# SLOVENSKI STANDARD
# SIST-TS CEN/TS 18086:2025

**01-januar-2025**

**Izpostavljenost na delovnem mestu - Nizkocenovni senzorji z direktnim odčitavanjem za merjenje lebdečih nanopredmetov ter njihovih agregatov in aglomeratov (NOAA) - Smernice za uporabo**

Workplace exposure - Direct-reading low-cost particulate matter sensors for measuring airborne NOAA - Guidelines for application

Exposition am Arbeitsplatz - Direkt anzeigende kostengünstige Feinstaubsensoren zur Messung luftgetragener NOAA - Leitlinen für den Einsatz



Exposition sur les lieux de travail - Capteurs de matière particulaire à lecture directe et à faible coût pour le mesurage des NOAA en suspension dans l’air - Lignes directrices pour l’application



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| 13.040.30 | Kakovost zraka na delovnem mestu | Workplace atmospheres |

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# CEN/TS 18086

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English Version

# Workplace exposure - Direct-reading low-cost particulate matter sensors for measuring airborne NOAA - Guidelines for application

Exposition sur les lieux de travail - Capteurs de matière particulaire à lecture directe et à faible coût pour le mesurage des NOAA en suspension dans l'air - Lignes directrices pour l'application

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The period of validity of this CEN/TS is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the CEN/TS can be converted into a European Standard.

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## European foreword

This document (CEN/TS 18086:2024) has been prepared by Technical Committee CEN/TC 137 "Assessment of workplace exposure to chemical and biological agents", the secretariat of which is held by DIN.

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# Introduction

The production and use of engineered nano-objects and their agglomerates and aggregates (NOAA) has increased over the recent years, as well as the concerns related to their potential adverse health effects. The measurement of nano-objects is particularly difficult because of the small size of the particles and small relative mass in comparison with other contaminants. Human exposure to NOAA is most likely to occur in workplaces, where they are produced, processed and handled in large quantities or over long periods of time. Continuous monitoring of such workplaces would improve exposure assessment, especially in cases where the exposure pattern is very inhomogeneous and large, and fluctuating background concentrations are present.

There has been an increased interest in the use of low-cost particulate matter (PM) sensors in different areas. Up to now, exposure concentrations are measured only during limited time periods and with limited spatial resolution, using expensive bulky static measurement and sampling equipment and/or direct reading personal monitors and personal samplers. In contrast, due to their low-costs and small size, the low-cost PM sensors allow for:

— the setting up of dense measurement networks in workplaces to monitor dust concentrations with high spatio-temporal resolution;

— use as personal monitors;

— use to produce information on the efficiency of process controls of NOAA-production facilities, the background and the far field.



Therefore, due to the lower costs compared with established scientific grade instruments, more devices can be employed for in total lower costs. The main purpose of such sensor networks is to estimate exposure levels in workplaces. At the time of writing this document, low-cost PM sensors should not be considered for any compliance measurements, because they cannot replace reference measurements e.g. with samplers for the respirable fraction. They should rather be considered as complementary to reference measurements. However, this limitation can become obsolete in the future, when new generations of low-cost PM sensors overcome the shortcomings of today's sensors. They can thus be applied as an indicator for exposure, as a warning system or to identify potential particle sources, e.g. as a permanent implementation of a Tier 1 exposure assessment (EN 17058 [1]). Individual threshold values may be defined to implement and/or initiate control measures.

The low-cost PM sensors available are based on measuring the light scattered by airborne particles, which depends on particle size, shape and refractive index. To calibrate the sensors for the determination of particle mass concentrations, average values for these properties, as well as for the effective particle density, must be assumed. The sensors are typically calibrated for use in ambient air monitoring. However, the particle properties assumed in the calibration for ambient use can be very different from those of particles encountered in workplaces. Due to the wide diversity of particle properties in workplace air, a single generalizable calibration for different workplaces is not feasible. In addition, measurement artefacts, e.g. stemming from relative humidity, can be different in workplace and atmospheric measurements.

Low-cost PM sensors exist with different levels of complexity, resulting in different wealth of information, ranging from a voltage output as a measure for the total particle concentration, via different size-integrated fractions of the mass and/or number concentration to number size distributions with high size resolution. The focus of this document is on those sensors that are able to deliver size-integrated number and/or mass concentrations in different size fractions. Most low-cost PM sensors were originally developed for ambient air quality monitoring and are thus calibrated following ambient sampling conventions, e.g. for $PM_{2,5}$ and $PM_{10}$ (US EPA 40 CFR part 62 [2] and 40

CFR part 53 [3], respectively), which are not identical with the sampling conventions for workplaces, e.g. for the respirable or thoracic fraction according to EN 481 (see Annex A).

The methods and procedures described in this document apply to the sensor modules only and not to complete devices, based on these. Sensor modules are considered to be low-cost, if their prices are at least 10 to 100 times lower than the prices of established instruments of comparable type, e.g. those described in CEN/TR 16013-2 [4] and CEN/TR 16013-3 [5].

# 1 Scope

This document gives guidelines on the use, calibration and evaluation of low-cost optical particulate matter sensor modules and systems for workplace exposure assessments.

This document is based on extensive laboratory and workplace tests for airborne NOAA.

This document is particularly aimed at engineered NOAA at workplaces and the sensors' applicability for process control of NOAA-producing plants via airborne particle concentration measurements in workplace air.

NOTE This document is also applicable to other airborne particles included in some of the tests during the prenormative research.

# 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 481, *Workplace atmospheres — Size fraction definitions for measurement of airborne particles*

EN 1540, *Workplace exposure — Terminology*

ISO 27891, *Aerosol particle number concentration — Calibration of condensation particle counters*

ISO 21501-1, *Determination of particle size distribution — Single particle light interaction methods — Part 1: Light scattering aerosol spectrometer*



# 3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1540 and the following apply.



ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at https://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

**3.1**
**adjustment of a measuring system**
set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured

[SOURCE: ISO/IEC Guide 99:2007, 3.11 [6]]

**3.2**
**advanced aerosol photometer**
measurement device that combines a photometric measurement of light scattered by a cloud of particles inside a measurement volume to determine total number and/or mass concentrations with spectrometric features to distinguish between concentrations in different particle size fractions

**3.3**
**aerodynamic aerosol classifier**
**AAC**
measurement device that size-classifies airborne particles according to the aerodynamic diameter based on classification of the particle relaxation time

**3.4**
**aerosol photometer**
measurement device that determines particle size-integrated number or mass concentrations by measuring the integral intensity of light scattered by a cloud of particles inside a measurement volume

Note 1 to entry: Photometers can only be calibrated for known particle size distributions.

**3.5**
**calibration**
operation that, under specified conditions, in a first step, established a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

[SOURCE: ISO/IEC Guide 99:2007, 2.39]

Note 1 to entry: In practice, a calibration is often done in conjunction with a later adjustment.



**3.6**
**condensation particle counter**
**CPC**
measurement device that determines in real-time the number concentration of airborne particles ranging from few nm up to several µm in size in a limited range of concentration, but does not discriminate between particles of different sizes or origin



**3.7**
**mobility particle size spectrometer**
**MPSS**
measurement device that determines number size distributions of airborne submicron particles based on electrical mobility analysis

**3.8**
**optical aerosol spectrometer**
measurement device that determines number size distributions of airborne particles by measuring the intensity of light scattered by individual particles inside a small measurement volume as a measure for the particle size and counting the number of scattered light pulses as a measure for the number concentration

Note 1 to entry: CEN/TR 16013-2 [4] also refers to Optical Aerosol Spectrometers as Optical Particle Counters.

**3.9**
**optical equivalent diameter**
diameter of a spherical particle with known refractive index that causes the same scattering light intensity as the particle under investigation

**3.10**
**$PM_x$**
particulate matter suspended in air which is small enough to pass through a size-selective inlet with a 50 % efficiency cut-off at x µm aerodynamic diameter

[SOURCE: EN 12341:2023, 3.1.16] [7]

Note 1 to entry: Commonly measured $PM_x$ fractions are $PM_1$, $PM_{2,5}$, $PM_4$ and $PM_{10}$. $PM_4$ is nearly identical with the respirable fraction.

**3.11**
**reference measurement instrument**
instrument that is calibrated against a traceable method and that is designated for the calibration of other measurement devices of a given kind in a given organization

**3.12**
**sensor module**
sensor and signal processing algorithms that determine number concentration and/or mass concentration and/or size distribution of airborne particles, based on the measurement of light scattered by particles

Note 1 to entry: Sensor modules are considered to be low-cost if prices are at least 10 to 100 times lower than established instruments of the same type.



**3.13**
**sensor**
individual sensor
physical unit that produces a signal related to the concentration of particulate matter in air

Note 1 to entry: The low-cost PM sensors available at the time of writing this document were all based on light scattering. This document might not be applicable to sensors working on a different measurement principle.



**3.14**
**sensor network**
set of multiple connected sensors or sensor systems that are spatially distributed to monitor particulate concentrations in a workplace with spatiotemporal resolution

**3.15**
**sensor system**
single integrated set of hardware that uses one or more sensor modules to produce a signal related to the concentration of particulate matter in air that can supply real time measurements

Note 1 to entry: Sensor systems contain many common components in addition to the basic sensing or analytical element that is used for detection. Common core components and functions can include:

— sensing detector (the actual sensor);

— sampling capability (generally active sampling for PM);

— power systems, which may include batteries;

— analogue to digital conversion;

— signal processing;

— local data storage;

— data transmission;

— enclosure.

# 4 Symbols and abbreviations

## 4.1 Symbols

| | |
|---|---|
| $a$ | Slope of linear fit curve [-] |
| $b$ | y-intercept of linear fit curve [1/m$^3$ or kg/m$^3$] |
| $C_N$ | Number concentration [1/m$^3$] |
| $C_m$ | Mass concentration [kg/m$^3$] |
| $C_c$ | Cunningham slip correction factor [-] |
| $d_{50}$ | Particle diameter, at which instrument reaches 50 % detection efficiency [m] |
| $d_{ae}$ | Aerodynamic equivalent diameter [m] |
| $d_{mob}$ | Mobility equivalent diameter [m] |
| $d_{opt}$ | Optical equivalent diameter [m] |
| $d_p$ | Particle diameter [m] |
| $I$ | Light intensity [cd] |
| $m$ | Refractive index [-] |
| $R^2$ | Regression coefficient [-] |
| $\alpha$ | Scattering parameter [-] |
| $\phi$ | Aperture angle [rad] |
| $\lambda$ | Wavelength of light [m] |
| $\eta$ | Detection efficiency [-] |
| $\rho_0$ | Unit density [1000 kg/m$^3$] |
| $\rho_{eff}$ | Effective particle density [kg/m$^3$] |
| $\rho_p$ | Particle density [kg/m$^3$] |
| $\Theta$ | Detection angle [rad] |



## 4.2 Abbreviations

| | |
|---|---|
| AAC | Aerodynamic Aerosol Classifier |
| APS | Aerodynamic Particle Sizer |
| CPC | Condensation Particle Counter |
| DEHS | Di-Ethyl-Hexyl-Sebacate |
| DEMC | Differential Electrical Mobility Classifier |

| | |
|---|---|
| ELPI | Electrical Low Pressure Impactor |
| LCS | Low-Cost Sensor |
| LOQ | Limit of quantification |
| MPSS | Mobility Particle Size Spectrometer |
| NOAA | Nano-objects, their agglomerates and aggregates |
| OAS | Optical Aerosol Spectrometer |
| PM | Particulate Matter |
| PSL | Polystyrene Latex |
| TEOM | Tapered Element Oscillating Microbalance |
| $TiO_2$ | Titanium dioxide |

## 5 Measurement principle of low-cost PM sensors

The available low-cost PM sensors are based on the measurement of light, scattered by particles inside a measurement volume, illuminated by a light source, within the sensor. The light-scattering sensors can be categorized in three sub-categories:

a) Spectrometers;

b) Photometers;

c) Advanced photometers.



In a spectrometer, individual particles are transported with a flow through the measurement volume. To ensure that at most a single particle is present inside the measurement volume, its size shall be small. Each individual particle causes a light pulse, whose intensity is determined with a photo-detector as a measure for the particle size. The pulses are furthermore counted and classified based on their height in order to obtain the number size distribution of the particles, based on the optical equivalent diameter (CEN/TR 16013-2 [4]). Mass size distributions are calculated from the number size distributions, by assuming the particles' refractive indices, shapes and densities, which often depend on the particle size. Different number and mass ($PM_x$) size fractions can be obtained from the corresponding size distributions by weighting them with the required sampling convention (see Annex A) and integration over the particle size.



In a photometer, the light scattered by a cloud of particles inside the measurement volume is measured (CEN/TR 16013-3 [5]). The measurement volume of a photometer is much larger than that of a spectrometer. A photometer cannot distinguish particle sizes and only delivers size-integrated information. Only for stable particle size distributions and compositions, the total light intensity measured by a photometer is proportional to the total particle mass and number concentration. Photometers usually report the mass concentration of one $PM_x$ fraction by assuming the (constant) particle number size distribution, refractive indices, particle shapes and densities.

Advanced photometers use a combination of a photometer and a spectrometer. The size of the measurement volume is usually in-between the sizes in spectrometers and photometers. An advanced photometer measures a photometric signal of a cloud of particles as an offset and a measure for the overall concentration. In addition, individual peaks sticking out of the offset signal are detected. These peaks stem from the typically rather low number of large particles, which, however, have a strong contribution to the mass concentration. These peaks are counted and classified based on their heights in order to differentiate between different size fractions [8]. Advanced photometers are thus able to deliver mass concentrations in more than one different size fraction. Some advanced photometers also deliver estimates of the number concentration in different size fractions.

Most available low-cost PM sensors apply the advanced photometric or photometric principle due to their lower complexity compared with the spectrometric principle. Whereas the overall measurement principles of the low-cost PM sensors are identical to the ones used in established, scientific grade measurement devices, there are some differences. For example, most low-cost sensors do not use a particle free sheath flow to protect the optics from fouling, which can have an effect on the measurement accuracy, longterm stability and durability.

The sensors typically provide the measurement results in terms of particle mass concentrations in one or more size fractions ($PM_x$) and in some cases also as particle number concentrations in one or more size fractions. It shall be noted that the intensity of light, scattered by particles depends on multiple particle properties, but not the particle mass and thus a bespoke calibration is needed in order to determine mass concentrations (see Clause 6). A detailed description of the measurement principle of the three sensor categories is provided in Annex E.

Advantages and disadvantages of the three sensor categories are listed in Table 1.

**Table 1 — Advantages and disadvantages of low-cost PM sensors**



| | Advantages | Disadvantages |
|---|---|---|
| **Photometer** | — No fan needed<br>— Lowest cost<br>— Wide concentration range<br>— Fast response to changes inside measurement volume<br>— Easy data handling (single data point per time step) | — Signal not exclusively proportional to mass concentration, specific calibration needed<br>— Dependent on particle size distribution, refractive indices, shapes, but not particle density<br>— Slow dynamic response without forced flow through measurement volume<br>— Single value for total light scattered only, no particle size differentiation |
| **Advanced photometer** | — Delivers concentrations in different size fractions<br>— Can deliver both number and mass concentrations<br>— Quick response to dynamic size distribution and concentration changes<br>— Lower costs compared with spectrometers | — Size fractions pre-defined by manufacturer and not freely selectable<br>— Signal not exclusively proportional to number or mass concentration, but dependent on particle size distribution, refractive indices and shapes<br>— Output relies on the typically undisclosed manufacturer calibration and algorithms |
| **Spectrometer** | — Delivers particle number size distributions<br>— Size-integrated number and mass concentrations can be calculated for any size fraction within measurement range<br>— Suitable for low concentrations; lower limit depending on measurement volume<br>— Quick response to dynamic size | — Not suitable for particle sizes below approximately 0,3 µm<br>— Not suitable for high concentrations; upper concentration limit due to coincidence error (depending on measurement volume)<br>— Signal not exclusively proportional to mass concentration<br>— More expensive than photometers and advanced |

| | | |
|---|---|---|
| | distribution and concentration changes<br>— Signal proportional to number concentration | photometers |

Figure 1 provides a decision tree for the choice of an appropriate sensor type, depending on the anticipated sensor application.

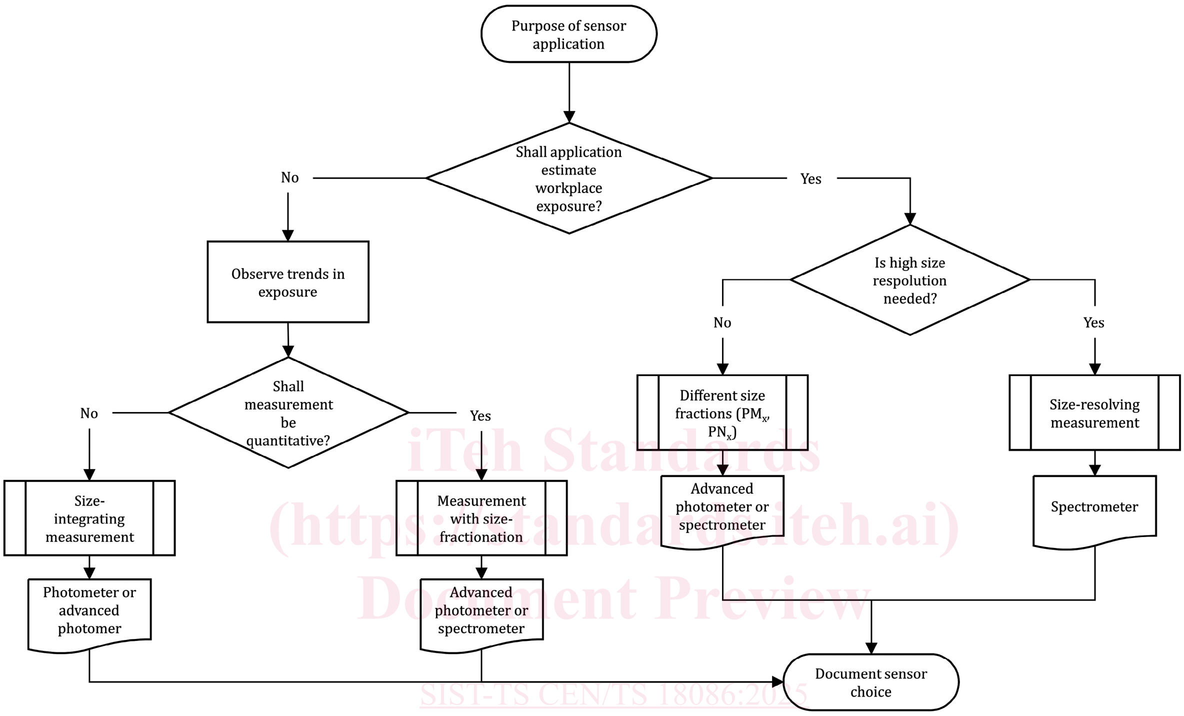




**Figure 1— Decision tree for the choice of a sensor type depending on purpose of its application in a workplace**

## 6 Usability of low-cost sensors for monitoring NOAA concentrations in workplaces

Due to their low-costs, PM sensors can allow for establishing measurement networks with high density to permanently monitor the spatio-temporal distribution of different dust fractions in workplaces. With such networks, it is possible to keep track of when and where concentrations increase and can therefore be a valuable indicator for potential particle leaks and areas of increased exposure. It shall, however, be kept in mind that the sensors use a measurement principle, which is based on many assumptions. Further, the possibilities for quality assurance, e.g. an inherent control of the sample flow rate, are reduced and consequently the measurement uncertainty is higher compared to reference instruments.

Therefore, low-cost sensor measurements shall not replace reference measurements for compliance testing according to regulations.

The possibilities to monitor NOAA concentrations is limited due to the detectable particle size range of the sensors. With optical light scattering devices like the PM sensors, particles with optical equivalent