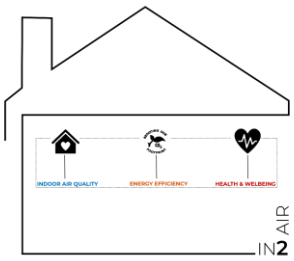

Approach undertaken for monitoring domestic air quality

Air quality measurements

The In2Air Study will measure $PM_{2.5}$, CO_2 temperature and humidity indoors, paired with $PM_{2.5}$, temperature and humidity outdoors. PM are a measure of inhalable smoke and fine dust particles such as those from cooking, smoking or outdoor traffic. Exposures to PM are associated with increased risk of allergic and respiratory diseases. CO_2 is a good indicator of the level of air exchange between indoor and outdoor environments. Raised levels of CO_2 are regarded as sign of inadequate ventilation and often used as a surrogate measure of the amount of outdoor air introduced into the home. Humidity is linked to occurrence of black mould in homes. The more frequently air quality (AQ) measurements are recorded by the AQ monitors, the more precisely the impacts of activities in or outside the home on indoor AQ can be identified.

Sampling period

We will measure matched indoor and outdoor air conditions for a minimum of 4 weeks duration before the homes are retrofitted with the energy efficiency measures. Current literature on the length of monitoring required to establish an indoor AQ baseline varies widely from a few days (e.g. 4 days) with weekend/weekday and seasonal sampling, up to 12 months[i,ii,iii,iv].

Equipment

Air quality measurements

One combined indoor monitor will be placed in the living room of each home, and one outside the property (so we can correct for relevant external factors). To contain study costs In2Air will deploy low-cost monitors. Another consideration has been to minimise the burden on participants. IQAirVisual Pro (AVPro) (indoor) and IQAirVisual Outdoor (AVO) have been selected for the In2Air study as they each combine $PM_{2.5}$, CO_2, temperature & relative humidity into a compact, quiet, unit minimising space required and disruption in participants homes. Both indoor and outdoor AQ is displayed on the indoor AVPro screen. Power and internet access (wi-fi connection) for the AVO are provided by a flat PoE ethernet cable (power and data) through a window, wall or door feed through.

Comms and data access

The AVPro and AVO monitors are linked together by Wi-Fi. We will provide a Wi-Fi hotspot (e.g. me-fi or pebble) to each home in order that researchers can connect to and manage the monitors remotely as well as download the data without needed to visit the residence.

The AVPro screen should be disabled so as not to provide information on the quality of air to study participants, which could alter behaviour. Measurements will continue to be taken and stored with the screen off. The screen can be disabled by turning on power saving mode and switching the screen off with the power button. A touch of the power button will switch the screen back on, the screen will not switch on and off automatically in the morning and evening.

The IQAir units will be networked to the IQAir data cloud where current and historic data can be viewed on the IQAir AirVisual mobile app (https://www.iqair.com/commercial/air-quality-monitors/airvisual-platform/air-quality-app) or on the IQAir web dashboard https://www.iqair.com/. Measurements will be available for the research team to download from the web dashboard.

Detailed historical data logs are held in the monitor's internal memory for up to 5 years, depending on measurement frequency. A .csv or .txt file containing all data can be downloaded wirelessly from the unit by logging into the same Wi-Fi as the AV units (this requires visiting the home) and using 'Samba' software on a laptop https://www.iqair.com/us/blog/resources/download-the-airvisual-node-pro-s-data-using-samba or by mobile phone https://support.iqair.com/en/articles/3343422-export-historical-data-from-your-airvisual-pro-using-a-mobile-phone

The indoor monitor screen shows easy to read traffic light air quality index indicators. This screen will be disabled in order not to influence the participants behaviour during the study.

Researcher contact details to be left with participants and also with the Community Centre warden in case of any issues with the monitors.

Placement of equipment

Indoor

Ideally the indoor monitor should be placed in a room most commonly used by occupants. For the In2Air study we have selected the living room. The monitor should be away from doors, openable windows, air supply vents and grilles (minimum 1 m >2 m if possible), and specific sources of pollutants (e.g. fireplace, or place where candles or incense are burned). If there are incoming ventilation supply points the monitor should be placed between these. The monitor should not be placed somewhere that would be a nuisance to the study participants, or use a socket that they regularly need, or have a trailing power cable that could be a trip hazard. Head height (where participants are breathing when seated) is desirable if possible. An adapter plug can be used in order that the Wi-Fi hotspot and AQ monitors use only one socket. See Table 12 BS40101:2022[v]

Outdoor

Placement near to any ventilation inlets (or frequently opened doors or windows) will give the quality of air that will be ventilating into the building. Shelter from direct sunshine and prevailing rain is desirable. When using paired indoor-outdoor units connected by cable, secure placement with no trailing cables should be ensured. Recommendations and consideration for installation of the IQAir Visual Outdoor in the IQAir Visual Outdoor User and Installation Manual pages 9-10, should be adhered to where possible. See Table 13 BS40101:2022[vi]

Where BS40101: 2022 guidance for placement cannot be followed a note to reflect this will be reported in the meta data.

Technical Information (extracted from AVO & AVPro User manuals)

Size

The indoor AVPro's dimensions are 21 x 12 x 8 cm, weight: 0.8 kg.
AVO dimensions are 16 x 7 x 20 cm
Wi-Fi hot spot approx. 10 x 6 x 2 cm

Sensor specifications

AVO & AVPro

Nephelometer: Laser light scattering technology with remote calibration. This technology is quieter than is typical gravimetric technology equipment. This particle count approach provides a calculated mass concentration based on assumed density and shape of the particles.

- $PM_{2.5}$ (Fine dust) 0 to 1,000 µg/m³ ±10 µg/m³ / or ±10%

Measurement frequency

AVPro: In standard mode the AVPro records time, $PM_{2.5}$, CO_2, temperature, humidity, AQI, and outdoor AQI data every 10 seconds

AVO: The AVO collects data every minute in standard mode.

A uniform sampling frequency of 1 minute will be selected for all outdoor and indoor monitors

Internet connectivity

AVPro: Wi-Fi (802.11 b/g/n - 2.4 GHz)

AVO: Ethernet (100 Mbit fast Ethernet), Wi-Fi (802.11 b/g/n - 2.4 GHz), optional: 3G/4G/LTE via USB modem

Power rating

AVO: 48VDC, 12 W

AVPro: AVPro has an internal rechargeable Li-on battery providing up to 4 hours of disconnected use. It will remain plugged in for the purposes of the In2Air study

Wifi hotspot: Average 6 W

Equipment energy use

Department of BEIS 2021 average electricity prices were 18.9 p per kWh, estimated to rise to 36 p per kWh by end of 2022. To ensure electricity costs are adequately covered we have also estimated a price for 50p per kWh.

Table 1: Estimated cost of electricity for equipment use for 1 month based on power rating and estimated price of electricity

Device	Wattage	Hours of use	kWh (per day)	31 days @ 36p/kWh	31 days @ 50p/kWh
AVO	12	24	0.288	£3.21	£4.46
AVPro (estimate)	15	24	0.36	£4.02	£5.58
Wifi hotspot (avg)	6	24	0.144	£1.61	£2.23
Sum				£8.84	£12.28

Equipment maintenance and recalibration requirements

The AVPro & AVO $PM_{2.5}$ sensor can benefit from maintenance, as laser (light-scattering) sensor readings may experience some degree of drift after a prolonged period of exposure to pollutants. The extent of this will vary depending how much pollution the sensor is exposed to. This 'drift' is likely to happen more quickly in high-pollution environments, for example in

cities with generally high outdoor pollution levels (e.g. US AQI frequently above 150). Additionally, whether the device is indoors or outdoors has an impact, since indoor environments generally have approximately 20% lower pollution levels than outdoors, even without any indoor filtration. If the sensor is in an indoor environment, in a place with generally low outdoor pollution levels (e.g. US AQI<50), then the sensor may not require replacement/recalibration for a number of years. If using the sensor in an outdoor, high pollution environment (AQI frequently > 150), then the sensor may require recalibration/replacement after approximately 12-18 months. These are guidelines - the best way to tell if your sensor is experiencing any drift, is to compare its readings with another relatively new sensor.[vi]

Default sensor mode takes measurements approximately 12x less frequently than Continuous sensor mode - so Continuous mode should expose the sensor to 12x more pollution over time, which may impact the rate of drift.

Without recalibration, the $PM_{2.5}$ sensor will continue to depict valid trends of higher and lower pollution levels, although it may lose a degree of precision over time. Users concerned with maintaining topmost accuracy in the long-term may want to recalibrate their $PM_{2.5}$ sensor every so often.

IQAir have a recalibration service. Currently, this requires your Node/Pro to be posted to one of the service centres.

AQ Reading metadata to be reported

Property data: • Site/Project; • Address; • Postcode;

Location of data point: • Floor/level, • Room/zone

Device: • Manufacturer of device; • Model; • Serial number; • Accuracy of data captured provided by the device (from technical data sheet or calibration record); • Calibration date (most recent)

Information should be stored in a spreadsheet with structure & naming according to Tables 5 & 6 in BS 40101:2022[vi]

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[i] National Center for Healthy Housing. Studying the Optimal Ventilation for Environmental Indoor Air Quality. Columbia, MD: Enterprise Community Partners. [Internet] 2022. [Accessed 31 May 2022]. Available from: https://nchh.org/ resource-library/report_studying-the-optimalventilation-for-environmental-indoor-air-quality.pdf.

[ii] Colton MD, MacNaughton P, Vallarino J, Kane J, Bennett-Fripp M, Spengler JD, Adamkiewicz G. Indoor air quality in green vs conventional multifamily low-income housing. Environmental science & technology. 2014 Jul 15;48(14):7833-41.

[iii] Lajoie P, Aubin D, Gingras V, Daigneault P, Ducharme F, Gauvin D, Fugler D, Leclerc JM, Won D, Courteau M, Gingras S. The IVAIRE project–a randomized controlled study of the impact of ventilation on indoor air quality and the respiratory symptoms of asthmatic children in single family homes. Indoor Air. 2015 Dec;25(6):582-97. doi.org/10.1111/ina.12181

[iv] BS 40101. 2021 Building performance evaluation of occupied and operational buildings – Specification. Draft. British Standards Institution, BSI Standards Limited.

[v] BSI, Building performance evaluation of occupied and operational buildings (using data gathered from tests, measurements, observation and user experience) — Specification BS 40101:2022

[vi] IQAir Knowledge Base https://www.iqair.com/us/blog/resources/airvisual-pro-maintenance-and-sensor-recalibration (accessed 09.09.22)