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AMBIENT AIR QUALITY MONITORING FOR HEALTHCARE SETTINGS

Key messages

1. Air quality monitoring at healthcare sites can help identify local pollution sources, understand exposure levels, and inform targeted actions.
2. Air pollutant levels may be measured using devices such as diffusion tubes (nitrogen dioxide) and small-form air quality sensors (particulate matter).
3. Understanding of site air pollution can inform measures to reduce emissions, and operational changes to reduce harmful exposure for patients and staff.

A guide from the WM-Air project team

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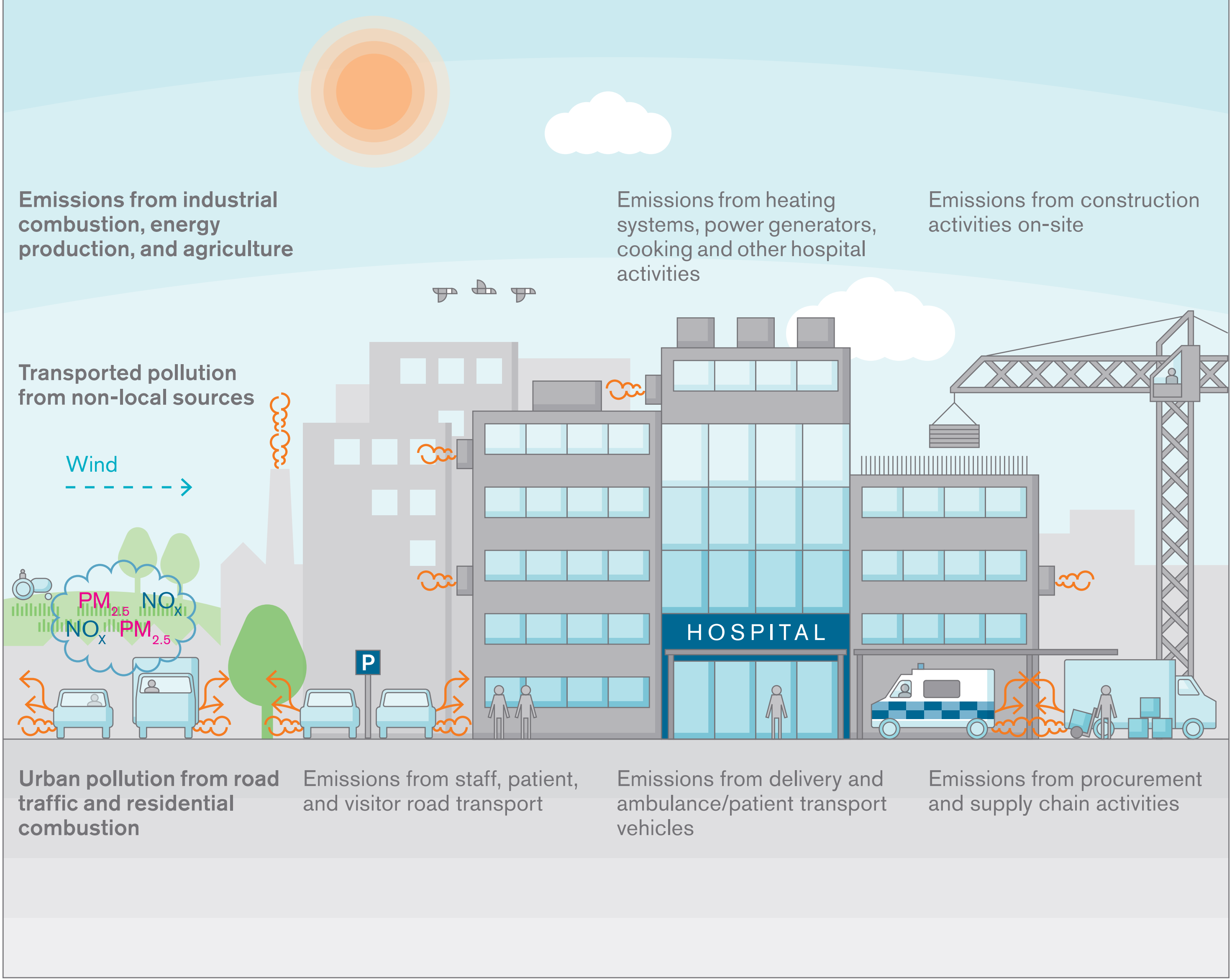
Fig 1. **Sources of ambient air pollution at healthcare sites**



Air quality measurements at healthcare sites can help providers to identify local pollution sources (Fig 1), understand exposure levels and inform targeted actions to protect the health of staff, visitors, and patients[1]. Healthcare providers can work in partnership with local authorities and others to design and undertake effective monitoring campaigns and to support analysis and interpretation of air quality data.

Health impacts of air pollution

Poor air quality leads to an estimated 29,000-43,000 early deaths each year in the UK with exposure to particulate matter (PM) and nitrogen dioxide (NO_2) of most public health concern[2].

Fine particulate matter ($PM_{2.5}$) can penetrate deep into the lungs and enter the circulatory system. Short and long-term exposure to $PM_{2.5}$ is associated with an increased risk of hospital admissions and early deaths due to respiratory and cardiovascular diseases including asthma, coronary heart disease, stroke, and lung cancer[3]. PM is classified by the International Agency for Research on Cancer as a Group 1 carcinogen[4]. A report published by the UK Government Committee on the Medical Effects of Air Pollutants (COMEAP) found that air pollution (particularly small-particle pollution) contributes to cognitive decline and dementia possibly due to damage to blood vessels in the brain[5].

NO_2 is an irritant gas, and short-term exposure to high levels (e.g. during high pollution episodes) can cause harmful respiratory effects such as lung and airway inflammation, asthma exacerbation, and increased susceptibility to viral and bacterial infections[6]. Long-term NO_2 exposure is also linked to increased risk of early death, although it remains unclear to what extent NO_2 itself contributes to this effect[7].

In England, the NHS and social care costs for $PM_{2.5}$ and NO_2 -related diseases were estimated to be £157 million in 2017 (also including diseases with less robust evidence of an association with these pollutants). Over the period from 2017 to 2035, this could reach a total cost of £18.6 billion if no action is taken[8].

Air pollution affects everyone (Fig 2), but it has a greater impact on vulnerable groups, including children, pregnant women, older people, individuals with underlying medical conditions, and those living in areas of high socioeconomic deprivation, thus exacerbating health and social inequalities[9].

Air pollution and healthcare services

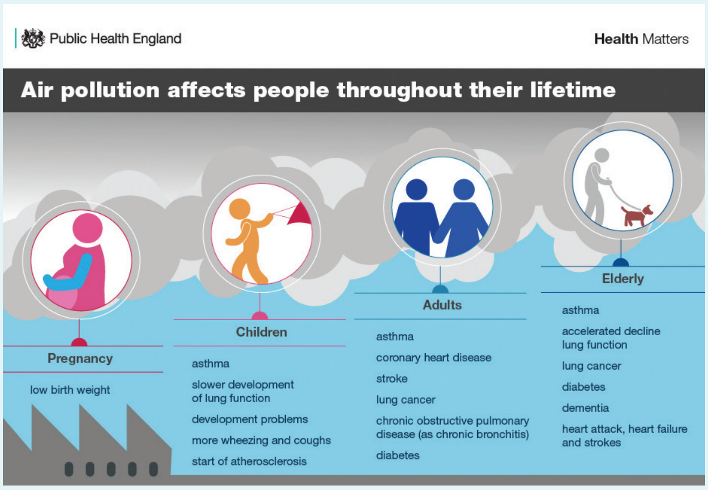
Poor air quality at healthcare sites is a risk for millions of people including some of the most vulnerable groups. A report by the British Lung Foundation in 2018[10] identified that 2,000 UK health centres were in areas with $PM_{2.5}$ levels exceeding the World Health Organization (WHO) 2005 health-based annual average Global Air Quality Guidelines. A more recent analysis conducted by City Hall[11] identified that every hospital and medical centre in London is in areas where air pollution exceeds the WHO 2021 Global Air Quality Guidelines[12].

The NHS Long Term Plan recognises the need to reduce air pollution to protect public health and to address health inequalities; of utmost importance is to identify and implement new ways of delivering clinical care to a diverse population with increasingly complex needs[13]. In addition to reducing air pollution, NHS England is committed to reducing carbon emissions and achieving net zero in terms of direct NHS Carbon Footprint by 2040[14]. Within the NHS Long Term Plan, at least 90% of the NHS fleet will use low-emissions engines (including 25% Ultra Low Emissions) by 2028, and primary heating from coal and oil fuel in NHS sites will be fully phased out[13].

The health care industry is itself also a major source of air pollution (Fig 1). On-site electricity and heating in NHS estates are the main sources of emissions, with the health sector accounting for around 5% of non-domestic gas consumption in England in 2019[15]. The NHS vehicle fleet and staff/patient transport services are also key emission sources, with NHS activities estimated to be responsible for around 3.5% of road traffic in England in 2017[15].

Self-assessment tools such as the Global Action Plan ICS Clean Air Framework may be used to track and report progress on air quality actions linked to mandated requirements of the NHS Green Plan, NHS Standard Contract and 'Delivering a Net Zero NHS' report. The framework may also be used to track progress with implementation of clean air actions.

Fig 2. **The lifelong impact of air pollution**



Source: Health Matters: Air Pollution, available at: https://www.gov.uk/government/publications/health-matters-air-pollution/health-matters-air-pollution#resources

Air quality limits and guidelines

There is no evidence of a safe level for human exposure to air pollution and any improvement in air quality is likely to bring additional short and long-term health benefits. The WHO Global Air Quality health-based guidelines[12] provide advisory insights into the air pollutant levels below which health impacts have not been reported; however these are not used to assess legal air quality compliance. In the UK, the current air quality limits[16] derive from EU Air Quality Directives, which were retained in the UK law in accordance with the EU Withdrawal Legislation. Some of these have been amended by the Environment Act 2021 which includes more stringent air quality targets for $PM_{2.5}$[17]. Current air quality objectives (England) and WHO 2021 health-based guidelines are summarised in Box 1.

Box 1. **UK air quality objectives (England)[16] and WHO 2021 Global Air Quality (health-based) guidelines[12]**

Pollutant	Averaging time	Air Quality Objective concentration (µg m^{-3})	WHO 2021 Guideline concentration (µg m^{-3})
NO_2	Annual	40	10
	24-hour	–	25
$PM_{2.5}$	Annual	20	5
		10 (to be achieved by 2040)[17]	
	24-hour	–	15

'NO_2 measurements from diffusion tubes can be indicative of compliance with legal limit values for annual average concentrations.'

'As an alternative to reference monitoring instruments, sensor units provide indicative measures of local air pollutant levels, including weekly, daily, and hourly, patterns.'

Monitoring ambient air quality

UK air pollution monitoring is undertaken through the Automatic Urban and Rural Network (AURN) managed by the Environment Agency on behalf of Defra[18]. Local authorities also carry out monitoring as part of their statutory duties to review and assess local air quality[19]. However, reference monitoring sites are sparsely distributed; there are currently only 171 sites nationally and few healthcare settings are in close proximity to a regulatory station. Public institutions, universities, businesses, and citizens may also undertake local air quality monitoring using a range of commercially available devices. Diffusion tubes and sensors can be affordable and accessible methods to assess air pollutant levels at healthcare sites much more readily than reference-grade instruments used at statutory monitoring sites. The following sections focus on these lower cost options.

Nitrogen dioxide

Diffusion tubes are widely used in the UK to monitor ambient NO_2. They consist of plastic tubes containing a chemical reagent that directly absorbs NO_2 from ambient air and require no power supply (Fig 3).

Diffusion tubes are relatively cheap (cost < £10 per tube including analysis) and simple to use. They are useful for providing long-term NO_2 measurements, such as changes over months or years, but do not identify short-term changes (e.g. over hours or days). Diffusion tubes are deployed for 4-week periods, and then sent to a laboratory for analysis. It is recommended that NO_2 diffusion tube monitoring is carried out for a minimum of six months, and ideally a year, due to seasonal variability.

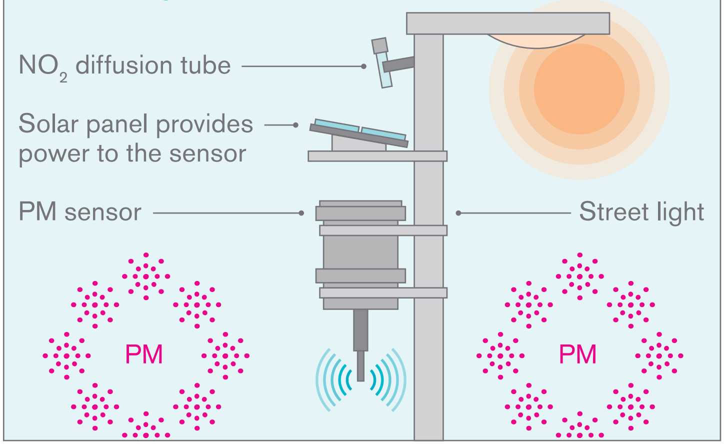
NO_2 measurements from diffusion tubes can be indicative of compliance with legal limit values for annual average concentrations. It is also recommended that diffusion tubes are co-located with reference instruments at regulatory air quality sites in the AURN[18]. Further information on NO_2 diffusion tubes is provided in the Technical Guidance LAQM.TG22 by Defra and in the NO_2 diffusion tube practical guidance by AEA Energy and Environment.

Fig 3. **An example of diffusion tubes installed at Queen Elizabeth Hospital, Birmingham**

Particulate matter

Small-form sensors are widely commercially available as a method for measuring ambient PM concentrations. These sensor units (typically priced £100s upwards) are a more affordable alternative to reference monitoring instruments used in the national networks to assess legal compliance. They are typically operated by solar or mains power supply, generating real-time data (e.g. over seconds, minutes, or hours) which can increasingly be accessed through online platforms (Fig 4).

Fig 4. **Air quality measurement devices retrofitted to a street light**



As an alternative to reference monitoring instruments, sensor units provide indicative measures of local air pollutant levels, including weekly, daily, and hourly patterns. They need to be regularly calibrated (ideally by co-location with reference instruments) to quantify uncertainties within measurements and improve data quality[20]. The best practice for co-location/calibration is to do so in an environment with similar characteristics to the sampling environment. It is also advisable to co-locate several sensors to check their consistency. PM sensors may be also affected by ambient humidity and temperature; therefore, measurements may need to be corrected.

There are a number of PM sensors that have been certified as suitable for indicative monitoring by the UK Environment Agency (EA), using the MCERTS instrument certification scheme (see Technical Guidance LAQM.TG22, section 7.175). MCERTS certified PM sensors are likely to offer better quality results, but data validation is still necessary to ensure high quality. Sensor data evaluation can be conducted by research partners or air quality contractors. The United States Environmental Protection Agency (EPA) have developed an Air Sensor Toolbox for air quality sensors offering advice not only on sensor use, but also on performance and evaluation.

To obtain a detailed understanding of PM concentrations at a healthcare site, multiple sensors are preferred to a single sensor, enabling network coverage to assess changes at different locations over time, as pollution levels may vary significantly across a site (see Queen Elizabeth Hospital Birmingham case study, page 5). Faulty and inaccurate sensors can also be more easily identified using a sensor network approach, with more data available to evaluate the accuracy and variability of the sensor performance. Further information and advice on the use of sensors for air quality monitoring can be found on the Defra website, and the WM-Air project page.

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CASE STUDY: Air quality monitoring at Queen Elizabeth Hospital Birmingham

University Hospitals Birmingham NHS Foundation Trust (UHB) is a key WM-Air project partner. The WM-Air study team undertook monitoring of ambient air quality at the Queen Elizabeth Hospital Birmingham (QEHB), a major ~1,200 bed tertiary NHS and military hospital in the Edgbaston area. Monitoring methods included the use of diffusion tubes for ambient NO_2 and sensors for $PM_{2.5}$.

NO_2 diffusion tubes were deployed at 4-weekly intervals across six monitoring locations selected to capture key local emissions sources (e.g. car parks, idling vehicles), and areas with high patient and visitor footfall (e.g. the main entrance). In addition, three diffusion tubes were co-located with reference instruments at the Birmingham Air Quality Supersite (BAQS).

Mean (average) NO_2 concentrations during the study period from mid-September 2020 to mid-August 2021 (27-37 µg m^{-3}) were within the annual mean legal limit value for England (40 µg m^{-3}) but substantially exceeded WHO 2021 health-based guidelines (10 µg m^{-3}). Levels varied significantly between locations, with the highest concentrations at the QEHB main entrance (Fig 5) likely due to localised vehicle emissions (e.g. buses, passenger cars, and ambulances) or residential combustion emissions (e.g. use of power generators, heating systems). NO_2 levels were highest during the winter months and lowest in summer.

$PM_{2.5}$ was monitored at the QEHB main entrance and nearby University Station from September 2021 to June 2022 using commercial sensors powered by solar cells with an internal battery. The sensors underwent a manufacturer data correction and calibration on the server. In addition, sensors were co-located with a reference instrumentation at the BAQS site for validation. Data were downloaded from the manufacturer's server. Instrument power outage caused extended gaps in the data collection during winter months, likely due to the limited solar energy generation.

$PM_{2.5}$ measurements at sensor locations and reference method locations, including BAQS and the AURN site at Birmingham Ladywood, showed good agreement likely reflecting the contribution of a wide range of regional $PM_{2.5}$ sources in this setting.

The mean $PM_{2.5}$ concentration during the study period (8 µg m^{-3}) was below the newly (future) annual mean legal limit for England (10 µg m^{-3}) but exceeded WHO 2021 health-based guidelines (5 µg m^{-3}). $PM_{2.5}$ levels were higher in spring than in autumn and showed two daily peaks, in the morning and evening. In spring, $PM_{2.5}$ was highest on Tuesday, while in autumn, $PM_{2.5}$ decreased from Monday to Friday and increased over the weekend (Fig 6).

A series of staff interviews were also undertaken to assess feasibility of air quality actions across the organisation[1]. This information combined with local monitoring data (from diffusion tubes and sensors) enabled UHB to implement operational and structural changes intended to reduce emissions and protect patients, staff, and visitors from pollutant exposure. The effectiveness of actions implemented will be further evaluated by air quality monitoring campaigns.

Fig 5. **Assessment of NO_2 pollution hotspots at QEHB. Average NO_2 concentrations from mid-September 2020 to mid-August 2021 and by season**

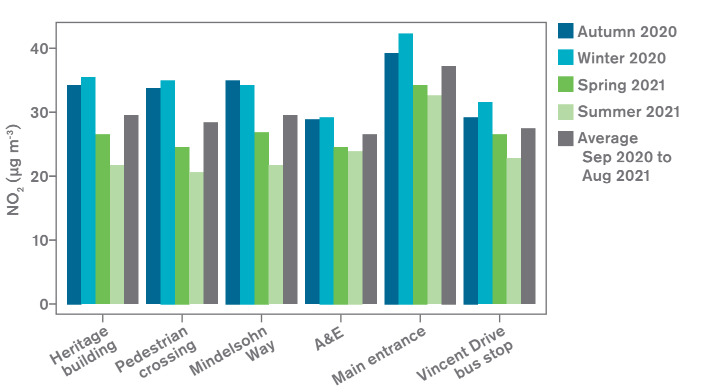
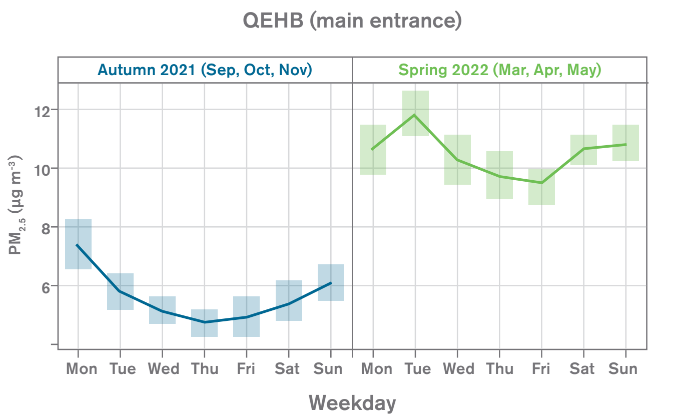


Fig 6. **Analysis of $PM_{2.5}$ weekday variation at QEHB**



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WM-Air: https://wm-air.org.uk
Birmingham Air Quality Supersite: https://clean-air-research.org.uk/aqst/

CHECKLIST: Air quality monitoring project pre-assessment

Planning an air quality monitoring project in healthcare settings can be a complex and challenging task. The below checklist is designed to help healthcare providers through the various stages of planning a project. By answering the questions, they can obtain an overview of the factors to be considered and estimate the associated costs. This will ensure that the project is more effective in achieving its objectives and saves resources, with the potential to significantly improve the quality of care for patients and staff. Simply mark the task as completed by checking the corresponding tick box(es).

1. Check availability of air quality data in your local area

This will help you better understand the current state of air quality and avoid duplicating existing efforts.

- [ ] **What air quality data is already available for your healthcare site(s)?**
  Identify which local authorities, organisations, and citizen science initiatives collect air quality data in your area. Consider approaching these groups to determine whether you can collaborate with them.
- [ ] **What are the pollutants of greatest concern in your area?**
  Research the types of air pollutants that are commonly found in your area and their potential sources.

2. Identify the purpose of air quality monitoring

This will help you determine aim and key questions to be addressed.

- [ ] **What do you want to achieve with your air quality monitoring project?**
  Typical objectives may include identifying the sources of air pollution, assessing health risks, evaluating the effectiveness of air pollution control actions.
- [ ] **Which type of pollutant and air quality data do you need to achieve your objectives?**
  Determine which air pollutants are of interest and consider their seasonal variations. Evaluate whether you want to identify short- (hours to days) or long-term (weeks to years) trends. Measuring temperature and relative humidity may be important because they can affect the behaviour and detection of air pollutants.

3. Assess the logistics

This will help you identify feasible monitoring locations and required permissions.

- [ ] **Where at the healthcare site(s) can measurements feasibly be undertaken?**
  Conduct a site survey to assess the practicality of operating monitoring equipment, including accessibility for installation and maintenance, environmental factors affecting monitoring, and personnel health and safety.
- [ ] **What permissions are required?**
  Consider any necessary access permits or insurance.

4. Assess the project costs

This will help you assess the source of costs and the budget needed.

- [ ] **What type of equipment is required and what is the capital cost?**
  Identify the appropriate instrument(s) to measure your air pollutants of interest. Develop a plan for installing, maintaining, and calibrating the instruments, and estimate the associated costs.
- [ ] **What resource is needed for data processing and interpretation and what are the cost implications?**
  Determine what staff resources are available within your organisation for data processing and analysis. Assess whether it is necessary to source these externally and estimate the associated costs.

5. Develop a plan for managing and sharing the data

This will help you manage your data and maximise their usefulness.

- [ ] **How will data be stored and managed long-term?**
  Develop a data management plan to store and organize your data during and after the monitoring campaign. Consider the duration and cost of any data management contract with commercial providers.
- [ ] **Who will be able to access the air quality data (e.g. staff, visitors, patients or the wider general public)?**
  Determine how air quality data will be used and shared, both during and at the end of the monitoring campaign. Consider developing a dissemination plan to increase awareness and impact.