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Indoor air —

Part 42:
Measurement of the particle number concentration by condensation particle counters

Air intérieur —

Partie 42: Mesurage de la concentration en nombre de particules au moyen de compteurs de particules à condensation

Reference number
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Foreword

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This document was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 6, *Indoor air*.

A list of all parts in the ISO 16000 series can be found on the ISO website.

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Introduction

People spend most of their day indoors where they are exposed to various sources of particles. Such particles can be dust particles, particles from combustion processes such as candles, cooking and fireplaces. Particles can also be emitted by do-it-yourself activities and the operation of electrical equipment such as printers. Classical building envelope materials are not efficient to prevent particle transport between indoor and outdoor environments. Sources of outdoor particles are various and include traffic and other combustion processes, and industrial and agricultural activities. Air exchanges are driven by natural infiltration and ventilation, but also mechanical ventilation present in the building.

All this can result in highly variable levels of indoor particles concentration that are not easily ascertained or assessed in terms of their impacts on health.

Epidemiological studies have shown that ultrafine particles (UFP) can have a negative impact on peoples' health.[1] Due to their very small size they can indeed penetrate deeply into the human body.

Particle measurement instrumentation allows determining either the total particle number concentration or the particle number size distribution. This document describes the general strategies for the measurement of indoor sub-micron particles with the focus on determining the total number concentration.

This document was prepared in response to the need for improved comparability of methods for particle measurement.

Indoor air —

Part 42: **Measurement of the particle number concentration by condensation particle counters**

1 Scope

This document specifies the measurement methods and strategies for determining the total number of airborne particles per unit volume of air indoor, using a condensation particle counter (CPC) for particles approximately between 10 nm to 3 µm.

NOTE As the particle number concentration is usually dominated by the ultrafine particle (UFP) fraction, the obtained result can be used as an approximation of the UFP concentration.

Quality assurance, determination of the measurement uncertainty and minimal reporting information are also discussed in this document.

This document is applicable to indoor environments as specified in ISO 16000-1.

This document does not address the determination of bioaerosols or the chemical characterization of particles. Nevertheless, some bioaerosols can be detected by the CPC and then contribute to the measured count of particles.

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 16000-1, *Indoor air — Part 1: General aspects of sampling strategy*

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

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

CEN/TS 16976, *Ambient air — Determination of the particle number concentration of atmospheric aerosol*

3 Terms and definitions

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

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

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

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

3.1
aerosol
multi-phase system of solid and/or liquid *particles* (3.2) suspended in a gas, ranging in particle size from 0,001 µm to 100 µm

[SOURCE: CEN/TS 16976:2016, 3.2]

3.2
particle
piece of matter with a defined physical boundary

Note 1 to entry: The phase of a particle can be solid, liquid or between solid and liquid, and a mixture of any of the phases.

[SOURCE: ISO 27891:2015, 3.23]

3.3
fine particle
particle that is less than a few micrometers in diameter

3.4
ultrafine particle
UFP
particle (3.2) with a diameter of 100 nm or less

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

3.5
particle number concentration
number of *particles* (3.2) related to the unit volume of indoor air

[SOURCE: ISO 27891:2015, 3.25, modified — Note 1 to entry and the symbol C have been deleted.]

3.6
detection efficiency
ratio of the concentration reported by an instrument to the actual concentration at the inlet of the instrument

[SOURCE: ISO 27891:2015, 3.11, modified — the symbol η has been deleted.]

3.7
D_x
particle diameter for which a detection efficiency of the percentage of x is obtained when the CPC result is compared to the reference concentration

Note 1 to entry: This detection efficiency is a function of the CPC itself, but depends also to some extent on particle type.

Note 2 to entry: For the purpose of this document, silver particles and test conditions described in ISO 27891 are considered.

3.8
nominal flow rate
volumetric flow rate indicated on the instrument specification sheet by the manufacturer

Note 1 to entry: The nominal flow rate is that flow rate, which a specific CPC model is designed for by the manufacturer. The real flow rate of individual instruments can differ from the nominal flow due to manufacturing tolerances.

[SOURCE: CEN/TS 16976:2016, 3.7]

3.9
factory-certified flow rate
volumetric flow rate of an individual instrument at the time of factory calibration, measured at its inlet under the actual air conditions, and documented on a check out certificate

[SOURCE: CEN/TS 16976:2016, 3.6]

3.10
actual flow rate
volumetric flow rate of an individual instrument, measured at its inlet under the actual air conditions

Note 1 to entry: It is recommended that the actual flow rate be measured in regular intervals during operation.

[SOURCE: CEN/TS 16976:2016, 3.1]

3.11
calculation flow rate
flow rate which directly relates count rate and particle number concentration

Note 1 to entry: This flow rate is used for instrument internal calculation of the particle number concentration. It depends on the instrument type and can be nominal, factory-certified or actual inlet flow rate. It can also include a calibration factor unless the total inlet flow is analysed.

[SOURCE: CEN/TS 16976:2016, 3.3]

3.12
calibration
operation that, under specified conditions, in a first step, establishes 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: JCGM 200:2012, 2.39, modified — the notes have been deleted.]

3.13
uncertainty
<of measurement> parameter, associated with the result of a measurement, that characterizes the dispersion of the values that can reasonably be attributed to the measurand

[SOURCE: JCGM 100:2008, 2.2.3, modified — the notes have been deleted.]

3.14
parallel measurement
measurement from a measuring system that takes samples from the same air over the same time period

[SOURCE: ISO 16000-37:2019, 3.13]

3.15
coincidence error
error that occurs with counting measuring methods when two or more particles are counted simultaneously as a single particle

Note 1 to entry: Coincidence error is related to particle number concentration, flow velocity through the sensing zone and the size of the sensing zone.

[SOURCE: CEN/TS 16976:2016, 3.4]

4 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

CPC condensation particle counter

DEG diethylene glycol

DEMC differential electrical mobility classifier

DMAS differential mobility aerosol spectrometer

MPSS mobility particle size spectrometer

QA quality assurance

QC quality control

SES size enhancer stage

SMPS scanning mobility particle sizer

SOA secondary organic aerosol

UFP ultrafine particle

5 Sources of airborne particles

5.1 General

Figure 1 shows the size range of airborne particles associated with different sources. These particles can be generated by activities or without activities or be transported by air movement. These sources are different in their time of action and in the number and type of particles generated [2],[3].

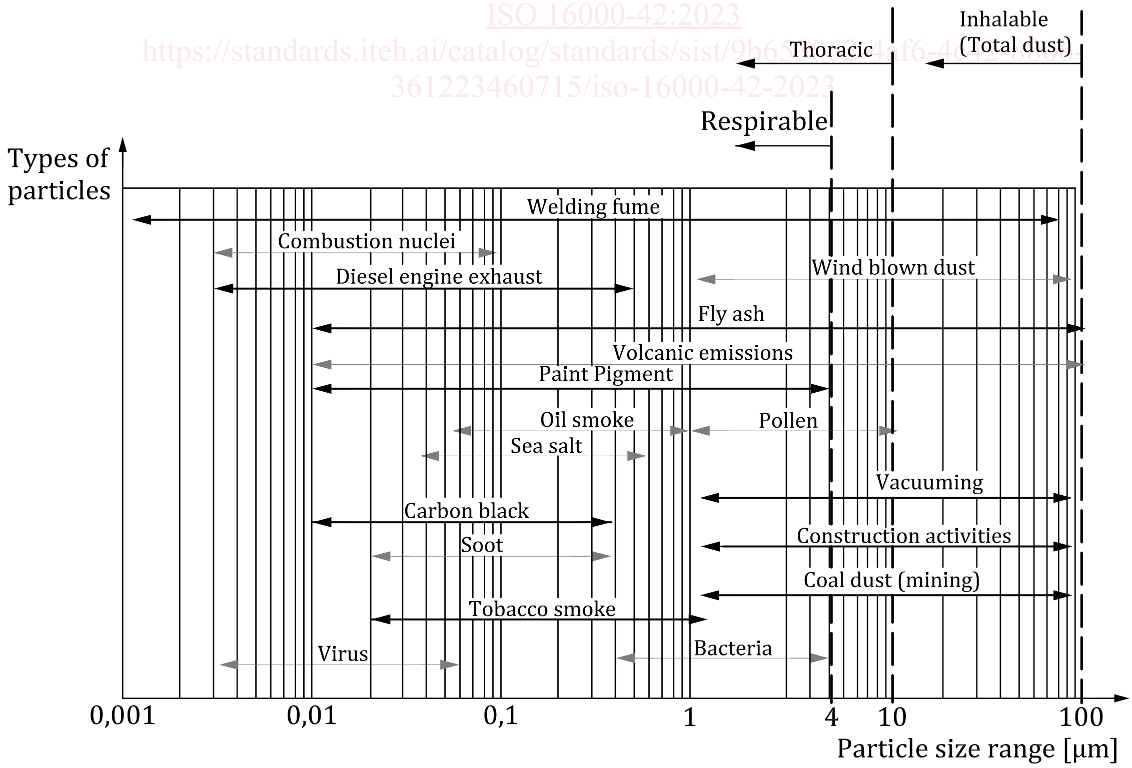


Figure 1 — Usual size range generated by usual indoor sources of airborne particles

Size range is different from one source to the other. Sources that can influence the indoor UFP concentration are briefly listed below. Nevertheless, the total number is always clearly driven by the smallest particles. Neglecting particles bigger than 1 µm will thus have an impact on total number which is much lower than the total uncertainty of the method.

5.2 Combustion of organic material

Each combustion of organic material releases particles of different sizes,[28] the majority of which are particles in the size range <1 µm, primarily in the UFP range <0,1 µm. Research has shown that when candles are burned, the level of UFP emissions depends on the candle material, but also the burn-up process and that high particle number concentrations of more than 10^5 particles/cm^3 can occur. Fine and ultrafine particles can also be released into the room air during the operation of fireplaces and stoves for example.

5.3 Smoking

Smoking is a significant anthropogenic and time-varying source of UFP indoors. Particle number concentrations >10^5 particles/cm^3 are easily produced, depending on the scenario under investigation.[4],[5] The use of electronic cigarettes (e-cigarettes) also leads to an increase in indoor air concentration of UFPs and PM2,5[6].

5.4 Cooking

Cooking activities of various kinds (e.g. baking, frying, deep-frying and toasting) can lead to very high increases in ultrafine particle number concentrations (>10^5 particles/cm^3). However, this can vary greatly depending on the type of activity, energy input, food, ventilation conditions and room geometry[7],[8].

5.5 Particle formation — Formation of secondary organic aerosol

Chemical reactions of the gas and aerosol phase can be responsible for the formation of new SOA and for the modification of existing particles in indoor environments. SOA are formed mainly in the presence of unsaturated compounds (e.g. monoterpenes) and ozone, nitrogen oxides and/or hydroxyl radicals[9]. User behaviour is also of great importance; for example, the use of chemical cleaning agents can produce significant amount of SOA particles[10].

5.6 Outdoor air

UFPs also enter the interior from outside, in particular through infiltration and ventilation processes. Typical external air sources are emissions from road traffic, combustion processes of all kinds and industrial emissions. Photochemically induced secondary formation can also be a relevant source in the outside air. During prolonged ventilation, the indoor and outdoor concentrations are usually equalized. After ventilation, the concentration changes again due to prevailing sources, sinks and dynamics.

5.7 Other sources

The operation of office equipment with laser printing functions (printers, copiers, multifunction devices) releases particles with diameters down to about 300 nm. Commercial and private 3D printers (e.g. fused filament fabrication printers), which are becoming increasingly popular, process plastic filaments into 3D objects in typical periods of up to several hours. Fine and ultrafine particles are emitted into the environment. Devices in the lower and middle price categories are usually not equipped with filters.[11] UFP and fine particles of various types, quantities and size distributions are also produced by processing spray paints and vanishes as well as by material processing, for example, grinding, sawing or drilling during renovation work and do it yourself activities. Cleaning activities, in particular vacuuming, can also lead to an increased release of UFP when using equipment without effective filtration. Such emissions are situation specific and depend to a large extent on the materials, products and equipment used as well as on the scope and frequency of the activity.

6 Dynamics of ultrafine particles indoors

6.1 General

In addition to the source emission of ultra-fine particles described in Clause 5, there are various dynamic processes which can affect the measurement result (see Figure 2). Particle number concentrations and particle size distributions indoors can indeed be subject to high spatial and temporal variability.

Responsible for this are:

— the number of possible emission sources, their spatial arrangement and time-dependent emission patterns;

— the contribution of the particles penetrating from the outside and associated influencing factors, such as environmental conditions (outdoor air quality, meteorology) and building conditions (ventilation conditions, ventilation systems with and without filtering, construction, tightness location of the object, floor);

— particle transport mechanisms (aerosol dilution, sedimentation, resuspension, thermophoresis and diffusion);

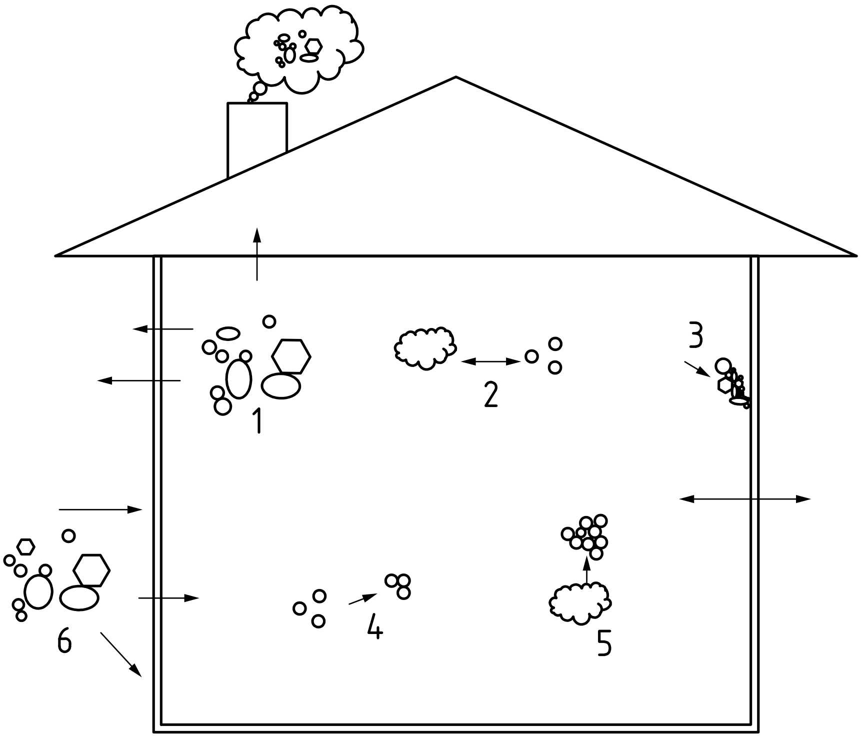
— the laminar or turbulent air movement and air mixing in the room;

— temperature and humidity;

— conversion by chemical (oxidation) and physical processes (coagulation, evaporation, re-condensation, gas-particle partitioning).

The processes depend on the concentration, size distribution and chemical composition of the emitted primary particles.[12] Compared to coarser particles, UFPs sometimes behave more like gas molecules; they follow the air flow in the room and are distributed primarily by diffusion processes. In contrast to coarser particles, sedimentation and resuspension are practically irrelevant for UFP. The speed and extent of coagulation effects are strongly dependent on the initial concentration, size and width of the size distribution of the primary particles. In spatially limited areas of very high number concentration (downstream from a source), for example, coagulation of primary particles can occur much faster than after homogeneous distribution of the particles over the entire spatial volume with a correspondingly smaller number concentration. At a concentration below approximately 10 000 cm^{-3}, coagulation effects in the ultrafine particle fraction typically occur only after a few hours[13].

These aspects should be considered when planning the measurement strategy and also when evaluating the measurements, for example, by measuring and analysing the time response of an aerosol or different aerosol size fractions over a longer period of time. In general, it should be considered that aerosol size fractions can also be present outside the measuring range of the instruments used.



Key
1 exfiltration
2 phase transition
3 deposition
4 coagulation
5 formation
6 infiltration

Figure 2 — Dynamic processes influencing indoor particle pollution according to Reference [2]

6.2 Infiltration and exfiltration

Since a building envelope is never completely sealed, particles from the outside air always enter the interior (infiltration equals to the input) and vice versa (exfiltration equals to the output). This inflow and outflow play a major role in the particulate pollution of the interior and is naturally increased when active ventilation systems are in operation. The infiltration of particles from the outside air can be described by a size-dependent penetration factor, which is called structural property of a room or building[14].

6.3 Deposition

The main mechanism for the precipitation or deposition of UFP on surfaces is transport by diffusion.[15] In purely laminar flow, deposition on surfaces is relatively slow. In practice, however, air flow and rough surfaces cause turbulence and a significant increase in deposition rate compared to the laminar case. Furthermore, the deposition rate increases with the decreasing particle diameter.

6.4 Particle formation, phase transition and coagulation

In the interior, particles can be newly formed by chemical and physical processes. Nucleation, condensation and coagulation can play a role. Conversely, particles can also be converted back into gaseous components. Coagulation is a process that is particularly effective in high particle number