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Protocol for quantification of exposure to Ultrafine Particles as part of Indoor Air Quality study

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Contents

Page

Foreword

This CEN Workshop Agreement (CWA 18408:2026) has been developed in accordance with the CEN-CENELEC Guide 29 “CEN/CENELEC Workshop Agreements – A rapid way to standardization” and with the relevant provisions of CEN/CENELEC Internal Regulations - Part 2. It was approved by the Workshop [CEN/WS TWINAIR, the secretariat of which is held by UNE] consisting of representatives of interested parties on 2026-05-22, the constitution of which was supported by CEN following the public call for participation made on 2025-10-06. However, this CEN Workshop Agreement does not necessarily include all relevant stakeholders.

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Introduction

Ultrafine particles (UFP) are particles with a mobility diameter smaller than 100 nm, which have been linked to a multitude of indoor activities such as cleaning, electrical or combustion heating, and cooking (Figure 1). Particulate matter (PM) is measured for outdoor ambient air quality using size-segregated categories of PM10 (particles with aerodynamic diameter < 10 µm) and PM2.5 (particles with aerodynamic diameter < 2,5 µm). Common measurement techniques of particulate matter (PM) include the use of low-cost and easily accessible PM sensors both outdoors and indoors (e.g., buildings, hospitals, houses, etc.), as well as wearable devices for personal sampling, using light-emitting diode (LED) or light amplification by stimulated emission of radiation (LASER) technologies.

As described in the ISO 16000 series, indoor air quality is directly related to the physical parameters and chemical pollutants present. These factors can affect occupants' health; thus, appropriate indoor air measurement strategies and techniques have been developed for individual stressors and groups (e.g., CO2, PM, Volatile Organic Compounds (VOC)). ISO 16000-1 presents the general aspects of sampling strategies for indoor air pollutants, while individual parts of ISO 16000 and described the sampling methodology for direct measurements of specific pollutants, such as PM2,5/PM10 in ISO 16000-34 and ISO 16000-37 for general sampling and fraction-specific measurements.

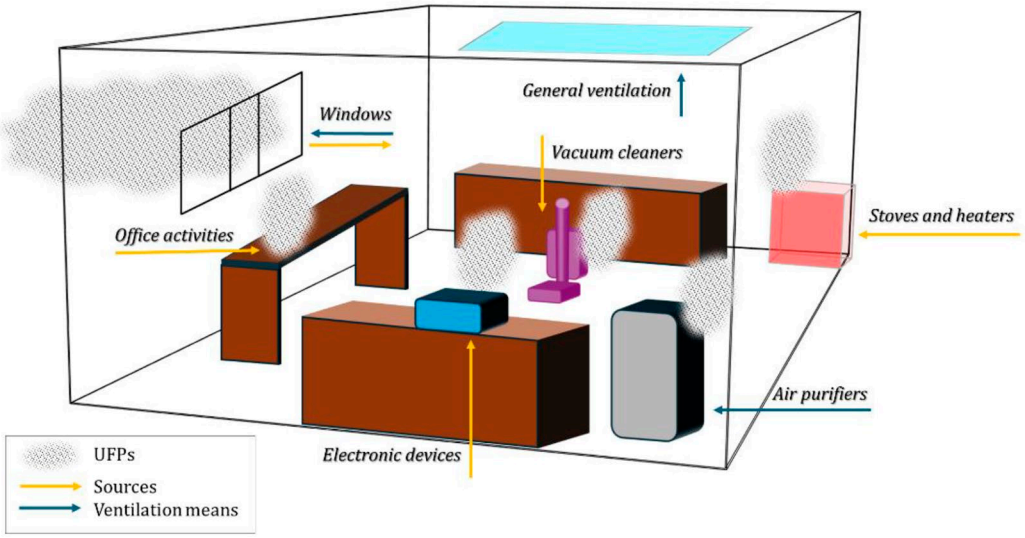


Figure 1 — Illustration of typical ultrafine particle (UFP) sources and ventilation options in an indoor environment

Building upon the foundational principles and measurement protocol guidelines defined in indoor air Standard series (ISO 16000), and especially ISO 16000-42 on UFP measurements, the current CWA presents a refined iteration representing the measurement methodology and calculation of UFP using a set of different measuring devices. In that way, potential drawbacks and limitations of individual devices are minimized, allowing a reliable monitoring of UFP concentrations in the indoor space.

The counting efficiency of optical sensors rapidly declines as particle size decreases below 300 nm; therefore, UFP measurements require highly specialized equipment and targeted protocols. At the same time, existing measurement protocols have been established for laboratory and industrial environments where engineered nanomaterials are manufactured and/or handled. In occupational settings, the protocols rely on clear separation of active processes and a prior definition of potential sources of release. As such, the challenge lies in their implementation for the evaluation of indoor quality, where no specific process steps are found.

The protocol for quantifying UFP exposure establishes guidelines and analytical procedures for measuring UFP in indoor settings. A two-step methodology is defined, taking into account information gathering, measurement design, performance, and analysis of findings. An appropriate questionnaire is required for collecting key room characteristics related to occupancy, room usage, and mobility. The core principles for equipment placement, room selection, and result evaluation are also specified.

Results incorporated in this CWA received funding from the European Union (EU)-funded project TwinAIR (Grant Agreement No.: 101057779). The proposed methodology has been refined through application across a wide range of indoor environments, including hospitals, schools, elderly care centres, universities, offices, and urban buses.

1 Scope

This document establishes a refined protocol for indoor exposure investigation to ultrafine particles (UFP; diameter < 100 nm).

The protocol comprises a two-step approach through information gathering and on-site measurements (1. defining the requirements for structuring a scoping questionnaire and 2. use of portable measurement equipment for ultrafine particles). The described approach extends from the direct measurement of UFP as outlined in the bibliography and ISO 16000 series by calculating the UFP via a set of different PM monitoring devices, potentially minimising the individual drawbacks and limitations of individual measuring systems and delivering the UFP concentrations in the indoor space. Where regulatory or compliance measurements are required, relevant ISO 16000 standards apply.

This protocol applies to different indoor settings, including offices, schools and universities, hospitals and care centres, dwellings, and public transport vehicles.

This protocol is not intended to be used in laboratories and industrial settings, which are covered by other existing CEN and ISO Standards, and it does not provide suggestions for exposure threshold values.

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.

ISO 16000-34, *Indoor air — Part 34: Strategies for the measurement of airborne particles*

ISO 16000-42, *Indoor air — Part 42: Measurement of the particle number concentration by condensation particle counters*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

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

3.1
ultrafine particle (UFP)
particle (3.2) with a diameter of 100 nm or less

[SOURCE: ISO 16000-34:2018, 3.8]

3.2
indoor air
air within an enclosed space, e.g., dwelling or public building

[SOURCE: ISO 4225:2020, 3.1.1.5]

3.3
indoor air quality
quality of air inside a building, described in terms of odour, physical parameters, chemical and biological pollutants

Note 1 to entry: Indoor air quality is directly related to the ventilation rate, air distribution patterns and pollution sources.

Note 2 to entry: Indoor air quality is important in ensuring human health, olfactory comfort and perceived comfort.

Note 3 to entry: Adapted from ISO 16813:2024, 3.21. The definition has been simplified to refer to a building in general, versus only non-industrial buildings, and the non-essential but relevant characteristics are now referenced in notes.

[SOURCE: ISO 16000-40:2019, 3.24]

3.4
ventilation
provision of air to an enclosed space to meet the needs of the occupants and/or the requirements of the equipment therein

[SOURCE: ISO 8861:1998, 3.2]

3.5
natural air ventilation
air circulation generated without a mechanical action

[SOURCE: ISO 19659-1:2017, 3.1.1.8]

3.6
mechanical ventilation
ventilation provided by mechanically powered equipment

[SOURCE: ISO 16814:2008, 3.22]

3.7
occupant
person who has occupied the indoor space, e.g., room in a building

3.8
pollutant
substance which either alone or in combination with other substances or through its products of degradation or emissions can have a harmful effect on human health or the environment (3.26)

[SOURCE: ISO 16000-32:2014, 3.7, modified]

3.9
condensation particle counter (CPC)
instrument that measures the particle number concentration of an aerosol

Note 1 to entry: For the purpose of this standard a CPC is used as a standalone instrument which measures the total particle number concentration within a device dependent size range.

[SOURCE: ISO/IEC 28360-1:2021, 4.8]

3.10
particulate matter (PM)
particulates, solid particles suspended in a gas

[SOURCE: ISO 18562-1:2024, 3.22]

3.11
optical particle counter (OPC)
light scattering airborne particle counter used for measuring the size and particle number concentration of particles suspended in air

Note 1 to entry: This device is described in ISO 21501-4.

[SOURCE: ISO 8573-4:2019, 3.2]

3.12
aerosol mass-based monitor
instrument that measures the mass concentration of particles in grams per cubic metre

3.13
particle size distribution
distribution of particles as a function of particle size

[SOURCE: ISO 17200:2020, 3]

3.14
assessor
entity performing the site-specific assessment

[SOURCE: ISO 19905-1:2023, 3.10]

4 Information gathering (Step 1)

4.1 Requirements for structuring the scoping questionnaire

The first step of the UFP evaluation includes the collection of the necessary information around the indoor space, comprising details around:

— Location,

— Room design/specifications,

— Room functions,

— Ventilation,

— Occupancy,

— Indoor air quality,

— Expected pollutants and prior measurements.

The required information allows the estimation of potential emission sources, the types of emitted PM and/or UFP, and the presence of other pollutants, e.g., total volatile organic compounds.

The current protocol follows a tiered structured approach as described in EN 17058, where a scoping questionnaire serves as Tier 1, allowing the assessor or the expert to evaluate the type and level of indoor air pollution at the workplace or the indoor environment (Figure 2).

The scoping questionnaire is shared with the operators or the managing staff of the indoor area, room or space where the assessment will take place, and needs to be filled out to decide if and how the on-site measurement campaign will take place (Tier 2) (Figure 2).

The outcomes of the Tier 1 and Tier 2 assessments will provide the necessary input to the assessor to estimate the UFP concentrations (as calculated in subclause 5.4) in the indoor air environment and evaluate the potential use of alternative or additional risk mitigation measures, following a hierarchical hazard control approach (ISO 45001).

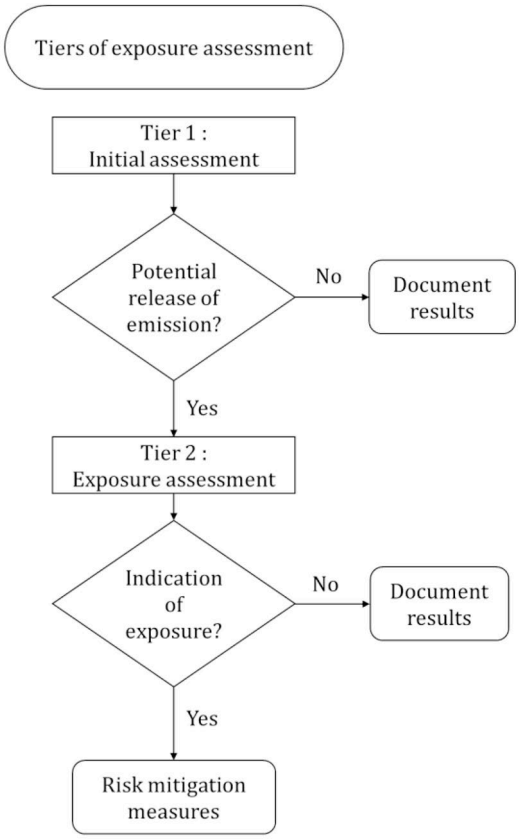


Figure 2 — Building blocks of tiered approach

4.2 Structure of the scoping questionnaire

4.2.1 General

For the information gathering, a structured scoping questionnaire is developed by the assessor(s), comprising three main parts:

— Information about the characteristics of the indoor area or room;

— Information about the activities taking place in the indoor area or room;

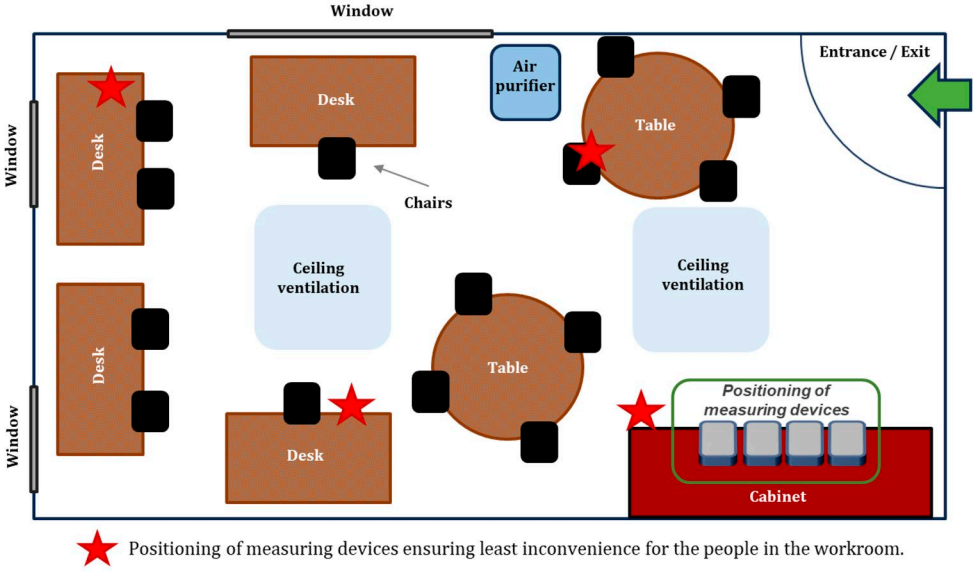
— Information about the occupancy and affected people.

The scoping questionnaire shall follow a similar format, and shall be built upon the information survey outlined in ISO 16000-34 and ISO 16000-42, which focus on indoor air quality measurements, data gathering approaches, and information required for assessing and analysing the measured values, hence correlating the UFP concentrations with the respective indoor conditions and potential sources.

People's mobility can potentially affect the PM and UFP concentrations, hence it is instrumental to record the occupancy levels.

4.2.2 Analysis of information:

The scoping questionnaire helps identify various emission hotspots in the workroom, such as cleaners, vacuum machines, printers, stoves/cooking devices, etc. Hence, it supports the positioning of measuring devices, ensuring the least inconvenience for the people in the workroom. Figure 3 shows an example of an indoor workspace, and a Star marks the potential positioning of the measuring equipment for the UFP concentration assessment. However, the position of least inconvenience shall be selected to avoid disturbing people, as this could affect the final results, as the activities will no longer reflect the expected operations in the room. The measurement strategy is based on the outlined protocol in the ISO 16000 series, in which the evaluation of the building's context – including its ventilation systems, potential pollutant sources, and environmental conditions – is the primary determinant of the appropriate timing and location of measurements.



NOTE Objects and instruments not at scale.

Figure 3 — Top-down illustration of typical example of indoor workspace

5 On-site measurements (Step 2)

5.1 Types of measuring devices

A set of particle size monitoring devices is required to monitor real-time UFP concentrations, as well as the correlation between UFP and other PM (10 nm – 25 µm).

A high-frequency particle sizer or a condensation particle counter (CPC) can be used solely for the direct measurement of UFP if it allows the distinct monitoring of particles <100 nm (e.g., through dedicated channels). Sampling intervals should be set to 1 second for high-accuracy monitoring of air quality variations and any alterations in the indoor environment.

In case of longer sampling intervals (e.g., per 1 minute), and/or not direct measurement of UFP through distinct channels, a set of monitoring devices can be used, including:

— a condensation particle counter;

— an optical particle counter (OPC);

— a monitoring device for particle size distribution of nano-sized and sub-micron particles;

— an aerosol mass-based monitor.

The first three instruments will allow the monitoring of ultrafine and sub-micron particles and therefore allow the calculation of UFP concentration in number of particles/cm^3, while the aerosol mass-based monitor monitors the other PM pollutants and provides a more detailed analysis on the other airborne particles which could interfere with the UFP measurements (Figure 4). The operation of CPCs relies on the condensational growth of nanoscale and submicron particles via vapor supersaturation of a vapour (e.g., isopropanol) on the particles, thereby increasing their size to a consistent level that enables detection by light-scattering techniques. In that way, the UFP, which previously scattered light too weakly due to its small size, can be monitored over time. On the other hand, OPCs use a direct light beam to detect PM as it is scattered or blocked, convert the signal to electrical signals, and subsequently provide real-time particle size concentrations and distributions. However, OPCs are limited to submicron particle sizes and cannot directly detect UFPs. Devices which measure ultrafine particle size distributions typically operate by electrically charging UFPs for subsequent sizing, e.g., by controlling the motion of particles in an electric field, and/or counting the charged particles by electronic means, e.g., an electrometer.

Detailed calculations based on the use of the set of three monitoring devices are included in subclause 5.4.

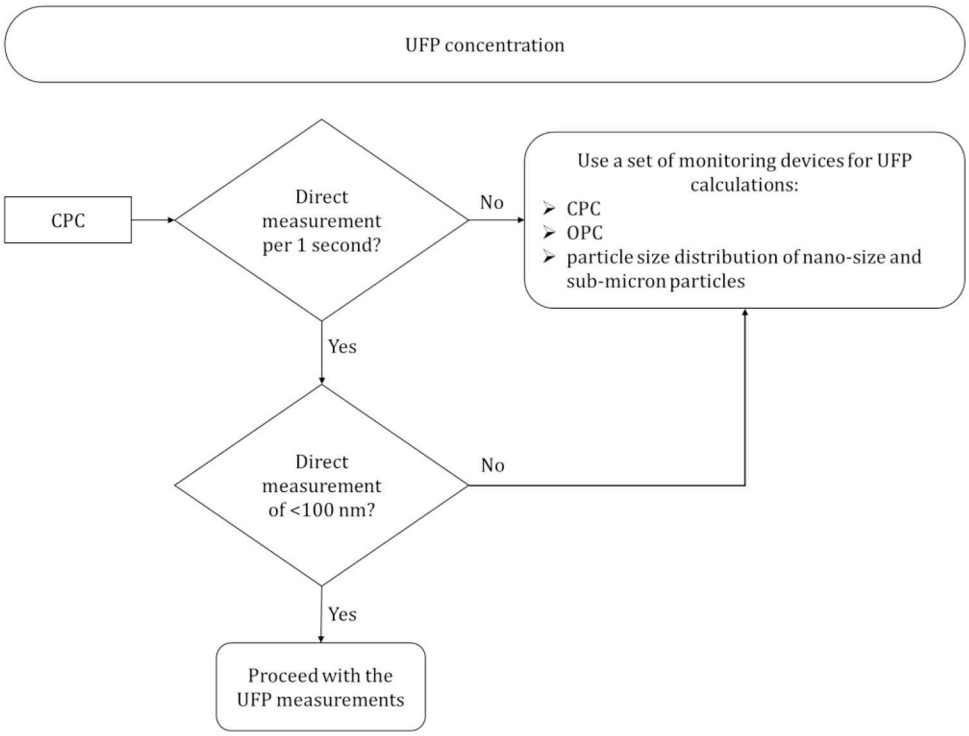


Figure 4 — Flow diagram of the equipment selection of UFP measurements

5.2 Design and keeping of logbook

Assessors of UFP concentrations in the indoor air environment shall keep a detailed and structured logbook, containing the activities in the room that may lead to the recorded emissions, as well as the background activities which can influence recorded spikes in UFP or micro-size particle concentrations (Table 1).

Through the logbook, the recorded particle concentrations over time can be matched with the various activities and people's mobility.

The logbook includes the timestamp of people's actions (e.g., entering/exiting the room, number of people, activities performed), positioning of equipment, background measurement (if possible before people entering the room or before initiation of activities), and any other actions that can potentially contribute to the generation of alteration of UFP concentrations in the indoor space (e.g., vacuuming, cleaning, opening windows of other HVAC equipment, etc.).

Table 1 — Example of a logbook containing measurements, background, people's mobility and activities in the indoor space

Time (hh:mm)	Event
8:00	People entering
8:05	Positioning of equipment
8:15	Background start
…	…
10:30	Vacuuming starts
…	…
14:15	Change of shift
15:45	Last people exiting
…	…

5.3 Measurements

5.3.1 Positioning of equipment

Measurement equipment should be positioned so that direct measurements of PMs, including UFPs, can be obtained, avoiding any inconvenience that could alter people's activities or the procedures taking place in the indoor environment.

Measuring devices should consider air currents and spatial variations during the measurement campaign. Therefore, windows, HVAC, or other systems that could affect airflow shall be identified and located prior to device placement; hence, forced and mechanical ventilation will not disturb the measurements, and recorded concentrations will be representative of the actual values in the indoor air. In that way, measuring devices should not be placed close to, under, or in front of mechanical ventilation setups (e.g., air purifiers, air conditioning units, open windows, etc.).

For the duration of measurements, assessors shall consider fluctuations in indoor activities (e.g., tasks, shifts, breaks, etc.) and adjust the duration accordingly. Also, measurement durations should be in accordance with the technical specifications of the measuring devices. For CPC devices, replenishing the condensation solvent (e.g., isopropanol) should be considered, and any pause, shutdown, or zero-check/calibration should be recorded in the logbook (subclause 5.2).

Pre-operation instrument checks, zero-checks, and calibrations shall be taken into account when planning the assessment and measurement duration.

5.3.2 Background measurements

Background measurements are included as part of the tiered assessment in EN 17058, ISO/TR 12885, and ISO 16000-34, covering the measurement of indoor air prior to a specific process (such as manufacturing technique or laboratory activity) which could potentially release airborne pollutants and PM, allowing the comparison of PM and UFP concentration between the initial values in the air and the values during the process under on-site monitoring.

In case of indoor air quality monitoring and UFP in the workplace or other residential indoor spaces, background could refer to the monitoring stage prior to people entering or activities commencing.

Background may not be applicable for indoor air quality when no main activity exists. However, background concentrations should be recorded when possible, and the duration of at least 45 minutes is recommended (including background) (following the methodological framework mentioned in EN 17058). Further comparison between recorded values and the background measurements can be calculated based on the mean recorded values and the standard deviation, as outlined in EN 17058 and ISO/TR 12885.

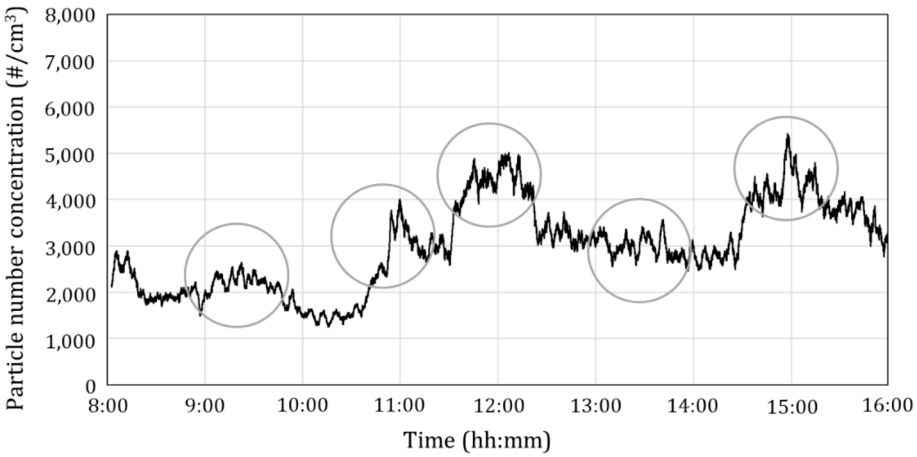
5.3.3 Analysis of results

The analysis of results allows the identification of hot-spots and peaks, and the comparison with the logbook on activities marked with a circle (Figure 5).

Over the duration of the measurements, the identified peaks shall be compared and contrasted against the recorded activities and events in the logbook (subclause 5.2). In that way, the emission events can be identified.

Further investigation requires the comparison with the rest of the equipment (in case of multiple measuring devices for UFP monitoring), hence it can be concluded if the recorded emission events contribute to UFP or larger PM particles.

Comparison of emission peaks with the background (if it exists) can be calculated based on the mean recorded values and the standard deviation, as outlined in EN 17058 and ISO/TR 12885.



NOTE Circles highlight recorded peaks in particle concentrations associated with various indoor activities.

Figure 5 — Indicative particle number concentrations of sub-micron particles over time, measured by a CPC

5.4 Calculation of UFP concentrations

UFP concentrations are calculated from data distributions for three measurement instrument categories: CPC, OPC, and particle sizer. This approach differs from the direct measurement of PM and UFP concentrations, as described in ISO 16000-37 and ISO 16000-42, and enhances the precision of identifying actual ultrafine particle emissions by leveraging the advantages of each instrument (e.g., sampling rate) rather than relying solely on individual channels corresponding to specific particle sizes.

$$\text{UFP calculation} = \frac{\left[CPC - \sum_{i=1}^{n}(OPC_i)\right]^{*} \sum_{j=1}^{m} PS_j}{\sum_{j=1}^{k} PS_j} \quad (1)$$

where

CPC	is the value reported by the CPC instrument;
OPC_i	is the value reported by the OPC instrument in channel i;
PS_j	is the value reported by the particle-sizer in channel j, and channel 1 is the first channel with a measuring range within the CPC measuring range;
n	the number of OPC instrument channels with a measuring range within the CPC measuring range;
m	the number of particle sizer channels with measuring range between the smallest size observable by CPC and 100 nm;
k	the number of particle sizer channels with a measuring range between the smallest size observable by CPC and the smallest size observable by OPC.

- The different instruments allow the identification of different concentration spikes, as well as better monitoring of which activities result in increased UFP concentrations, balancing out the technical limitations of each device.
- Better comparison with NanoReference Values and Occupational Exposure Limits (OELs). Especially through the comparison with the results from the mass-based aerosol monitoring devices, which take into consideration the PM1-PM10 particles.
- Repeatability also supports the identification of time-dependent emission phenomena.
- An example of UFP calculations is included in Annex A.

6 Limitations and other pollutants affecting the measurements

Bioaerosols are suspended airborne particles, ranging from approximately 0,003 μm for viruses, 0,25–20 μm for bacteria, and 1–30 μm for fungi, with pollen grains reaching sizes of up to 100 μm, that contain biological constituents, including viable and non-viable bacteria, fungal spores, viruses, pollen, bacterial endotoxins, mycotoxins, β(1→3)-glucans, and other biologically derived metabolites. Despite not being explicitly included in the current guidelines, bioaerosols may contribute to human exposure relevant to allergies, respiratory infections, and other respiratory health outcomes. The presence of bioaerosols in the sampled air may contribute to measured particle number size distribution, and mass concentrations, but conventional aerosol instruments cannot distinguish biological from non-biological particles. In research where biological validity forms an important consideration, these models can thus need to be augmented with methods of bio-aerosols analysis, such as filtration with subsequent analysis using molecular, culture, or microscopic methods.

Aerosol mass-based monitoring devices measure particulate matter mass concentrations and can record particles associated with bioaerosols; however, they cannot distinguish biological particles, such as bacteria, viruses, and fungal spores, from non-biological particulate matter. The CPC measuring devices measure particle number concentrations across nanoscale to micrometre sizes. An alternative approach is to measure the total concentration reported by the particle sizer if it has measurement and data analysis techniques which enable accurate resolution of the number concentration of UFPs as defined. These instruments can detect particles within the size range of many bioaerosols, but do not identify particle composition or biological viability. Especially in cases where CPC uses alcohol solvents (e.g., isopropanol), so that vapours enlarge particles for optical counting; this process does not reduce, destroy, or selectively affect bioaerosols and does not provide biological characterization. The OPC usually measures particle size and number concentrations in the 0,3-10 µm size range. Although it can detect particles that may include bioaerosols, it does not determine whether the particles are biological or their viability. Its output is just the size distribution and particle counts.

Annex A
(informative)

Example of UFP measurement protocol application and UFP calculation

A.1 Measuring equipment

During the application of the protocol within the TwinAir project (Grant Agreement No.: 101057779), the following were used:

- CPC: CPC 3007 (TSI Inc. Shoreview, MN, USA).
- OPC: Aerotrak 9306-V2 (TSI Inc. Shoreview, MN, USA).
- Particle sizer: TSI NanoScan SMPS 3910 (TSI Inc. Shoreview, MN, USA).
- Mass-based monitoring: DustTrak DRX 8534 (TSI Inc. Shoreview, MN, USA).

Data collection and logging time per instrument is:

— CPC3007 uses isopropanol for the measurement of sub-micron particles (10 nm – 1 μm) at 1 s data collection and logging time.

— Aerotrak 9306-V2 measures particle concentration in six adjustable channels (ch) set at ch1: 0,3 – 0,5 μm, ch2: 0,5 – 1 μm, ch3: 1 – 2,5 μm, ch4: 2,5 – 4 μm, ch5: 4 – 10 μm, ch6: 10 – 25 μm, at 1 s data collection frequency and data logging every 1 min.

— NanoScan SMPS 3910 uses isopropanol for the particle size distribution of the sub-micron particles through 13 channels from 10 nm to 420 nm, at 1 min data collection and data logging times.

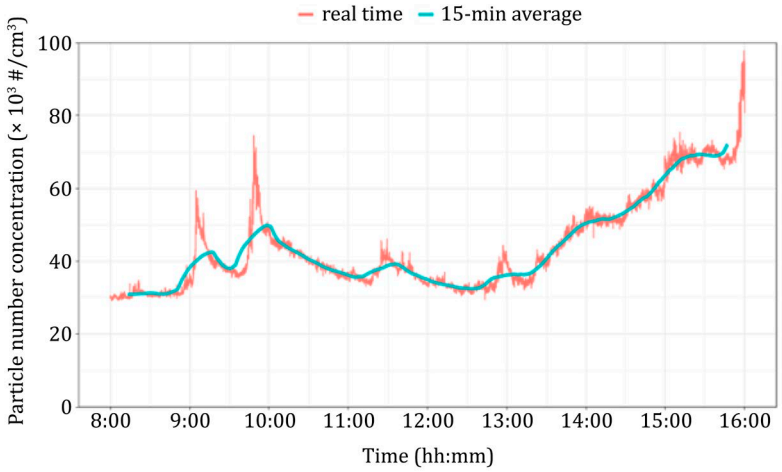
— DustTrak DRX 8534 is a four-channel mass-based real-time aerosol monitoring device of 0,1 μm to 15 μm PM in four individual and cumulative channels set at PM1 (particles < 1 μm), PM2,5 (particles < 2,5 μm), PM4 (< 4 μm), PM10 (< 10 μm), while the fifth channel displays the total concentration of particles < 15 μm over time (Total). The device was set to 1 s data collection to accurately monitor particle concentration over time, with a 1-minute logging frequency.

A.2 Acquired data

During an on-site campaign at an indoor workspace, the following PM and UFP concentrations were recorded following the activities in the room and people's mobility (Figure A.1 – Figure A.4).

Several peaks have been identified in both the CPC and OPC devices, indicating emission events. Further assessment requires comparing the emission events with the campaign's logbook to identify the cause of the spikes in particle concentrations.

The results from the aerosol mass-based monitoring device (Figure A.4) highlights the emission of both sub-micron (PM1) and larger (e.g., PM10) particles, providing a more in-depth understanding of the events and particle concentration, while larger PMs can be compared with the general OELs for particulate matter.



NOTE Red line represents the measured values of sub-micron particle concentrations. The cyan line represents the 15-min moving average values.

Figure A.1 — Sub-micron (< 1 µm) particle measurements using the CPC3007 during the measurement campaign at the workplace

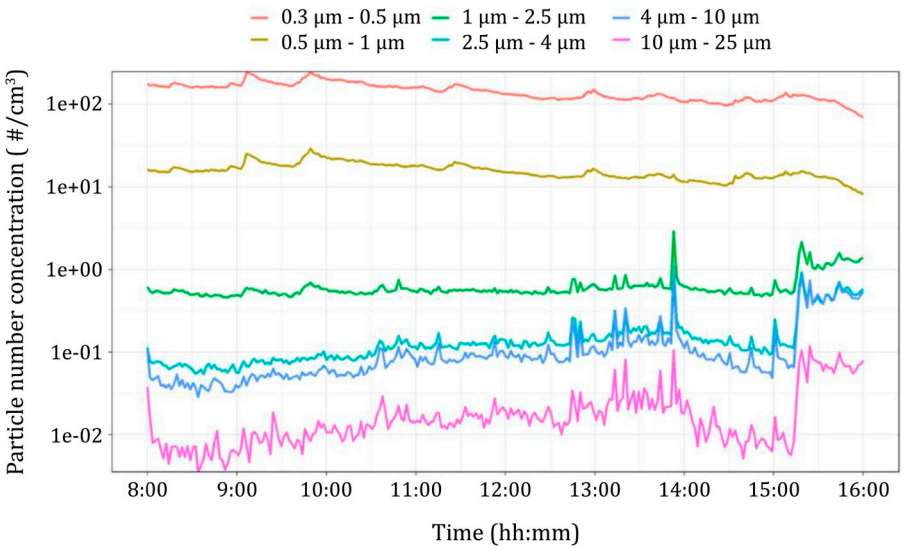


Figure A.2 — Particle number concentration measurements using the Aerotrak 9306-V2 during the measurement campaign at the workplace

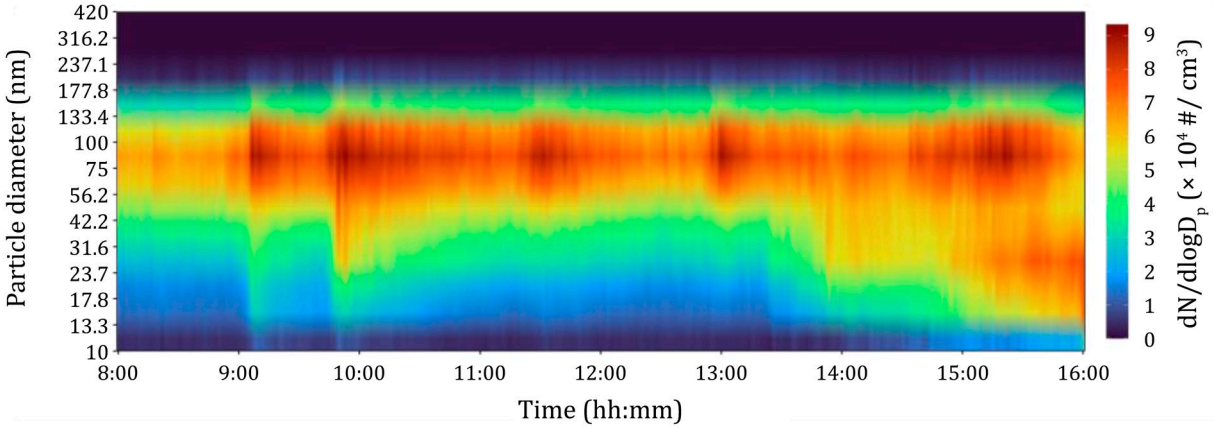


Figure A.3 — Particle size distribution of the sub-micron and ultrafine particles using the NanoScan SMPS 3910 during the measurement campaign at the workplace

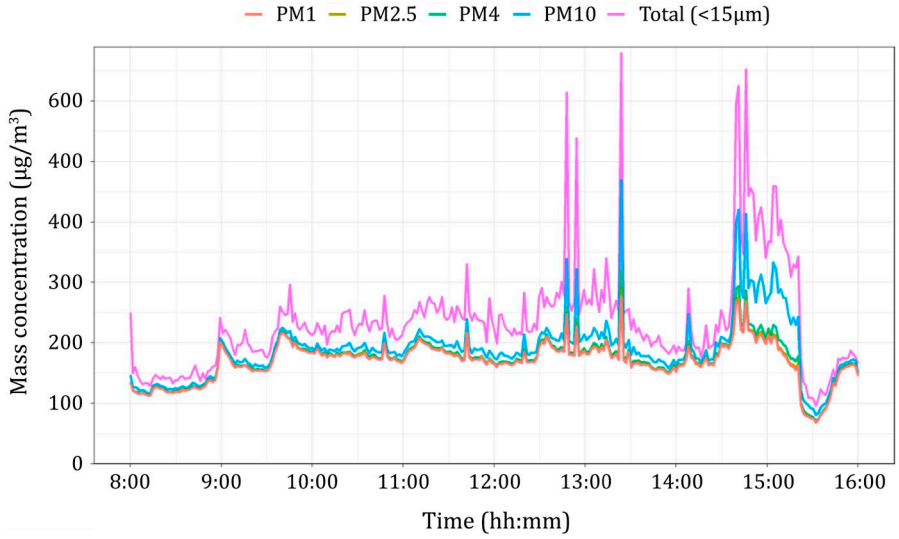


Figure A.4 — Mass-based particle concentration measurements using the DustTrak DRX 8534 during the measurement campaign at the workplace

A.3 UFP calculation

When applied for the specific instruments above, Formula 1 gives the following equation for each minute of measurement:

UFP calculation =

$$\frac{\left[CPC\ 3007 - Aerotrak\ 9306 - V2\left(ch\_300\_500 + ch\_500\_1000\right)\right]^{*}\ NanoScan\ SMPS\ 3910\left(1-8\right)}{NanoScan\ SMPS\ 3910\left(1-12\right)} \quad (2)$$

where

CPC 3007 is the 1-minute average of values reported by the CPC instrument;

Aerotrak 9306 – *V2* (*ch*_300_500 + *ch*_500_1000)	is the sum of values reported by the OPC instrument in channels between 300 nm and 1μm;
NanoScan SMPS 3910 (1 – 8)	is the sum of values reported by SMPS in channels between 10 nm and 100 nm;
NanoScan SMPS 3910 (1 – 12)	is the sum of values reported by SMPS in channels between 10 nm and 300 nm.

Formula 2 applied to the first 6 minutes of the measurement presented in Figures A.1 to A.4 provides the following particle concentrations (Table A.1).

Table A.1 — Example of Formula 2 application during the measurement campaign at the workplace

Input (#/cm^3)				Output (#/cm^3)
CPC 3007	*Aerotrak* 9306 – *V2* (*ch*_300_500 + *ch*_500_1000)	*NanoScan SMPS* 3910 (1 – 8)	*NanoScan SMPS* 3910 (1 – 12)	UFP calculation
29859,70	193,2749	33451,15	44486,57	22307,31
30271,32	185,14	32171,09	43587,44	22206,05
30230,65	187,8116	33013,1	44410,01	22332,97
29865,53	186,6248	32796,06	43976,06	22133,66
30376,90	180,2162	32902,03	44206,03	22475,03
30516,73	179,2778	33144,94	43988,99	22858,75

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