MAYOR OF LONDON

GUIDE FOR MONITORING AIR QUALITY IN LONDON

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CONTENTS

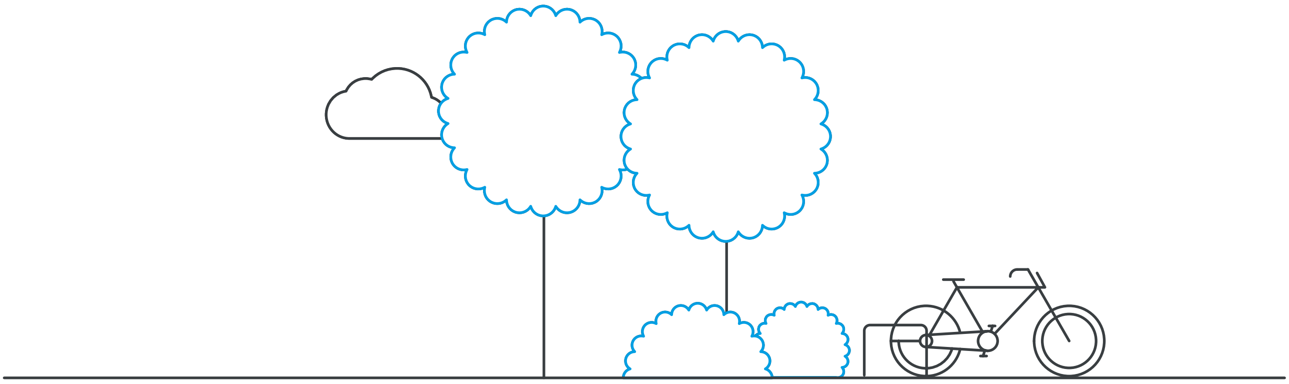
INTRODUCTION

This guide is for anyone wanting to monitor air quality in London using diffusion tubes or low-cost sensors. It gives an overview of current monitoring in London. It also has resources to help you design your study, information on monitors and how to interpret your results. The Mayor, Sadiq Khan wants Londoners to engage with air quality issues in their local area. Citizen-led monitoring studies are a great way to do this. This research can be used at a local level in awareness campaigns. It can also be used to advocate for air quality improvements and measures to reduce public exposure, like changes to school layouts.

MONITORING IN LONDON

Continuous monitoring station at Marylebone Road

London has one of the world's biggest air pollution monitoring networks. It includes nearly 100 'continuous' monitors. These are highly accurate and measure air quality pollutants in near real-time. Hundreds of lower tech measurements are also made using diffusion tubes. These monitors are mainly funded by London boroughs as part of their duties under the **Local London Air Quality Management (LLAQM) framework.** Most boroughs have at least one or two continuous monitoring stations.



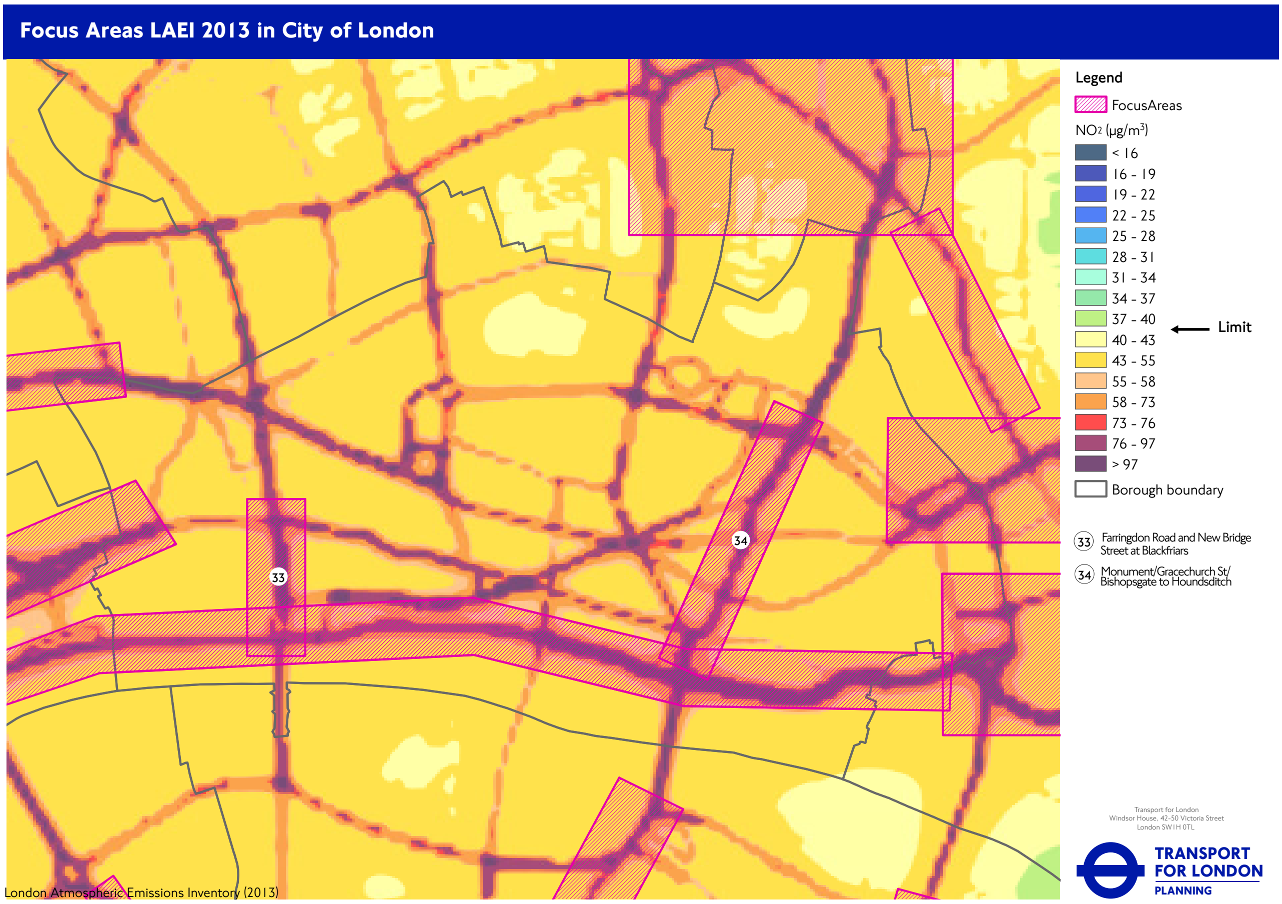
Joining a monitoring study is a great way to promote local air quality

You can view data from the continuous monitors on the **Londonair** and **Air Quality England** websites. It can be hard to find places to put these monitors due their size and need for power supply. They are also expensive to run. This limits the number of continuous monitors, and thus coverage of the network. However, this monitoring can be supplemented and extended using low-cost air quality monitors and sensors. These cheaper monitors are not as accurate. However, they are far smaller, cheaper and easier to use. Joining a monitoring study is a great way to engage in active environmental monitoring and help set the local air quality agenda.

SITING

Where air quality monitors are sited is very important. Monitors located as little as 5m apart can return very different measurements as pollution levels vary hugely over both time and space. This section outlines points to consider when placing your monitors, and the different types of monitoring sites. The most important consideration, especially in cities like London, is the how near monitors are to emissions sources. In London, pollution hotspots mainly occur near busy roads. So most monitoring sites are categorised as kerbside, roadside or urban background. A description of each site type is given later in this guidance. For a monitoring campaign to be successful, you should aim to combine all three site types.

How busy a road is can give you a good idea of pollution levels. However, you must remember that the highest concentrations of pollutants don't always occur by the busiest roads. Whether the air can flow freely can be a huge factor in ambient pollution. For example, a dual carriageway in open countryside may have lower concentrations than a single carriageway road lined by tall buildings. This is known as the street canyon effect. Similarly, wind speed and direction can also have a big impact on pollution. These factors help to explain why levels of pollution vary so much in different parts of the city.



When choosing where to put your monitors, how much pollution the public is exposed to should be a deciding factor. Public exposure is highest in areas where lots of people (like pedestrians, cyclists, drivers, bus passengers, schoolchildren) are near to emission sources (like cars) and thus high concentrations of pollutants. As well as the Londonair website, the Mayor produces pollutant concentration maps of the city within the London Atmospheric Emissions Inventory **(LAEI).** Concentration maps and **air quality focus areas** can help you to identify pollution hotspots. These maps, along with local knowledge, can help you choose the location of your monitoring sites.

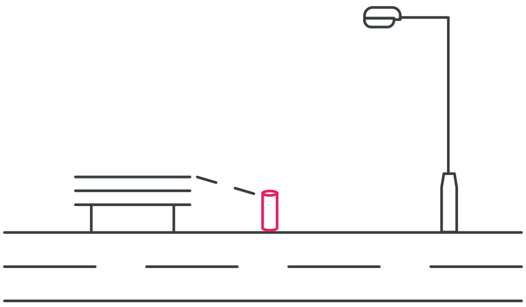
TYPES OF MONITORING SITES

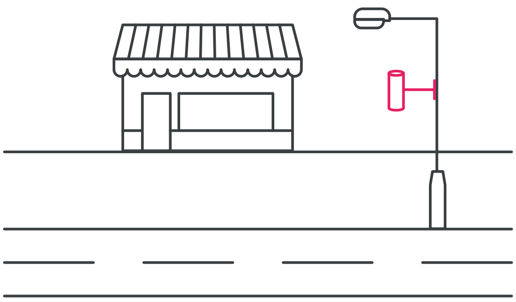
Kerbside monitoring:

Kerbside sampling sites are within 1m of the kerb of a busy road. These sites will probably return the highest readings in your study. These measurements will be dominated by road traffic emissions. Due to how near the road they are, the concentrations shown will usually be higher than what public is exposed to. The monitor would usually be mounted to kerbside railings or street furniture.

Roadside monitoring:

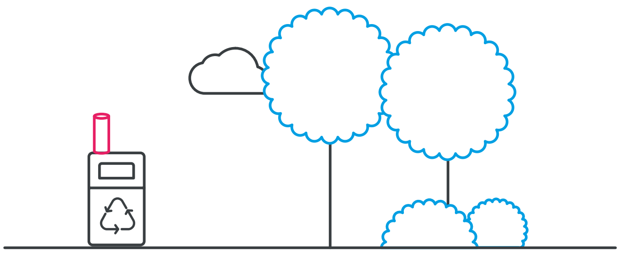
Roadside sites are within 1 – 5m of a busy road and ideally located at breathing height. They give a better idea of public exposure than kerbside sites. Roadside sites are useful for identifying potential health hazards from traffic hotspots - especially those frequented by large numbers of pedestrians. Roadside monitors are usually mounted on lamp-posts or road signs.





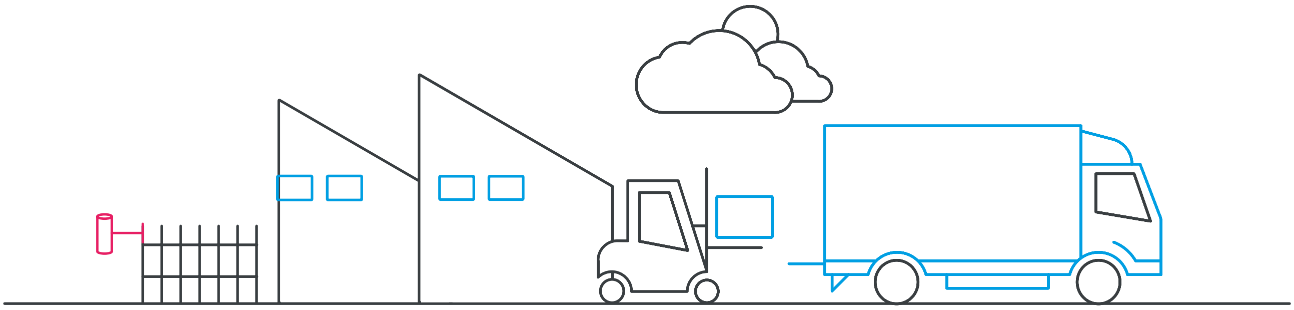
Urban background:

Background sites should not be dominated by one single nearby pollution source. In London, traffic is the main source to watch out for. You should also be aware of nearby construction sites, flumes for gas boilers or diesel generators, petrol stations, multi-storey car parks and airports. Background sites should be at least 50m away from any of these large sources, and more than 30m from busy roads (roads with over 30,000 vehicles per day, for example, an A road like Wandsworth Bridge Road). They should also be more than 10m away from a main road and 5m away from anywhere vehicles stop with their engines idling. Quiet roads within residential areas, schools and other public buildings can be used as background sites if open space is not available. However, the monitor must always be more than 1m from the kerb. The benefit of urban background sites is they're usually representative of all the other urban background locations within an area of several km^2.



MONITORING FOR A SPECIFIC PURPOSE OR SCHEME

Sensors and monitors can also be a good way to measure the air quality impact of specific changes. Examples include replacing a lane of traffic with a cycle lane, installing a green wall or a 'no idling' scheme outside a school. Likewise, they can monitor an increase in air pollution due to a new source, like a large construction site. However, it is hard to measure pollutant concentrations and what influences them. That means it can be very tough to measure a single change, especially if it is small.

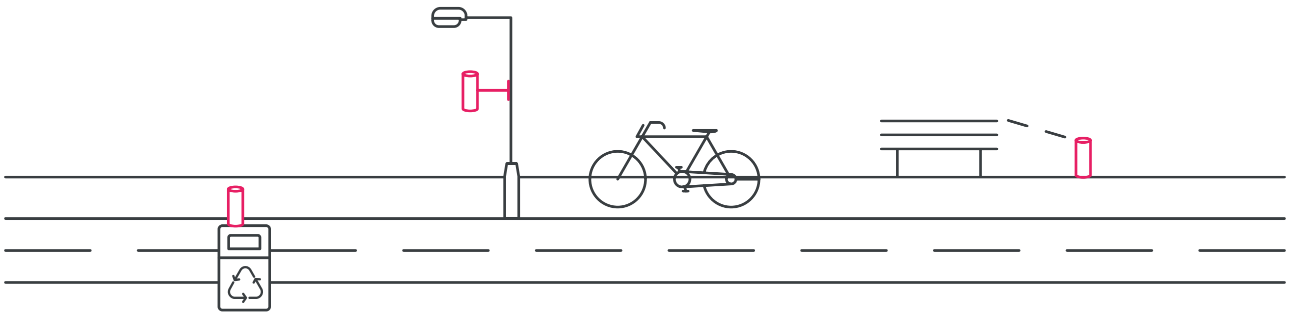


The most important thing for this kind of study is to establish the 'baseline' level of concentrations. This means taking measurements before the scheme for enough time to determine what the pollutant concentrations were before. By doing this you will be able to later attribute any improvement (or deterioration in air quality) to the new scheme (or source). The longer the baseline period of the study, the more trustworthy the findings will be. The minimum period you should do this for is three months, but 12 months is better. Pollution varies by season so it may be hard to separate the effect of weather from the impacts of the new scheme.

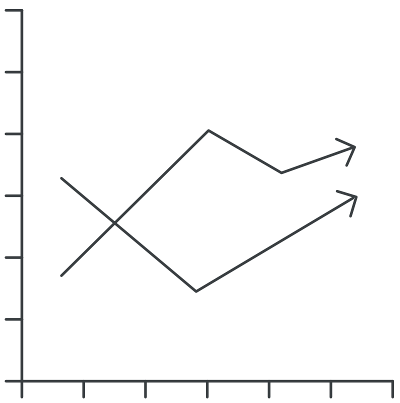
That's why your baseline study should be a full year, or 3-6 months at the same time of year to the main measurement study. A baseline study from a cold, wet winter will be no use if the main study is in a hot, dry summer. There would be too many other factors at play.

Carry out the baseline study 12 months before

The monitors must be placed at the same location during the baseline study and main study. Many of the same siting rules apply as stated previously. However, if you are monitoring something specific you should try and place the monitors in locations where the change would have the biggest impact. For example, if a lane of motor traffic was being turned into a cycle lane you'd put a monitor on the kerb/ roadside of the side being converted. If you have multiple monitors, you can then place them at equal distances from this central point. This way you would also capture the any concentration changes in the surrounding area.



Once you have both sets of results, depending on the type of monitor you have, compare hourly, daily or monthly average concentrations. If you have daily and hourly averages, make sure you compare the same time period from both studies (compare a Monday to a Monday). It might be possible to see an increase / decrease between the baseline and main study. However, be aware the impact of one change is likely to be hard to pick up using the monitors available to you. Even with the most accurate monitors, improvements in air quality can be difficult to detect without long-term studies (years as opposed to months) and complex analysis. This is because pollutant concentrations depend on so many factors (wind, weather, background pollution from other countries) that you have no control over. If you find an increase between the baseline and main study when you expected a decrease it doesn't mean your scheme has failed and vice versa.



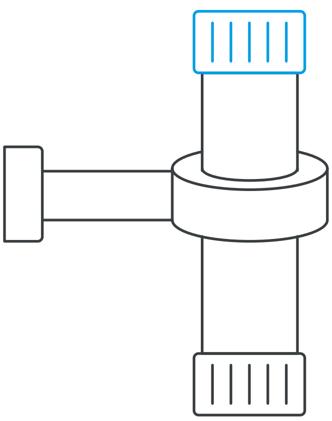
Even with the most accurate monitors, improvements in air quality can be difficult to detect

DIFFUSION TUBES (NITROGEN DIOXIDE, NO_2)

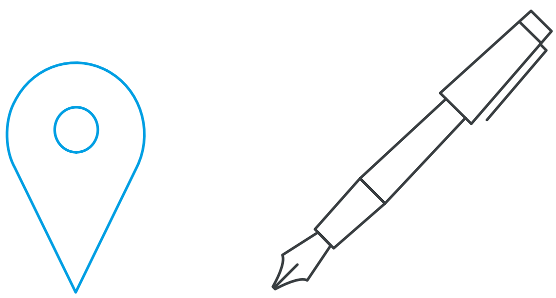
A diffusion tube is essentially a small plastic test tubes that contain a material that reacts with NO_2 in the air. Diffusion tubes are already used by councils to complement automatic monitoring data. They are a cheap and effective tool for measuring nitrogen dioxide (NO_2). Each tube costs less than £10 including analysis afterwards. Diffusion tubes are prepared by a laboratory, used in the measurement study and then returned for analysis. Because of the low-cost of the tubes, measurements can be taken simultaneously at multiple locations in the same area.

The tubes are clear plastic with rubber stoppers at each end. They contain a steel mesh coated with a chemical which absorbs NO_2. When the tube is opened (by removing one of the rubber stoppers) the coated steel mesh is exposed to the air and absorbs NO_2. The ideal duration of exposure for each tube is between 2–4 weeks. As NO_2 concentrations vary by season it is recommended diffusion tube monitoring programmes span a full year (that is twelve 4-week exposures). Tubes should be stored in a fridge both before and after exposure. Tubes should be clearly numbered with a waterproof pen or weatherproof label. Each number should correspond to a different location and period of exposure. You must keep a good record of your labelling as this is essential for interpreting your results from the lab. Make note of the exact GPS coordinates of each monitoring site. These are easy to find using free mapping tools online, like Google maps.

Diffusion tube

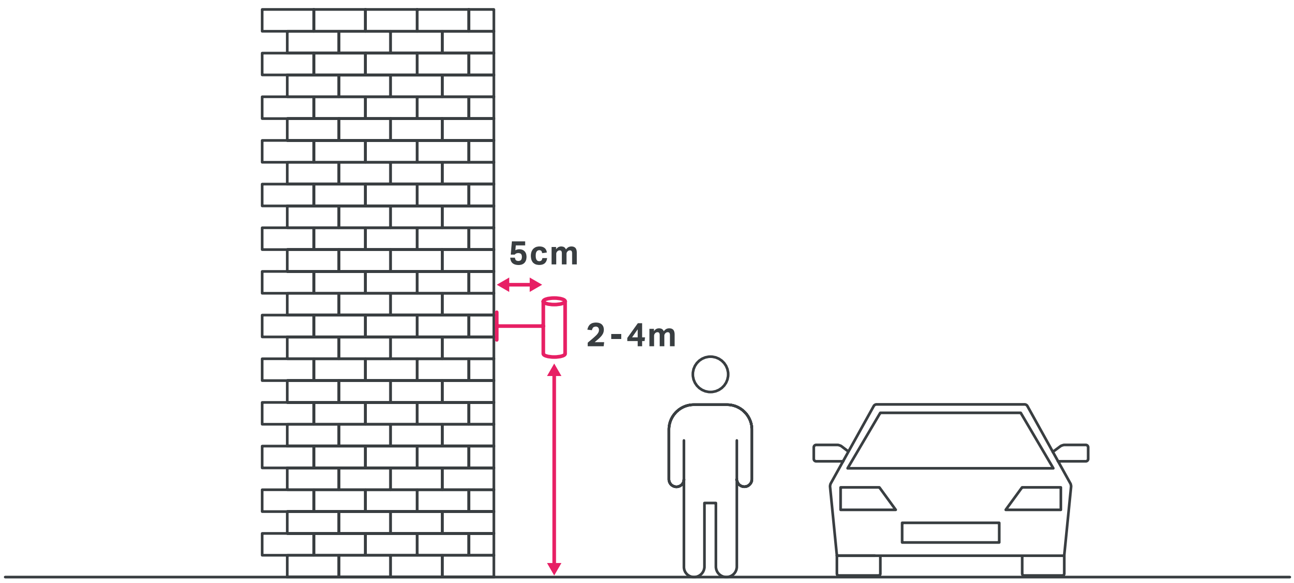


Carefully label locations on each tube



THINGS TO BE AWARE OF WHEN CHOOSING MONITORING SITES FOR THE TUBES

It is import the immediate area around the tube is open enough to allow air to flow into it. If air does not flow freely into the tube, the resulting measurement may be an underestimate. Neither should tubes be placed in locations where turbulence from passing vehicles can distort the air flow around the tube, as this can lead to an overestimate. Tubes should ideally be placed at breathing height. However, to reduce the risk of tampering or theft in busy locations it is recommended they be placed 2–4 m above the ground. All tubes in the same monitoring campaign should be placed at the same height. Emission concentrations typically fall with height. Be aware tubes placed far above street level may underestimate public exposure. Tubes should always be installed vertically with the open end pointing downwards. You should also know that some surfaces, such as walls, act as an NO_2 sink. They may reduce concentrations immediately next to the surface, resulting in an underestimate. For this reason, tubes should not be directly affixed to surfaces. There must be a spacer block of at least 5cm between the surface and the tube. You can get spacer blocks from the lab which prepared your tubes.

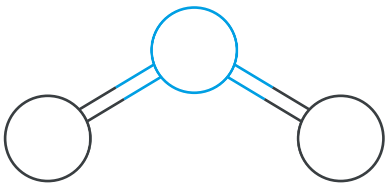


Tubes should ideally be placed at breathing height

INTERPRETING YOUR RESULTS

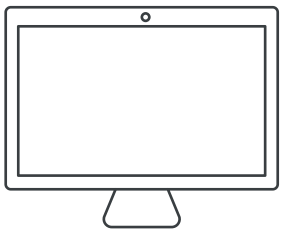
When you've completed your study, return the tubes to the lab. The lab technicians measure how much NO_2 has been absorbed by the mesh. Knowing the length of exposure and the total NO_2 absorbed they can calculate an average NO_2 concentration for the exposure period. The measurements are expressed in micrograms per cubic metre (µg m^{-3}). This is a time specific average. If your monitoring campaign spans a year you can take the average of all 12 months to calculate the annual average. If your study does not span a full year, here is some **guidance to help you annualise your measurements**.

The lab technicians measure how much NO_2 has been absorbed



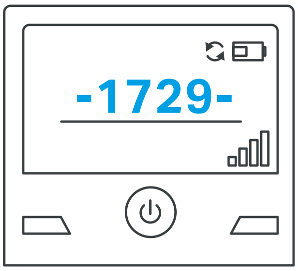
Diffusion tubes do not have the same time resolution as the automatic monitors. They are also considerably less reliable. The main limitation of diffusion tubes is they can report large over or underestimates. This is known as bias. It is very important that the bias in any diffusion tube study is identified and the measurements adjusted accordingly before results are reported. Fortunately, there is an easy way to remove the bias from your measurements. Bias will be roughly constant across all tubes from the same laboratory, prepared the same way in any year. You can find out the bias of the tubes in your study by comparing with similar studies. You will find these recorded in the National Diffusion Tube Bias Adjustment Factor Spreadsheet. This contains adjustment factors calculated from diffusion tube studies across the UK. To remove the bias from your measurements, multiply each one by the bias adjustment factor in the far-right column.

Remember to multiply results by the Bias Adjustment Factor



Annualised bias-adjusted results can then be compared to the EU air quality limit value of 40 µg m^{-3}. That is the legal limit for the annual average NO_2 concentrations set by the EU for the protection of human health.

For more detail and a worked example see the **London Local Air Quality Management Technical Guidance 2016**.



Low cost sensors can measure a wide number of pollutants

LOW-COST SENSORS (PARTICULATE MATTER)

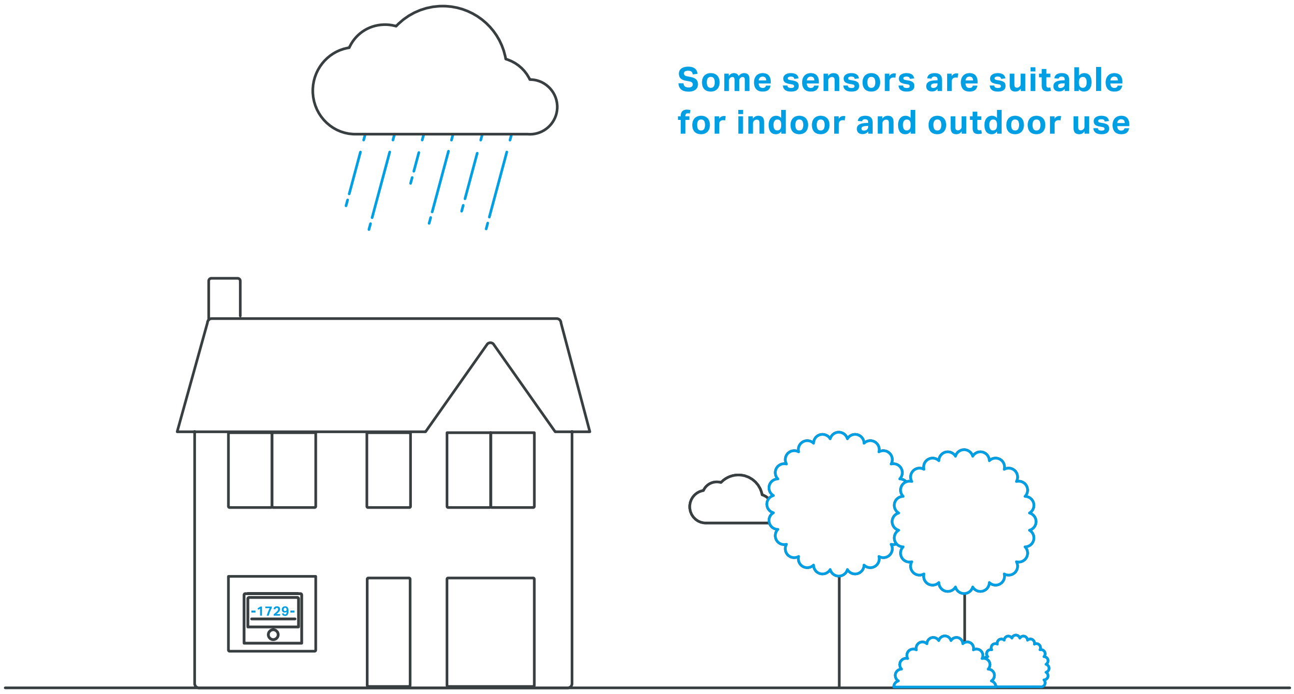
In recent years, there has been a growing market for low-cost air quality sensors. These can be bought online for as little as £150. Sensors have been developed to measure a wide number of pollutants including NO_2, particulate matter (PM), ozone (O_3) and carbon monoxide (CO). When choosing a sensor to buy, you must remember that not all are equally reliable. Also, some sensors that measure multiple pollutants are reliable for some pollutants but not for others. Here is some guidance from the Air Quality Sensor Performance Evaluation Centre **(AQ-SPEC)**. This independent testing of the most popular low-cost sensors shows they are not yet able to reliably measure NO_2. If you want to measure NO_2 then a diffusion tube study is still recommended, until the sensors are proved more reliable.

However, please note that this is a rapidly evolving market. We hope some of the emerging sensors will fill this gap soon.

Very few of the sensors tested gave reliable measurements for PM_{10}. Many did provide accurate results for $PM_{2.5}$. $PM_{2.5}$, refers to particulate matter less than 2.5 micrometres in diameter. These tiny particles, along with NO_2, are responsible for the worst health effects linked with poor air quality. Shop around and look for independent reviews of the different sensors available and make sure they are reliable for the pollutant you're interested in. The Mayor's latest Environment Strategy announced he will establish a process for accrediting monitors for different purposes. When choosing a siting location for your sensor, do follow the advice given above and remember the sensors are more valuable than diffusion tubes. That means there is more risk of theft or damage. Try to place the sensor somewhere it won't attract attention. Unlike diffusion tubes, sensors give readings in near real time and don't need to go to a lab. Some sensors will send the results via wi-fi to a smartphone app. Others will require you to download results after the measurement study. Real-time data means it's easier to scrutinise trends and measurements can be compared more easily to automatic monitoring data. It also means the measurement period can be shorter than the month required by diffusion tubes.

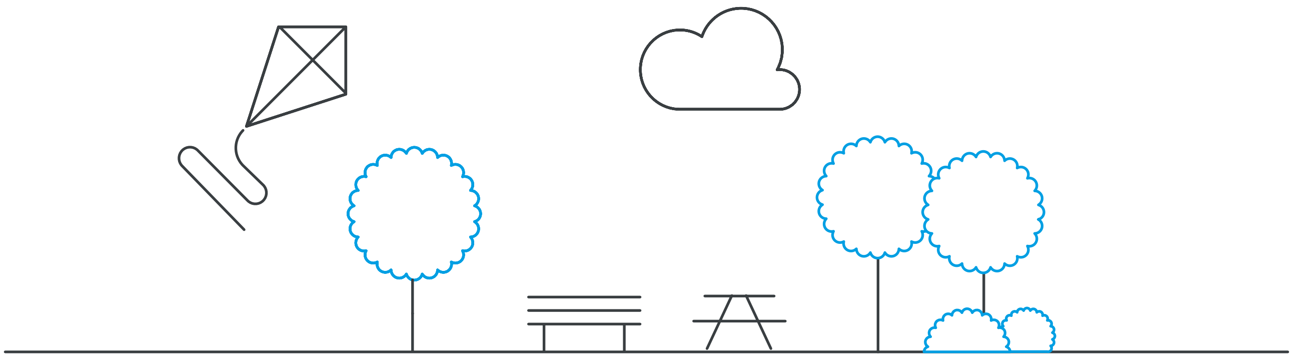
Some sensors will send the results via wi-fi to a smartphone app

It is important to choose the right sensor for your purpose. Some sensors are suitable for indoor and outdoor use. Others can only be used indoors. For outdoor studies, you may prefer to opt for a sensor with a battery rather than a mains power supply.



If you do choose an outdoor sensor you can check its reliability with a co-location study. This is a good way to verify sensor measurements against a more reliable monitor. In London, you can use one of the automatic monitors from the city's network. To do this you mount your sensor within 1m of the inlet of a continuous monitor. You can then compare your results over the same period looking at the Londonair or Air Quality England websites. The correlation between your sensor and the automatic sensor can be easily quantified using an x-y scatter plot in excel. **This brief video explains how this works: https://www.youtube.com/watch?v=kiCeJHwpYDQ.** Be sure to match up the measurement averaging period of the sensor and the automatic monitor.

Depending on the sensor you choose, the measurements may be reported in µg m^{-3}, parts per billion (ppb) or parts per million (ppm). In the EU, air quality limits values are set in µg m^{-3}. If your sensor reports in ppb/ ppm you will need to convert to µg m^{-3} to interpret the results. This can be done by multiplying by a simple conversion factor. **Here is a list of conversion factors for different pollutants.** As with the diffusion tubes, you can annualise your results to get an annual average concentration. For $PM_{2.5}$ the EU air quality limit to safeguard human health is an annual average of 25 µg m^{-3}, although the World Health Organization guideline limit is 10 µg m^{-3}. In London, annual average $PM_{2.5}$ concentrations are typically in the mid-teens. However, they can exceed 18 µg m^{-3} at some very busy and congested roadside/junction locations.



The Mayor has committed to new concentration targets for $PM_{2.5}$, with the aim of meeting World Health Organisation guidelines by 2030

4 QUESTIONS TO ASK BEFORE BUYING A LOW COST AIR QUALITY SENSOR

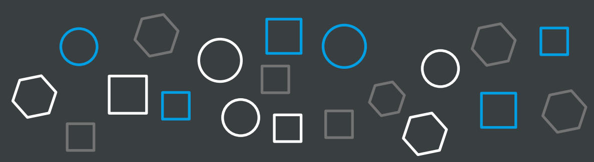
1

WHAT'S YOUR CONCERN?

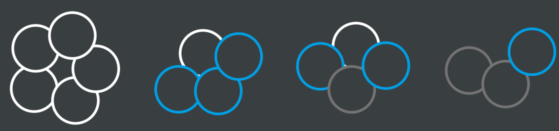
WHAT POLLUTANTS?

Find the pollutants you're concerned about by determining the sources near you

Particulate Matter

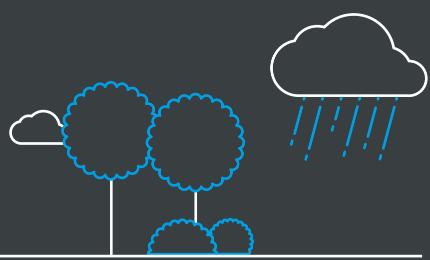


Gases (NO_2)



Indoors Monitors run on mains electricity

Outdoors Must be waterproof



2

DO LOW-COST SENSORS REALLY WORK?

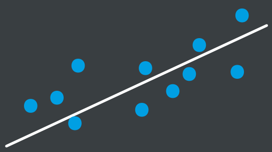
IS IT ACCURATE?

Look for:

Independent verification by experts

Tests in lab and field environments

Shows agreement with continuous monitor (from co-location study)



Proof of validation

IS IT SENSITIVE ENOUGH?

Can my sensor detect concentrations found in ambient air?

Often sensors can't detect low concentrations

3

WHAT FEATURES DO YOU NEED?

Size and Shape
Is it attractive, wearable, moveable, bulky?

Weatherproof
If outdoors, is it protected from harsh weather conditions?

Power
Battery, outlet, solar?

Communications
Can it send data?
Are there data charges?

App
Can you view current data?
What phones are supported?
Does the app require the Internet?

Website
Can you see other supporting data? Are the visualizations understandable?

Alerts
Notifications of high concentrations

Data
Who owns the data? Are the data public or private; can you control that? Can you access historical data?

Health info
Are numbers converted into health messages? Are they understandable?

Maintenance
Does it require expendables (e.g. filter tape)? How is it calibrated?
Does the sensor wear out?

Manual
Does the manufacturer provide operating instructions including maintenance and calibration?

Reliability
Is it built to last? How long?

4

WHAT WILL IT COST?

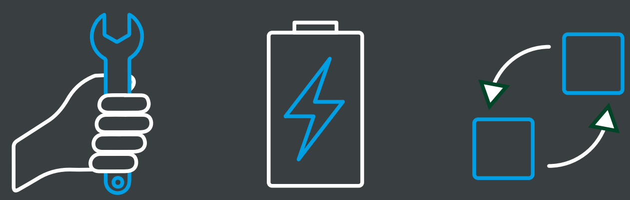
PURCHASE COST

£150-£500
1-2 Pollutants | Less Accurate

£500-£2,000
1-3 Pollutants | More Accurate

£2,000-£10,000
1 / 4+ Pollutants | More Accurate

LONG-TERM COST



- **Maintenance**
- **Upkeep**
- **Replacement**

Some low cost sensors need to be replaced within 1 year so factor this into your budget.

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WHAT TO DO WITH YOUR RESULTS

The results of your monitoring study can contribute to London's ever-expanding pool of air quality monitoring data. To make sure your results can be easily linked with existing data you must know the GPS coordinates of your monitoring sites, the exact length of the study, and results in annual average $\mu g\ m^{-3}$. For diffusion tube studies, you must also report which lab analysed the data, which bias adjustment factor you used and results before and after adjustment for bias. For sensor studies, you must state which sensor has been used. If you have been able to do a co-location study this should be reported too. Sensor studies can report results for hourly and annual averages but these must be clearly shown. In future, we hope to be able to develop a platform to ratify and share data from independently managed sensors. We will update this document with more details if this goes ahead. Your results cannot be used for compliance assessments. However, they are extremely useful as indicative studies and will help raise awareness of air quality issues.