

Selecting low-cost sensors for air quality monitoring



National Environmental Science Program

Guidance for primary and secondary schools

About this fact sheet

Low-cost sensors to monitor air quality are developing rapidly. Dozens of models with wide-ranging costs and capabilities are now available to the Australian market. This can make it time-consuming to select a model that's fit-for-purpose.

This fact sheet provides guidance for those in primary and secondary schools who wish to buy low-cost sensor devices for air quality monitoring projects. It describes key features or concerns to consider, and complements our online low-cost sensor selection tool: monitors.cleanairstars.com







This guidance covers low-cost sensors that measure particulate matter (PM), polluting gases, and volatile organic compounds (VOCs). It does not cover carbon dioxide (CO₂) monitors, such as the Aranet4, commonly used to check whether indoor ventilation is adequate.

Match the device with your monitoring goals

It's important to choose a low-cost sensor that suits the goals of your air quality monitoring project. For example, at your school you may wish to:

- educate students and others about air quality
- raise awareness about air pollution
- monitor exposure to determine health risks
- facilitate action to reduce exposure to unhealthy air and maintain a clean breathing environment.

If your goals are educational, such as a student project to study local air quality, you may wish to select a device that's intuitive and easy-to-use, and has features to sustain engagement, like a readily viewable display screen, or the option to send automatic notifications.

<p>Pollutants Measured</p>  <p>PM_{2.5} NO₂</p>	<p>Data Storage and Transmission</p>  <p>Wifi Card Cloud</p>	<p>Sensor Housing for Different Weather Conditions</p>  <p>Rain Cold Heat</p>
<p>Data Visualisation</p>  <p>On the sensor Web App</p>	<p>Power</p>  <p>Plug Battery Solar</p>	<p>Data Privacy</p>  <p>Open access Closed access</p>

Key user concerns for selecting low-cost sensors

The following are some key things to consider when selecting a sensor model for your air quality monitoring project.

Indoor, outdoor or portable?

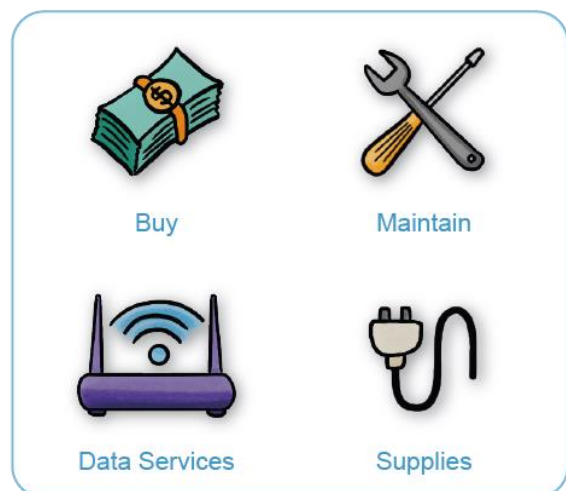
If your school's project is only concerned with indoor air quality, consider buying one of the many affordable models specifically geared for indoor monitoring.

If monitoring air pollution outside the school is your project's goal, look for one of the more weather-proof monitors designed for outdoor use. Be aware that if a monitor is specified solely for outdoor use, it's not a good idea to use it for indoor monitoring as well. Instead, look for one of the models labelled as suitable for **both** indoor and outdoor use.

A growing number of portable monitors also make it possible to monitor air in multiple locations. For example, students doing an air quality project could use these devices to explore air pollution sources inside and outside the school and along roadways.

Consider device costs & related expenses

Air quality sensor devices vary greatly in cost. This fact sheet and associated online tool define low-cost sensors as devices costing less than AUD\$10,000. Device cost generally increases with the number of pollutants measured and the degree of sensor accuracy and sensitivity.



Most models are available for a one-off purchase price, but some manufacturers offer units on a subscriber basis. 'Plug and play' models offer the option to easily replace individual sensors on the device, an attractive option for longer-term monitoring projects.

Many manufacturers offer discounts if buyers purchase multiple units.

When costing a device for your project, consider the total costs of ownership.

This includes not only purchase costs or subscription fees for the device, but additional and long-term operating costs as well, such as:

- mounting and installation costs
- subscriber services for data transmission, storage or visualisation
- power costs (for example, if solar panels are needed)
- technical support
- maintenance, including repairing or replacing sensor components
- calibration services.

Select a device that measures your target pollutants

Be sure the device you choose measures the pollutants you wish to study. Be aware that the types and number of target pollutants that a device measures can affect its cost.

Here are three main classes of target pollutants measured by low-cost sensor devices:

1. **Particulate matter (PM)** refers to small airborne particles, including those from burning fuels. PM₁ are ultra-fine particles of diameter 1 micron or less (100 times smaller than a millimetre); PM_{2.5} are fine particles of 2.5 microns or less; and PM₁₀ particles of 10 microns or less. These small particles pose a health hazard because they can travel deep into lungs, some even into your bloodstream. Most low-cost sensors measure PM_{2.5} with reasonable accuracy (see 'Accuracy' section) but typically do a poor job of measuring PM₁₀. Sensors that measure PM generally have a lifetime of 1-4 years, depending on the brand and model.

2. **Gas pollutants:** Nitrogen dioxide (NO₂) or ozone (O₃) are the main polluting gases of interest to air quality monitoring projects. Low-cost sensors generally measure gases with less accuracy than PM sensors. It's possible, but generally more costly, to purchase devices that do accurate gas measurements. Gas sensor lifetimes vary, but generally range from 6 months to 2 years.

3. **Volatile organic compounds (VOCs):** This class of pollutants spans a wide range of particles, some with short- or long-term adverse health effects. Most sensors do a poor job of measuring VOC pollutants accurately and can be very costly.

Consider sensor attributes that affect data quality

Accuracy: Depending on your project's goals, accuracy may be important. Accuracy varies among the different models of low-cost sensor devices, and even within a model for the different pollutants its sensors detect. Check the device's accuracy for each pollutant you wish to measure.

Accuracy refers to how well a sensor's pollution measurements agree, or correlate, with measurements of a highly accurate reference instrument, such as the type typically operated by state regulatory agencies. Accuracy is often expressed as an R² value, a statistical term called the coefficient of determination. The closer the R² value to 1, the stronger the correlation and the greater the accuracy, with 1 being perfect correlation. There is no Australian standard for R² values for low-cost sensors, but the US Environmental Protection Agency selects a target value of R² ≥ 0.70 in its evaluations of PM_{2.5} sensors.

Reliable manufacturer information about accuracy is often lacking. However, independent evaluations are available for

some models. These can provide insights into sensor accuracy and other aspects of device performance (see 'Resources'). Independent performance evaluations may also help you understand how sensor readings vary with humidity or temperature. Be aware, however, that these evaluations can also provide biased statistics due to changes in pollutant levels and seasonal conditions.

There are fewer independent evaluations available for gas and VOC sensor performance than for PM, but the number of these evaluations is increasing, so it's worth checking. If your project aims to record weather data such as temperature, humidity, barometric pressure or wind, it's a good idea to check the device's accuracy for these types of data as well. If your chosen model is not accurate enough, you may wish to buy a separate weather station.

Precision refers to how well a sensor reproduces a measurement under identical conditions, that is, the agreement among repeat measurements. High sensor precision may be important if you wish to measure small differences in the levels of a pollutant.

Sampling rate (also called sampling interval or sampling frequency) is the rate or time interval of a sensor's measurements. Sampling rate may be important if your monitoring project needs to capture a pollutant plume that changes rapidly in concentration or is short-lived in time. Be aware some sensors reduce their sampling rate if their power source switches from mains to battery or solar.

Measurement range and detection limit: Make sure the device you choose can measure target pollutants across the full range of interest to your project, from highest to lowest concentrations. Check manufacturer technical specifications for the limit of detection, the lowest concentration of a pollutant the device can detect.

Calibration: For some monitoring projects, it's important to demonstrate the accuracy of sensor measurements. Calibration is a way to

check and adjust sensor settings, to ensure their measurements compare well with a known and certified standard. These calibrations may be necessary to account for impacts that various air pollutants and weather (particularly humidity and temperature) can have on sensor accuracy.

Some sensors are calibrated at the factory prior to sale. Manufacturers may also offer customers the option to return their unit to the factory to be recalibrated. For some air quality monitoring projects, it may be important to field calibrate a device by locating it alongside a reference instrument (co-location). If calibration is important to your project, investigate further before you buy. Identify any additional related costs for the calibration process, and factor in the time needed to carry out this step.

Consider how the device manages data

Data transmission: Check how the device transmits data and make sure this suits your project. Some models only offer Wi-Fi transmission. Be aware that dependable and sufficiently strong Wi-Fi transmission can be extremely difficult to obtain and sustain in schools and other government buildings, and in unsecured outdoor areas.

Fortunately, most manufacturers offer a range of other transmission options, including Bluetooth, satellite, 4G and low-power wide-area network (LoRaWAN). A minority of more basic models simply store data on the device, for example, on an SD card, for manual retrieval.

Regardless, be sure to factor in any additional costs for data retrieval or transmission, such as mobile subscription services.

Data storage, handling and access: For some projects, a device's capacity for on-board data storage may be important. For devices that only store data locally, you'll need to manually access or physically upload to

the data to a website or computer data analysis tool. For many models, data is stored on central servers, from where you can download it. For some products, data can be called through an Application Programming Interface (API).

Manufacturers use models or equations to convert raw sensor data into final reported pollution information. If access to raw data (for calibration) or other formats is important to your project, check with the manufacturer to make sure it's available. Access permission, ownership rights, privacy and data sharing may be other important data considerations for your project.

Display/visualisation: A device with a readily viewable display screen may be useful to keep students and other users engaged in a project, but not all brands offer this feature. Some models offer coloured LED displays designed to alert users about air quality changes.

More typically, you'll also have the option (or be required) to visit a website or use an app to view your project's air quality data. Some vendors offer sophisticated web-based data visualisation, usually for a fee.

Consider ease of use

Useability is likely to be crucial in primary and secondary school settings. People involved in air quality monitoring projects may include custodial staff, facility managers, school officials, teachers and students. Intuitive and easy-to-use devices are especially important if people with widely varying expertise plan to use them.

Before you buy, learn what knowledge is needed to operate the low-cost sensor device. Find out if you'll need to buy tools, computers or software. Check whether it will be easy to tell if the device continues to operate properly, providing uninterrupted data over time. Consider factors like device size and weight, especially for portable models.

Installation: Is the device easy to install? Does it have flexible options to ensure its installation is compatible with your planned location, and doesn't become difficult or expensive? Models that reduce the complexity and expertise required for installation are likely the best bet. Also consider whether the device needs to be resistant to theft or vandalism.

Power options: A low-cost sensor device must suit your needs in terms of power availability. Plug-in devices are the best option for stationary monitoring, but you'll need to ensure power is accessible. Models with batteries or with USB power supplies are useful for short-term or mobile data collection. Solar power is an option for some models, but requires attention paid to orientation and battery size.

Operation and maintenance: Make sure the device is robust enough to perform well. Will it tolerate expected wear and tear, such as being dropped if it's a portable unit? If it's outdoors, will its enclosure withstand extremes of heat, cold or moisture and dust?

Determine whether you'll need special expertise to maintain the device over time. Does it have a warranty, a good-quality manual and online support? Check the manufacturer's reputation for responsive customer service, such as online help and a dedicated support team. Some vendors offer a fee-based technical support plan, and in some cases, this support can also extend to design and implementation of your project.

All air pollution monitors have limited lifespans and generally become less accurate over time. Check manufacturer information to see how long you can expect the sensors to operate before they need servicing and replacement.

Resources

CleanAir Schools Program for air quality monitoring

- [CleanAir Schools](#)

Independent evaluations of low-cost sensors

- [Airlab](#)
- [AQ-SPEC Air Quality Sensor Performance Evaluation Center](#), of California's South Coast Air Quality Management District (SCAQMD). Due to geo-blocking, you may need a VPN to access SCAQMD web pages.
- [Evaluation of emerging sensor performance](#) (US EPA)

Guidance on how to plan and run low-cost sensor monitoring projects

- [Community in action: A comprehensive guidebook on low-cost sensor](#) (SCAQMD)
- [The enhanced air sensor guidebook](#) (US EPA)

Guidance on air filters to improve indoor air quality

- [Clean Air Stars](#)