Quality assurance and quality control

To ensure the good and correct performance of low-cost sensors, it is necessary to perform periodic checks. Some manufacturers offer factory calibrations, but these tests often do not reflect the exposures encountered at the workplace. The checks suggested in this guidance sheet will help you to identify: devices that malfunction, devices that under- or overestimate exposure, and/or devices with a change in performance over time (drift). The following two tests (or a combination of both into one test) are recommended and are further explained below:

- Test for accuracy: how close are the low-cost sensors' measurements to a reference device for the substance of interest?
- Test for precision: how comparable are the trends in data of identical low-cost sensors?

Accuracy: Compare with a reference instrument

- All low-cost sensors (but preferably a minimum of 3 low-cost sensors) should be tested in co-location together with a predefined reference device for at least 4 hours side-by-side at a workplace setting. Predefined reference devices are high-end real time aerosol monitors (within their service/calibration period) or gravimetric sampling with a recognised sampler for the size fraction of interest. When using gravimetric sampling, make sure enough samples (N>3) are collected for meaningful analyses and that these are analysed as per standard. Keep in mind that gravimetric sampling provides average (arithmetic average, AM) values for the entire measurement period, which is different for direct reading instruments.
- The low-cost sensors should be static and should not move during the testing. They are oriented in the same direction such that air flows do not interfere with other similarly placed devices measuring the same exposures.
- The testing environment preferably has some variation in exposure over the measurement period. If your exposure is typically low/high, make sure you also test under these conditions. Ideally a location is selected at the workplace where these devices are normally used (or planned to be used).
- After a minimum of 4 hours testing, the data can be analysed using these suggested methods:
    - Data should be examined graphically by plotting the time series of all the instruments in a single graph.
    - The difference between the low-cost sensors and predefined reference device is calculated. The sensor mean and reference device means firstly need to be calculated, then the following equation is used.

      $$Equation\ 1: Difference\ = \frac{\text{Sensor mean} - \text{Reference mean}}{\text{Reference mean}} \times 100$$

      If the difference is positive, it means that the low-cost sensor overestimates compared to the reference; when negative the low-cost sensor underestimates.
    - Correlation between the reference and each instrument should also be calculated. A correction factor should be calculated to adjust the low-cost

sensor data when there is a difference of >±10% (as suggested by CEN/TS 18086). We suggest using the freely available Industrial Hygiene Statistical Analysis Tool (IHSTAT)[1] excel template for this.

  - Next, when using the low-cost sensor, this factor should be applied as long as the low-cost sensor is used in the situation (specific type of exposure and circumstances) for which the calibration factor is derived. Even when applying the correction factor, low-cost sensors should not be used for compliance purposes. The interpretation of quantitative results after the correction needs to be done with caution and conservativeness.

- Testing the accuracy should be done before the low-cost sensors are used and we recommend repeating this co-location testing every 12 months (or earlier if the equipment is showing unusual or unexpected results or is used on a daily basis). Also when the low-cost sensors are used more continues, we suggest earlier co-location testing ~every 3 months.
- We suggest archiving the test results over time, so low-cost sensor differences over time can be compared using the accuracy results from each test.
- Due to the limited availability of predefined reference devices and the complexity of the data analyses we suggest involving an expert with expertise in calibration for this check. Often the suppliers of the low-cost sensors have suggestions on who to approach.

Precision: Testing the low-cost sensors side-by-side

- All low-cost sensors (but preferably a minimum of 3 low-cost sensors) should be tested in co-location for a minimum of 24 hours side-by-side at a workplace setting. Alternatively, if you have only one or two low-cost sensors, a comparison with a high-end aerosol real-time monitor (similar as for the accuracy) is also recommended.
- The low-cost sensors are positioned static and do not move during the testing. They are oriented in the same direction with air flows not disturbing other devices experiencing the same exposures.
- The testing environment preferably has some variation in exposure over the day. If your exposure is typically low/high, make sure you also test under these conditions. Ideally a location is selected at the workplace these devices are normally used (or planned to be used).
- After the minimum of 24 hours testing, the data can be analysed using these suggested methods:
  - Data should be examined graphically by plotting the time series of all the instruments in a single graph.
  - The variation between the instruments is calculated. This can be done by dividing the average standard deviations from the low-cost sensors by the average concentration of all tested low-cost sensors together, multiplied by 100% (equation 2).

[1] American Industrial Hygiene Association (AIHA). (n.d.). *IHSTAT macro (free version) tool download*. https://www.aiha.org/public-resources/healthierworkplaces/healthier-community-resources/apps-and-tools-resource-center/aiha-risk-assessment-tools/ihstat-macro-free-version/ihstat-macro-free-version-tool-download

$$Equation\ 2: Variation\ = \frac{\text{Standard deviations sensors}}{\text{Average concentration sensor}} \times 100$$

  - An acceptable variation is defined as within 30% for low-cost sensors.

- Assessing the precision is done before the low-cost sensors are used and we recommend repeating this co-location testing every two months (or earlier if the equipment is showing unusual or unexpected results).
- We suggest archiving the test results over time, so low-cost sensor differences over time can be followed by comparing the precision values from each test.