene and cyclohexane. After extraction extracts were centrifugated and evaporated to dryness in a mild stream of nitrogen. Then samples were re-dissolved in acetonitrile.

For extraction of PAHs from dust sample, the accelerated solvent extraction (ASE) was used. About 0.5 g of each dust sample was weighed, dust samples were mixed with a diatomaceous earth and transferred in an extraction cell. The extraction was carried out at 125 ˚C in two static cycles, as extraction solvent mixture of cyclohexane and toluene was used. Extracts were evaporated to dryness by Rocket GeneVac. Samples were resolved in acetonitrile, centrifuged 10 min at 3000 rpm, and passed through a syringe filter 13 mm, 0.2 µm into the vials for chromatography (Jakovljević et al., 2022).

The analysis of PAH was carried out using a high-performance liquid chromatography (HPLC) with a fluorescence detector. For separation of PAH Zorbax PAH (4.6 x 100 mm, 5µm) column was used. Mixture of acetonitrile and water (60:40, v:v) was used as a mobile phase. The following 11 PAHs were determined: fluoranthene (Flu), pyrene (Pyr), benzo(a)anthracene (BaA), chrysene (Chry), benzo(j)fluoranthene (BjF), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), benzo(a)pyrene (BaP), dibenzo(a,h)anthracene (DahA), benzo(ghi)perylene (BghiP), and indeno(1,2,3-cd)pyrene (IP).

3.2.5 Microplastics

The descriptions of the different analytical methodologies used by the Ferrara and Zagreb pilots and Vilnius campaign to determine the concentration of airborne microplastics are given below.

Vilnius campaign

Optical microscopy is a commonly utilised method for microplastics analysis, employing visible or ultraviolet light to magnify and observe particles. By scrutinising the morphology, color, and dimensions of microplastics under a microscope, analysts can differentiate them from other substances. This technique enables swift sample screening, aiding in the recognition of various forms like fibres, fragments, or beads. Nonetheless, optical microscopy has limitations in polymer identification, necessitating supplementary methods for comprehensive characterisation.

µ-FTIR (Fourier-transform infrared spectroscopy) with an FPA (Focal Plane Array) detector and imaging is an advanced technique used for comprehensive microplastic analysis. This method involves exposing microplastic samples to infrared radiation and examining the absorption spectra of the resultant signals. FPA-FTIR utilises a grid of detectors to scan isolated microplastic residues on a filter paper with high lateral resolution, enabling analysis and identification of microplastic particles <20 µm without the need for pre-sorting the filter area. This technology allows for the recording of numerous spectra in a single measurement or thousands of spectra within a minute for microplastic analysis, alongside capturing dimensions for each particle size. The obtained spectra are then compared against a database of various natural and synthetic polymers within the software library, which has been established through rigorous benchmark tests emphasising quality and accuracy.

Zagreb pilot

Laser direct infrared (LDIR) spectroscopy is used for detecting, quantifying and characterising microplastics by shape, size and polymer type. This method is able to quantify microplastic particles down to a diameter of 20 µm and categorise them by shape as fibres, fragments or spheres. The method uses a quantum cascade laser as the IR source in a wavenumber range of 1800 to 975 cm^{-1}. The obtained spectra are compared to the instrument library to identify a type of polymer. The results will be further evaluated and compared with the µ-FTIR spectroscopy.

Ferrara pilot

The samples solution is transferred to a pyrolysis cup. The ethanol solvent is removed at 55 ◦C and 75 µL of an 8 mM $CaCO_3$ solution is added to stabilise the pyrolysis products. The analysis is performed using a gas chromatography - mass spectrometer equipped with a multi-shot pyrolyzer (pyro-GC/MS) and an automatic sampler. A capillary separation column is installed on the instrument. The collected compounds are separated and analysed by the analytical conditions used for pyro-GC/MS are as follows:

- Pyrolyzer: Furnace temp. 600°C, Interface temp. 320°C

- Injector: constant temperature at 300°C, splitless mode, constant carrier gas (He) flow at 1.0 $mL \cdot min^{-1}$;
- Column: 5 % diphenyldimethylpolysiloxane, 30 m length, 0.25 mm I.D., 0.5-µm film
- Oven: starts at 40 °C for 2 min., rises 20 $°C \cdot min^{-1}$ up to 280 °C and stops for 10 min., rises 40 $°C \cdot min^{-1}$ up to 320 °C and stops for 15 min.
- Transfer line: constant temperature at 300 °C;
- Mass spectrometer: constant temperature at 230 °C, acquisition in SIM mode. Ionization method: Electron ionization (EI)

The mass concentration (Cm), obtained from the chromatographic analysis, was converted to the number concentration of particles (Cp) by using the following equation, assuming that the particle shape was a sphere:

$$Cp = 6Cm/\pi\rho(D_{50})^3$$

where ρ is the density of each polymer and D50 is the aerodynamic diameter at a 50% cut point.

3.2.6 Radon

The integrated measurement of the average radon activity concentration using an SSNTD (solid-state nuclear track detectors) is based on the following elements: a) passive sampling 30 – 90 days, during which the alpha particles, including those produced by the disintegration of radon and its short-lived decay products, transfer their energy by ionizing or exciting the atoms in the polymer; this energy that is transferred to the medium leaves areas of damage called “latent tracks”; b) transport of the exposed sensors to the laboratory for the appropriate chemical, or electrochemical, processing, for example the transformation of the “latent tracks” into “etched tracks” counted with a suitable system; the number of these “etched tracks” per surface unit area is linked to the exposure of the radon by the calibration factor previously defined for sensors from the same manufacturing batch of SSNTD processed chemically, or electrochemically, and counted under the same conditions; and c) determination of the average activity concentration from the radon exposure value, the sampling duration and consideration of the background noise.

Additionally, a good screening method for indoor radon determination is a 3-day measurement with activated charcoal filters. The principle is that radon is adsorbed on activated charcoal encapsulated in a container. The ^{222}Rn activity concentration is determined by gamma-ray spectrometry of its decay products (^{214}Bi and ^{214}Pb) after their equilibrium is reached. Both methods are standardised (ISO 11665-4:2021).

By now radon was measured only in Zagreb pilot but will probably be extended to other pilots as well.

3.2.7 Microbiome

Sample collection and DNA isolation

Dust samples are collected from children's bedding using DUSTREAM® Collector vacuum cleaner filters that are placed on the vacuum cleaner nozzle. The samples are then stored at -20°C until isolation to preserve genetic material and to eliminate mites. Dust is weighted on analytic scale Axis ALN120 and target mass of each sample was around 50 mg. A mass of 50 mg was chosen after several trial isolations and has showed to have the best yield. Isolation of genetic material is carried out using DNeasy ® PowerSoil ® Pro Kit. DNeasy ® PowerSoil ® Pro Kit is used for isolation of microbial genomic DNA from all soil types and difficult samples such as sediment. Isolation steps are performed following DNeasy ® PowerSoil ® Pro Kit Handbook. Isolated DNA is stored at -20C as recommended in the protocol. See Figure 8

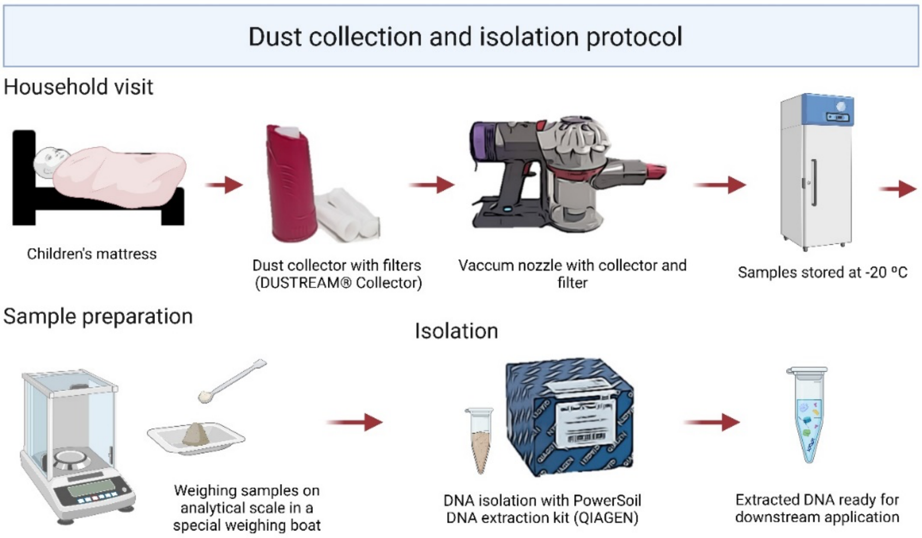

Figure 8 Illustration of the dust collection and isolation protocol in the Zagreb pilot

Library preparation and sequencing

Library preparation has been performed following Illumina 16S Metagenomic Sequencing Library Preparation protocol. Quantity of isolated DNA is examined on Qubit 3.0. Concentrations of DNA isolates range from 5.24-135 ng/uL. All samples are diluted and normalised to 5 ng/uL, according to the 16S Metagenomic Sequencing Library Preparation protocol. Diluted samples are amplified in PCR Agilent SureCycler 8800 using specific sets of primers for bacteria. The variable region V3–V4 of the 16S rRNA gene is targeted, using forward primer 341f (5′- CCTAYGGGRBGCASCAG-3′) and reverse primer 806r (5-GGACTACHVGGGTWTCTAAT-3). PCR protocol for bacteria is: 95°C for 3 minutes, 30 cycles of 95°C for 30 seconds, 55°C for 30 seconds and 72°C for 30 seconds and a final step of 72°C for 5 minutes. A negative template-free control is also included in this step. After the PCR, quality of PCR products and size of the fragments is verified on the automated electrophoresis platform 4200 TapeStation System. The next step includes clean-up of PCR products using MagSi-NGSPREP Plus* beads. Then the index PCR is performed when unique adapters are attached to each amplicon product, followed again by a clean-up using MagSi-NGSPREP Plus* beads. The same program as in the first PCR step is used, but with a reduced number of cycles (15 cycles). In the next step the libraries are again quantified using Qubit 3.0., normalised using the procedure described in the Illumina 16S Metagenomic Sequencing Library Preparation protocol and pooled. Pooled libraries are denatured with NaOH and denatured libraries are adjusted to a final concentration of 16 pM. The run includes a 5.0% PhiX internal control. MiSeq Reagent Kit v3 is used for sequencing and after sequencing on the MiSeq instrument demultiplexed fastQ-files with 16S rRNA gene and ITS fragments are generated.

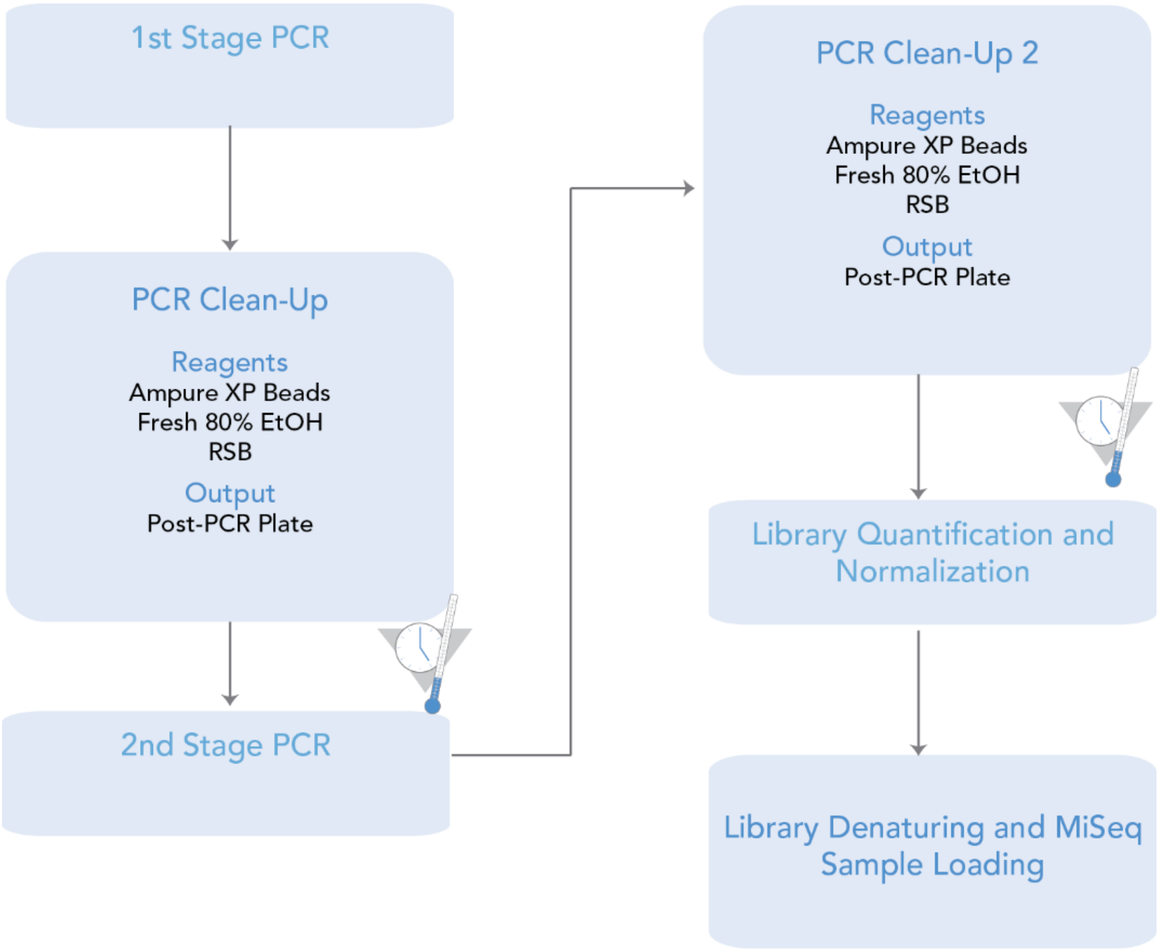

Figure 9 Illustration of the library preparation and sequencing for the DNA extracted from the dust samples

Data analysis

The obtained 16S rRNA gene and ITS fragments will be processed at TUG using well established bioinformatic pipelines. The raw sequences will be demultiplexed using cutadapt, followed by removal of low-quality and chimeric sequences using the DADA2 algorithm. Feature tables and amplicon sequencing variants (ASVs) will be generated within QIIME2 and subsequently classified with the vsearch algorithm and the most recent SILVA v132 (bacteria) and UNITE (fungi) databases. Data transformation, statistical analysis, and microbial community profiling will be done within R and R studio. This will include routine analysis and visualisations, such as evaluation of alpha and beta diversity and relative abundance. General linear models will be established to study influencing factors, derived from sensors monitoring (indoor) air quality. Furthermore, indicator taxa will be identified by constructing co-occurrence networks.

4. Tools for IAP System Set-up

As the Internet of Things (IoT) experiences exponential growth, the deployment of wireless sensor networks (WSN) has become ubiquitous, monitoring diverse infrastructures across various domains such as healthcare, energy, transportation, smart cities, building automation, agriculture, and industry. This surge in data generation necessitates effective visualisation methods to make sense of the vast amounts of information produced by IoT devices. The integration of IoT devices in smart buildings, coupled with Big Data technologies and visual analytics tools, has transformed indoor air quality monitoring systems. The holistic approach encompassing room and building analytics, visualisations, benchmarking, anomaly detection, and predictive modelling ensures a comprehensive understanding of indoor environmental conditions. The scientific precision applied to these monitoring systems contributes to informed decision-making, fostering a healthier and more comfortable indoor living and working environment. As smart buildings continue to evolve, advancements in indoor air quality monitoring will play a pivotal role in shaping the future of sustainable and intelligent living spaces. In the next chapter, we summarised the advancements of IAQ research in the monitoring technology and visualisations domain. The 20 Best Practices on system set-up, based on an extensive IAQ projects review, will help future research to make well-informed decisions for their IAQ observatories set-up(s). Task T3.2 structure is explained below on Figure 10, based on the overall EDAQI project structure displayed above on Figure 1:

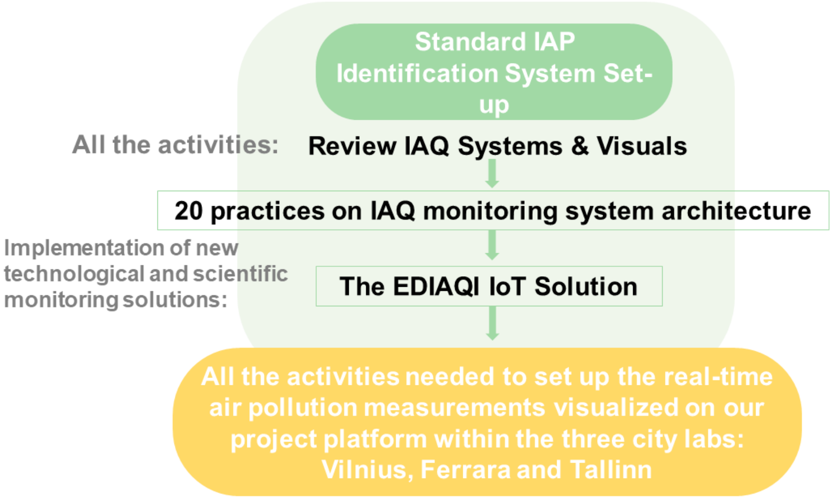

Figure 10 Diagram illustrating the structure of T3.2 within the EDIAQI project

In the following subsections, we report on how these three cities achieved their respective city labs by covering all the technical aspects for setting up a monitoring station, aimed at guiding future researchers and by presenting the T3.2 observatory and widget that is aligned with the extensive literature review of IAQ project carried out in the past 20 years. In addition, the characterisation of IAQ in the households in Zagreb pilot is also described.

4.1 20 best practices of technical setup for real-time air pollution measurements to guide future IAQ researchers

Sunyoung Kim (2010), pioneered a home-based $PM_{2.5}$ monitoring system, inAir, aimed at visualising and disseminating real-time indoor air quality information via an iPod, with the overarching objective of heightening public awareness about IAQ. The inAir application employed standard Wi-Fi networking to seamlessly transmit collected air quality data to a central server and receive shared data from other users in real-time. Additionally, it served as a robust platform for generating visualisations based on both local and remote air quality datasets. For indoor air quality measurement, a commercially available air quality monitor, the DC1100 manufactured by Dylos, was utilised. The measured data was obtained by embedding an AVR-based Arduino within the air quality monitor. The Arduino, intricately connected to an iPod Touch, was instrumental in processing, visualising, and wirelessly transmitting the data. The integrated inAir system served as a stationary platform, offering a comprehensive visualisation of both measured and shared indoor air qualities across various locations. This pioneering project marked one of the earliest instances of providing users with an effective screen-based visual representation. After 2010, mobile-phone-based visualisation and information presentation methodologies started to gain prominence in the field.

Cheng et al. (2014) devised a cloud-based $PM_{2.5}$ monitoring system tailored for office buildings. Leveraging the AirCloud API and a visualisation web app, they implemented a cloud-based architecture incorporating a Raspberry Pi microcontroller. This setup facilitated the collection of both indoor and outdoor $PM_{2.5}$ air pollution level data from a commercial monitor and public websites, respectively. A computational model was intricately crafted to autonomously activate HVAC systems in office buildings a few hours prior to working hours, particularly during periods of elevated air pollution. Additionally, Cheng et al. (2014) introduced another cloud-based $PM_{2.5}$ monitoring system with a distinct objective. This initiative primarily focused on designing a cost-effective $PM_{2.5}$ sensor and formulating cloud-based analytics algorithms. These algorithms, powered by artificial neural networks, served to calibrate the low-cost $PM_{2.5}$ sensors and infer $PM_{2.5}$ mass concentrations in locations lacking dedicated sensors. The monitoring process hinged entirely on meticulously designed mechanical structures to maintain optimal airflow. On the cloud side, the authors established an air quality analytics engine, capable of learning and developing models based on measured air quality data obtained from sensors. This cloud-based engine played a pivotal role in real-time calibration of mini Air Quality Monitors concurrently inferring $PM_{2.5}$ mass concentrations. The system demonstrated commendable accuracy at a reduced cost, ensuring extensive coverage capabilities.

Alhmiedat and Samara (2017) engineered a low-cost ZigBee WSN architecture designed for real-time IAQ monitoring. The system allows for the installation of four sensor nodes within the indoor environment, enabling data collection over a span exceeding four weeks. The environmental data collected are subsequently transmitted for analysis utilising the ZigBee communication protocol. In their study, the authors conducted IAQ assessment during kitchen cooking activities, focusing on the analysis of CO_2, NOx, and ammonia. Various sensors strategically placed in the bedroom, living room, and office area gathered relevant input. This setup facilitates real-time monitoring of all factors contributing to indoor air quality. However, potential enhancements to the system involve addressing power consumption issues and refining the accuracy of monitored parameters.

Wu et al. (2017) conducted research that could prove to be useful for accompanying pilots in the EDIAQI project, in the Digital Twin and AI tasks, namely in WP4. They showcased that by mobile microscopy and machine learning techniques, it is possible to achieve precise quantification and impact analysis of PM. The authors introduced a cost-effective and portable PM imaging, quantification, and sizing model named C-Air, with results accessible through a mobile-based application. The implementation involved the utilisation of a remote server for the automated processing of crucial digital holographic microscope images, ensuring accurate PM measurements. The system demonstrated the capacity to furnish valuable statistics pertaining to density distribution and particle size, achieving a sizing accuracy of approximately 93%. Notably, C-Air can be customised to detect specific air bioaerosol particles such as mold and pollens. The performance evaluation of C-Air encompassed testing in both indoor and outdoor air environments.

Zampolli et al. (2004) devised a low-cost model incorporating an electronic nose with a solid-state sensor array for the purpose of IAQ monitoring. Employing advanced pattern recognition techniques and an optimised gas sensor array, the research focused on quantifying NOx, CO, VOCs, and RH. The electronic nose's performance was assessed under real operating conditions, continuously monitoring NO_2 concentrations at 20 ppb and CO at 5 ppm for a minimum of 45 days. This methodology not only facilitated the identification of individual pollutants but also discerned the presence of diverse contaminants in the test environment. The system demonstrated feasibility in detecting NO_2 and CO levels in indoor air. The obtained results were subsequently utilised to effectively manage the operation of heating, HVAC systems in indoor environments, ensuring optimal air quality without disruption.

Kim et al. (2014) study centred on the real-time assessment of IAQ by focusing on seven parameters (CO_2, VOCs, SO_2, NO_x, CO, PM, O_3). Experimental trials were conducted in three distinct settings: a large church, a medium-sized classroom, and a small living room, aiming to discern the influence of various factors on IAQ. The researchers deduced that numerous elements contribute to the modulation of indoor air quality, including wind patterns, spatial location, airflow dynamics, the presence of individuals, and room dimensions. A noteworthy observation surfaced regarding the substantial power consumption associated with gas sensors. Consequently, the critical selection of appropriate sensor nodes is imperative. The findings underscore the significance of judiciously evaluating sensor characteristics and environmental settings for effective calibration, ensuring the reliability of the system and the accuracy of obtained results. Future research endeavours are encouraged to delve into refining environmental settings and sensor attributes to enhance the robustness of calibration processes.

Yu and Lin (2015) developed an advanced wireless sensing and control system to address health concerns arising from IAP. The system consists of three integral components:

- Data Acquisition: This segment facilitates the collection of environmental indicator values, including CO_2 concentration, RH, and temperature, through a polling mechanism.
- Data Analysis: Responsible for data collection, this component interfaces with the AutoRegressive Integrated Moving Average (ARIMA) prediction model to analyse air quality trends within the premises.
- Data Feedback: This component triggers necessary actions based on fuzzy results, potentially issuing warning messages or automatically adjusting fan speed. Each sensor node in this hardware architecture adheres to the IEEE1451.4 standard, with ZigBee technology establishing the communication channel.

  The software architecture is structured into three distinct sections:

- Data Monitoring Agent: Acting as a bridge between software and hardware.
- Air Quality Analysing Agent: Monitoring air quality trends and initiating relevant actions in response to elevated pollution levels.
- Application Agent: Providing services for data display, automatic control, and alerts.

  The final ARIMA prediction model-based IAQ monitoring system underwent real-time deployment in nine diverse areas of Taiwan, including the Environmental Protection Administration, universities, and elementary schools. System performance evaluation involved two tests: validation of the accuracy of the prediction model and validation of energy-saving performance. The system facilitated informed decisions regarding ventilation equipment based on predetermined threshold levels of air quality parameters.

Pillai et al. [8] implemented a sensor network dedicated to IAQ monitoring utilising the Controller Area Network (CAN) interface. To facilitate real-time experimentation, sensors were strategically deployed in a defined area, with a serial standard bus communication network employed for seamless information exchange among them. The CAN protocol, specifically designed for high integrity serial bus communication, operates at high speeds, supporting information exchange rates ranging from 20 kbit s^{-1} to 1 Mbit s^{-1}. Leveraging the CAN protocol enabled researchers to establish a highly reliable, efficient, and cost-effective communication link between display nodes and sensor nodes. Rigorous hardware tests validated the system's capability, providing highly accurate IAQ monitoring with minimal processing time.

Abraham and Li (2014) presented a cost-effective Wireless Sensor Network (WSN) system tailored for IAQ monitoring. The system integrates low-cost micro gas sensors targeting CO, VOC and CO_2 with the Arduino microcontroller serving as the central processing unit. A mesh network was established using the ZigBee module, ensuring a communication solution characterised by low power consumption, cost-effectiveness, and wireless capability. Data calibration for the micro gas sensor networks was meticulously conducted through the Least-Square Method. This calibration methodology enabled researchers to assess the present state of IAQ while gathering valuable data for comprehending the long-term implications of poor air quality on human health. The proposed system underwent a comparative analysis with the standard GrayWolf System, revealing its independence from variations in humidity and temperature.

Kang and Hwang (2016) introduced an air quality monitoring system designed to evaluate the applicability of the Comprehensive Air Quality Index for precise assessment of IAQ. The authors further proposed a real-time Comprehensive Indoor Air Quality Indicator (CIAQI) system, renowned for its efficacy in navigating dynamic environmental changes. Notably, this system demonstrates high efficiency in processing capacity and minimal memory overhead. For the creation of a realistic experimental setup for monitoring indoor air environments, the authors incorporated sensors for VOC, PM10 (particulate matter with the aerodynamic diameter below 10 µm), CO, temperature, and humidity. System performance was benchmarked against the absolute concentration of pollutants considered for the ambient Air Quality Index (AQI) using a Simple Moving Average scheme. The results indicated that the proposed CIAQI system exhibits superior adaptability to real-time changes in IAQ. Additionally, owing to its modest memory utilisation, the system was identified as a cost-effective solution for Internet of Things (IoT)-based air quality monitoring.

Bhattacharya et al. (2012) developed wireless system dedicated to IAQ monitoring, concentrating on pivotal parameters encompassing humidity, temperature, gaseous pollutants, and particulate matter. The system employs a comprehensive approach to assess indoor environmental health, quantified through the AQI. Simultaneously, it provides real-time inputs for the control of HVAC systems. In alignment with smart building applications, the authors have developed a toolkit capable of measuring live air quality data, presented graphically and numerically for enhanced accessibility and analysis.

Ahn et al. (2017) designed a microchip incorporating six atmospheric sensors to measure VOCs, light quantity, humidity, temperature, fine dust, and CO_2. The assessment of atmospheric changes was carried out utilising deep learning models. The efficacy of the proposed Gated Recurrent Network (GRU) model was then benchmarked against alternative models, including Long Short-Term Memory (LSTM) networks and linear regression. The proposed system demonstrated superior performance, achieving an accuracy of 85% across diverse parameter settings, outperforming the comparison models.

Pitarma et al. (2016) created an affordable IAQ monitoring unit by employing a WSN system, microsensors, XBee modules, and Arduino technology. They focused on five key IAP parameters: luminosity, CO_2, CO, humidity, and air temperature, all of which were monitored in real-time through a web portal.

The wireless communication network linking the sensors to the gateway was established using the XBee module, which employed the ZigBee networking protocol and adhered to IEEE802.15.4 radio standards. The sensors used for real-time measurements included the SHT10 sensor for Relative Humidity (RH) and temperature, the MQ7 sensor for CO, the T6615 sensor for CO_2 measurement, and the LDR5 mm sensor for light detection. The web interface was designed utilising a MySQL database and Personal Home Page (PHP). The primary objective of this system's design was to provide users with immediate updates on potential exposure risks within their living environment.

Benammar et al. (2018) engineered a comprehensive end-to-end indoor air quality monitoring system leveraging WSN technology. The system prioritised the measurement of key parameters, including RH, ambient temperature, Chlorine (Cl2), O3, NO2, Sulfur Dioxide (SO2), CO, and CO_2. Communication between sensor nodes and the gateway was facilitated through XBee PRO radio modules. Within the scope of this study, the sensor nodes comprised calibrated sensor units, a Waspmote data storage unit, and a Gas Pro sensor board serving as a sensor interface. The gateway's principal role involved processing IAQ data collected from targeted sites and ensuring reliable dissemination via a web server. The system seamlessly integrated with an open-source IoT web server platform named Emoncms, providing long-term storage and real-time monitoring of IAQM data. The design exhibited a sophisticated amalgamation of smart mobile standards, WSN, and various sensing technologies, culminating in the development of a scalable smart system for IAP monitoring. To address power requirements effectively, the authors implemented separate battery units dedicated to the sensor network.

Saad et al. (2013) devised a comprehensive environmental monitoring system dedicated to assessing parameters intricately linked to air quality. The primary focus encompassed RH, temperature, PM) and gaseous pollutants known to directly influence human health. Employing a WSN, data from the designated location were systematically collected and subsequently transmitted to the base station through the WSN node. To facilitate real-time analysis of IAQ, a bespoke server programme was developed and implemented on the computer system, acting as the central hub for accessing and processing the acquired data.

Tiele et al. (2018) directed their attention toward the design and implementation of a portable, economically feasible indoor environment monitoring system. The scope of this study encompassed pivotal parameters characterising indoor air quality, including sound levels, illuminance, CO, CO_2, VOCs, PM10 and $PM_{2.5}$, RH, and temperature. Experimental investigations were conducted both within indoor workspaces and outdoor environments. A quantifiable metric, the indoor environment quality index, was introduced by the authors to gauge the comprehensive percentage of indoor environment quality.

Moreno-Rangel et al. (2018) conducted a study evaluating the usability, accuracy, and precision of a cost-effective IAQ monitor in a residential setting. Addressing concerns related to cost and complexity associated with prevailing scientific solutions for IAQ monitoring, the authors introduced a dependable and budget-friendly system tailored for household use. The study concentrated on key parameters, including $PM_{2.5}$, CO_2, VOCs, RH, and temperature. Rigorous sensor calibration preceded installation to ensure measurement adequacy. Data analysis involved the utilisation of FOOBOT monitors, assessing the percentage of time pollutant levels exceeded thresholds established by the World Health Organisation. Additionally, statistical analysis for measurement accuracy enhancement was performed using IBM SPSS Statistics in this study.

Idrees et al. (2018) systematically addressed challenges in IAP by devising an Arduino-based platform dedicated to real-time IAQ monitoring. The study delved into critical aspects such as computational complexity, infrastructure considerations, and procedural efficiency in design. Utilising the IBM Watson IoT platform and Arduino board, the authors fashioned a prototype for the real-time IAQ monitoring system. The investigation targeted eight parameters significantly influencing human health in indoor environments: RH, temperature, O_3, SO_2, NO_2, CO, $PM_{2.5}$ and PM_{10}. A notable advantage of this system lies in its ability to alleviate the computational load on sensing nodes by nearly 70%, thereby extending battery life. To enhance measurement accuracy, standard calibration procedures were applied to sensor networks. The authors implemented a data transmission strategy aimed at minimising power consumption and reducing redundant network traffic. The proposed monitoring system comprised three integral layers: the sensing layer, edge computing layer, and application layer. The model achieved a commendable 23% reduction in overall power consumption, and its performance underwent validation in diverse environmental settings.

B.Sivasankari (2017) proposed an IoT-based system designed for IAQ monitoring. The analytical framework was implemented on a Raspberry Pi model, and various parameters were scrutinised, including Relative Humidity (RH), temperature, concentrations of NO_2, CO, and smoke. The study employed MQ series sensors, a Mics 2714 NO_2 sensor, an LM-35 sensor, and a DHT11 sensor for measurements. To facilitate direct interfacing of sensors with the Raspberry Pi module through eight distinct channels, an analogue-to-digital converter was integrated into the system. Notably, the system's functionality extended to generating alarms to signal elevated emissions concentrations, serving as a proactive indicator of heightened air pollution levels within the monitored premises.

Arroyo et al. (2019) introduced an air quality measurement system featuring a distributed sensor network coupled with a cloud based WSN infrastructure. The data collection in the field was facilitated by low-power ZigBee motes. Simultaneously, an optimised cloud computing system was deployed for the comprehensive processing, monitoring, storage, and visualisation of the acquired data. This laboratory investigation centred on the measurement of VOCs, including xylene, ethylbenzene, toluene, and benzene. The data processing phase employed sophisticated techniques such as Multilayer Perceptron, Principal Component Analysis, Support Vector Machine, and Backpropagation learning algorithms.

To sum up: various techniques exist for real-time monitoring, models based on WSN and IoT dominate research. The current imperative is to achieve and visualise real-time IAQ monitoring, issuing alerts to building occupants promptly. The IoT approach emerges as a vigorous solution, ensuring minimal power consumption, negligible time delays, and enhanced interaction with the physical world.

Table 8 List of different techniques which can be used for IAP monitoring

IAP standard identification set-up base:	Communication Interfaces	Microcontrollers	Data Access Systems	APIs
Particle (Spark Core)	Wi-Fi, cellular, and mesh networking	ARM Cortex-M3	Particle Cloud	RESTful API for seamless integration
Arduino	Wi-Fi, Ethernet, Bluetooth	Various Arduino boards with different microcontrollers	Arduino Cloud	Arduino Cloud API and compatibility with third-party platforms
Raspberry Pi	Wi-Fi, Ethernet	Broadcom BCM283x	Local storage, cloud platforms	Python scripts, integration with various cloud platforms
Adafruit IO	Wi-Fi, Ethernet	Compatible with various microcontrollers	Adafruit IO platform	RESTful API, MQTT

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Bosch IoT Suite	Wi-Fi, Zigbee	Supports various hardware, including Bosch sensors	Bosch IoT Cloud	RESTful API, MQTT
Microsoft Azure IoT	Wi-Fi, Ethernet	Compatible with various hardware	Azure IoT Hub	RESTful API, MQTT, AMQP
AWS IoT Core	Wi-Fi, Ethernet	Compatible with various hardware	AWS IoT Core	RESTful API, MQTT

A critical challenge in IAQ observatory development revolves around the high cost and substantial power consumption of sensor nodes. In real-time applications, these sensor units find placement in diverse environments, spanning industrial settings, homes, offices, and public buildings. In all instances, the sensor unit design demands meticulous consideration of size, cost, power efficiency, communication protocol, and performance under varying temperature and humidity conditions. Presently, sensor calibration stands as the primary hurdle for future researchers, aiming to guarantee precise real-time monitoring.

Efficient IoT systems offer a promising avenue in this domain. Leveraging IoT architecture and the Raspberry Pi microcontroller, equipped with built-in Wi-Fi communication features, facilitates rapid data transfer. The technical requirements for the most efficient IAQ monitoring in the EDIAQI pilots in WP4 are explained in detail in the next two chapters.

4.2 The EDIAQI IoT solution

The EDIAQI IoT solution adheres to a standard IoT architecture, comprising autonomous wireless devices situated at the network edge, responsible for collecting and transmitting data to a centralised Cloud platform. Additionally, the solution incorporates an Edge gateway tasked with aggregating data from all sensors within a building before forwarding it to the Cloud platform. This architectural framework is illustrated in Figure 11 below. Utilising mesh networking technology for sensor communication enables the deployment of a large number of sensors with minimal cost and configuration overhead

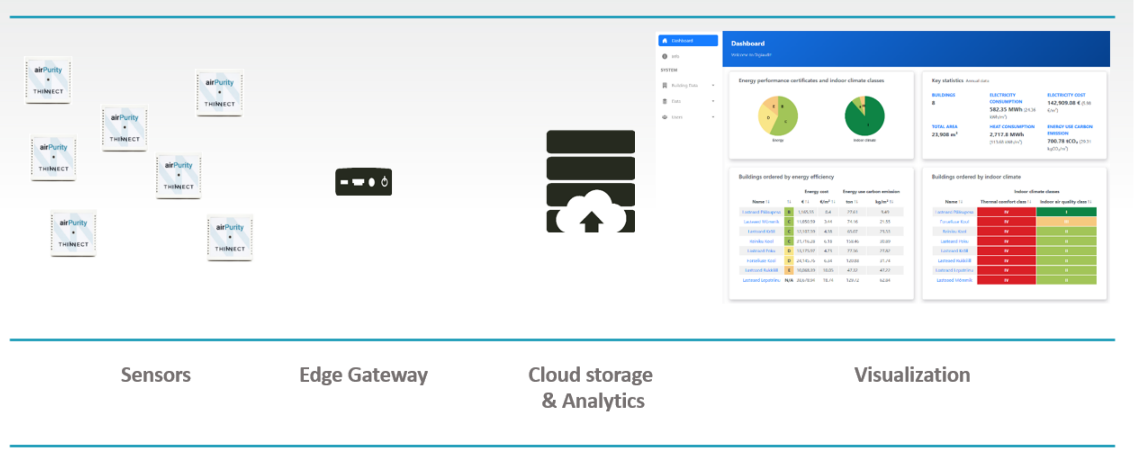


Figure 11 IoT sensing solution employing an Edge gateway.

The advantages of implementing a gateway-based solution leveraging a mesh network for sensor communications are twofold:

1. Increased deployment flexibility and elimination of the need for establishing or relying on network infrastructure, as opposed to WiFi-based alternatives.
2. Reduced investment and operational costs compared to cellular-based solutions.

Moreover, the EDIAQI IoT solution incorporates Mist computing architecture, distributing intelligence to the network edge for remote management of Edge functionality. Mist computing complements Fog computing, which locates intelligence in gateways at the network edge, and Cloud computing, where intelligence resides in the Cloud.

Through Mist computing, data can be pre-processed at Edge nodes, facilitating aggregation, averaging, and filtering as necessary. Intelligent data communication triggers can also be implemented to prompt immediate data transmission when predefined parameters deviate. This approach minimises data transmission to the Cloud, conserving power and enabling long battery life for battery-powered sensing devices, provided proper software implementation.

The combination of affordability, ease of installation, and battery-powered functionality streamlines the deployment of the recommended EDIAQI IoT indoor climate sensing solutions, delivering actionable insights to building occupants.

4.3 IT specifications for T3.2 observatory and widget for visual representation

To establish a robust IAQ monitoring system, this section outlines the IT requirements encompassing Mist, Fog, and Cloud Computing architectures, cloud computing, and IoT system requirements. Additionally, it elucidates the technical setup of sensors to monitor various parameters crucial for IAQ assessment, based on the survey in T3.2.2 carried out by TROPOS in spring 2022.

IT Specifications

Programming Mist, Fog, and Cloud Computing architectures for IAQ monitoring in the EDAQI project and beyond requires a multidisciplinary approach, combining expertise in embedded systems, networking, data analytics, and cloud computing. By leveraging the strengths of each architecture, organisations can deploy scalable, resilient, and cost-effective IAQ monitoring solutions tailored to their specific requirements and operational constraints.

1. **Mist, Fog, and Cloud Computing Architectures:**
    - Mist Computing: Implement edge computing solutions to process data locally, reducing latency and enhancing real-time response for critical IAQ monitoring.
    - Fog Computing: Utilise fog nodes to pre-process data collected from sensors before transmitting it to centralised cloud servers, optimising bandwidth usage and ensuring data integrity.
    - Cloud Computing: Employ cloud-based platforms for comprehensive data storage, analysis, and visualisation, enabling remote access and management of IAQ monitoring systems.
2. **Cloud Computing and IoT System Requirements:**
    - Scalability: Ensure the system can accommodate varying sensor deployments and data influxes, facilitating seamless expansion as monitoring requirements evolve.
    - Security: Implement robust encryption protocols and access controls to safeguard sensitive IAQ data from unauthorised access or tampering.

- Interoperability: Foster compatibility between different sensor models and communication protocols to facilitate seamless integration within the monitoring ecosystem.
- Data Analytics: Leverage advanced analytics tools to derive actionable insights from IAQ data, enabling predictive maintenance and proactive intervention to mitigate potential air quality issues.

Remote Monitoring: Enable remote access to IAQ monitoring dashboards and alerts through secure web or mobile interfaces, empowering users to monitor air quality status in real-time from anywhere.

Programming Mist, Fog, and Cloud Computing architectures for monitoring indoor air quality (IAQ) involves a combination of edge computing, fog computing, and cloud computing techniques to process, analyse, and store data collected from IAQ sensors. Below are steps to program each architecture:

Mist Computing:

a. **Edge Device Configuration:**
    - Identify edge devices (e.g., microcontrollers, Raspberry Pi) deployed within the monitoring environment.
    - Install operating systems (e.g., Linux) and necessary software libraries for data collection and processing.
    - Configure edge devices to communicate with IAQ sensors via appropriate interfaces (e.g., UART, SPI, I2C).

b. **Data Collection and Preprocessing:**
    - Develop firmware or software scripts to collect sensor data in real-time.
    - Implement algorithms for initial data preprocessing, such as noise filtering and data aggregation.
    - Ensure efficient resource utilisation to handle data processing tasks within the limited computational capabilities of edge devices.

c. **Local Analysis and Alerting:**

- Programme edge devices to perform basic data analysis tasks, such as threshold-based anomaly detection.
- Implement alerting mechanisms (e.g., email notifications, LED indicators) for detecting IAQ abnormalities or events of interest.

Fog Computing:

d. **Fog Node Setup:**
    - Deploy fog nodes (e.g., industrial gateways, edge servers) at strategic locations within the monitoring environment.
    - Configure fog nodes with appropriate hardware specifications and networking capabilities.

e. **Data Aggregation and Filtering:**
    - Develop middleware or fog computing software to aggregate sensor data from edge devices.
    - Implement data filtering algorithms to remove redundant or irrelevant data before transmission to the cloud.

f. **Local Processing and Decision Making:**
    - Program fog nodes to perform intermediate data processing tasks, such as statistical analysis or pattern recognition.
    - Implement decision-making logic based on local IAQ conditions and predefined rules or policies.

Cloud Computing:

g. **Cloud Infrastructure Setup:**
    - Provision cloud resources (e.g., virtual machines, databases) from a cloud service provider (e.g., AWS, Azure, Google Cloud).
    - Configure networking, security, and access control policies to ensure data confidentiality and integrity.

h. **Data Ingestion and Storage:**

- Develop APIs or data ingestion pipelines to receive sensor data from fog nodes or edge devices.
- Store IAQ data in cloud-based databases or data lakes, ensuring scalability, durability, and accessibility for analysis.

i. **Data Analysis and Visualisation:**

- Implement data analysis algorithms using cloud-based analytics services (e.g., AWS Lambda, Azure Machine Learning).
- Visualise IAQ trends, patterns, and anomalies through dashboards or web applications using frontend frameworks (e.g., Grafana, documented as the most used tool for IAQ visuals in the 20 Best Practices section).

j. **Integration and Automation:**

- Integrate IAQ monitoring system components with existing enterprise IT systems or third-party services (e.g., building management systems, weather APIs).
- Implement automation scripts or workflows for system maintenance, backup, and disaster recovery procedures.

3. **Technical Setup of Sensors (based on D3.2 Recommended parameters to monitor, listed here to utilise all data collection necessary for comprehensive IAP estimation):**

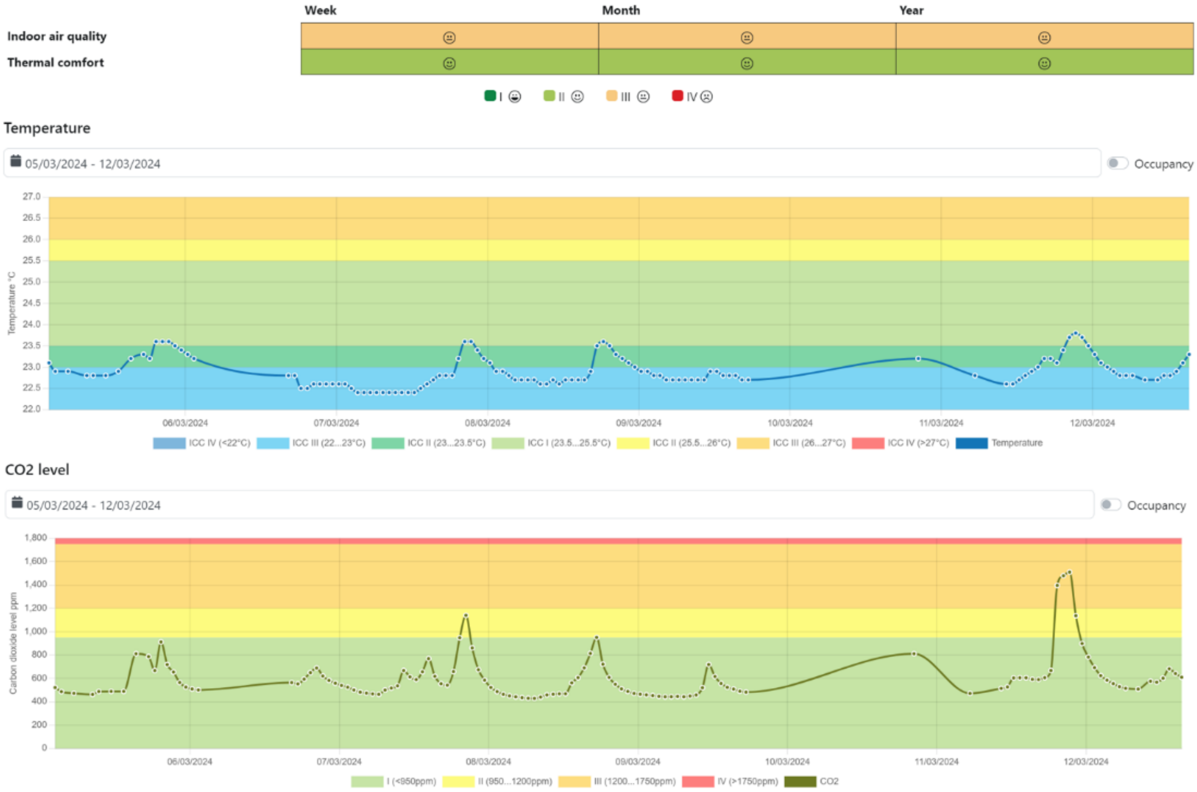
- **$PM_{2.5}$, PM_{10}, and PM_1 Monitoring:**
  - Utilise optical particle counters capable of measuring particulate matter (PM) concentrations in µg/m³.
  - Ensure sensors adhere to WHO guidelines, with a focus on detecting $PM_{2.5}$ and PM_{10} levels below annual mean thresholds of 10 µg/m³ and 20 µg/m³, respectively.
  - Optionally, include PM_1 measurement capabilities to assess finer particulate matter distribution for comprehensive IAQ evaluation.
- **Relative Humidity (RH) and Temperature (T) Monitoring:**
  - Deploy RH and T sensors to gauge environmental conditions affecting PM sensor accuracy and human comfort.

    - Opt for sensors with high accuracy and stability to provide reliable RH and T readings crucial for interpreting PM sensor data effectively.
- **Black Carbon (BC) Monitoring:**
    - Employ BC sensors utilising optical methods to estimate black carbon content in the atmosphere.
    - While not yet regulated, ensure sensors can detect BC concentrations in µg/m³, aligning with possible forthcoming EU guidelines for IAQ assessment.
- **NO and NO_2 (NOx) Monitoring:**
    - Install NO and NO_2 sensors to measure nitrogen oxide concentrations in µg/m³.
    - Given the health implications associated with NO_2 exposure, aim to maintain levels below WHO's interim target of 20 µg/m³ annually.
- **CO and CO_2 Monitoring:**
    - Deploy CO and CO_2 sensors to detect combustion-related gases in µg/m³ or ppm/ppb.
    - Ensure sensors can indicate elevated levels of CO and CO_2, alerting users to potential health hazards and external air pollution ingress.
- **Ozone (O_3) Monitoring:**
    - Utilise O3 sensors to measure ozone concentrations in µg/m³ or ppm/ppb.
    - Adhere to WHO's interim target threshold of 120 µg/m³ for O3 exposure, considering its respiratory health implications and synergistic effects with NOx.
- **Volatile Organic Compound (VOC) Monitoring:**
    - Deploy VOC sensors capable of detecting volatile organic compounds in µg/m³.
    - While individual VOC concentrations typically pose minimal health risks, monitor specific VOC components for potential carcinogenicity and indoor air quality degradation.

- **Sulphur dioxide (SO_2) Monitoring:**
    - Integrate sulphur dioxide sensors to assess sulphur dioxide -related health risks associated with $PM_{2.5}$ exposure.
    - Ensure sensors accurately measure sulphur dioxide concentrations in µg/m³, aiding in comprehensive IAQ evaluation.

The observatory (points 1-2 above) has the purpose of collecting and visualising data collected by the IoT indoor climate sensors (point 3 above). All data collected by sensors is associated with the area or room from where the data has been collected. For every data modality, such as temperature, humidity, CO_2 level, VOC level, PM concentration, room or area specific tags are created in the observatory information system. The approach also enables quick and simple visualisation and analysis of the room indoor climate based on the collected data based. Any sensor deployed in a room, or an area is associated with the specific system data tags with appropriate data modality for that area or room, which ensures that even in case a device is replaces, the data remains intact and can be processed. This approach eliminates the need for a permanent association in the data model between specific sensor devices and the rooms and areas they are located, providing more flexibility while maintaining strong data associations.

For the scientific observatory the data is visualised on data graphs that enables analysis of data. If needed, the data can be also downloaded for detailed analysis via KNOW platform. For each room a graph is created for every data modality that is collected in that room, enabling comprehensive analysis of the collected data in a graph format. For each graph the time period visualised can be specified by the user.



	Week	Month	Year
Indoor air quality	😐	😐	😐
Thermal comfort	🙂	🙂	🙂

Temperature

05/03/2024 - 12/03/2024 ○ Occupancy

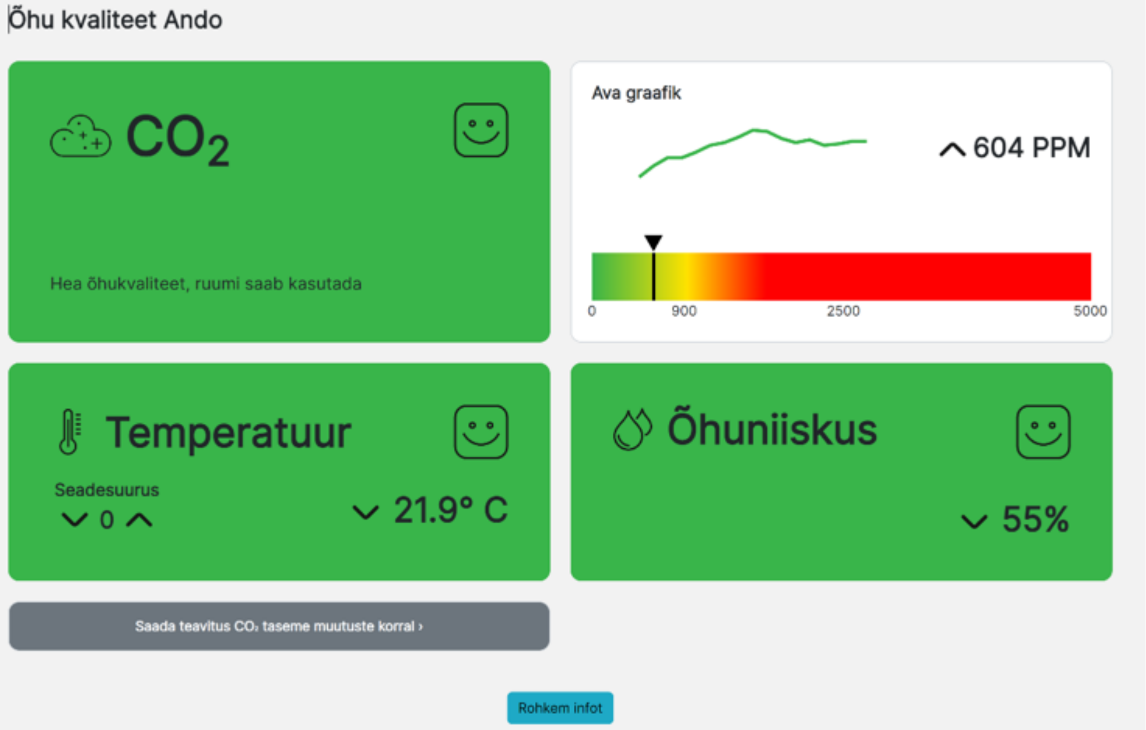
CO2 level

05/03/2024 - 12/03/2024 ○ Occupancy

Figure 12 The T3.2 Observatory

Science to citizen widget

To simplify the interpretation of the data by the citizens a visual widget was adopted that presents the indoor climate data in an easily understandable way for any user. The visual widget makes use of the same room or area specific data that is collected by the sensors and stored in the database. A pre-processing step for assessing indoor climate quality is applied prior to visualisation to enable an easily comprehendible visualisation.



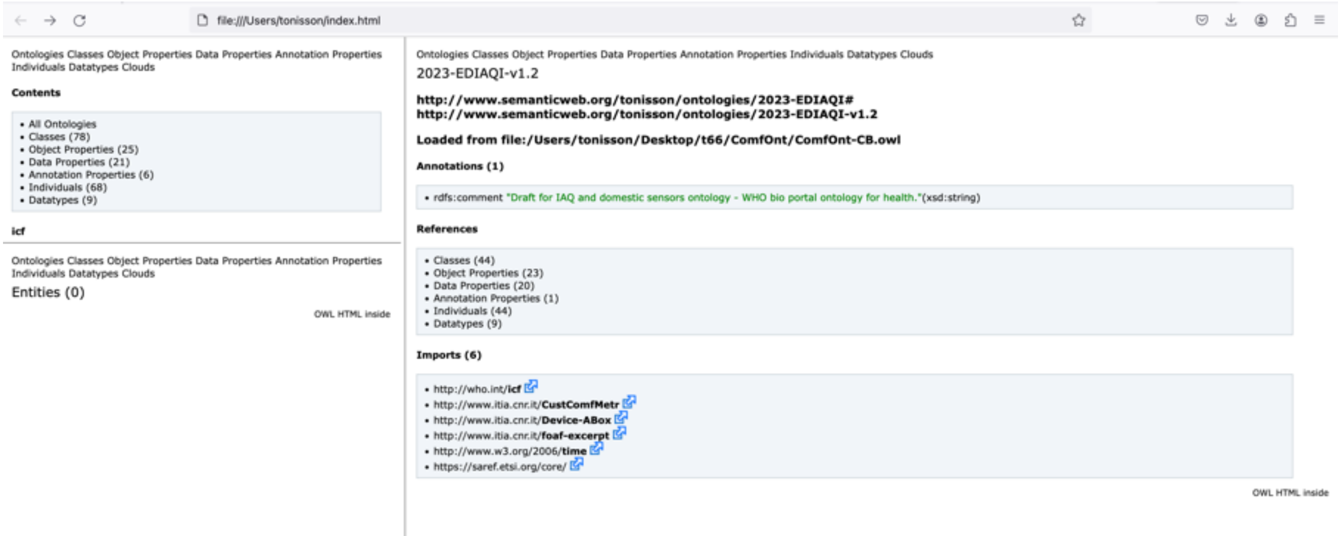
Hea õhukvaliteet, ruumi saab kasutada

Figure 13 The IAQ visuals recommended for an uptake in WP4 and applied in T3.2 QR code experiment for involving citizens and stakeholders in Tallinn

4.4 Interoperability solutions with HEALTH e.g. toxicology, health related parameters

T3.1b investigated ontologies as a possible interoperability solution for health conditions and IAQ. An initial review of EDIAQI relevant state-of-the-art was presented by the TROPOS team at the Air Protection 2023 Conference in September 2023. The work continued for the purposes of later update in WP7; T7.4 by introducing a novel EDIAQI ontology tailored for integration into smart home IoT systems.

The novel ontology created for the EDIAQI purposes, harnesses ontological representations of occupants' health status, comfort metrics, and available devices to deliver indoor environmental conditions optimised for both health and desired activities within the household. Building upon the foundational principles of Thinnect initial sensor technology, which primarily targeted CO_2 measurement, our proposed ontology merges elements from the World Health Organization (WHO) ontology for diseases and disabilities with validated ontologies from leading projects such as iZeb and CasAware (Spoladore et al., 2017) among others. This synthesis results in an innovative ontology specifically engineered for comprehensive monitoring of indoor air quality, health indicators, and energy management. The structural blueprint of this ontology is elucidated below:



Ontologies Classes Object Properties Data Properties Annotation Properties Individuals Datatypes Clouds

Contents

- All Ontologies
- Classes (78)
- Object Properties (25)
- Data Properties (21)
- Annotation Properties (6)
- Individuals (68)
- Datatypes (9)

icf

Ontologies Classes Object Properties Data Properties Annotation Properties Individuals Datatypes Clouds

Entities (0)

OWL HTML inside

Ontologies Classes Object Properties Data Properties Annotation Properties Individuals Datatypes Clouds

2023-EDIAQI-v1.2

http://www.semanticweb.org/tonisson/ontologies/2023-EDIAQI#
http://www.semanticweb.org/tonisson/ontologies/2023-EDIAQI-v1.2

Loaded from file:/Users/tonisson/Desktop/t66/ComfOnt/ComfOnt-CB.owl

Annotations (1)

- rdfs:comment "Draft for IAQ and domestic sensors ontology - WHO bio portal ontology for health."(xsd:string)

References

- Classes (44)
- Object Properties (23)
- Data Properties (20)
- Annotation Properties (1)
- Individuals (44)
- Datatypes (9)

Imports (6)

- http://who.int/**icf**
- http://www.itia.cnr.it/**CustComfMetr**
- http://www.itia.cnr.it/**Device-ABox**
- http://www.itia.cnr.it/**foaf-excerpt**
- http://www.w3.org/2006/**time**
- https://saref.etsi.org/core/

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Figure 14 The EDIAQI ontology as a possible tool for uptake in the IAQ and health domain based on the review presented at Air Protection 2023 for WP7

The interface facilitates inhabitant interactions within rooms, while the ontologies underpinning the knowledge base are systematically reasoned and stored within a semantic repository. This research will be presented by KNOW, TROPOS, TalTech and THINNECT at Karlsruhe at the prestigious *Human und Mensch 2024* conference (1-4 September 2024) and the results, including the full code in Java can be found in the conference proceedings (creative commons license).

The ontology as tool for a possible update in WP7 later, lays the groundwork for enhanced indoor environmental quality management, promising tangible benefits for occupants' well-being and productivity applied in smart home technologies.

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Deliverable D3.1

Indoor Air Pollution Observation Toolkit

Work Package 3
Science
Version: Final

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