



Guideline

Particulate Matter Sensors in the Workplace

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Guideline for Particulate Matter Sensors in the Workplace

This guideline is developed to support occupational hygienists in correctly using low-cost particulate matter (PM) sensors for characterizing exposure to hazardous substances in the workplace.

The information in the guideline is developed in collaboration between occupational hygienists from the working group 'Sensors in the Workplace' and researchers from TNO. Recent insights, practical experiences, and scientific research results have been used. Due to ongoing developments in sensors and related technologies, the guideline will be [updated](#) regularly.

Scope of the Guideline

The guideline focuses on PM sensors, of which the [sensing element](#) falls into the low-cost category (up to approximately €200). In this segment of sensors are currently only sensors available that can

measure particles with diameters of approximately 0.3 to 12 μm . Sensors for ultrafine particles ($< 0.3 \mu\text{m}$) and inhalable dust (also particles $> 12 \mu\text{m}$) or other exposures (e.g., gases) are outside the scope of this guideline. Additionally, the guideline specifically focuses on exposure measurements in the workplace.

Reading Guide

The guideline contains both theoretical and practical information. From the summary and through the links in the document, more in-depth information can be found. The buttons on the right side of the document can be used to quickly switch between chapters.

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1 Summary

What do we mean by Sensors in this Guideline?

This guideline focuses on the application of PM sensors (abbreviated to just 'sensors' in the remainder of the guideline). Sensors are devices that can measure the concentration of dust in the air and can be used to measure exposure to hazardous substances that occur as particles in the air. This guideline focuses on sensors with a low-cost sensing element. These types of sensing elements can currently only measure particles around the respirable and thoracic fraction.

Why Measure with Sensors?

Compared to traditional measurements based on filters, these sensors are *cheaper* (no pumps, cyclones, filters, and laboratory analyses are needed), more *informative* (by measuring every minute/second), and *faster* (results are immediately readable). However, sensors also have limitations such as varying accuracy between situations and less specificity (they do not distinguish between types of dust).

In some situations, it may be interesting to use sensors in addition to or instead of traditional measurements.

Applications of Sensors

Sensors are particularly suitable for identifying causes of exposure, raising awareness, comparing and prioritizing situations, determining differences between employees, and monitoring the effectiveness of control measures.

Limitations of Sensors

Sensors cannot be directly used to compare with limit values or for inclusion in an exposure register. A situation-specific calibration is required first.

Selecting a Sensor

To select a sensor, it is important to ensure that the sensor is suitable for the intended application. Check at least the following:

- The sensor measures the correct *particle size* (e.g., respirable dust or PM_{2.5}).
- The *concentration range* of the sensor matches the expected concentrations in the workplace.
- The *measurement frequency* (number of measurements per minute/second) is high enough.
- The sensor is suitable for the intended *environment* (e.g., suitable for use in ATEX zones).
- The level of *connectivity* is appropriate for the application.

Additionally, in certain situations, it may be relevant to check the following properties: *alarm functions, storage space, battery life, feedback, dimensions, attachment methods, included software, and extra (context) sensors*.

Using a Sensor

Before using a sensor, it is advisable to check the following:

- The internal clock of the sensor is synchronized with the local time.
- There is sufficient storage space available.
- Other settings (e.g., measurement frequency) are correctly configured.
- The battery is sufficiently charged.
- The inlet and outlet of the sensor are clean and not blocked when in use.

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It is also useful to periodically:

- Check differences between sensors through colocation.
- Test for drift or contamination through a bump test or comparison with a reference.
- Clean the sensors or replace the sensing element if there is visible contamination or abnormal results.

Processing and Interpreting Data

There are various ways to interpret and analyze sensor data:

- *Visual inspection:* By looking at the PM concentration trend over time, you can identify when exposure peaks occur. It can also provide information about (increasing) background concentrations.
- *Comparative analyses:* By comparing datasets from, for example, two employees, you can determine how they differ. This can be based on average exposure, but also on the variation in exposure (many or few fluctuations/peak exposures).

Implementing Sensors Successfully

To achieve successful (sensor) measurements, it is important to collaborate with the (measured) employees. Only if the employee wears the sensor correctly will good results be obtained. Therefore, it is important to discuss the purpose of the measurements in advance and with whom and in what form the data will be shared.

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2 Why Measure with Sensors?

Exposure to hazardous substances can negatively impact a person's health. Therefore, exposure is assessed and controlled if necessary. For substances in particulate form (such as wood dust, quartz dust, flour dust, etc.), exposure is normally determined gravimetrically by collecting dust on a filter. This measurement method provides an average exposure over the entire measurement duration. The analyses take place in a laboratory, making the measurements relatively expensive and often taking several weeks before the results are available. The method results in an exposure value that can be compared with a limit value to determine whether the exposure is sufficiently controlled.

The reduction of occupational diseases seems to be stagnating, despite efforts by the government and businesses. More detailed information on exposure could possibly change this. Sensors can contribute to this. Sensors are small, digital devices that measure the concentration of dust in the air. They measure at high frequency (ranging from measurements per second to minute), making the course of the concentration or exposure during measurement visible. Additionally, they provide immediate measurement results, eliminating the need for laboratory analysis.

Compared to gravimetric exposure measurements, sensors have the following advantages:

- *Cheaper to use*, allowing for more measurements. This way, more employees can be measured more frequently. It also makes it more feasible to, for example, continuously monitor PM concentrations in a room using multiple sensors.
- *More informative*: Due to the high measurement frequency, you can see exactly which activities and conditions lead to high exposure, providing better insight into where, when, and why exposure occurs.

- *Faster*: Measurement results from sensors are available in real-time or immediately after the measurement period, making it clear whether there is high exposure in the measured situation. This allows for earlier prevention of further exposure.

However, sensors also have the following limitations:

- *Variable accuracy*, meaning sensors cannot be used to demonstrate compliance with limit values. Sensor measurement results can show both structural deviations (bias) and random deviations (noise). The magnitude of these deviations varies per situation and must therefore be investigated per situation to correct for them.
- *Less specific*, as sensors measure all dust particles in the air. Therefore, they cannot distinguish between different types of dust, unlike follow-up analysis on a filter sample for gravimetric determination.

Overall, sensors can help provide a more complete picture of exposure to substances, answering in more detail who is exposed and where and when the exposure occurs. With this insight, interventions can be more targeted to further reduce the disease burden from occupational exposure.

These advantages and disadvantages of sensors were widely recognized during the symposium of the Dutch Association of Occupational Hygiene (Nvva) in 2022. However, occupational hygienists also indicated that they currently lack sufficient knowledge and information to use the right sensor, and to use them correctly for realistic purposes. This guideline aims to address this need for more knowledge.

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3 What Are PM Sensors?

A sensor is a device that can measure the concentration of PM in the air. These sensors are used for various applications, such as measuring indoor and outdoor air quality, automating ventilation and extraction systems or measuring vehicle emissions. In occupational hygiene, sensors are increasingly being used to map exposure to hazardous substances.

The definition of a sensor is an element that can detect and measure physical or chemical properties of the environment. In practice, the entire device used in the workplace is called a sensor, but it actually consists of much more than just a sensor (Figure 3.1). To distinguish, we refer to the detecting part as the sensing element and the entire device as the sensor.

In this guideline, we focus on PM sensors that contain a low-cost optical sensing element. These sensors are also known as Low-Cost Sensors (LCS). There are also (much) more expensive direct-reading PM monitors (Direct Reading Instruments; DRI), but these use different techniques or are equipped with additional techniques to obtain better results.

Figure 3.1: Interior of a sensor, with some components indicated and named.

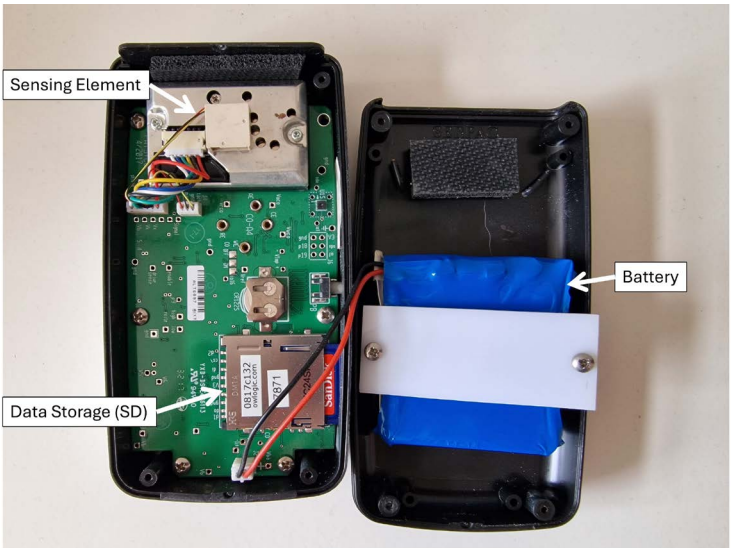


Table 3.1: Definitions of a Sensor and Sensing Element.

Sensor	Sensing element
Complete device used for exposure measurements. Often contains a sensing element, battery, data storage/communication, control, and housing.	Part of a sensor that detects the number of particles in the air.

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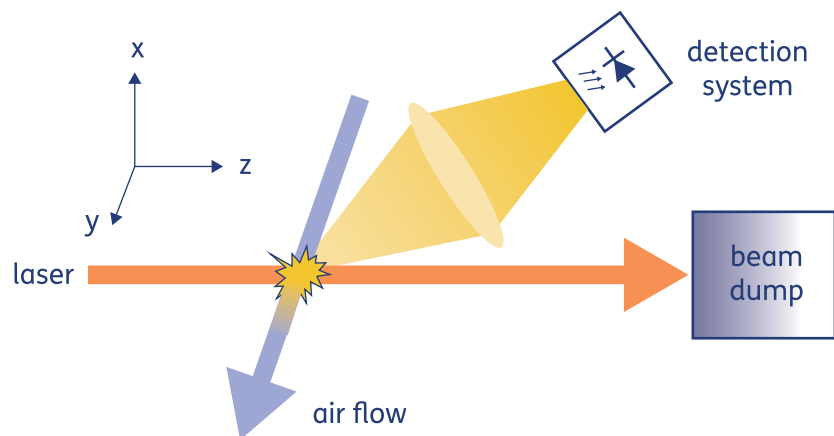
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Sensors come in many shapes and sizes and can therefore vary significantly in price (often ranging from a few hundred to thousands of euros). For example, there are sensors that immediately display what they measure on a screen but do not store any data. There are also sensors equipped with internal data storage, a Bluetooth or Wi-Fi module for wireless data transmission, additional (PM) sensors, housing, and a microprocessor to control everything. There are standalone sensors with, for instance, an SD card, but also sensors connected to a dashboard, where you essentially purchase the entire service package. However, all these sensors use similar sensing elements.

3.1 How Do Sensing Elements Work?

In general, all optical sensing elements work in a similar way. They consist of a light source, a detection chamber, and a light detector (Figure 3.2). Air with particles is drawn from the environment and crosses a light beam (often a laser), causing the light to scatter or absorb. The light detector measures the intensity of the scattered or non-absorbed light at one (or more) specific angles. The angle(s) at which light is detected is a choice of the manufacturer. The signal from the light detector is converted into a concentration of particles in the air.

Figure 3.2: Optical sensing elements consist of a light source, detection chamber, and light detector.



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3.2 Different Types of Sensing Elements

Sensing elements have small differences in how particles are detected. They can be divided into Optical Particle Counters (OPCs), photometers, and nephelometers (Figure 3.3).

With OPCs, particles are drawn into the detection chamber one by one, and particle size is determined based on the scattering angle. As a result, these sensing elements can report both the number and size of the particles. In photometers, multiple particles are drawn

into the measurement chamber simultaneously. Photometers measure light absorption (or actually the loss of intensity), where the more particles in the measurement chamber, the weaker the signal at the detector. Therefore, photometers are more suitable for measuring higher concentrations than OPCs. Nephelometers are a combination of an OPC and a photometer. All particles are drawn into the detection chamber simultaneously, but the intensity of the scattered light is measured at an angle.

Figure 3.3: Measurement principles of optical sensing elements.

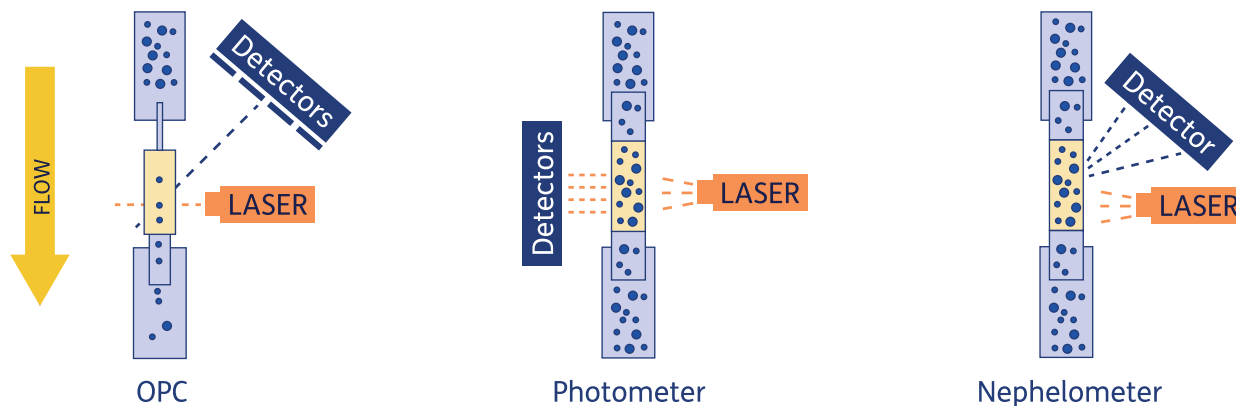


Table 3.2: Differences Between Types of Sensing Elements.

Type of Sensing Element	OPC	Photometer	Nephelometer
Typical characteristics	- Accurate particle size determination, - many size bins, - Lower concentration range (typically 0 - 1 mg/m³), - More expensive than nephelometers.	- No particle size selection by sensing element (cyclone or filter needed), 1 size bin, - Higher concentration range (typically 0.1 - 100 mg/m³), - Possibility for field calibration (zeroing), - Currently less available.	- Particle size distribution is not measured but calculated based on a standard distribution, - Lower concentration range (typically 0 - 1 mg/m³), - Most common sensing element in commercial sensors, - Cheapest type of sensing element (~€50).
Examples	Alphasense OPC-N3, Alphasense OPC-R2,	PATS+ (out of production) SKC HAZ-DUST 7204 (not low-cost)	Sensirion SPS30, Plantower PMS5003, PMS7003, Tera Next-PM, Novasense SDS011

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Sensing elements differ in the light source used, airflows and channels, possible heating element, angle(s) at which scattered light is measured, and the algorithm that translates the signal into the output. This results in differences in price and quality. Sensing elements currently cost around €10-100 each. They are commercially available, but it is not practical to use them for workplace measurements without integration of other components, such as a battery and data storage.

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4 What can PM Sensors be used for?

At present, sensors can only be used for comparative or indicative measurements, such as comparing concentrations or exposures between individuals or situations. Sensors are well capable of tracking the trend in concentration or exposure: if the concentration in the air increases, the value of the sensor measurement also increases (Figure 4.1). Although sensors provide concrete numbers ($\#/cm^3$ or $\mu g/m^3$) as output, the reliability of these numbers is currently too low to use sensors directly for quantitative exposure determination. [Calibration](#) is required for this purpose.

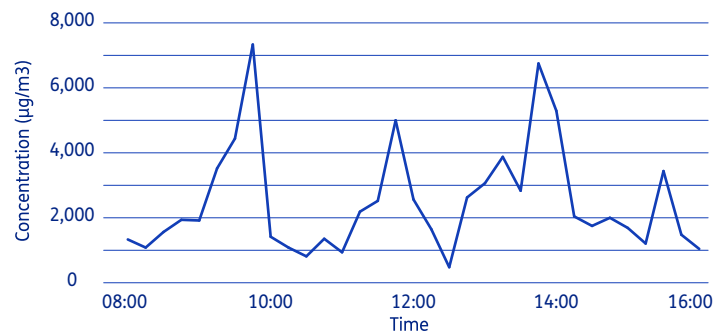


Figure 4.1: Example of an exposure profile over time from a sensor. This profile shows when the peak exposure moments are, which can help identify the causes.

Sensors can be used both stationary and personally. If an individual wears the sensor in their breathing zone, the personal exposure of that person is measured. By placing a sensor next to an emitting source, the emission of the source is measured. Therefore, the placement of the sensor(s) depends on the purpose. For example, sensors can be used effectively for:

- *Identifying causes of exposure:* Sensors display the exposure trend over time. By adding contextual information (e.g., which tasks were performed at which times), it is easy to identify the main causes of exposure. Combining sensors with video (Video

Exposure Monitoring; VEM) can be helpful when collecting context information is challenging.

- *Awareness and training:* Sensors can be used to visualize an employee's exposure during their work activities. Visualizing exposure can be very convincing, for example, by showing measurements with and without extraction or comparing well and poorly positioned extraction. Personal work habits can also lead to exposure, such as shaking out bags, sweeping instead of vacuuming, or placing one's head between the emission source and the extraction to get a better view. VEM can also be very useful for this purpose.
- *Prioritizing situations:* Sometimes there are multiple situations where particle exposure plays a role and gravimetric measurements may be needed. By measuring these situations sequentially with the same sensor, the situation with the highest exposure can be prioritized for gravimetric measurements.
- *Determining differences between employees (e.g., evaluating a SEG):* By measuring different employees with a sensor, an indication of differences in exposure between employees can be obtained.
- *Monitoring the effectiveness of control measures (other than personal protective equipment):* For example, by placing a sensor next to a source that is being extracted, it can be monitored whether the extraction is still effective.

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5 What can't PM Sensors be used for?

Currently, there is limited insight into the performance of sensors and how this varies between sensors and situations. Research that compared sensors with traditional gravimetric measurement methods has shown that the accuracy of a sensor can vary significantly depending on the substance being measured. For example, a sensor may underestimate concentrations when measuring welding fumes but overestimate concentrations when measuring wood dust. This structural under- or overestimation is called bias. Additionally, different types of sensor can show different levels of bias for the same compounds (as shown in the example in 5.1).

Due to this limited insight into performance, it is difficult to determine in advance how much a sensor measurement deviates from the actual substance concentration. Therefore, sensors cannot currently be used directly as a replacement for gravimetric determinations, such as for *comparing with limit values or inclusion in an exposure register*.

Besides these quantitative applications, there are semi-quantitative applications where sensors can be used. Measurements are not used for quantitative assessment of concentration or exposure, but rather for comparing situations, such as calculating a reduction factor for a control measure. In principle, it is possible to perform measurements before and after controls are implemented and calculate a reduction factor based on the average concentrations. However, laboratory experiments show that the over- or underestimation of sensors compared to gravimetric measurements does not need to be constant at increasing concentrations (a non-linear response¹). As a result, the calculated reduction factor only provides an indication of effectiveness and

cannot be used to determine whether exposure is adequately controlled.

The above does not mean that it is impossible to perform quantitative measurements with sensors. By calibrating sensors, structural deviations can be corrected, and the accuracy of a sensor can be determined. Calibrated sensors can generally be used for quantitative exposure measurements. But, how this calibration should be performed, how a calibration translates to different situations, and how many measurements are needed for a calibration is still unclear. Since there is no scientific consensus on this yet, sensor measurements are not generally accepted for demonstrating compliance with a limit value. Research is currently being conducted on this, and as soon as more clarity is available, it will be added to the guideline. A brief description of how a calibration can be performed and what to consider is given in [Chapter 8.1.1](#).

¹ Ruiter S, Kuijpers E, Saunders J, et al. Exploring Evaluation Variables for Low-Cost Particulate Matter Monitors to Assess Occupational Exposure. *Int J Environ Res Public Health*. 2020;17(22):8602. Published 2020 Nov 19. doi:10.3390/ijerph17228602

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5.1 Example of Welding Fume Experiments

A good example of how different sensors produce different measurement values is shown via three experiments conducted with four different types of sensors (A, B, C, and D) and a welder in a small, enclosed space. The sensors were mounted on a stand two meters away from the welder. The welder performed three experiments with three different welding techniques (5.1a, b, and c), which differ in the amount of welding fumes released. For experiment 1, one minute of welding was followed by one minute of rest, and for experiments 2 and 3, this was one minute of welding and two minutes of rest. The pattern was repeated three times per experiment. The raw measurement results of the sensors are shown in Figure 5.1.

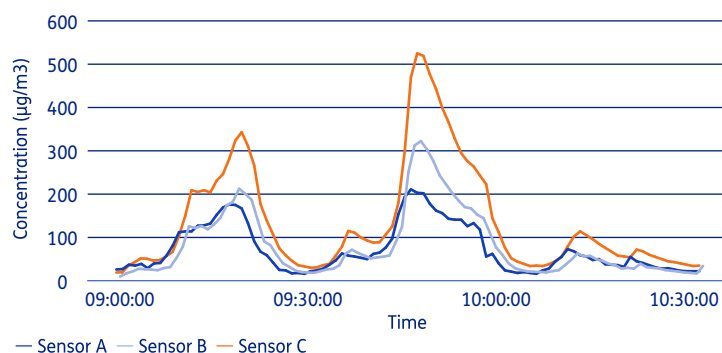


Figure 5.1a

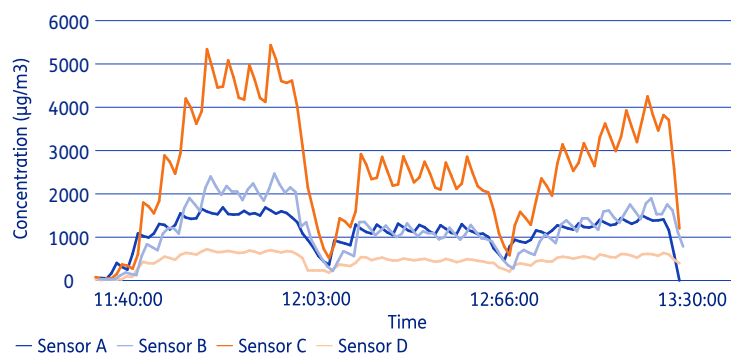


Figure 5.1b

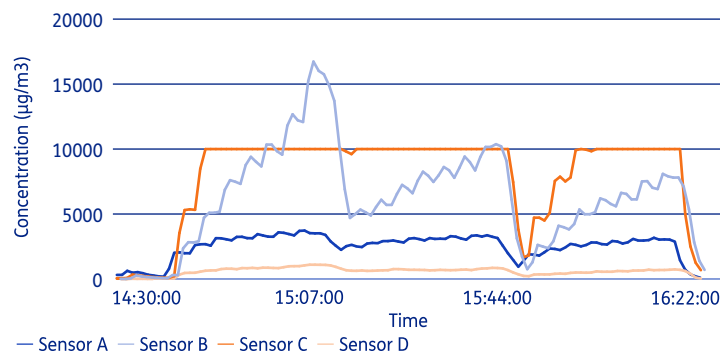


Figure 5.1c: Measurements of four different sensors in a simulated work environment with one welder. Each graph represents one experiment. In experiment 1, one minute of welding was followed by one minute of rest, and for experiments 2 and 3, this was one minute of welding and two minutes of rest. Each experiment has three replicas of half an hour.

Experiment 1 (Figure 5.1a) shows that all sensors accurately reflect the changes over time, although the pattern of one minute of welding and one minute of rest is not visible. Additionally, the differences in measured concentrations are relatively limited. In experiment 2 (Figure 5.1b), the measured concentrations are higher, and the differences between the sensors become larger. The general changes over time are still observed by all sensors. In experiment 3 (Figure 5.1c), the concentrations are even higher, and the differences between the sensors increase further. It can also be seen that one sensor has a built-in upper limit of 10 mg/m³, causing the measurements to flatten out.

Although the differences between the sensors are significant, this does not necessarily mean that one sensor is better than the other. By calibrating the sensors, structural under- or overestimation can be corrected. These results show that each sensor requires a different calibration model. It is also possible that multiple calibrations are needed for one type of sensor, depending on the welding technique used. The composition of welding fumes can vary per welding technique, which may affect the degree of over- or underestimation of the sensor.

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All this indicates that most sensors can be directly applied for qualitative applications (such as identifying peak exposures and variation over time), but also that absolute measurement values cannot be directly used without calibration.

5.2 Technical Limitations of PM Sensors

The limitations of sensors have various technical causes. The most common ones are explained below.

5.2.1 Particle Size Range

Due to the technique used, optical [sensing elements](#) cannot detect particles smaller than ~300 nm. Additionally, particles larger than ~12 µm cannot be efficiently drawn into the sensor without a pump. Therefore, sensors are suitable for measuring the respirable and thoracic fractions, but they miss the ultrafine particles (UFP) and inhalable dust fraction (<100 µm). UFPs generally do not contribute much to mass but they can significantly contribute to particle number concentrations in the air. Since PM exposure is usually expressed in mass concentrations, the absence of UFP detection is not considered as a significant limitation.

For all types of optical sensing elements, the signal from the light detector is converted by an algorithm into the output that the sensor provides, such as particle numbers (#/cm³) or mass concentrations (µg/m³ or mg/m³). The output is often given for different particle size fractions (size bins). Most sensing elements are developed for outdoor measurements and provide PM₁, PM_{2.5}, and PM₁₀ as output. Not all sensing elements actually measure particles of different sizes; some calculate the concentration per size bin using an algorithm. This does not necessarily cause problems in practice, but it can be useful to know when interpreting the measurement results. Whether a sensor measures or calculates this can be easily determined ([see 7.2.1](#)).

5.2.2 Concentration Range

The concentrations that sensors can measure depend, among other things, on the [type of sensing element](#) in the sensor. Most sensors and sensing elements are developed for environmental measurements (general indoor or outdoor air), where typical concentrations are much lower than in the workplace. Sometimes this is adjusted by a sensor manufacturer by building an air diluter into the sensor.

5.2.3 Type of Particles

The algorithm that translates the signal from the sensing element into particle numbers or mass concentration is usually developed for one specific situation, such as measurements in outdoor air. However, particles can differ from each other in properties that affect the measurement. For example, a silica particle has a different density, shape, and refractive index than a wood dust particle. Since most sensors are developed for outdoor air, the algorithm is often optimized for typical particles found in outdoor air. These can differ significantly from (a mixture of) particles relevant in a workplace, causing measurement results in the workplace to deviate.

Structural under- or overestimations based on the type of particle can be corrected through [calibration](#).

5.2.4 Environmental Factors

The output of sensing elements can also be influenced by environmental factors. For example, humidity affects particle size. As particles tend to absorb water (hygroscopicity), this effect will be greater. The same amount of particles in the air with the same particle size distribution will therefore lead to a higher sensor output in mass at high humidity, with a higher representation in larger particle fractions. Some sensors use heating elements to counteract this effect.

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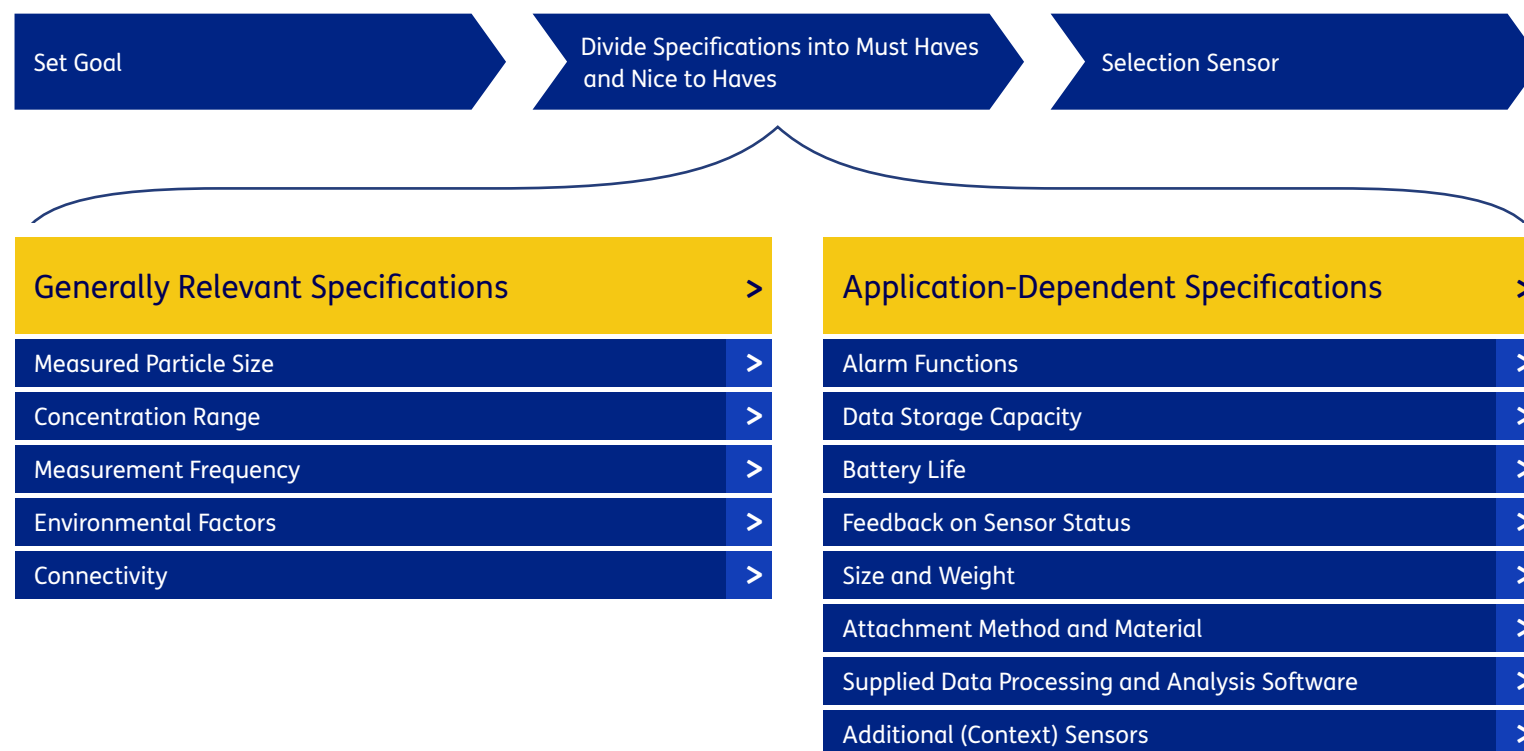
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6 What to Consider When Selecting a Sensor?

Different sensors are characterized by different properties. Whether certain properties are important depends on how the sensor will be used. For example, if you want to continuously measure dust concentrations, it is important that the measurement data is automatically processed and stored, while this is much less important if the sensor is used incidentally.

When purchasing a sensor, it is therefore important to first determine the purpose for which the sensor will be used. Based on this, you can list the specifications the sensor must have. These specifications can be divided into essential specifications (must-haves) and specifications that are only desirable (nice-to-haves) (Figure 6.1).

Figure 6.1: The purpose for which the sensor is used determines the specifications the sensor must have.


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To assist in compiling this list of specifications, the following paragraphs describe the specifications of sensors with a brief explanation of when or why they might be important. This list of specifications is further divided into specifications that are almost always relevant and specifications that are often only relevant for certain applications.

6.1 Generally Relevant Specifications

6.1.1 Measured Particle Size

Most optical particle sensors have a [measurement range of 0.3 – 12 µm](#) and are therefore suitable for measuring respirable or thoracic fractions. Sensors are generally not suitable for measuring ultrafine particles or inhalable dust. The fact that sensors are in the measurement range of respirable and thoracic dust does not mean that sensors always report these fractions. Because most sensors are developed for environmental applications, they often report particle size fractions PM_{2.5} or PM₁₀. Sometimes the PM₄ or PM₅ fractions are reported, which are relatively close to the respirable fraction. It is also possible to [calculate](#) the respirable fraction from different particle size fractions.

6.1.2 Concentration Range

Sensoren hebben vaak een (aanbevolen) meetbereik. Het is verstandig om te bepalen welke stofconcentraties verwacht worden tijdens de metingen en in welk concentratiebereik je graag onderscheid zou willen kunnen maken (zit er bijvoorbeeld nog een verschil in interpretatie tussen 10 en 11 mg/m³?).

Sensors often have a (recommended) measurement range. It is wise to determine which dust concentrations are expected during the measurements and in which concentration range you would like to be able to distinguish (for example, is there a difference in interpretation between 10 and 11 mg/m³?). Additionally, it is important to know (and this is not always clear in advance) how the sensor handles measurements above the recommended concentration range. Sometimes a sensor has a cutoff and does not give higher values than, for example, 10 mg/m³, even if the

concentration is much higher in reality. For identifying exposure peaks, this may not be a problem, but for calculating an average exposure, this will lead to an underestimation. [See also experiment 3 in the welding fume example.](#)

6.1.3 Measurement Frequency

Sensors measure at a high frequency, namely every second to every few minutes. It is relatively easy to convert the data with high time resolution to a lower time resolution, but it is not possible to increase the resolution of the data after the measurement. If a lower time resolution is chosen, it is important to know what the sensor does: does it take one measurement during that period, or does it average the data over the entire period? This can be checked with the supplier. For some sensors, the measurement frequency is adjustable.

For detecting exposure peaks during very short tasks (e.g., emptying a bag of powder), a measurement frequency of 1 measurement per second is recommended. If it concerns the average exposure over a day, a lower resolution can suffice.

6.1.4 Environmental Factors

The environment in which the sensor will be used can influence the requirements for the sensor. This may involve requirements for temperature or humidity resistance, resistance to high airflows, or applicability in ATEX zones (explosive environments).

6.1.5 Connectivity

A sensor transfer measurement data to a central storage using multiple methods:

- **Direct to a cloud**, using an LTE/IoT SIM card (similar to how a smartphone uses an internet connection) or via an existing Wi-Fi network. The user can view the data via a supplier's website, where the data can often also be downloaded.
- **Indirect to a cloud**, where the data is first transferred, often via Bluetooth, from the sensor to a nearby positioned stationary gateway (can also be a phone). The gateway then uploads the data to a cloud via a SIM card. If the sensor and gateway are

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too far apart, the data is not transferred from the sensor to the gateway. To prevent data loss for that period, it is important that a sensor has internal memory. Sometimes the data is visualized (in real-time) on a phone used as a gateway, but the data cannot be downloaded from the phone. To access the data, the supplier's website must be used.

- **From internal sensor storage**, where the sensor data is downloaded after the measurement by connecting it (often with a cable) to a docking station or a computer. A docking station can function as a gateway to the cloud or can be connected to a computer to view the data. The data can then be stored either locally or in cloud storage.

6.2 Application-Dependent Specifications

6.2.1 Alarm Functions

Some sensors can provide feedback to users when a (self-defined) threshold value is exceeded through optical, vibration, or sound signals. These are often sensors specifically designed for workplace exposure measurements. If an alarm is not (only) to be given via the sensor but also via a central system, it is important to also consider the connectivity of the sensor (see 6.1.5 Connectivity).

6.2.2 Data Storage Capacity

For some applications, it is important to check whether the sensor has sufficient storage capacity to store all measurements. Most newer sensors have considerable storage capacity, which may only become too small during long measurement periods (>1 week) with high measurement frequencies (1 measurement per second).

6.2.3 Battery Life

For wireless sensors, it is good to consider in advance the duration of each measurement. Most sensor batteries last a day to a week. Battery life is strongly influenced by the sensor settings (e.g., measurement frequency), low temperatures (cold batteries can negatively impact battery life), and wear from prolonged use.

6.2.4 Feedback on Sensor Status

Some sensors provide feedback on the status of the measurement, such as whether the sensor is on, what concentration is being measured, or how long it has been measuring. This can be via a display or a colored LED light.

6.2.5 Size and Weight

For personal measurements, it is desirable that the sensor is small and light, especially if it is used for a long time, for example, for continuous monitoring. It is also important that the sensor does not interfere with the usual working method. The maximum dimensions of most common sensors for personal measurements are 15x10x5 cm and a weight of 250 grams.

6.2.6 Attachment Method and Material

For personal exposure measurements, the sensor must be attached in the breathing zone (often on the shoulder or lapel) of the employee. There are various options for attachment. Some sensors have a (crocodile) clip that can be attached to work clothing. Sometimes sensor manufacturers provide a harness or a belt/band to which the sensor can be attached. Which solution fits best depends on the application. Keep in mind that it is important to ensure that the sensor's inlet remains free, that the sensor may need to be regularly removed (e.g., during breaks, end of shift), and that there may be other equipment the employee already wears (e.g., a tool belt).

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6.2.7 Supplied Data Processing and Analysis Software

Most manufacturers also provide software for processing and/or analyzing the collected sensor data. Sometimes this only helps visualizing a single measurement series in a figure, but in other cases it offers more options, such as editing, grouping, or annotating the measurement data.

6.2.8 Additional (Context) Sensors

Some sensors contain multiple sensing elements and can measure other exposures besides PM (e.g., noise or volatile substances). Additionally, some sensors also collect contextual information, such as the location of the measurement using GPS.

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7 Quality Controls

Because the performance of sensors can vary greatly between different applications, it is important to ensure that the sensor is functioning properly. To guarantee that a sensor works correctly, quality controls are necessary. The type and frequency of these controls depend on the situation, such as the age of the sensor, how often it is used, and at which concentrations the sensor is used.

Quality controls can be divided into routine checks before a measurement session, one-time checks before initial use, and periodic checks.

Figure 7.1: Quality controls for sensors can be performed routinely before a measurement session, once before the sensor is put into use, and periodically.

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7.1 Routine Checks Before a Measurement Session

Before using a sensor, it is advisable to check the following (if relevant):

- Is the internal clock of the sensor synchronized with the local time?
- Is there sufficient storage space available?
- Are the other settings (e.g., measurement frequency) correctly configured?
- Is the battery sufficiently charged?
- Are the inlet and outlet of the sensor clean and not blocked when worn by an employee?

7.2 One-Time Checks Before Initial Use

Before using a sensor for measuring exposure in the workplace, it is recommended to perform some tests to check that the sensor is operating as expected. The following sub-sections describe several tests that can provide insight into this. Not all tests are relevant for all applications.

7.2.1 General Tests at First Use of the Sensor

When the sensor is used for the first time, it is useful to perform some tests to check if the sensor works as expected. This is useful for all applications. First, you fully charge the sensor. Then, place the sensor in a relevant environment and start the measurement. Measure until the sensor's battery is empty (or at least as long as the intended application). Try to simulate some (peak) exposures during the measurement, for example by placing dust sources near the sensor (burning candles or incense, shaking pillows, smoke detector test spray). Check the following points during and after the test:

- Is there a way to see if the sensor is on? For example, a light that is turned on?
- Are the settings correct for the intended application? Are the settings adjustable?
- Is the internal clock correct? Is it automatically updated?
- How long does the battery last?
- Can you access the data as expected, and does the sensor provide data without gaps?

- What is the ratio of concentrations between the size bins (e.g., ratio PM₁:PM_{2.5})?
 - If this varies, the sensor actually measures different particle sizes.
 - If this does not vary, the particle size distribution is determined by the algorithm.

7.2.2 Differences Between Sensors (Colocation Test)

Different sensors of the same type can sometimes give different measurement results (Figure 7.2). This can be due to variations in the production process or because the manufacturer calibrates each sensor individually. It is therefore good to test in advance whether these differences in measurement results occur when you have purchased multiple sensors.

To do this, place multiple sensors next to each other (preferably all sensors that will be used). Try to orient the inlets in the same direction. Ensure that the outlet of one sensor does not blow into the inlet of another sensor. During the measurement, ensure gradual variations in concentration levels, preferably corresponding to the concentration range of the intended application. Also, ensure a period with minimal exposure (the baseline). Measure for several hours to days.

After the test, check the differences in measurement results between the sensors. Do this visually (compare the peak pattern and the baseline) or calculate average values if necessary. Differences in peak pattern heights are less important for this test, as this may also be due to experimental variation.

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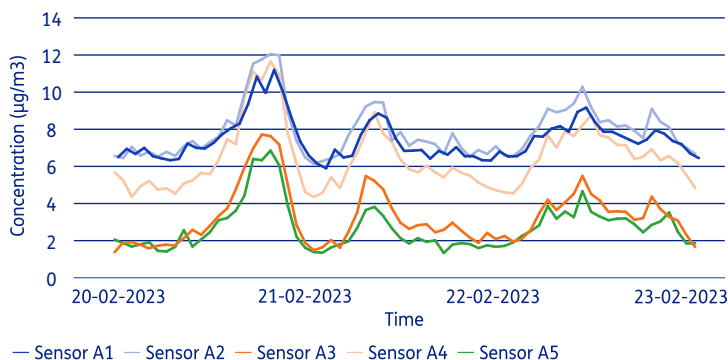
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Figure 7.2: Example of sensors with inter-device variation.



7.2.3 Response Time and Timestamp

Sensors can differ in the speed at which they respond to changes in exposure. Therefore, it is advisable to investigate in advance how quickly a sensor responds to changes. A slow response to short-term exposure peaks can lead to underestimation of average concentrations.

Additionally, it is advisable to check whether the internal clock of the sensor is set correctly and matches the local time. If this is not the case, it becomes very difficult to explain patterns in the measurements afterward.

To test the response time and the internal clock, expose one or more sensors to rapidly changing PM concentrations. This can be done, for example, with smoke detector test spray. Record the exact moments when the peak exposures are started. This can be done most easily via the clock on a smartphone, which is synchronized with universal time.

Check how quickly the sensor responds to rapid changes in concentrations, for example by calculating how quickly the sensor goes from background to a relevant concentration (e.g., the time from 0 to $1000 \mu\text{g}/\text{m}^3$). Consider whether this response speed is

sufficient for the intended application based on the duration of the tasks and expected exposures. Also, check whether the exposure peak is measured at the correct time by checking whether the timestamp of the first measurement with an increase matches the time when the exposure was performed. Differences in timestamps are often due to differences in time zones (e.g., local and UTC) and/or standard time.

7.3 Periodic Checks

During the use of sensors, it is important to periodically check whether the sensor is functioning properly and whether the measurement data is still reliable. Due to frequent use, measurement results may start to deviate over time compared to when the sensor was new (drift). This can occur, for example, because PM settles on the light source and/or light detector in the sensing element, weakening the light signal. Depending on the type of sensing element, this weakening can lead to overestimation or underestimation of the concentration. Accumulation of PM can also cause blockages in the sensor or sensing element, resulting in less air passing through the sensor and lower concentrations being measured. This can lead to underestimation of exposure over time.

Drift can be corrected or prevented in various ways. Regularly cleaning the sensor/sensing element can limit drift, for example by blowing it out (be careful to block any fans so they do not spin in the wrong direction and break). Some sensors are also designed so that the entire sensing element can be easily replaced. Proper maintenance of sensors is specialized work and requires opening the sensor (which may void the factory warranty). Always discuss periodic checks with the manufacturer/supplier of the sensors.

Testing whether and how much a sensor drifts can be done in various ways. Comparing with a reliable reference is the most reliable method but may be more difficult to perform regularly. A bump test or a [colocation test](#) can then be used as an alternative.

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7.3.1 Comparison with Reference

The best way to test whether sensors drift is to periodically (e.g., every six months) compare the sensors with parallel measurements from a reliable reference.

Place a reliable reference (e.g., a calibrated Direct-Reading Instrument or a gravimetric sampler) next to the sensor and measure the exposure with both methods. Compare the measurements with each other. In the case of gravimetric measurements, the [average of the sensor measurement must first be calculated](#).

If the difference between the sensor and the reference changes over time, this indicates drift.

7.3.2 Bump Test

By regularly (e.g., every six months) exposing the sensor in a controlled manner to a known concentration of dust, it can be determined whether the sensor shows drift.

Place the sensor in an enclosed space and introduce a known or well-repeatable exposure. This can be done, for example, by weighing a quantity of test dust and dispersing it in a standardized manner. Some manufacturers also offer specialized kits for performing such tests.

To determine whether the sensor shows drift, compare the results of the different semi-annual tests. If a clear decrease in response is visible over time, this indicates drift.

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8 Converting Data to Information

After a measurement, the data is processed and interpreted. This chapter provides examples of how sensor data can be corrected to improve accuracy. Additionally, examples are given on how to convert measurements into actionable information.

Figure 8.1: Sensor measurements can be corrected to better match actual concentrations or desired forms, or analyzed to extract key information from the measurements.

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8.1 Correcting Sensor Data

Various steps can be taken to correct sensor measurements so that they better match actual concentrations. Below are examples for calibration, manually calculating mass concentrations, and calculating respirable dust fractions.

8.1.1 Calibration of PM Sensors

To use sensors quantitatively, they must first be calibrated. This can be done by performing parallel measurements with sensors and a reliable reference (e.g., a gravimetric sampler). These data pairs can be used to create a calibration model that corrects sensor measurements. How exactly a calibration should be performed is still being researched. However, some general principles are already proposed:

- The data pairs on which the calibration model is based must be representative of the situation being measured. It is not possible to develop a calibration model for one exposure situation and apply it to exposure situations with PM of a different composition.
- There must be sufficient spread in the concentrations of the data pairs. For example, a calibration model developed based on data pairs between 0.1 and 1 mg/m³ PM is not suitable for correcting measurements of 5 mg/m³.
- Sufficient data pairs are needed to develop the calibration model. How many are needed depends on the accuracy of the sensor, with fewer data needed for more accurate sensors. Scientific research is ongoing to provide a specific estimate for the number of data pairs needed. However, experience shows that at least 10 to 20 data pairs are needed for a good calibration model.

TNO is currently researching how many data pairs are generally needed to develop a calibration model and whether it is possible to develop sector-wide calibration models based on large data sets. Additionally, the accuracy of sensors is being compared with that of accepted measurement methods such as exposure models and gravimetric measurement methods, to frame the practical application of sensor measurements for demonstrating compliance with a limit value. n.

The outcomes of this research will be published in a later version of the Guideline, including a more detailed description of how PM sensors can be calibrated.

8.1.2 Converting Particle Counts to Mass Concentrations

Most sensors report the mass concentrations of the PM measured (e.g., in µg/m³ or mg/m³). Some sensors also provide particle number concentrations (e.g., in #/cm³). Based on the particle counts, the mass concentration can be calculated using physics formulas. This has the advantage that the user can add specific particle properties (such as density or shape factor) in the conversion. For converting particle counts to mass concentrations, various formulas can be used. At a minimum, information is needed about the number of particles, the average particle size (derived from the size bin where the concentration is measured), and the density of the material (equation 1). When the density is unknown, a value of 1 g/cm³ (the density of water) is often used. Table 8.1 provides densities of common materials.

$$Eq.1: M = \frac{\pi}{6} D^3 N \rho$$

Where M stands for the mass concentration in µg/m³, D for the average diameter of the particles in cm, N for the number of particles in #/cm³, and ρ for the density of the material in g/cm³.

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Table 8.1: Densities of Various Materials (from Hinds et al., 2022²).

Material	Density (g/cm ³)	Material	Density (g/cm ³)
Aluminum	2.7	Paraffin	0.9
Aluminum oxide	4.0	Plastic	1-1.6
Ammonium sulfate	1.8	Pollen	0.45-1.05
Asbestos	2.0-2.8	Polystyrene	1.05
Asbestos, chrysotile	2.4-2.6	Polyvinyl toluene	1.03
Coal	1.2-1.8	Cement	3.2
Fly ash	0.7-2.6	Quartz	2.6
Glass	2.4-2.8	Natriumchloride	2.2
Granite	2.6-2.8 i	Sulfur	2.1
Ice	0.92	Starch	1.5
Iron	7.9	Talc	2.6-2.8
Iron oxide	5.2	Titanium dioxide	4.3
Limestone	2.7	Wood (dry)	0.4-1.0
Lead	11.3	Zinc	6.9
Marble	2.6-2.8	Zinc oxide	5.6
Natural fibers	1-1.6		

Example Calculation:

Converting a particle concentration of quartz dust to mass concentrations.

Measurement data:

Number of particles (N) = 1000 #/cm³

Average particle diameter (D) = 1.75 μm

Density (ρ) = 2.6 g/cm³

Substituting into equation 1 gives:

$$\pi/6 \times 1.753 \times 1000 \times 2.6 = 729.60 \mu\text{g}/\text{m}^3$$

8.1.3 Converting Size Bins to Relevant Dust Fractions, e.g., Respirable Dust

Sensors often report concentrations in particle size fractions used in environmental applications (e.g., PM_{2.5} consists of all particles smaller than 2.5 μm), while for workplace applications, respirable dust is often measured. In this case, it can be useful to convert the concentrations of the PM fractions to the respirable fraction.

This can be done using the ISO7708 conventions. This standard describes the contribution of a certain particle size to the respirable dust fraction.

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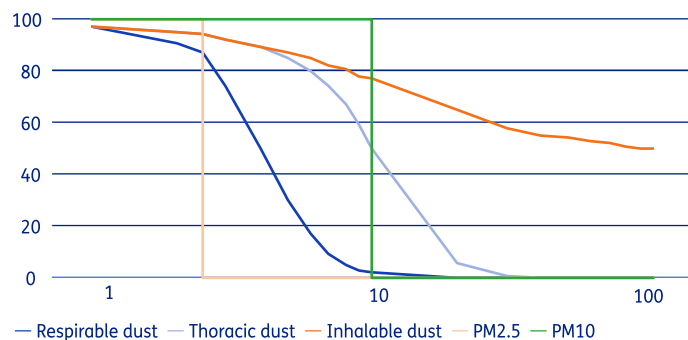
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² Hinds, William C., and Yifang Zhu. Aerosol technology: properties, behavior, and measurement of airborne particles. John Wiley & Sons, 2022.

Figure 8.2: Particle size fractions according to the ISO 7798 conventions.



For the calculation, the mass concentrations are first divided into the smallest possible size bins, each with a defined upper and lower limit. The average diameter per size bin is used for the calculation. The mass concentrations of the different size bins are summed, proportional to their contribution as defined by the respirable convention (Table 8.2).

Table 8.2: Size Bins and Contribution to Respirable Dust Fraction.

Size Bin of the Sensor (µm)	Used Diameter for Calculation (µm)	Contribution to Respirable Dust Fraction (%)
0.3 – 0.5	0.4	98.81
0.5 – 1	0.75	97.75
1 – 2.5	1.75	92.98
2.5 – 5	3.75	56.39
5 – 10	7.5	6.047

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Example Data:

The table below provides a typical representation of sensor data over different particle size fractions. Note that the fractions overlap (PM2.5 contains both particles smaller than 1 µm and between 1 µm and 2.5 µm).

Timestamp	PM1	PM2.5	PM5	PM10
09:00:00	25 µg/m ³	30 µg/m ³	50 µg/m ³	100 µg/m ³
09:01:00	30 µg/m ³	40 µg/m ³	80 µg/m ³	160 µg/m ³

Step 1:

Converting PM Fractions to Size Bins

First, the measurement values are converted to size bins, which give the concentrations within a specific particle size. This is done by determining the differences between the PM concentrations (e.g., all particles between 1 and 2.5 µm = PM2.5 – PM1).

Timestamp	Bin1 (avg. 0.65 µm)	Bin2 (avg. 1.75 µm)	Bin3 (avg. 3.75 µm)	Bin4 (avg. 7.5 µm)
09:00:00	25 µg/m ³	(30 – 25 =) 5 µg/m ³	20 µg/m ³	50 µg/m ³
09:01:00	30 µg/m ³	10 µg/m ³	40 µg/m ³	80 µg/m ³

- Bin 1 is PM1 with an average particle size of 0.65 µm (average between 0.3 and 1 µm).
- Bin 2 is PM2.5 – PM1 with an average particle size of 1.75 µm.
- Bin 3 is PM5 – PM2.5 with an average particle size of 3.75 µm.
- Bin 4 is PM10 – PM5 with an average particle size of 7.5 µm.

Step 2: Calculating Contribution to Respirable Fraction

Next, the contribution of the size bin to the respirable fraction is calculated, according to the percentages from the respirable convention.

Timestamp	Bin1 (0.65 µm)	Bin2 (1.75 µm)	Bin3 (3.75 µm)	Bin4 (7.5 µm)
09:00:00	25 * 0.9835 = 24.58 µg/m ³	5 * 0.9298 = 4.649 µg/m ³	20 * 0.5639 = 11.28 µg/m ³	50 * 0.06047 = 3.024 µg/m ³
09:01:00	29.51 µg/m ³	9.298 µg/m ³	22.56 µg/m ³	4.838 µg/m ³

Step 3: Summing Size Bins

Finally, the concentrations of the different size bins are summed.

Timestamp	PM1	PM2.5	PM5	PM10	Respirable Fraction
09:00:00	25 µg/m ³	30 µg/m ³	50 µg/m ³	100 µg/m ³	24.58 + 4.649 + 11.28 + 3.024 = 43.53 µg/m ³
09:01:00	30 µg/m ³	40 µg/m ³	80 µg/m ³	160 µg/m ³	66.21 µg/m ³

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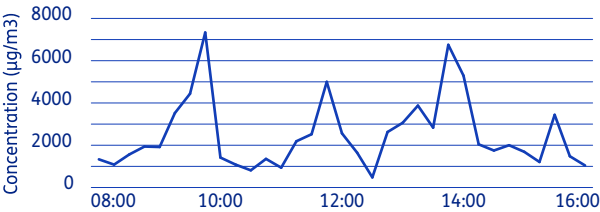
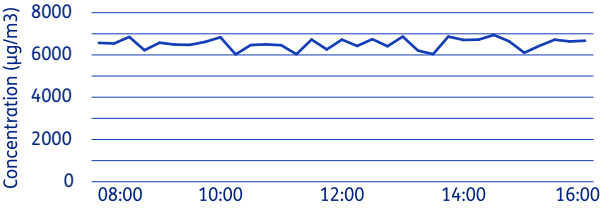
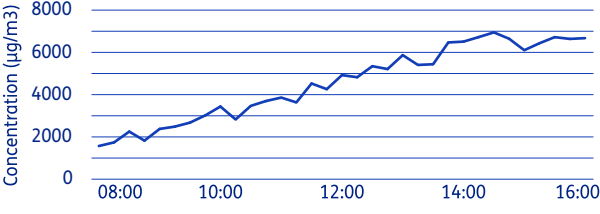
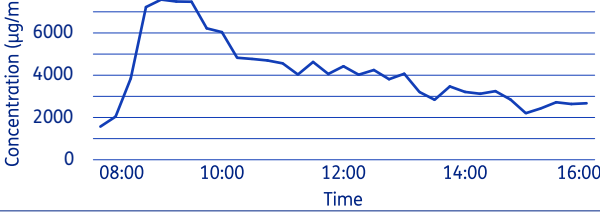
8.2 Analyzing Sensor Measurements

Because sensors measure at a high frequency, changes over time can be displayed. A display of concentrations over time is called an exposure profile. These exposure profiles can provide information on how/where/when a person was exposed, but various analyses can also be performed to gain more insight.

8.2.1 Interpreting Exposure Profiles

A common first step is to visually inspect an exposure profile. By looking at when the moments of high exposure occurred and determining which activities were performed at those times, it can be determined why an employee was exposed. The shape of the exposure profile can also provide general information about the exposure. Figure 8.3 provides some tips for interpreting an exposure profile.

Figure 8.3: Interpretation of Exposure Profiles.

Exposure Profile	Description	Interpretation
 The graph shows concentration (µg/m³) on the y-axis (0 to 8000) and time on the x-axis (08:00 to 16:00). The profile features several sharp, distinct peaks, with the highest reaching approximately 7000 µg/m³ around 09:30 and 13:30.	Many peak exposures	Exposure comes from temporary sources. Likely specific tasks or locations.
 The graph shows concentration (µg/m³) on the y-axis (0 to 8000) and time on the x-axis (08:00 to 16:00). The profile is a relatively flat line fluctuating between approximately 6000 and 7000 µg/m³ throughout the day.	Constant high concentrations	Exposure is related to a continuous process and/or activity.
 The graph shows concentration (µg/m³) on the y-axis (0 to 8000) and time on the x-axis (08:00 to 16:00). The profile shows a steady, almost linear increase from about 2000 µg/m³ at 08:00 to a peak of about 7000 µg/m³ at 14:00, followed by a slight decline.	Concentration increases during measurement	Dust may repeatedly enter the air, causing accumulation. For example, dust blows up after initially settling on the ground.
 The graph shows concentration (µg/m³) on the y-axis (0 to 8000) and time on the x-axis (08:00 to 16:00). The profile shows a sharp rise to a peak of about 7500 µg/m³ at 09:00, followed by a slow, gradual decline to about 3000 µg/m³ by 16:00.	Concentration decreases slowly after a peak	Combination of a dust-generating activity and limited general control measures (such as room ventilation).

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In some cases, due to the high measurement frequency and lower accuracy of the sensors, an exposure profile can be very erratic (a lot of noise). This can make it difficult to detect patterns over time. The exposure profile can be smoothed by calculating a moving average, for example by calculating the average of the 10 previous data points at each data point.

8.2.2 Summary Statistics: Calculating Averages and Standard Deviations from Sensor Data

Exposure profiles of different employees performing similar tasks are never identical. This is caused by differences in the duration or order of tasks performed, personal work habits, or differences in working conditions. These differences make it difficult to compare different exposure profiles. Therefore, it can be useful to summarize the profiles using certain statistical measures, such as the average or standard deviation

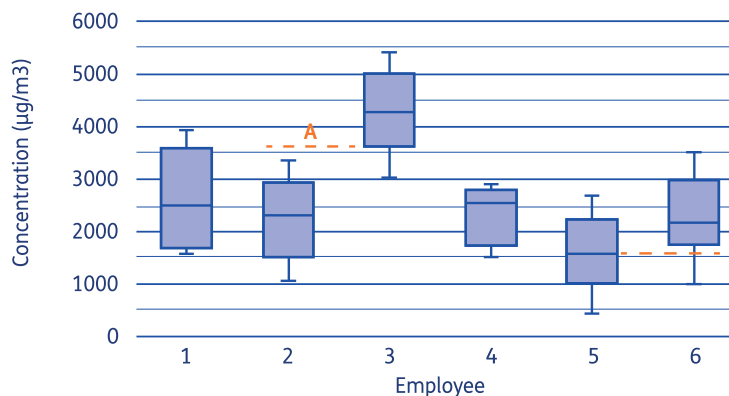
Use the arithmetic mean for averaging sensor data, not the geometric mean (which is often used for various other calculations in occupational hygiene). Comparisons with reference measurements have indicated that the arithmetic mean corresponds best. Note: Calculating averages allows exposure profiles to be compared, but the average value is not reliable enough to compare with limit values.

In addition to the average, it can also be useful to calculate the standard deviation of a measurement series. This is a measure of the spread of the individual data points. A higher standard deviation indicates more variation in the measured concentrations and likely more peak exposures.

8.2.3 Visualizing Comparisons: Boxplots

To compare multiple exposure profiles, including the spread of individual data points, boxplots can be used. This can be relevant for comparing daily measurements of employees belonging to the same job group. Differences in the size of the boxplots indicate differences in variation in exposure, and differences in the height of the boxplots indicate differences in concentrations. A general rule when comparing boxplots is: if the boxes (Q1 to Q3) between groups do not overlap, there is almost certainly a significant difference between the measurements (line A in Figure 8.4). If the median of one of the boxplots falls outside the box of the other, there is likely a difference between the two groups (line B in Figure 8.4).

Figure 8.4: Boxplots of Daily Measurements of 6 Employees Belonging to the Same Job Group.



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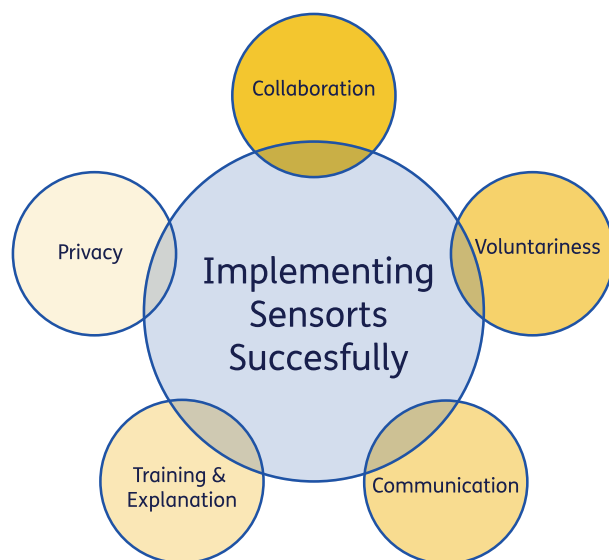
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9 Implementing Sensors Successfully

Besides carefully considering which sensor to use for which application and ensuring that the sensor data provides the necessary information, there are a few other topics that require attention:

Figure 9.1: To successfully use sensors, it is important to consider how the data will be used and prepare accordingly.



9.2.1 Collaboration for a Better Work Environment

The best results are obtained when there is collaboration between the employer, employee, and occupational hygienist. It is therefore advisable to be transparent and involve both the employer and employees in the plan to use sensors, explaining the purpose, what exactly will be measured, who owns the data, where and how long the data will be stored, what information will be communicated to whom, and what the follow-up actions will be.

9.2.2 Voluntariness

Good collaboration also includes giving employees the option not to wear sensors if they do not wish to.

9.2.3 Communication

As with conventional measurements, it is important to communicate the results carefully. Compared to conventional measurements, the advantages of sensor measurements (more informative and faster) necessitate extra careful communication.

It is good to make agreements with all involved parties in advance about what information will be communicated to whom and for what purpose. It is important to discuss concerns about potential misuse of data and agree on measures to prevent this. The occupational hygienist can play an intermediary role by analyzing the data themselves and only communicating the results.

If raw sensor data is discussed with employees, it is important to put the results in perspective. What does a number or a peak in an exposure profile mean? Is the employee at risk or not? And what will be done to further protect the employee's health? This deserves special attention if a sensor is used in real-time and the measurement results can also be seen by employees.

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9.2.4 Provide Training and Explanation to Employees

Provide employees with training and explanations so they can use sensors correctly (e.g., ensuring the inlet is not covered by clothing or material, recognizing when the battery is empty or the internet connection is lost, and taking appropriate action). Employees are crucial for the correct use of sensors and for collecting good data. They can also provide valuable information about whether the sensor is functioning properly and whether it is practical to work with a sensor.

9.2.5 Privacy and Data Protection

There is often a question of whether sensor data is personal data and falls under privacy legislation. In principle, if an individual can be traced from the sensor data, the data falls under privacy legislation. However, the likelihood that an individual can be traced from sensor data alone is very small. This is different if, for example, GPS data is also stored; then it does involve sensitive data. To interpret and feedback sensor data, more information needs to be stored than just the sensor data. This is no different from conventional exposure measurements. If sensitive data is collected, employees can be asked for consent through an informed consent form. This form should clearly state what data is collected for what purpose, where the data is stored and for how long, who has access to the data, and what the employees' rights are regarding the sensor data. The data should then be stored anonymized or pseudonymized, with encryption and access authorization considered.

Sensor suppliers may use automatic cloud storage for sensor data from their sensors. This makes the data automatically accessible to them and traceable to the sensor's IP address (approximately to the postal code level). Although individuals are not traceable, this may apply to companies where the measurements are conducted. Additionally, cloud storage may be located in parts of the world with different privacy rules than in the Netherlands, making it unclear who has access to the data in the cloud.

The use of video can be very helpful in understanding an exposure profile. However, a lot can be seen on video, even with a body-worn camera: colleagues, business processes, information on screens or phones, contents and codes of lockers, etc. It is important to prepare employees well for this and make them aware. This applies not only to the measured employee but also to colleagues. It also requires discretion from the occupational hygienist and, in consultation with the employee, careful selection of images that are shown more widely.

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10 Further Information

10.1 Commercially Available Particle Sensors

Table 10.1 provides a list of commercially available particle sensors developed for measuring exposure in the workplace. This list is included in the guideline because occupational hygienists indicated a need for it.

Table 10.1: List of Particle Sensors.

Sensor (Manufacturer)	Description
UPAS V2.1+ (Access sensor technologies)	Mainly used in research applications. Measures fine dust (PM ₁ , 2.5, 4, and 10) and various other parameters and includes a sampler for gravimetric samples.
XD1+ (Trolex)	Specifically developed for workplace use. Measures PM ₁ , 2.5, 4.25, and 10. Can be controlled/read with an app.
DustCanary TREND 420 (Air-Met)	Specifically developed for workplace use. Measures respirable dust. Can be controlled/read with an app
Dustlight (Latai GmbH)	Specifically developed for workplace use. Measures PM ₁ , 2.5, and 10. Can be controlled/read with an app.
AeroGuard (Plymovent)	Specifically developed for workplace use. Only suitable for stationary use. Measures PM ₁ , 2.5, 4, and 10 and various other parameters. Can be controlled/read with an app.
OmniTrak (TSI)	Modular system with sensors for various exposures. PM module measures PM ₁ , 2.5, 4, and 10.

Table 10.2: Tools and Information Sources on the Use of Sensors.

Description	Link
Lecture by Prof. John Volckens on the operation of PM sensors and their use in exposure research.	Youtube
Air Quality Sensor Performance Evaluation Center, which tests a large number of air quality sensors (mainly for environmental applications).	AQ-SPEC website
EVADE software for linking video recordings to sensor measurements.	NOISH-website
Information sheets on how to handle sensor data in relation to privacy.	TNO-website

Note: The following list does not provide a complete overview, and inclusion in this list does not guarantee the accuracy of the sensors.

10.2 Tools and Other Information Sources

The tools and information sources in Table 10.2 can be used to obtain further information about the use of sensors (in the workplace).

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Version Number	Version Date	Adjustments
1.1 (concept)	18-03-2025	Process feedback from the 'Sensors in the Workplace' sounding board group, NLA, and SZW.
1.0 (concept)	13-12-2024	First concept

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