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Guidance on low-cost air quality sensor deployment for non-experts based on the AirSensEUR experience

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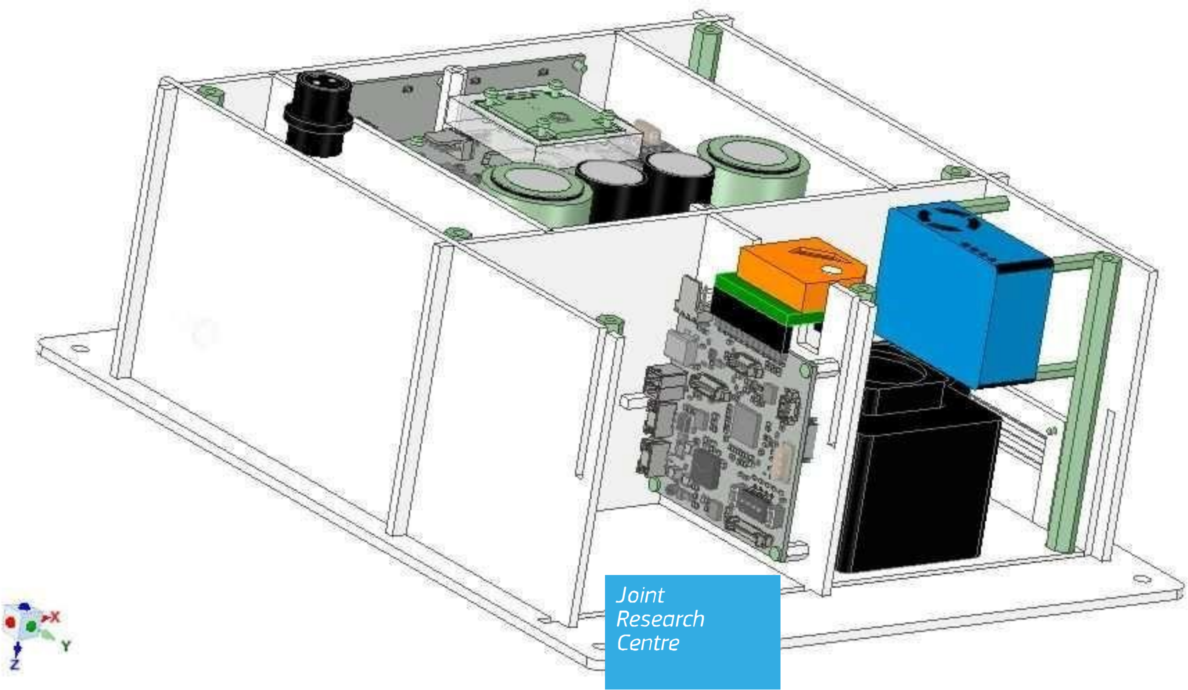

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Contents

Abstract

Low-cost sensors (LCSs), thanks to their affordable costs, size and relatively ease of use, make the monitoring of air quality possible for general public with limited knowledge of sensor technology, data analysis and visualisation. Nevertheless, due to the huge range of available LCSs and relatively new practise in implementation, a guide helping on knowing sensor technology, pros and cons… is necessary for non-expert users.

This guidance aims at providing information on deploying LCSs by public, e.g. citizens, non-governmental organisations, local-authorities, communities… The guidance describes the selection of LCSs, verification and utilisation of LCSs data but not calibration of LCSs. The guidance focuses on LCSs of particulate matter, ozone, nitrogen dioxide, carbon monoxide, and nitrogen monoxide.

In this guide, we summarised the types of LCSs, details of JRC-developed open source AirSensEUR Sensor System and major steps of designing a monitoring study using such Sensor Systems. For single use of Sensor System, measurement accuracy should be assessed at a reference air quality monitoring station, otherwise, some uncertainty in measurement must be considered when data are used. It is recommended to integrate such single use Sensor Systems into city-air quality sensor network, if exists, which will help to monitor air quality city-wise.

Sensor networks are crucial to monitor air quality temporally and spatially, and this guide summarises designing monitoring network, verification, quality control and data usage etc.

Foreword

The opinions expressed in this article do not necessarily represent those of the European Union. The work was carried out in the framework of a European Parliament Pilot Project named “Integrating smart sensors and modelling for air quality monitoring in cities” proposed by the European Parliament and implemented by the European Commission (Service contract no. 07027747/2019/812686/SER/ENV.C.3).

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1 Introduction

This guidance aims at providing information on deploying low-cost sensors (LCSs) to be utilised by general public, e. g. citizens, non-governmental organisations, local-authorities, communities… This guidance does not describe the calibration of LCSs which is explained elsewhere ([1]).

The guidance includes:

- Selection of LCSs including general performance information, price, pros and cons etc.
- Design of field study for the verification and drift check of LCSs data.
- Utilisation of LCS data.

LCSs, thanks to their affordable costs, size and relatively easiness to use, make the monitoring of air quality possible for general public with limited knowledge of sensor technology, data analysis and visualisation. Nevertheless, due to huge range of available LCSs and relatively new practise in implementation, a guide helping on knowing sensor technology, pros and cons, major steps of usage etc. is necessary for non-expert users.

The guidance focuses on LCSs of particulate matter (PM, including PM_{10}, $PM_{2.5}$ and PM_1), ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO), and nitrogen monoxide (NO).

This guidance is written out of the experience gained within the European Parliament Pilot Project named "Integrating smart sensors and modelling for air quality monitoring in cities" ([2]) using the AirSensEUR Sensor System ([3]). However, the principles and applications can be implemented to any field study.

LCSs are only capable of sensing, and need additional electronic components in order to become fully operational air quality monitoring systems. LCSs are generally integrated into so- called "Sensor System", which also includes power supply and/or batteries, sampling capability, signal processing, local data storage, data transmission and protective box against extreme weather conditions. Those additional elements of Sensor Systems add up costs into sole cost of LCS. Other operational costs such as power supply, internet connection, data servers as well as personnel needed for selection of sampling sites, installation, calibration, maintenance, data validation and reporting also add up to total cost of air quality monitoring using LCS.

Out of the experience gained from the Pilot Project, another guidance report describing the calibration and deployment of LCSs aimed at air quality monitoring experts is available ([1]).

([1]) Yatkin, S., Gerboles, M, Borowiak, A and Signorini, M., Guidance on low-cost sensors deployment for air quality monitoring experts based on the AirSensEUR experience, EUR XXXXX, Publications Office of the European Union, 2022, Luxembourg, to be published.

([2]) Pilot Project "Integrating smart sensors and modelling for air quality monitoring in cities " proposed by the European Parliament and implemented by the European Commission (Service contract no. 07027747/2019/812686/SER/ENV.C.3)

([3]) https://airsenseur.org/

2 Low-cost sensors

Generally, the LCS for monitoring of gaseous air pollutants are grouped into four categories based on the principles of operation and technologies relying on: resistive or metal oxide sensors, electrochemical or amperometric sensors, non-dispersive infrared radiation absorption (NDIR), and photo ionisation detectors. The particle-counting PM LCSs measure light scattered by individual particles in an air stream.

A detailed website including information about commercially available LCS was recently released by The European Commission - Joint research Centre (JRC) ([4]).The JRC has also recently published a thorough review of low cost sensors (Karagulian et al., 2019).

2.1 Metal oxide sensors

These LCSs consist of a metal oxide (resistive or semiconductor MOx) whose resistance or conductivity change when exposed to oxidative gas(es). Reaction of such gases with heated MOx leads to electrons trapping and accumulation on sensor surface, which creates a negative charge acting as a barrier for electrons, thus conductivity changes. Changes in conductive is usually proportional to concentrations of oxidative gas(es) in air and can be monitored using an external circuit. MOx-LCSs can measure non-methane hydrocarbons, CO, carbon dioxide (CO_2), NO, NO_2 and O_3.

Pros:

- Low cost: 10 - 15 € per sensor.
- Good sensitivity, from mg/m^3 to µg/m^3, or from ppm to low-ppb.
- Long lifespan and resilience against extreme weather conditions.

Cons:

- Sensitive to significant temperature and humidity variations.
- Long response time, between 5 and 50 min.
- Instability of baseline response.
- Possible drift in sensitivity thus requiring frequent calibration.

Need relatively large power due to heater.

2.2 Electrochemical sensors

Electrochemical (EC) LCSs (EC-LCS) are based on oxidation-reduction reaction between air pollutant(s) and sensor electrodes dipped in an electrolyte. Reaction produces an electrical current between electrodes, which is proportional to concentrations of air pollutants. EC-LCSs are used to measure NO_2, NO, O_3, CO, and sulfur dioxide (SO_2).

Pros:

- Moderate cost: 50 - 150 € per sensor.
- Good sensitivity, from mg/m^3 to µg/m^3, or, from ppm to low-ppb.
- Very short response time, between 30 and 200 s.
- Unlike MOx-LCSs, no need for large power.

Cons:

- Sensitive to temperature and humidity variations with lower extent than MOx-LCSs.
- Poor selectivity: shows cross-reactivity with similar molecule types.
- Shorter lifespan than MOx-LCSs, and highly dependent on exposed gas levels.

([4]) https://web.jrc.ec.europa.eu/rapps/pub/aqsensors/

— Less resilient to weather conditions than MOx-LCSs.

— Possibility of dryness in electrolyte due to combination of low humidity and high temperature.

2.3 Non-dispersive infrared radiation absorption sensors

The non-dispersive infrared radiation absorption (NDIR) sensors are based on the absorption of infra-red lights specific to molecules. While infrared light from a source passing through a gas, the specific wavelengths are absorbed following the well-known Beer-Lambert law, which this absorption is logarithmically proportional to gas concentration and length of the beam path. NDIR-LCSs are widely used to measure CO_2 concentrations and occasionally for CO.

Pros:

— Moderate cost: 100 – 350 € per sensor.

— Good selectivity and sensitivity for CO_2, between 350 and 2000 ppm.

— Very short response time, 20 – 120 s.

— Limitedly drifting in sensor sensitivity.

— Long lifespan.

— Little maintenance and power requirement.

Cons:

— Affected from temperature, humidity and pressure, and therefore need corrections.

— High detection limits for other gases than CO_2.

2.4 Photo ionisation detectors

Photo ionisation detectors (PIDs) use high-energy photons to excite and finally to ionise organic molecules. The incident energy of photons in PIDs is typically ~ 10 eV, thus only organic molecules with ionisation energy equals to or less than that energy can be excited. These ions generate an electric current proportional to excited organic compounds.

Pros:

— Much cheaper than conventional volatile organic compounds (VOCs) measurements: 400 € per a LCS; 5000 € per a handheld device.

— Small temperature dependence and humidity sensitivity.

— Fast response time.

— Good sensitivity: down to mg/m^3, sometimes to $\mu g/m^3$.

Cons:

— High power consumption.

— High detection limits: down to ppm, a few down to ppb.

— Linearity deviations between high and low concentrations.

— Not selective: VOC speciation impossible.

— Important short term drift.

— Requiring frequent maintenance and calibration.

2.5 Optical particle counters

Optical particle counters (OPCs) are equipped with light source and detector enable to measure light scattered by individual particles in an air stream. Laser diode is the most common light source used in such LCS. These LCS counts individual particles falling into several size bins.

Pros:

- Moderate cost: 25 to 400 € per sensor.
- Fast response time, in order of 1 second.
- Capability of measure several PM fractions.
- Good sensitivity, in the range of 1 μg/m^3.

Cons:

- Conversion from particle counts to PM mass is based on theoretical models.
- Measured signals are affected from several parameters such as particle shape, colour and density, humidity, and refractive index etc.

2.6 Sensor Systems

To become operational, LCSs are generally integrated into so-called Sensor Systems ("CEN/TS 17660-1 Air quality — Performance evaluation of air quality sensor systems — Part 1: Gaseous pollutants in ambient air," 2021) including power supply and batteries, sampling capability, signal processing, local data storage, data transmission and protective box against extreme weather conditions. Without sensors, the price of Sensor Systems ranges between 1000 and 8000 Euro.

Other operational costs are power supply, internet connection, data servers as well as personnel needed for selection of sampling sites, installation, calibration, maintenance and data validation and reporting.

3 AirSensEUR Sensor Systems

The Sensor Systems developed by the JRC in collaboration with Liberaintentio S.r.l (IT), namely AirSensEUR version 3.1 (Gerboles et al., 2022), is an open sensor platform project aimed at measuring air quality accurately using LCSs. Both hardware schematics and the software running on the units or the calibration procedures implemented as a post-processing of the collected data are described under public licenses ([5]).

The data collected from the units are stored locally and sent periodically to and external server hosting an InfluxDB database ([6]) for offline post-processing and/or calibration. AirSensEUR can use other protocol of data transmission including Sensor Observation Services ([7]) (SOS) (Kotsev et al., 2017), iFlink ([8]) and LoRa for partial data transmission ([9]). The data is generally transferred via GPRS/LTE or via WiFi connections, although other internet connections are possible including wired connection through rj45.

AirSensEUR includes a PolyTetraFluoroEthylene (PTFE) enclosure with a size of 26 cm x 22 cm x 10 cm and a weight of 2 kg, battery included. The PTFE enclosure is inserted in a stainless -steel protecting cover. The overall size provided of protective stainless-steel cover overall size is 35cmx32cmx30cm except for the rooftop cover, which is made from a 42cmx45cm aluminium plate.

Table 1 gives an overview of the measured pollutants, the sensor type and manufacturer. The OPC-N3 has 24 size bins (0.3/0.35 – 40 µm) and the PMS5003 has 6 size bins (> 0.3 µm); both with a counting efficiency of 50% at 0.3 µm and 100% at 0.5 µm.

Table 1. The sensors included in the AirSensEUR Sensor Systems

Supplier- Sensors	Parameters	Sensor type	Raw units	Abbreviation
Bosch Sensortech - BMP280	Atmospheric pressure	Piezo-resistive	hPa	BMP280
Sensirion - SHT31	Ambient temperature	Semi-Conductor	°C	SHT31TE
Sensirion - SHT31	Ambient relative humidity	Semi-Conductor	%	SHT31HE
Sensirion - SHT31	Internal temperature	Semi-Conductor	°C	SHT31TI
Sensirion - SHT31	Internal relative humidity	Semi-Conductor	%	SHT31HI
Alphasense - CO-A4	CO	Electrochemical	nA	CO-A4
ELT - D-300-3V	CO_2	NDIR	ppm	D300
Alphasense - NO-B4	NO	Electrochemical	nA	NO-B4
Alphasense - NO2-B43F	NO_2	Electrochemical	nA	NO2-B43F
Alphasense - OX-A431	O_3	Electrochemical	nA	OX-A431
Alphasense - OPC-N3	PM_{10}	Optical Particle Counter	µg/m³	OPC-N3
Alphasense - OPC-N3	$PM_{2.5}$	Optical Particle Counter	µg/m³	OPC-N3
Alphasense - OPC-N3	PM_1	Optical Particle Counter	µg/m³	OPC-N3
Alphasense - OPC-N3	Number of particles	Optical Particle Counter	counts/mL	OPC-N3
Plantower - PMS5003	PM_{10}	Nephelometer	µg/m³	PMS5003
Plantower - PMS5003	$PM_{2.5}$	Nephelometer	µg/m³	PMS5003
Plantower - PMS5003	PM_1	Nephelometer	µg/m³	PMS5003
Plantower - PMS5003	Number of particles	Nephelometer	counts/0.1L	PMS5003

Source: JRC, 2022.

([5]) ec-jrc/airsenseur-sensorsshield. (European Commission, Joint Research Centre (JRC), 2022); ec-jrc/airsenseur-sensorshost. (European Commission, Joint Research Centre (JRC), 2022); AirSensEUR Calibration. (European Commission, Joint Research Centre (JRC), 2021) and ec-jrc/airsenseur-box. (European Commission, Joint Research Centre (JRC), 2019).

([6]) https://docs.influxdata.com/

([7]) https://www.ogc.org/standards/sos

([8]) https://iflink.nilu.no/en/home/

([9]) https://lora-alliance.org/

The gas sensors for NO_2, CO, NO and O_3 are installed on the AirSensEUR Chemical Shield (version R31), PM and CO_2 sensors are installed on the Exp1Shield R10. In addition, the sensor box is equipped with sensors for monitoring temperature and relative humidity inside the AirSensEUR box nearby chemical sensors and other sensors for monitoring ambient air temperature, relative humidity and atmospheric pressure outside the AirSensEUR box on a Flyboard.

While installation in field, the instructions given in Annex 1 must be maintained for a smooth operation and data transfer given in its section 6. The more detailed instructions on the installation and operation of the AirSensEUR system can be found at https://airsenseur.org/website/download/airsenseur-user-manual-v3-1/. Note that the version of AirSensEUR may change in the download tab/folder.

4 Designing of field study of low-cost Sensor Systems

4.1 Sensor networks

Sensor networks contain a set of pre-calibrated and verified Sensor Systems followed by deployment in field in accordance with pre-determined monitoring objectives. Sensor networks require inclusion of stakeholders with several roles and levels of expertise, e.g., national/local air quality monitoring agencies, municipalities, universities, private sector, public engagement etc. Sensor networks may aim at monitoring of air quality for public exposure, source apportionment etc. purposes.

Sensor network monitoring study should be designed according to the desired data quality objectives (DQO) and data usage. For example, the technical committee 264, working group 42 for sensors of the European Committee for standardisation is currently developing protocols for sensor performance evaluation ("CEN/TS 17660-1 Air quality — Performance evaluation of air quality sensor systems — Part 1: Gaseous pollutants in ambient air," 2021) based on the DQO set in the European Air Quality Directive("2008/50/EC: Directive of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe," n.d., p. 50). For population exposure studies, Sensor Systems should be deployed at locations with different population characteristics, e.g., busy streets, indoor and outdoor, background and rural sites etc. Duration of data collection should be selected to cover temporal variations of pollutants, e.g., 4-weeks cycles in four seasons.

For source apportionment studies, e.g., around airports, field study should be designed to gain information on the contribution of local source(s) in vicinity, regional background etc. Such field campaigns are expected to be long-lasting, thus validity of calibration models should be verified frequently to ensure data quality, continuity and integrity.

The field study ideally includes two steps: field calibration or verification and deployment. Field calibration is out of the scope of this guidance report, see the guidance report for expert[1].Field calibration or verification must be conducted at an air quality monitoring station (AQMS). In both cases, a quantitative objective for the accuracy of LCSs data shall be defined. This metric will be used to accept the calibration or will raise the need for correction. Deployment can be carried out at any location to collect data in line with objectives. For field study, the following must be considered for site selection and preparation for data collection:

— **Identifying stakeholders and collaboration partners**: Considering the scope of data collection at an AQMS for calibration and afterwards for deployment, stakeholders and partners must be identified and contacted to provide infrastructure, data and logistic. Local/national air quality monitoring bodies and municipalities can be contacted for such partnerships.

— **Communication between Sensor Systems and a central database**: Data storage and internet access must be maintained and planned prior to any study. The data will be stored, monitored, quality checked, treated and possibly made available for partners/public using such facilities.

— **Power and internet availability**: Power and internet requirements of selected Sensor Systems must be ensured and checked. AirSensEUR works with 220 V electricity, which the power cord should absolutely not be extended. If extension cord is used, the power supply is likely to be discontinuous, which leads to frequent stop/start. If data will be transmitted and monitored remotely, the internet access must be supplied either with a WIFI dongle, a SIM card or radio connection…

— **Space and safety**: Enough space, particularly when many Sensor Systems collocated at an AQMS, and good safety must be ensured without increasing the distance between LCSs and reference sampling inlet. Safety of Sensor Systems must be maintained by restricted access, sheltered for strong wind, heavy rain, vandalism and other factors. Occupying by insects such as spiders is fairly common, thus site selection must be accordingly. In case sensors get wet, they will not function properly, so maximum attention must be drawn in particular not to install up-side-down.

— **Quality check (QC) while data collecting**: An automated data QC with warning ability would save significant operational time, allow timely interventions in case of malfunctioning, and assure data integrity and continuity. The raw data of AirSensEUR can be monitored via a dedicated website on Grafana ([1]).

4.2 Single use of Low-cost sensor

The Sensor Systems can be utilised for single monitoring by general public at a site where information about air quality is desired, e.g., house, garden, etc. Sensor Systems without calibration models are difficult to implement for such monitoring since it would require high-level expertise for calibration. In addition, collocation of Sensor Systems at an AQMS would not always be possible. For single use, pre-calibrated commercial LCSs is the best option because calibration at an AQMS would not be necessary. However, verification of pre-calibrated LCSs data by collocation at an AQMS is helpful to evaluate the accuracy of measured air pollution. Access to AQMS should be provided prior to deployment for such verification purposes that may be repeated over time. The pre-calibration of commercial LCSs is usually performed in laboratory and/or field tests, and provides a certain level of accuracy for conditions similar to calibration ones. Deploying commercial systems without verification in an AQMS would bring some uncertainties in accuracy, but it most likely captures the temporal variation of air pollution, which is also critical to determine the temporal hot-spots.

In many cities, such single monitoring efforts can be integrated into city-air quality monitoring network, if it exists. Additional quality control checks can be performed by the network management in order to validate the single used LCS data and to include it into the existing network allowing air quality to be assessed city-wise rather than at the location of the single use LCS.

4.3 Calibration adjustment and verification methods

Commercial Sensor Systems may or may not provide default calibration models/functions. However, methodology of calibration is usually not open source. Therefore, readings from Sensor Systems should be checked for accuracy, ideally at an AQMS. Correction factors or models shall be derived from a field study where Sensor Systems are collocated along with reference analysers. These corrections are usually simple linear models, not requiring advance knowledge of modelling or high computing resources. Such field experiments should be conducted long enough to capture temporal variability of air composition, e.g., 1 week. Another period shall serve to verify correction factors/models. Acceptance criteria of verification shall be pre-defined in line with monitoring purposes.

Open-source Sensor Systems such as AirSensEUR may or may not provide calibration models. When calibration models of open-source Sensor Systems are provided, the procedure described in the previous paragraph shall be followed for determining correction factors and verifying those. Verification should be performed periodically for long-lasting monitoring studies, e.g., seasonal checks. If calibration models of open-source systems are not provided, a calibration field study must be conducted prior to deployment which requires expertise in data analysis and modelling. For such calibration procedure, the user is referred to the guidance prepared for experts ([1]).

Four main methods can be used for calibration correction and verification purposes:

— **"Routine collocation"** is a method which Sensor Systems are collocated at an AQMS before deployment and frequently during deployment. This method provides information about between sensor comparability and sensor-specific drift (deviation from original calibration) at the site of calibration but not site-specific drift. It requires frequent collocation of all deployed Sensor Systems at an AQMS, thus, it is quite labour intensive and expensive. It is usually not practical for monitoring networks with large amount of Sensor Systems involved.

— **"Permanent collocation"** is a method which select Sensor System(s) can be permanently deployed at calibration AQMS or at representative proxy AQMS, and drift at proxy site is detected and corrected for all other deployed Sensor Systems with the assumption of same drift in all sensors. This method is cheap and easy to implement, however, it is unable to provide information about sensor-specific drift as well as it cannot detect any poorly performing deployed Sensor Systems.

— **"Mobile collocation"** is a method which a mobile reference station is circulated frequently between deployment sites. This is very expensive and labour intensive method, however, it provides information about sensor-specific drift as well as it can detect any poorly performing deployed Sensor Systems.

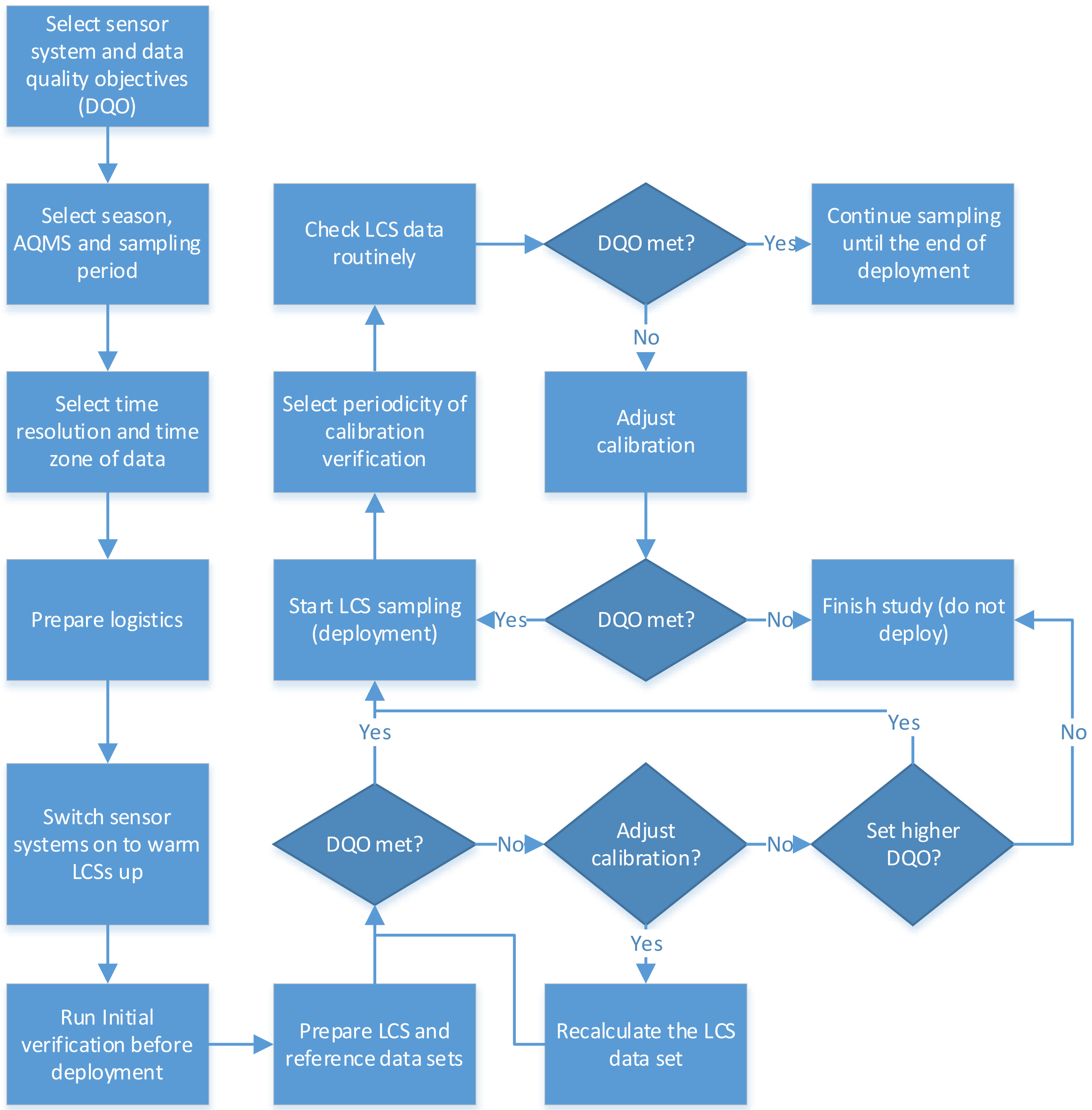
— "**Golden sensor"** or **"gold pod"** is the same method of "mobile collocation" but using a well-performing Sensor System(s) [the ''golden sensor''] frequently collocated at deployment sites instead of mobile reference station. Although it is moderately labour intensive method, it provides information about sensor-specific drift, poorly performing Sensor Systems and limitedly between sensor comparability.

It is recommended to calibrate subset of extra Sensor Systems during the calibration collocation study for the purposes of replacing of failing sensors to ensure data continuity, and to implement the aforementioned "Permanent collocation" or "Golden sensor" approaches for drift correction.

4.4 Check list of operations from verification to deployment of Sensor Systems

The flowchart of standard operation procedure of verification study using Sensor Systems at an AQMS The flowchart of standard operation procedure of verification study using Sensor Systems at an AQMS followed by deployment is given in Figure 1.

Figure 1. The flowchart of the standard operation procedure of verification study and deployment



Source: JRC, 2022.

The standard operation procedure for the verification experiment performed at an AQMS and the deployment can be described as below:

- Select a model of Sensor System using section 2, web page etc., considering pre-determined LCS Data Quality Objectives required for monitoring study.
- Decide on the season, location of reference station site and sampling period so that air composition will be as close as possible to expected levels when sensors system are deployed.
- Decide on time resolution of reference data, e.g., 15 or 60 minutes, and assure availability of such reference data. Verify that the time zone of reference data is identical to the one of the Sensor System data as well as two datasets are synchronised.
- Prepare logistics, e.g., holder and protection for all Sensor Systems, power supply, internet connection, space etc., if many Sensor Systems shall be collocated together.
- Switch Sensor Systems on before data collection to allow to warm LCSs up. For NO, warming up may take for longer than other LCSs, thus starting date/time should be determined accordingly. Warming up data must be invalidated. For the AirSensEUR systems, the recommendations on the duration of LCS warm-up can be found elsewhere (Yatkin et. Al., 2022). Refer to the manufacturer data specifications for other LCSs.
- Run initial verification before deployment. Monitor the air pollutants using reference measurement methods corresponding to the pollutants measured by LCSs.
- Prepare a dataset with times series for LCSs and reference measurements.
- Check if the LCS measurements meet the DQO using for example the method available elsewhere (Yatkin et al., 2022). This evaluation may require involving some expertise that may be outside the skill of the general public.
- If LCS does not meet the DQO, then decide on whether or not to correct the LCS calibration and method. In case of calibration correction, calculate LCS-specific correction factors/models per each Sensor Systems.
- If correction of calibration is not possible, either the deployment should not be carried out, or, the DQO shall be downgraded.
- If the DQO is met, deploy Sensor Systems.
- Check routinely quality of collected deployment data.
- Decide on periodicity of verification, at least once every year except for O_3 that shall be checked every 6 months. Nevertheless, a routine verification every 6 months is recommended for better control of the drift check. Information about drift is given in **Table 2**.

Field experiment for verification shall be designed considering the parameters in **Table 2**. Design of experiment is led by Sensor Systems to be deployed, deployment site characteristics, and expected air composition including meteorological factors and pollutants. **Table 2** indicates duration of experiment, time resolution of data acquisition and periodicity of calibration verification.

Table 2. Parameters to take into consideration to design a verification experiment for the sensors included in AirSensEUR

Sensors	CO-A4	NO-B4	NO2-B43F	OX-A431	PMS5003	OPC-N3
Season	Avoid period with low level (<0.2 ppm)	Avoid summer, sensor cannot perform when NO is low and T(1) is high	Avoid summer	Summer	Intersection of highest concentrations and humidity(2)	Intersection of highest concentrations and humidity(2)
Duration	1 week	1 week	1 week	1 week	1 week	1 week
Type of reference station	Any type	Similar to the type of deployment site	Similar to the type of deployment site	Likely not critical	Likely not critical	
Time resolution	15 or 60 min	15 or 60 min	15 or 60 min	15 or 60 min	15 or 60 min	15 or 60 min
Drift check over time	Small drift observed over one year, calibration might be re-adjusted for better performances	The sensor cannot perform in summer if NO is low and T(1) is high	Drift can be significant if high T and low NO_2 is observed in summer	Significant drift, highly recommended to re-adjust in winter	Small drift observed over one year, calibration might be re-adjusted for better performance	Small drift observed over one year, calibration might be re-adjusted for better performances

(1): Avoid periods affected by high contribution of Saharan dust
(2): Temperature

Source: JRC, 2022.

4.5 Installation of Sensor Systems

It is highly recommended to have Sensor Systems ready to be installed, since mounting components requires a certain level of expertise and training. If Sensor Systems are not ready to use, sensors must be installed into system properly. Follow the instructions in Annex 1 for proper installation of AirSensEUR system. The major steps are as following:

— Open the AirSensEUR top cover and connect battery following instructions at Annex 1 Section 4. Battery and SIM card.

— If data push to cloud is going to be carried out using GPRS, install a SIM card with regular data subscription into the GSM USB key. The pin of the SIM key should be erased. Use a normal smartphone to erase PIN.

— Connect the GPS antenna to the control panel, and install it at a place non obstructed by buildings, trees etc. to satellites.

— Turn on the power switch. Follow instructions at Annex 1 Section 5.

— Press the capacitive button P2, located on the front control panel and hold for half a second. After a few seconds, the LED3 in the control panel starts blinking with a 50/50 pattern thus identifying the booting phase. Please note that, for the very first time the Host is turned on, the procedure could take some minutes because the system should generate some unique cryptographic keys associated with the Secure Shell services. As soon as the process terminates, and the system is ready to run, the LED3 will blink with an “heartbeat” like pattern.

— Start the WIFI interface, press the P9 (USER2) capacitive button located on the control panel. The LED8 will start blinking for a few seconds, then the LED lights up red permanently indicating the WIFI interface is active. Press P9 to shut down the WiFi interface. When the WiFi interface is on, it is visible on the list of available WiFi connections with the "ASE" name. The password required to pair to this interface is "ASE". AIRSENSEUR default Host IP is set to 192.168.100.1.

- Configure WIFI or GSM data push following the instructions of Annex 1 Section 6.
- Start data acquisition and enable data push, see Annex 1 Section 5.

4.6 Monitoring of proper functioning and maintenance

It is highly recommended to monitor the proper functioning of Sensor Systems frequently to detect any malfunctioning of sensors, drift, power supply problems, possible obstacles in inlets of PM sensors (e.g., spider webs), bad GPS connection etc. Immediate interventions should be taken in such cases to assure the maximum data continuity and quality. Many of interventions, such as cleaning the air path, may not require re-calibration or calibration verification. However, replacing malfunctioning sensors would require a calibration. In case of substitution, it is recommended to calibrate and verify subset of extra Sensor Systems during calibration collocation study for the purposes of replacing of failing sensors to ensuring data continuity, and to implement the "Permanent collocation" or "Golden sensor" approaches for drift correction.

The only available tool to check the AirSensEUR systems almost online is the Grafana web platform ([1]). The Grafana web platform is designed to monitor the LCS data. Nevertheless, many potential problems can be easily identified by routine QC of raw data. Many commercial Sensor System manufacturers offer data visualisation tools with or without extra costs, which real time sensor data can be checked for QC purposes.

4.7 Utilisation of LCS data

The final (modelled) LCS data can be visualised almost in real-time for several purposes including public awareness of pollution in the neighbourhood, short- and long-term pollution trends, pollution rose graphing etc. Many commercial Sensor System manufacturers offer data visualisation tools with or without extra costs for such purposes. When sensor network is designed covering temporal and spatial variation of population, real-time pollution mapping using LCS data with GIS modelling will inform population about hot-spot time and location of pollution as well as will allow authorities to take preventive interventions. Modelled LCS data can also be utilised for pollution forecast modelling as well as verification of any forecast modelling.

For single use, LCS data give temporal variation of air pollution in locations where Sensor Systems are installed. Personal exposure to air pollution can be assessed temporally. Some types of Sensor Systems are also suitable for monitoring of indoor air quality.

5 Conclusions

Low-cost sensors have recently attracted huge attention of not only scientific community but also public community, vulnerable communities from air pollution etc., thanks to their lower equipment and operational costs compared to conventional analysers. In addition, their small sizes and low energy requirement make them easy to implement with a limited need of expertise. However, the huge amount of commercially available sensors with different technology and features brings a need of guidance for non-experts in order to help on selecting suitable sensors and implementation in field for air quality monitoring.

In this guide, we summarised the types of low-cost air sensors, details of JRC-developed open source AirSensEUR Sensor System and major steps of designing a monitoring study using such Sensor Systems. For single use of Sensor System, measurement accuracy should be assessed at an AQMS, if possible, otherwise, some uncertainty in measurement accuracy must be considered when data are used for evaluating of air pollution exposure. Such monitoring exercise without calibration verification will serve capturing temporal variation of air quality, which is also helpful for assessment of personal air pollution exposure. It is highly recommended to integrate such single use Sensor Systems into city-air quality sensor network, which will help to monitor air quality city-wise.

Sensor networks are crucial to determine the temporal and spatial variations in air quality, and this guide summarises the major steps of designing monitoring network, verification, QC and data usage etc.

References

2008/50/EC: Directive of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe [WWW Document], n.d. URL https://eur-lex.europa.eu/eli/dir/2008/50/oj (accessed 8.22.19).

CEN/TS 17660-1 Air quality — Performance evaluation of air quality sensor systems — Part 1: Gaseous pollutants in ambient air [WWW Document], 2021. URL https://www.boutique.afnor.org/en-gb/standard/din-cen-ts-176601/air-quality-performance-evaluation-of-air-quality-sensor-systems-part-1-gas/eu174644/322334 (accessed 10.7.21).

Gerboles, M., Spinelle, L., Signorini, M., van der Broecke, J., 2022. User Manual AirSensEUR vs3.

Kotsev, A., Gerboles, M., Spinelle, L., Signorini, M., Jirka, S., Matthes, R., Schade, S., Craglia, M., Villani Maria, G., 2017. AirSensEUR: an open data/software /hardware multi-sensor platform for air quality monitoring. Part C: INSPIRE and Interoperable Data Management (EUR - Scientific and Technical Research Reports). Publications Office of the European Union. https://doi.org/10.2760/93699

Yatkin, S., Gerboles, M., Borowiak, A., Davila, S., Spinelle, L., Bartonova, A., Dauge, F., Schneider, P., Van Poppel, M., Peters, J., Matheeussen, C., Signorini, M., 2022. Modified Target Diagram to check compliance of low-cost sensors with the Data Quality Objectives of the European air quality directive. Atmospheric Environment 273, 118967. https://doi.org/10.1016/j.atmosenv.2022.118967

List of abbreviations and definitions

AQMS	Air Quality Monitoring Station
CO	Carbon monoxide
CO_2	Carbon dioxide
DQO	Data quality objectives
EC	Electrochemical
JRC	Joint Research Centre
LCSs	Low-Cost Sensors
NDIR	Non-dispersive Infrared radiation
MOx	Metal oxide
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
O_3	Ozone
OPC	Optical particle counter
PID	Photo-ionisation detector
PM	Particulate matter
PTFE	PolyTetraFluoroEthylene
QC	Quality check
SO_2	Sulfur dioxide
SOS	Sensor Observation Services
T	Temperature
VOCs	Volatile Organic Compounds

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Annexes

Annex 1. Installation of sensors into the AirSensEUR box

Mounting of gas sensors

Figure Annex 1: Installation of sensors in the shields.

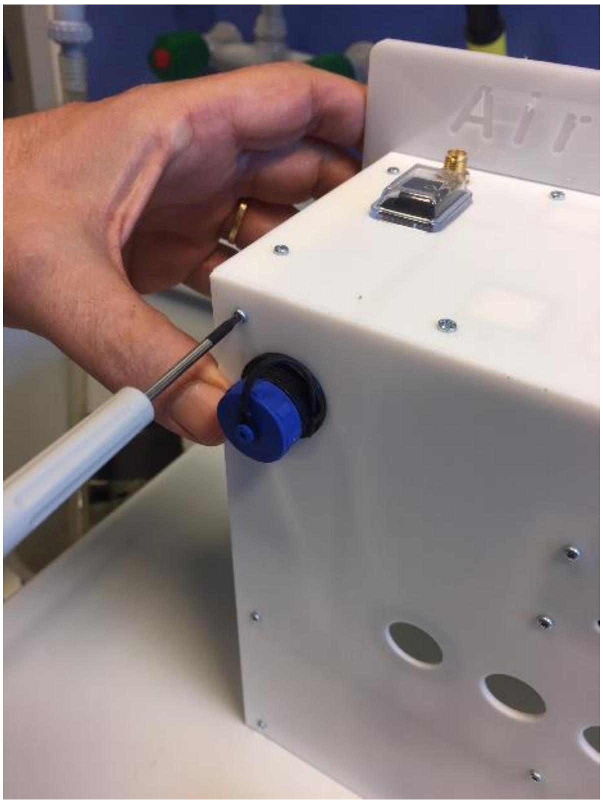
<table>
<tr>
<td>
</td>
<td>Equipment:

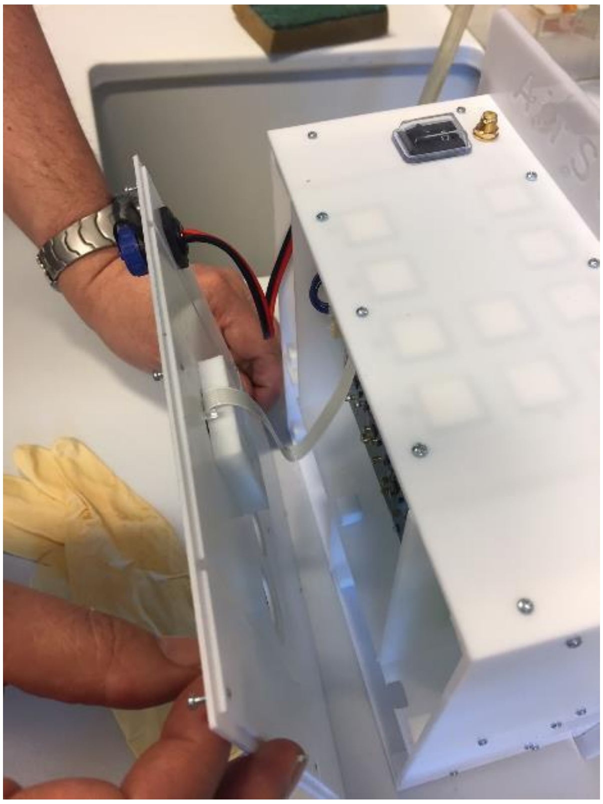
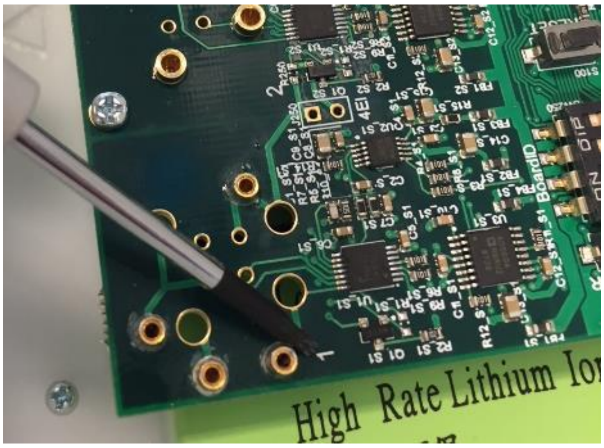
Screwdriver Philips PH1

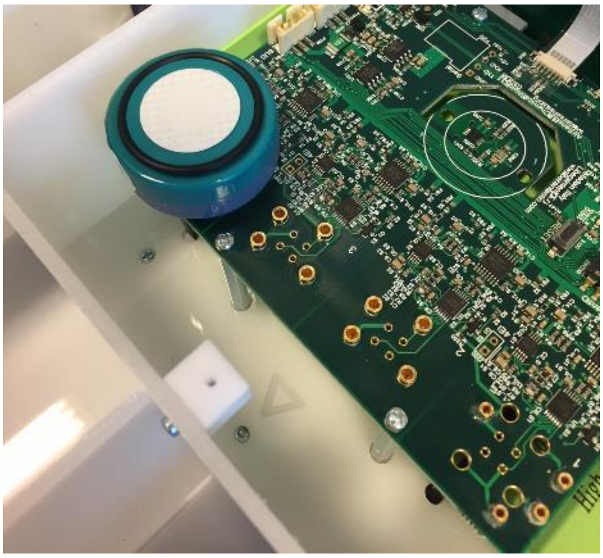
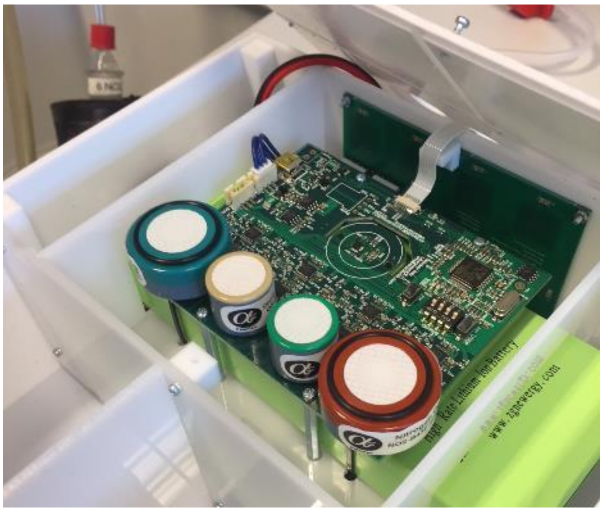
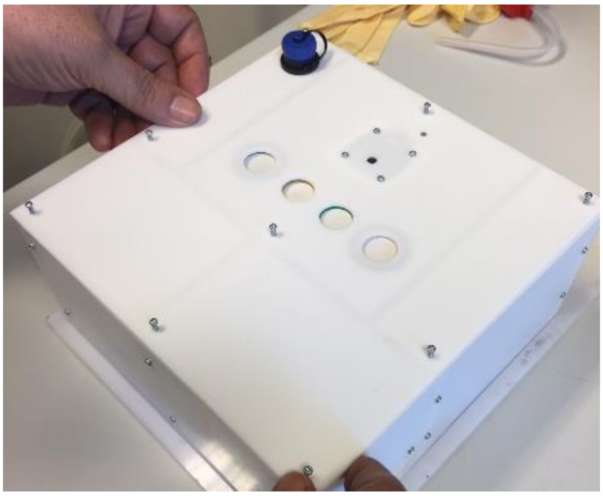
One Sterile glove

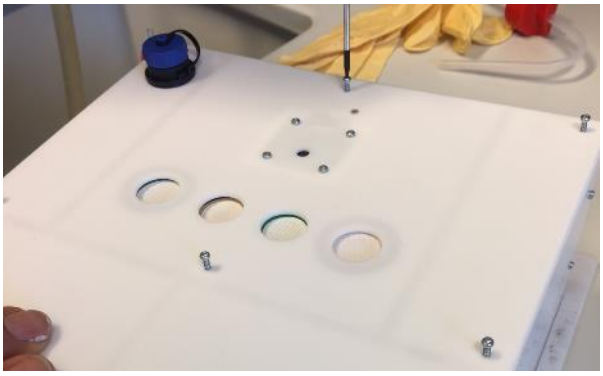
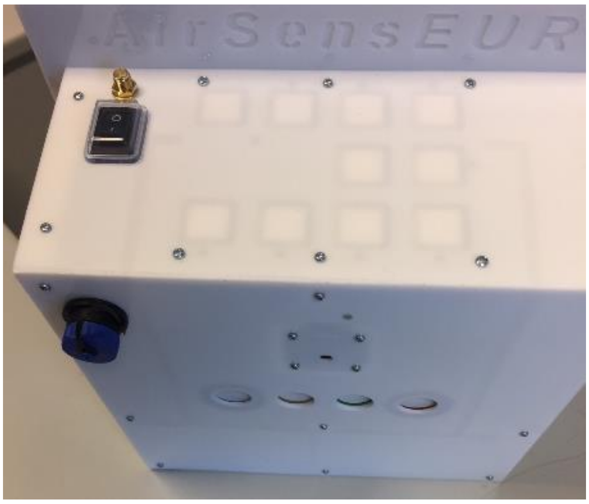
AIRSENSEUR box including host and chemical sensor shield

4 sensors: Alphasense NO-B43F, CO-A4, OX-A431 and NO-B4. Other sensors can be used.</td>
</tr>
</table>

	On the bottom part of the AIRSENSEUR box, untighten the screws.
	Keep the 4 screws holding the temperature and relative humidity sensor tighten. These are the screws between the power supply and sensor holes.

	Slightly open the bottom cover of the box, taking care not to damage the electrical wire of the temperature sensor and the power supply.
	Locate the sensor identification number on the PCB: 1, 2 , 3 and 4.

	Wear a clean glove to avoid skin grease on the sensor membrane. Insert the correct sensors into the sensor socket. Press until the end until hearing an audible “click”.
	Typical sensor list: Sensor 1: NO2-B43F Sensor 2: CO-A4 Sensor 3: OX-A431 Sensor 4: NO-B4
	Put back the bottom cover on the box. The sensor membrane should remain visible.

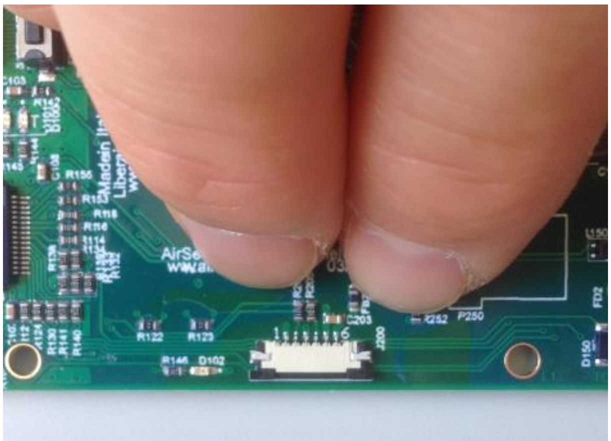
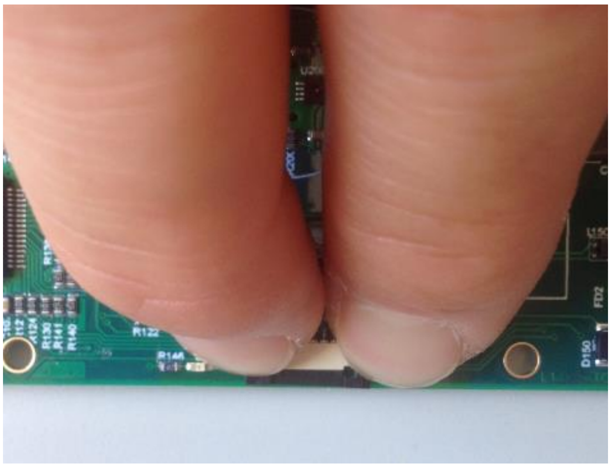
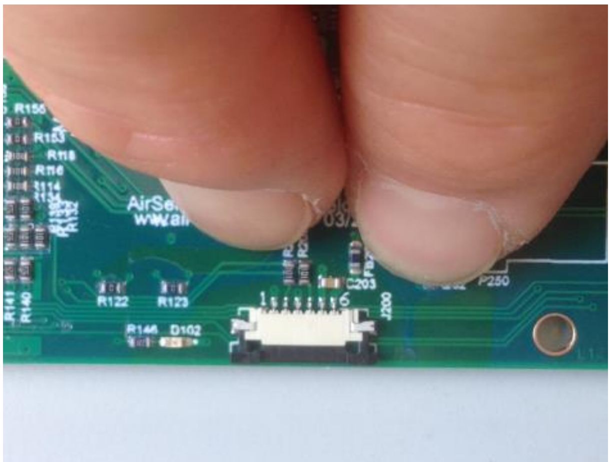
	Tighten down the mounting bolts.
	The AirSensEUR Box is ready.

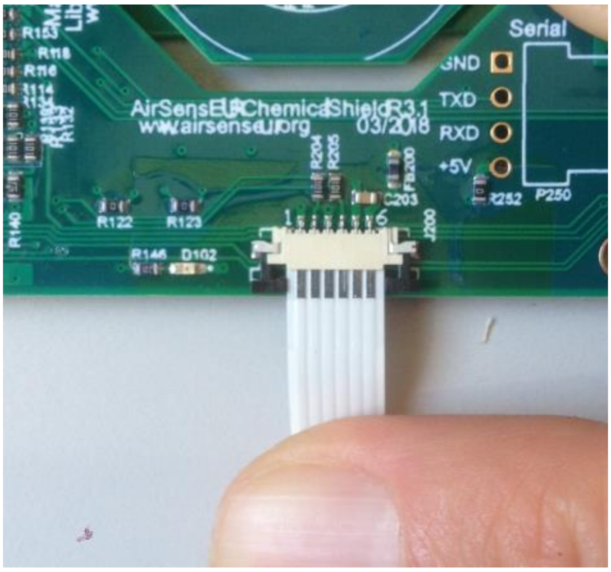
Source: JRC and LiberaIntentio S.r.l., 2022., AirSensEUR.org, 2022

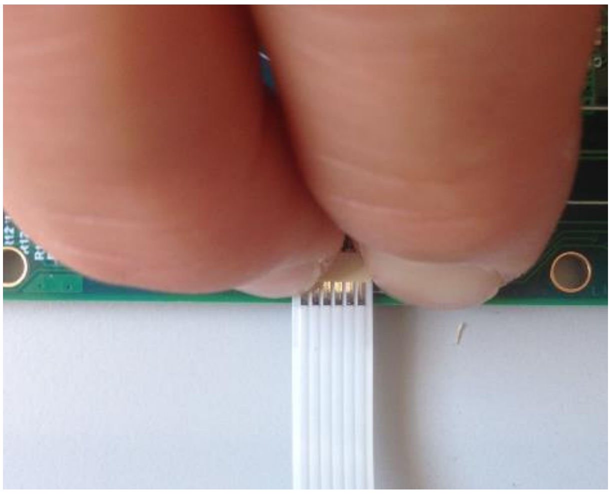
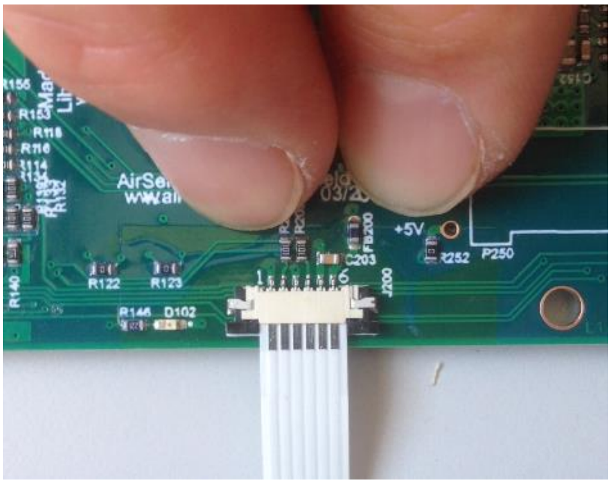
2. Temperature and humidity flyback

The temperature and humidity flyback board implements an extra temperature and humidity sampling point targeted to measure external temperature and humidity. This flyback board needs to be connected to the chemical shield R3.x through a flexible flat cable. You'll find a pair of ZIF connectors (ZIF refers to Zero Insertion Force) to accommodate this requirement. ZIF connectors have a small black plastic holder that needs to be moved in the proper position to allow for the flexible flat cable to enter in the connector. The plastic holder needs to be moved back in the original position to retain the cable in the proper location and assure electrical contact between the flat cable and the connector terminals. The following pictures refers to the chemical shield side. The same procedure applies to the flyboard.

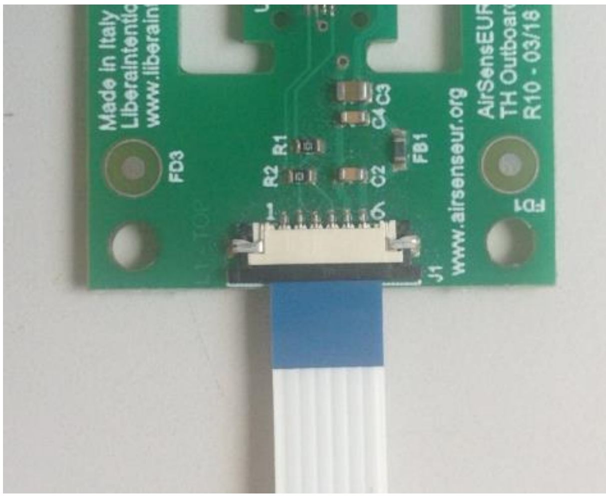
Figure Annex 2: Installation of ZIF connector for temperature and relative humidity sensors

	Look at the ZIF connector on the chemical shield. You'll find a small black plastic holder that can be moved from his default position. The picture on the left shows the black plastic holder in the factory default position.
	Apply a small force to the outermost edges of the black plastic holder in order to have it shifted out from the connector. NOTE: avoid to apply too much force because the plastic holder may be irremediably damaged.
	The left picture shows the black plastic holder in the "open" position. The connector is now ready to accept the flat cable.

<table>
<tr>
<td>


</td>
<td>Carefully insert the flat cable into the white connector. Have the silver contacts oriented like in the left picture.</td>
</tr>
<tr>
<td>

</td>
<td>
Carefully apply force to the outermost edges of the black plastic holder in order to have it shifted into the connector.
This action will lock the flat wire cable into the connector.
NOTE: avoid to apply too much force because the plastic holder may be irremediably damaged.
</td>
</tr>
<tr>
<td>


</td>
<td>Your cable is now locked into the connector.</td>
</tr>
</table>



You may want to repeat the procedure for the temperature/humidity flyboard. In this case, be sure to have the flat cable oriented with silver contacts downwards.

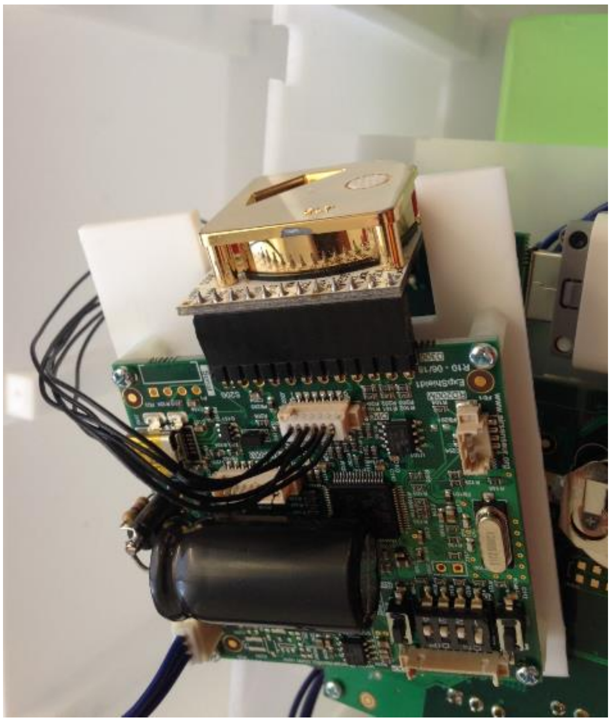
Source: JRC and LiberaIntentio S.r.l., 2022., AirSensEUR.org, 2022

3. ELT D-300-3V CO2, Radon RDM200M, Alphasense OPC-N3 and Plantower PMS5003 sensor shield

To connect CO_2, Radon and PM sensors, an ExpShield1 shield is needed. Please note that this shield is able to automatically detect if a sensor is present, so it's not mandatory to have all sensors connected. This allows AIRSENSEUR units to have only PM sensors (either OPC-N3, or Plantower PMS5003, or together), only CO_2 sensors and/or only Radon sensors, or any combination of sensors.

Follow the same procedure listed above to remove the bottom cover then remove the top and the bottom covers.

Figure Annex 3: Installation of corresponding sensors in ExpShield1 shield



Take the plastic separator located between the two chambers where the Radon and OPC-N3 sensors should be placed.

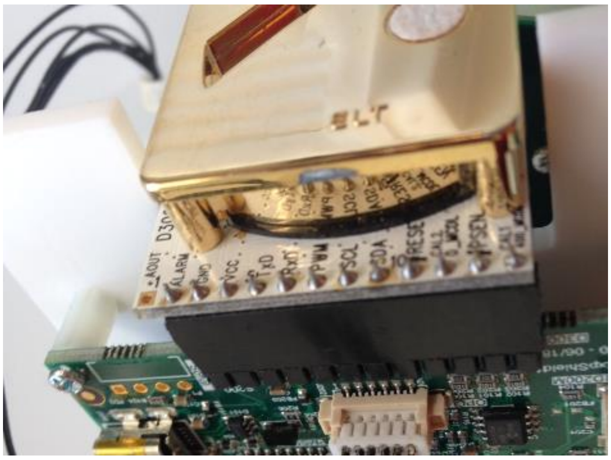
With four M2 screws, fix the ExpShield1 following the picture on the left side.

Insert the D-300-V2 on top of the board.

Insert the black 6 pin cable on the connector marked “OPC”. The opposite side should be addressed to the OPC-N3 device.

Connect the Sensor Bus plug (tree wire cable) to the socket marked SensorBus (ExpShield1 has two sockets for that purpose: they’re equivalent, so, just use the one you feel better).

Turn ON the 1st DIP switch to identify the board with ID=1.

<table>
<tr>
<td></td>
<td>NOTE: D-300-V2 is manufactured without the black strip connector visible on the picture. You need to hand solder this connector. ExpShield1 provides a male 12 pins header but the D-300-V2 has 13 holes on his side. To properly solder the 12 pin strip connector, take care to leave the 1st (marked as AOUT) pin open.</td>
</tr>
<tr>
<td>
</td>
<td>Remove the RD200M holder shown on the left picture by firmly bending with a pincer.

Connect to the sensor the 4 wires provided cable.</td>
</tr>
<tr>
<td>
</td>
<td>Place the RD200M sensor into the enclosure. The sensor is blocked to the proper location by some millings on the internal plastic separator, and by a plastic holder located on the box edge. Use a M2 screw to fix the sensor to that plastic holder.

Connect the Radon sensor to the RD200M marked socket on the ExpShield1.

Gently insert the ExpShield1 from the bottom side.

Connect the Sensor Bus cable to an empty Sensor Bu socket.</td>
</tr>
</table>

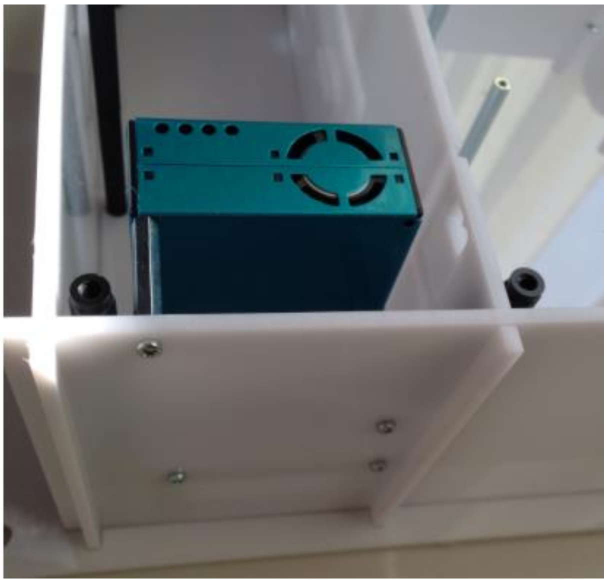
Put back the bottom cover by tightening down the mounting bolts.

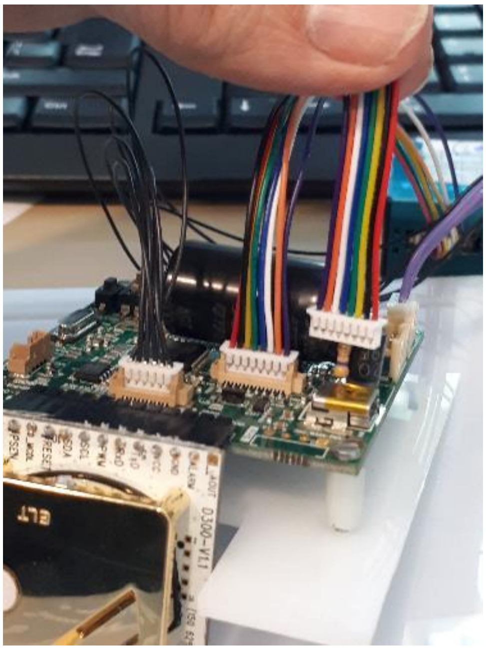
Fix, to the AIRSENSEUR top panel, the OPC-N3 sensor with four M3 screws and connect to the black cable coming from the ExpShield1.

Put back the top cover by tightening down the mounting bolts.

The AirSensEUR box is now ready to go with Radon, CO_2 and OPC-N3 sensors.

Mount two metallic M2x20 spacers in the PMS5003 holes.

	Fix the PMS5003 metallic spacers to the plastic side of the PM chamber by means of two M2 screws. The PMS5003 cable may reach the ExpShield1 by means of the holes left by the ELT sensor and the chassis.



Source: JRC and LiberaIntentio S.r.l., 2022., AirSensEUR.org, 2022

NOTE: for Plantower PMS5003 sensor and ExpShield1 R10: the connector on the Plantower PMS5003 is in reverse order compared to the one present to the ExpShield1 R10. For this reason, when connecting the PMS5003 sensor to the ExpShield R10, you can't use the ribbon cable provided by the PMS5003 manufacturer.

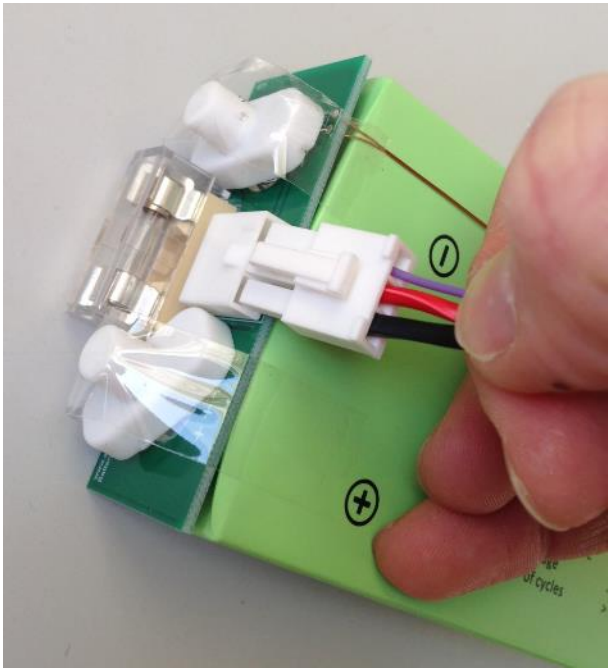
When mounting the PMS5003, check that the position of the cable is like in the picture above (cable held with hands has the wrong cable setting, while the one connected to the sensor is correct).

4. Battery and SIM card

The AirSensEUR units, for safety reasons, are delivered with unconnected internal batteries. To properly start a new AirSensEUR unit, some actions should be performed.

Through a Philips PH1 screwdriver remove the top screws. You are then able to remove the polycarbonate top cover.

Figure Annex 4: Installation of battery and SIM card

	(Optional if you're not using WiFi as the main data-push channel. See next chapters for further information on how to enable WiFi for data transfer). Remove the GPRS modem dongle from the USB socket, then install a SIM on it. You should remove the protection cover in order to access the SIM socket. The modem is compatible with full size SIMs so, if you have a mini or micro SIM, you need an optional adaptor. When inserting the SIM: pay attention to the reference corner. It should be aligned as reported in the picture (this is the case of a Huawei E303 dongle, different brand/model can have different positions). Assure that your SIM has been already activated with a standard mobile phone. Assure that your SIM has a valid GPRS data plan. Assure that your SIM is not PIN protected. If you're not sure, please check with a regular mobile phone then disable any PIN for the SIM. Install the protective cover then insert back the GPRS modem into the USB connector in the host board.
	Connect the battery cable. Insert the floating white connector into the white socket present on the battery holder. You may help the insertion process holding the battery from the back side. The connector cannot be reversed and can be installed in a single way only. This is reported in the following picture. Pay attention to the thinnest wire on the right side of the socket. If you're not in this case, you should move to the connector on the opposite side of the cable.

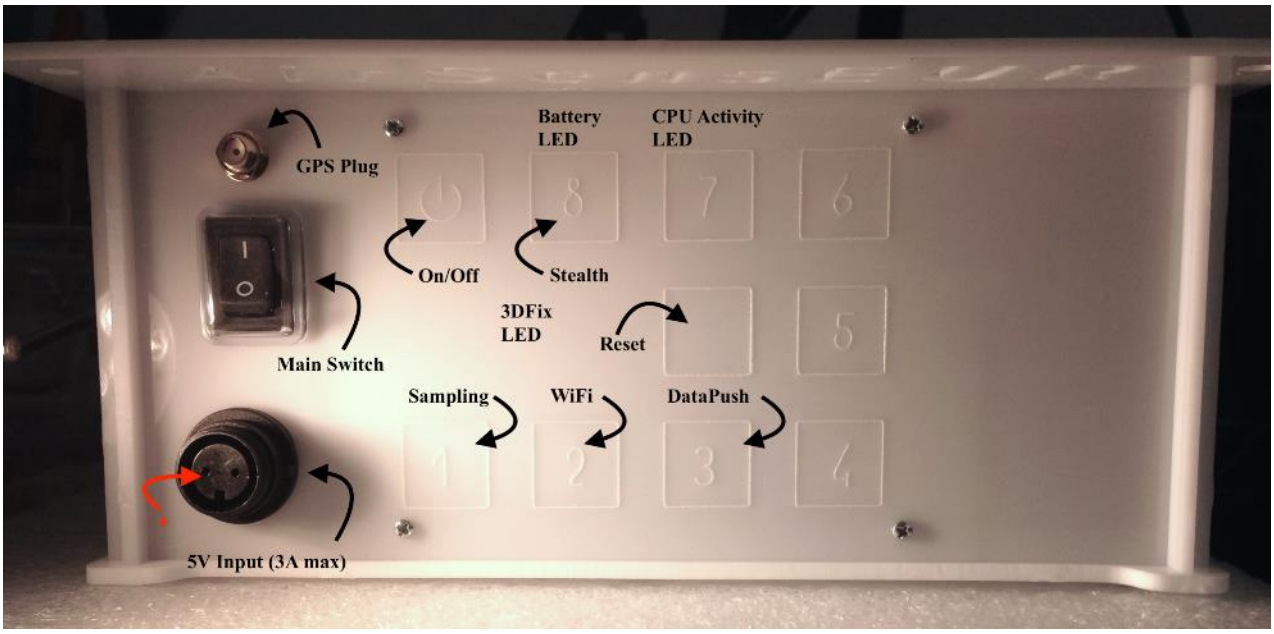
Source: JRC and LiberaIntentio S.r.l., 2022., AirSensEUR.org, 2022

NOTE: AirSensEUR enclosure is mainly made in PolyTetraFluoroEthylene (PTFE) material. PTFE material tends to be highly sensitive to scratches. Please ensure your working top is clean and remove all objects that may scratch the enclosure surfaces.
NOTE: The top is protected by a film that can be removed before re-installing the top panel on the unit.

5. Use of control panel and LED signification

The AirSensEUR Host panel implements 8 software-controllable LEDs and 8 software-controllable capacitive buttons assigned to specific functions. A Main switch controls the overall power status of the box. Two extra capacitive buttons are addressed to power on/off the unit and reset the unit respectively.

Figure Annex 5: The AirSensEUR control panel



Source: JRC and LiberaIntentio S.r.l., 2022., AirSensEUR.org, 2022

Software controllable LEDs and pushbuttons are operational only when the Linux kernel has been started. Being software based, their functionality can be modified by kernel parameters and/or bash shell scripts. Hereafter are the functions already defined:

- 3DFix. This LED is directly connected to the GPS module. When off it indicates that the GPS module is not powered; when blinking in a 50/50 pattern it indicates that the GPS module is powered on but no valid 3DFix is available. As soon as the 3DFix is available the LED will flash periodically with a short blinks.
- Touch area On/Off. This button handles the main board power status. When in off status, pressing for more than a second will power up the Host; when in on status, pressing for more than a second will start a graceful shutdown of the Host. This button is disabled when running in stealth mode (see below).
- Touch area 1: Sampling on/off. Pressing the button will start/stop the sampling process. This involves turning on/off the on-board GPS module. The LED blinks when the operation is in progress but is steady on when the sampling process has been started. When in stealth mode (see below) the LED flashes each 6 seconds to signal a sampling procedure active. The LED is always off when no sampling is running.
- Touch area 2: WiFi Access Point functionality on/off. Pressing the button will start/stop the Access Point WiFi functionality. The LED blinks when the operation is in progress but is steady on when the WiFi Access Point functionality is turned on (the Host is broadcasting their name and ready to accept clients connections).
- Touch area 3: Data synchronisation process scheduler on/off. Pressing the button will enable/disable the data synchronisation scheduler. When the LED is on, the data synchronisation process is triggered based on the scheduled program. When the LED is off, the scheduler is disabled i.e. no synchronisation with external server will be done. The LED blinks when the synchronisation is taking place.

— Touch area 8. Pressing this push button toggles the stealth mode. When the stealth mode is on, all software configurable LEDs (except for the battery charge status) are forced off thus reducing the battery power consumption. Exiting from stealth mode restores the software configurable LEDs status.

Some notes on the stealth mode:

- - when not in stealth (i.e. after the boot and/or if required by pressing the "stealth" capacitive button), all buttons and LEDs operate normally.
- - when in stealth mode (i.e. after 6 minutes of control panel inactivity and/or if when pressing the "stealth" button), all LEDs are disabled, except for the 3DFix and the sampling LED (see above). In stealth mode all software controller capacitive buttons (except for the "stealth", obviously) acknowledges with a couple of "beep", but does not activate/deactivate the function. At the same time, the On/Off and Reset areas are disabled. Actions are no longer possible in "stealth" mode. This includes the possibility to turn off or reset the device. To perform any action, it's mandatory to unlock the control panel by pushing on the "stealth" button.

— CPU Activity LED (over the touch area 7). This LED blinks in a 50/50 pattern when the system is in the boot/shutdown status. The LED blinks in a heartbeat like pattern when the system is ready and operating. The pulse frequency is proportional to the CPU load status.

— Battery LED (over the touch area 8). The LED is off when Host is powered by battery. The LED flashes when the battery is charging but is steady on when the battery is charged.

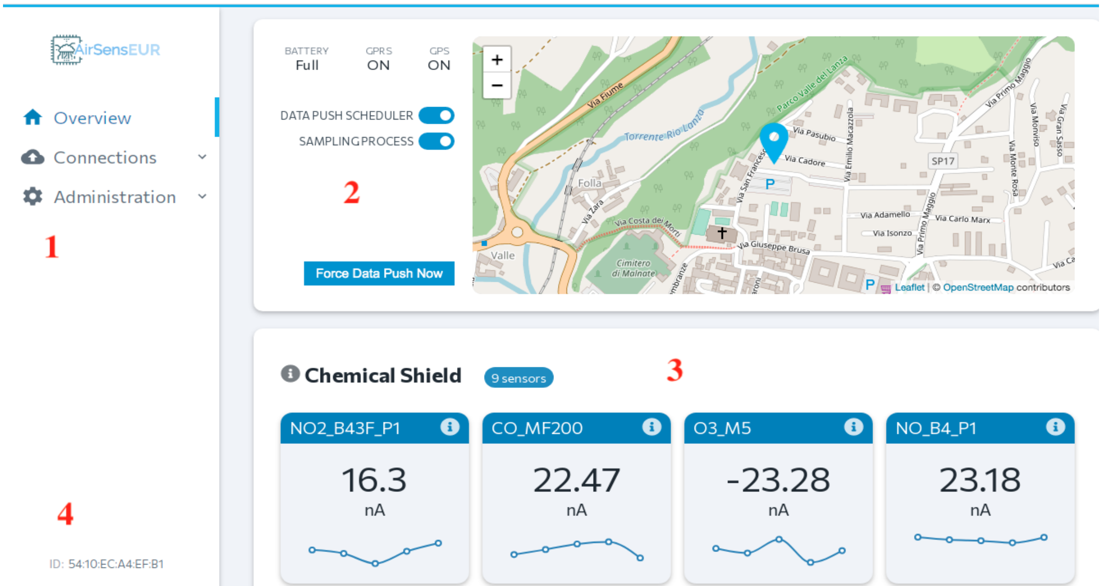
— Reset touch area. Touching this area for a period of more than three seconds forces the CPU reset. This button is disabled when in stealth mode (see above).

6. Configuration of WIFI data push

6.1 WIFI connection to the AirSensEUR Web Interface

1. Enable WIFI on the control panel of the AirSensEUR box. When enabled, the Host is reachable as a WiFi private network named AirSensEURxx. If, for some reason, the WiFi button is not working, see the notes in the end of this section. The client should be enabled to receive dynamically an IP address as the AirSensEUR Host acts as a DHCP server.
2. On your mobile phones, tablets or notebooks, connect in WIFI selecting the AirSensEURxx Access Point. The default password is "AirSensEUR", upper case matters.
3. Open a browser at 192.168.100.1. The Overview page should be shown as seen in Figure Annex 6.

Figure Annex 6: Overview page of the AirSensEUR Web Interface



Source: JRC and LiberaIntentio S.r.l., 2022., AirSensEUR.org, 2022

The overview page reports all the information about the AirSensEUR in running status. Referring to the picture above, the menu section is labelled with “1”. You can use this section to move between pages targeted to different configuration purposes.

The section labelled with “2” shows the last AirSensEUR box known position, determined by the GPS coordinates retrieved from the last sampling campaign, as well the status of battery charger, GPS and GPRS dongle. The checkboxes “Data Push Scheduler” and “Sampling Process” report the scheduler and sampling process status; by clicking on that, it is possible to turn on/off the related processes. Lastly, the button “Force Data Push Now” allows the data push process to forcibly start.

The section labelled with “3” shows the installed shields and related sensors, as detected in the latest sampling campaign. If no samples were found in the very last period, for a specific sensor or for the whole sensor set, it will be reported by the related sensor widgets.

The section labelled with “4” reports the unique ID associated with the AirSensEUR host unit.

Hovering with the pointer, or clicking, the “i” icon available on each shield and sensor panel, you’ll be able to retrieve detailed information on the serial bus ID, firmware, and serial number for each installed shield, or, in case of sensor widgets, to retrieve the associated channel number and sensor serial ID (if applies).

NOTE: When pressing the WIFI button, if the LED lights a few times (5) and then switched off, it is likely that the MAC Address of the WIFI USB is incorrect in the file /etc/udev/rules.d/70-persistent-net.rules. Just delete this file and reboot AirSensEUR. The 70-persistent-net.rules will be updated at the next WiFi startup.

To remove the file, either remove the microSD and mount the SD in a Linux OS and delete the file or, if possible, use the rescue mode to start a bare Linux kernel and shell then mount the local microSD to delete the file.

6.2 Setup InfluxDB engine data push

This page allows you to specify the relevant information to connect to a remote InfluxDB server.

You can reach this page by clicking on the “Influx” item under the “Connections” menu.

In order to enable the data-push via InfluxDB server you should enable the engine by clicking on the “Enable” checkbutton. When enabled, the page will show as in the above picture. The form requires some information needed to point to an external InfluxDB server. The main information is:

- Hostname: the IP address or URL of your remote server
- Port: the TCP-IP port where the InfluxDB server should be reached (defaults to 8086)
- Database: the database name in the remote InfluxDB server
- Dataset: the measurement table in the remote database
- Username: authenticating user in the remote influxDB server
- Password: authenticating password in the remote InfluxDB server
- Encrypt Transaction: when true, the HTTPS protocol will be used instead of unsecure HTTP transactions. If enabled, your server needs to support this feature
- Use Line Protocol: use the most recent line protocol when transacting with the remote InfluxDB server. It may be set to false to allow connections with old InfluxDB server versions.

If you’re not able to find the required information, please ask your InfluxDB server provider. Press “Save” to confirm and update the InfluxDB configuration in the AirSensEUR box. When enabled, the local data will be sent to the specified InfluxDB server each time the data-push process is triggered, either manually from the overview page, or automatically by the scheduler. Data will be pushed through WiFi or GPRS, whatever channel is available.

6.3 Setup 52North engine data push

52North engine configuration is partially available through the 52North option under the Connections menu.

In order to integrate 52North data-push you should enable the engine by clicking on the “Enable” checkbutton. When enabled, the page will show as in the above picture.

The most relevant information may be specified via this form are:

- Hostname: the IP address or URL of your remote server
- Port: the TCP-IP port where the InfluxDB server should be reached (defaults to 8080)
- FOI: Field Of Interest in 52North associated with the AirSensEUR box
- Endpoint: main endpoint to reach the 52North server
- Offering Name: offering name associated with the AirSensEUR box
- Update location: when enabled, the retrieved GPS coordinates will be send together with data on each insertObservation POST
- Observation by ID: when enabled, the observation ID is specified on each insertObservation POST.

If you're not able to find the required information, please ask your 52North server provider. Press "Save" to confirm and update the 52North configuration in the AirSensEUR box. When enabled, the local data will be sent to the specified 52North server each time the data-push process is triggered, either manually from the overview page, or automatically by the scheduler. Data will be pushed through WiFi or GPRS, whatever channel is available.

NOTE: 52North configuration through the WebPanel is not completed. You should specify all the sensors URLs by editing the 52North configuration file as defined in https://airsenseur.org/website/download/airsenseur-user-manual-v3-1/, Section 5.2.1.4 Setup 52North SOS engine data-push

6.4 Setup OpenVPN

If required, AirSensEUR may instantiate a private network with a remote OpenVPN server. You can access the OpenVPN setup page by clicking on the "VPN" option under the "Administration" menu.

NOTE: A VPN is not strictly required to connect to a remote server and push data. VPN may be useful for remote administrative purposes because it allows you to reach your AirSensEUR unit deployed in the field. In order to set up a VPN you need an OpenVPN server together with cryptographic certificates to be assigned to your AirSensEUR unit. Setting up the OpenVPN server is out of scope of this document.

In order to enable OpenVPN in AirSensEUR, you should enable the engine by clicking on the "Enable" checkbutton. When enabled, the page will show as in the above picture. The form allows you to specify the most OpenVPN relevant information:

- Hostname: the IP address or URL of your remote server
- Port: the IP port where the InfluxDB server should be reached (defaults to 1194)
- Protocol: either UDP or TCP
- Use LZO Compression: when enabled, data transfer is compressed over the wire
- nsCertType: when enabled, the server certificate needs to be a "server type"
- Public server cert: the public certificate associated with the remote OpenVPN server. It may be provided by a .cert file. Open the file with a text editor and copy the whole content on this edit box
- Public client key: the public key associated with your AirSensEUR unit. It may be provided by a .key file. Open the file with a text editor and copy the whole content on this edit box
- Public client cert: the public certificate associated with your AirSensEUR unit. It may be provided by a .cert file. Open the file with a text editor and copy the whole content on this edit box

Confirm the setup by pressing "Save". The VPN will be instantiated at the next unit reboot.

6.5 WiFi settings

WiFi configuration can be addressed by clicking on the "WiFi" option under the "Administration" menu. These configuration pages allow for setting up the WiFi to operate either in Access Point mode rather than to connect to an infrastructure WiFi in client mode. The latter option is quite useful if you don't have (or don't want) a mobile network connection through GPRS.

When operating in client mode, the WiFi becomes the main interface for the AirSensEUR to connect to the public Internet, to push samples and to interact with VPN servers.

6.5.1 WiFi settings in Access Point mode

Access Point mode is the factory default operation mode for WiFi. It allows you to connect to AirSensEUR through the WiFi mode and to access the configuration web panel at http://192.168.100.1 address.

Through the WiFi settings page, when Working mode "Access Point" is selected, you can modify the SSID broadcasted by the unit, and the WPA Password (AirSensEUR) is needed to access the AirSensEUR box.

When clicking on "Save", AirSensEUR tries to apply the new settings. When applying the settings, your local network will temporarily disconnect and a dialog box will be shown asking to wait for the network-back in operating mode.

NOTE: if your controlling device is located near known networks, it may be possible that your device automatically switches to another network instead of waiting for the AirSensEUR network to become available again. In this situation, force your device to connect to AirSensEUR WiFi network as soon as possible.

As soon as the AirSensEUR network becomes available, a dialog will be shown. In this dialog is reported the new IP that will be assigned to the AirSensEUR, and the option to confirm and save the new network configuration.

By pressing "OK", the new configuration will be applied. You'll have to connect to the new SSID and/or new password in order to continue using AirSensEUR.

6.5.2 WiFi settings in Client mode

WiFi client mode allows AirSensEUR to connect to a known WiFi access point, and to integrate to a third party network. When operating in access point mode, sampled data will be pushed to an external server through this channel. This allows users to avoid GPRS contracts.

In order to connect to an external access point, either insert the target SSID and WPA-PSK password in the "SSID" and "Password" fields, then press "Save".

Available SSIDs may be, optionally, scanned by clicking on "Scan networks". After a while, the list of available networks will be populated as reported in the picture below.

NOTE: when operating in "AP Mode", in order to scan nearby networks, AirSensEUR needs to temporarily turn off the WiFi network. In this situation, if your controlling device is located near known networks, it may be possible that your device automatically switches to another network instead of waiting for the AirSensEUR network to become available again. In this situation, force your device to connect to the AirSensEUR WiFi network as soon as possible.

As soon as the list of available devices is filled out, click on the desired name to copy the SSID into the SSID field.

When clicking on "Save", AirSensEUR tries to connect to the specified SSID with the provided password. If successful, a new dialog box will be shown, reporting the IP that will be assigned to the unit and a set of OK/Cancel buttons. Click on "OK" to confirm and apply the new configuration.

NOTE: When testing the provided WiFi SSID and password, AirSensEUR needs to temporarily turn off the WiFi AP network. In this situation, if your controlling device is located near known networks, it may be possible that your device automatically switches to another network instead of waiting for the AirSensEUR network to become available again. In this situation, force your device to connect to the AirSensEUR WiFi network as soon as possible.

NOTE: In order to properly operate, AirSensEUR needs to receive an IP through an external DHCP server. Be sure you have a working DHCP server in your infrastructure.

NOTE: If, for any reason, you need to reset AirSensEUR in AP mode but you don't have access on it through WiFi, you can reset the default configuration by following the procedure indicated at https://airsenseur.org/website/download/airsenseur-user-manual-v3-1/, Section 5.8 WIFI mode: go back to Access Point mode from Client Mode

6.6 GPRS/WAN settings

GPRS or WAN communications can be set up through the configuration panel available when clicking the "GPRS/WAN" option under the "Administration" menu.

Starting from the microSD revision 0.12, AirSensEUR supports GPRS or USB to wired LAN dongles compatible with the ethernet over USB protocol off the shelf. This is the case, for example, for the Huawei E3372 LTE USB Stick or the TP-Link UE300 USB3.0 to Gigabit ethernet adapter.

With GPRS/LTE dongles compatible with ethernet over USB protocol, the APN and the SIM pin cannot be configured through the AirSensEUR web interface, but needs to be done through the proprietary dongle administrative interface. For some dongles, unlocked SIMs can be simply inserted in the dongle with no additional configurations needed. This is true, for example, for the Huawei E3372h-320 dongle. When the auto-configuration is not supported by the dongle, instead, or for SIMs locked by a PIN, the configuration can be done by extracting the dongle from AirSensEUR and plugging it in a standard PC or MAC, thus following the instructions targeted for that specific device.

USB to wired ethernet adapters are supported off the shelf only with dynamic IP address assignment through DHCP. Static IP addresses need to be configured by manually modifying the /etc/network/ifcfg-eth0 file through SSH, if required.

Either when using GPRS/LTE dongles or USB to wired ethernet adapters, click to the "Enable" checkbutton to use the GPRS/LTE or WAN channel for data transfer and VPN instantiation. When enabled, the configuration page will look like the one shown in the picture above.

Users may decide to persist GPRS/LTE or WAN connections after each data push by switching the option "Always On".

NOTE: Always On connections are useful if you want to be able to access your AirSensEUR remotely through VPN at any time. This, moreover, is power and bandwidth hungry. This option is useful especially for wired LANs but may be quite expensive for GPRS/LTE dongles where it is better to shut-down the connection and power-off the dongle when not needed (so, at the end of each data-push process).

For GPRS/LTE dongle not supporting the ethernet over USB protocol, but falling to the "old style" AT commands through virtualized serial line over USB (this is true, for example, with Huawei E303C GPRS dongles), the option "The dongle is ethernet Ready" needs to be turned off. This allows to start a local PPP section each time the data push is started. For these dongles, the APN (and optionally SIM PIN) is needed.

Turning off the "The dongle is ethernet Ready" option reveals the APN and PIN input text fields.

If you like to test the GPRS/WAN connection, fill in the "Host to Ping" field with a known public IP and/or URL, then press "Test". AirSensEUR uses the provided configuration to start the GPRS/WAN dongle then ping the specified host. The results will be shown in the area below the "Host to Ping" field. Please note that this operation may require several minutes to properly complete.

When satisfied with the provided configuration, click on "Save" to apply.

6.7 Date and Time, data push scheduling

This page allows for configure local date and time, and for defining the scheduling for the data-push transfer process.

The configuration page is shown by clicking on the "Date and Time" option in the "Administration" menu.

Through the field "UTC Time" it is possible to select the time and date to be set on the AirSensEUR unit. Note that, for design requirements, AirSensEUR time and date refers, always, to UTC.

The page is also used to define the times at which the data push scheduler runs during the day. In blue are marked the hours where the data-push will run; greyed out hours do not participate in the data-push scheduler. To enable/disable a specific hour, click on the associated square.

The new settings are applied by clicking on "Save".

6.8 Configuration Backup and restore

Through this page it is possible to backup and restore the current configuration, and to download the whole collected database in sqlite format.

You can access this page by clicking on the “Backup” option under the “Administration” menu option.

- Click on “Configuration Backup” in order to store the current AirSensEUR configuration into a local airsenseur-config.tar file. The downloaded file may be used to restore, lately, the configuration of an AirSensEUR box.
- Click on “Data Backup” to retrieve the local sample database in sqlite format. The airsenseur-data.tar file will be transferred to your local device. Please note that this file may be several Gbytes and, for this reason, it may take several time to complete.

NOTE: When exporting the whole dataset, the sampling process will be temporarily disabled until the end of the procedure.

- Click on “Choose file” in order to specify a local airsenseur-config.tar file to be used to restore a known configuration. As soon as the file has been selected, click on “Restore Configuration” to start the process. A warning message will inform you that the current configuration in the AirSensEUR box will be overridden with the one contained in the .tar file.

NOTE: You can’t undo this operation. Be sure you’re applying a valid known configuration backup before proceeding, or your AirSensEUR will become unusable.

- Click on “Remove All Data” to destroy your current dataset. This may be useful, before starting a new sampling campaign, to free up some space in the microSD when all data from previous sampling campaigns were already sent to a remote server.

NOTE: You can’t undo this operation. If not already sent to an external server, all sampled data will be lost.

6.9 Log file and remote reboot

The page available through the “Maintenance” option under the “Administration” menu allows you to read the most important log files for debug purposes.

The same page allows you to remotely reboot the AirSensEUR unit.

Several log files are available. Select the relevant log file through the dropdown, then press “Refresh” to have it displayed in the text box.

To remotely reboot the AirSensEUR unit, click on “Reboot AirSensEUR”. A confirmation dialog will be shown to prevent unwanted reboots.

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