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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

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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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.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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].

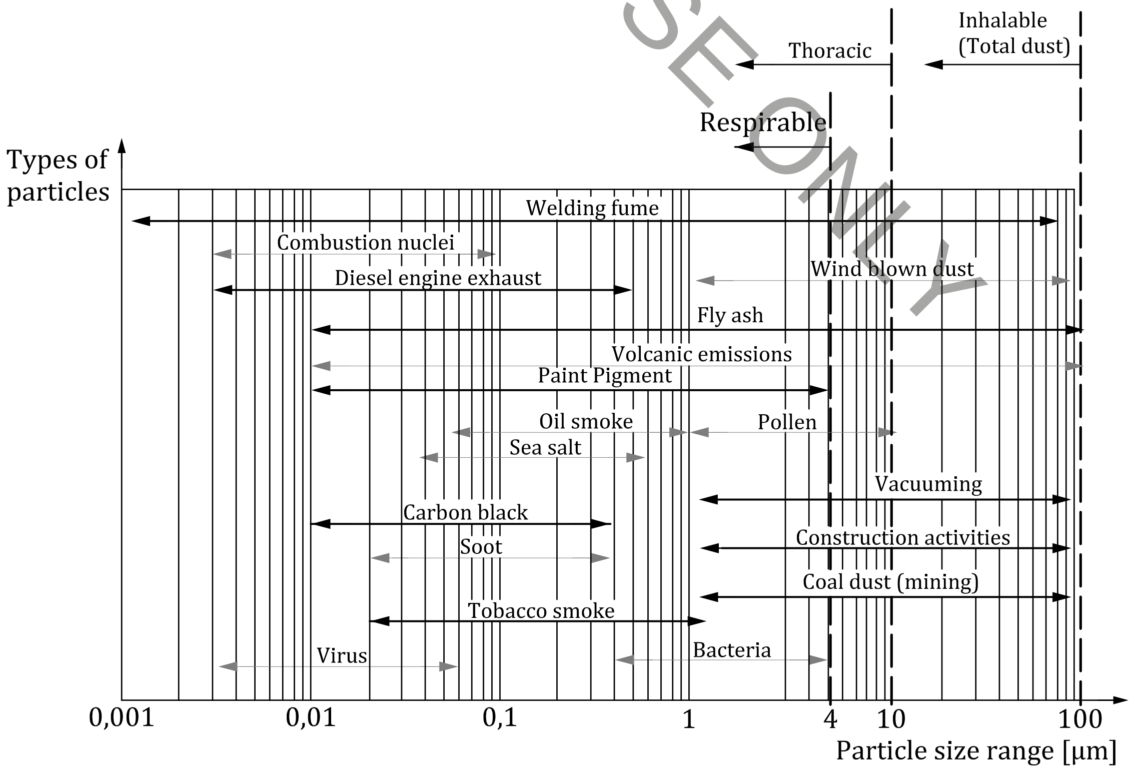


Figure 1 — Usual size range generated by usual indoor sources of airborne particles

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

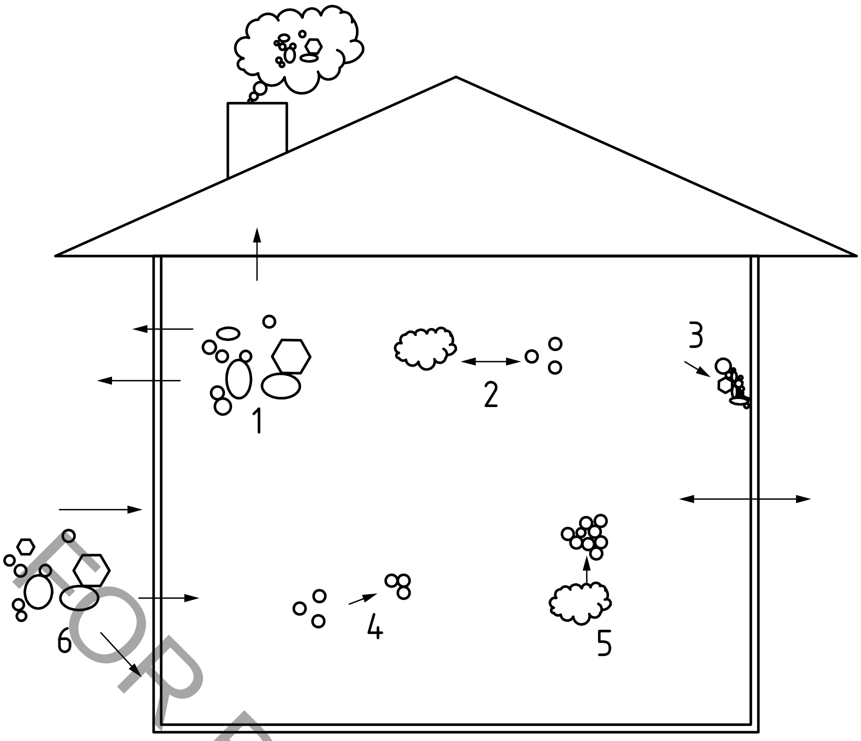
In addition to the source emission of ultra-fine particles described in Clause 5, there are various dynamic processes which can affect the measurement result (see Figure 2). Particle number concentrations and particle size distributions indoors can indeed be subject to high spatial and temporal variability.

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 concentrations and turbulent flow conditions. Therefore, number and size distribution can differ depending on the distance to a particle source.

Resuspension of UFP is not often observed. When UFPs impact a surface (e.g. wall, furniture), they are generally permanently linked to this surface.

7 Principle of measurement

7.1 General

In a CPC, particles are grown by vaporizing a working fluid that supersaturates and condenses onto the primary particles to form bigger droplets which are then detected using scattered light.[16] This process is necessary since UFPs are too small to be directly detected by an optical instrument.

There are several different methods to achieve supersaturation needed to initiate condensational growth:

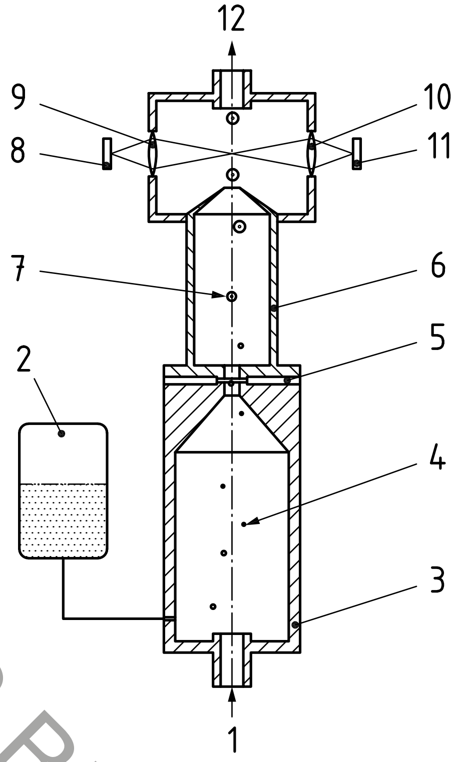
- laminar flow and diffusional heat transfer;
- turbulent mixing of sample air with particle free gas flow saturated with the working fluid;
- adiabatic expansion of the sample air and working fluid vapour mixture.

7.2 Working fluid

To initiate the condensation growth of particles, a minimum saturation ratio with respect to a condensable vapour shall be present. The most common CPC is the laminar flow design using alcohol (see Figure 3), as saturation can be easily obtained with this type of working fluid.

N-butanol CPC shall be the reference method for the determination of the particle number concentration of atmospheric aerosol in ambient air in Europe, as specified in CEN/TS 16976:2016, and is commonly used worldwide for this type of measurement. Using similar instrument indoors and outdoors will lead to a better comparison between measurement results, but indoor toxicity aspect should also be taken into account and n-butanol is considered as possibly harmful when inhaled over long periods. N-butanol CPCs have also a very strong smell.

Isopropanol CPC is an alternative as it provides similar results with fewer nuisances indoors. Any alcohol CPCs can be used, provided measures are taken to filter the exhaust and avoid olfactory nuisances (i.e. using a carbon trap or another emission removal system). Alcohol released by the instrument can also interfere with volatile organic compounds (VOCs) and particular care should thus be taken in case of parallel measurement.



Key

1	aerosol inlet
2	vapour substance reservoir
3	heated saturator
4	UFP
5	thermoelectric cooling and heating device
6	condenser
7	droplet (not true to scale)
8	light source
9	illumination optics
10	receiving optics
11	photodetector
12	aerosol outlet

SOURCE Reproduced from ISO 27891.

Figure 3 — Example of a CPC design

CPCs that use water as working fluid are also regularly used in indoor settings to avoid odour and toxicity problems. Strongly hydrophobic particles can possibly not be counted correctly[17] and particular care should thus be applied to ensure correct results when using water CPCs (see Annex C).

In a mixing type CPC, the supersaturation is achieved by adiabatically mixing the sample air with heated particle-free air saturated with the working fluid. The grown droplets are counted individually using an optical particle counter. By changing the mixing ratio between sample and vapour laden clean air, the supersaturation and thus the smallest detectable particle size can be changed easily. The user should select the right parameter to leisure with a particle diameter at 50 % of the normalized detection efficiency, D_{50}, of 10 nm (or 7 nm, see 7.2)[18].

In an expansion type CPC, the supersaturation is achieved through adiabatic expansion of a gas mixture containing both aerosol sample and the working fluid vapour. Expansion triggers particle growth through condensation. In a typical form of expansion CPCs, the optical detection is done by measuring the scattered light of a population of growing droplets. Through Mie-theory, the particle number concentration can be calculated. It is not recommended to use this type of CPC as the uncertainty of measurement is higher than with other techniques[19].

7.3 Minimal detection size

7.3.1 General

The number concentration of enlarged droplets is equal to the number concentration of the primary particles (condensation nuclei) with a size larger than the Kelvin diameter determined by the supersaturation achieved in the instrument. Minimal detection size is thus an intrinsic characteristic of the instrument and it can deeply influence the final counting result. No comparison between instruments with different D_{50} is possible without additional experimental effort. The lower detection limit of a CPC is typically controlled by the difference between saturator and condenser, and carefully maintained at a constant level.

CPCs with a D_{50} of 10 nm have been selected as reference for this document.

Using a CPC with a D_{50} = 7 nm instead of 10 nm is allowed.

NOTE 1 National regulations can apply.

NOTE 2 Many CPCs can detect particles down to 5 nm. Alcohol CPCs optimized for the small size range (UF-CPCs) use the same particle counting technique as conventional CPCs but are further optimized to enlarge very small particles more effectively and reduce losses, which allow detection down to 3 nm. To extend the detectable size range of an alcohol CPC further, a SES is used upstream. By using DEG, a working fluid with low vapour pressure and high surface tension, even extremely small nuclei down to 1 nm can be enlarged and counted.[20] In the latest design of water CPCs, an additional conditioning section in which the aerosol is brought to 100 % relative humidity at ambient temperature is added before entering the heating section in order to better specify the state of the aerosol and improve the counting efficiency for different aerosol materials down to about 1 nm.[20] Increasing the sensitivity down to smaller sizes can provide insight into particle formation processes, but also increases the cost and the maintenance effort. Losses are also much higher and makes data interpretation sometimes complex. Taking all aspects into account, 10 nm is a good consensus. This value is also expected to be adopted in the future for ambient air monitoring and car exhaust regulations.

NOTE 3 In the automotive sector, a D_{50} of 23 nm is used as of the date of publication of this document, but more and more epidemiologic studies push to decrease this value to 10 nm in future regulations as a large fraction of the engine emission is for the moment neglected. This will also provide a better estimate of the real impact that the automotive sector has on ambient air quality.

7.3.2 Optical detection after enlargement

7.3.2.1 General

The droplets produced by the condensation process are then transported through a light beam. The light scattered by the droplets is collected by a receiving optic under a defined solid angle (receiver aperture) and guided onto a detector (e.g. photodiode).

7.3.2.2 Single count detection

At low concentrations, the droplets cross the light beam one after another, thus producing single electrical pulses at the detector output. From the count rate of these pulses and the calculation flow rate, the total number concentration of particles per unit of volume can be determined.

7.3.2.3 Coincidence correction

There is always a finite probability that two or more particles will transit a CPC's optical detection system in a given time interval. The resulting electrical pulses can become indistinguishable from one another, depending on their magnitudes and shapes, the time difference(s) between them, and the signal processing method and speed for individual pulses. This occurrence is known as a coincidence event. As the concentration of particles entering the CPC increases, the probability of a coincidence event increases, and the coincidence error leads to a systematic underestimation of the actual particle number concentration.

Most manufacturers specify concentration ranges for which coincidence events can be neglected (usually up to 10^4 particles/cm^3 to 10^5 particles/cm^3). Modern CPCs have electronic circuitry capable of compensating it automatically by built in algorithms (so called dead-time correction algorithms; “single count”, “single count mode with continuous lifetime coincidence correction”, “correctional mode” and other synonyms all have essentially the same meaning) to a certain limit (usually up to 10^5 particles/cm^3 to 10^6 particles/cm^3).

7.3.2.4 Photometric mode

For higher particle number concentrations, single pulses are no longer used to determine the particle number concentration, but the light scattered by the whole population of particles present in the sensing volume is used as an analogue signal (photometric method).

Since in the ideal case droplet growth due to condensation yields the same size independently of the size of the condensation nuclei and since the optical properties of the droplets are determined essentially by the condensing material, there is, in principle, a linear relationship between this photometer signal and the particle number concentration.

Determining this relationship requires a strict calibration which is quite difficult to obtain in the field. Furthermore, very high particle number concentrations lead also to a depletion of the vapour concentration by the condensation process. This leads not only to nonlinearity of the calibration curve but also influences the lower detection limit of the CPC. Also, contamination of the optical surfaces will change the measured photometric signal.

To avoid higher concentration counting, dilution systems can be used upstream of the CPC. Dilution is another factor to control in the field and also increases measurement uncertainty.

Due to these effects, the uncertainty of the number concentration measured using photometric mode is higher compared to concentration measured using single particle counting mode.

7.3.3 Particle size distribution

As the final droplet size is almost independent of the initial diameter of the particle, a CPC does not provide information about the initial size of the particles.

If size information is required, a DEMC should be used. The resulting combination with a CPC is known as DMAS. Further information is given in Annex B.

Although the information about the size is important as this parameter often drives the toxicity of the particles, the scope of this document has been limited to the determination of the total particle number concentration in the size range of the CPC.

7.4 CPC minimal requirement

CPC minimal performance criteria are listed in Table 1. All criteria refer to the counting mode of the CPC, including counting with coincidence correction, after any pre-determined calibration factors have been applied.

The CPC’s counting efficiency shall be traceably calibrated by a reputable calibration laboratory and based on an internationally accepted and accessible procedure. Silver particles shall be used to run these tests. Follow ISO 27891.

For other criteria, it is recommended to follow the test procedures specified in CEN/TS 16976.

Table 1 — Main CPC performance criteria

No.	Performance characteristic	Criteria
1	Actual flow rate	≤5 % of the difference to the nominal flow rate ≤2 % of the difference to the factory-certified flow rate
2	Number concentration measurement range Lower limit Upper limit Dynamic range	≤100 cm^{-3} (based on at least 1 500 particle counts) ≥10 000 cm^{-3} (including coincidence correction) At least 3 orders of magnitude If the measured concentration reaches more than 95 % of the upper limit specified by the manufacturer, the measurement result should be rejected.
3	Number concentration detection limit	Smaller than lower limit of number concentration measurement range
4	Concentration response Slope Linearity	 1 ± 0,05 All residuals <4 % of the measured value
5	Detection efficiency at low particle size	D_{50} = 10 nm ± 1,0 nm (or 7 nm ± 1,0 nm – see 7.3.1) Diameter for which the normalized efficiency reaches 90 %, $D_{90:}$ $D_{90} < 20$ nm
6	Detection efficiency at intermediate particle sizes	>95 % at 40 nm ± 10 nm
7	Upper particle size detection limit	>90 % detection efficiency at 1 000 nm ± 100 nm
8	Zero count rate	<1 min^{-1}
9	Response time	$t_{rise} < 5$ s $t_{fall} < 5$ s $\left\|\frac{t_{rise} - t_{fall}}{t_{rise}}\right\| < 10$ % or < 0,5 s where t_{rise} is the time taken by the CPC signal to reach 95 % of the final concentration, when a change in the concentration applies to the CPC from a value below 100 cm^{-3} to a constant concentration above 5 000 cm^{-3} (usually near zero using an absolute filter); t_{fall} is the time taken by the CPC signal to decrease by 95 %, when a change in the concentration applies to the CPC from a value above 5 000 cm^{-3} to a concentration below 100 cm^{-3} (usually near zero using an absolute filter).
10	Dependence of flow rate on supply voltage	≤5 %
11	Maximum uncertainty of temperature and pressure sensors	$T \leq 3$ K $P \leq 1$ kPa
12	Effect of failure of main voltage	Instrument parameters shall be secured against loss.

The instrument shall enable the following parameters to be recorded in 1 min time intervals:

- date, start time and end time of each reported concentration;
- calculation flow rate;
- raw concentration (count rate divided by the calculation flow rate), in cm^{-3};

- concentration with internal coincidence correction (based on the calculation flow rate), in cm^{-3};
- saturator temperature, in K;
- condenser temperature, in K;
- temperature and absolute pressure at the point of flow rate measurement;
- warning and error flags (e.g. signal quality out of tolerance, too high concentration, flow problems, saturator or condenser temperature out of range, working fluid level too low, light source malfunction).

7.5 General sampling requirements and recommendations

Before operating the CPC, the operating instructions of the manufacturer shall be followed, particularly with regard to the set-up of the equipment, the quality and quantity of consumable products necessary, and the CPC warm up time.

The measurement shall take place in the centre of the room at approximately 1,5 m height, as specified in ISO 16000-1 and ISO 16000-34, except for special recommendations in Clause 8.

The sampling volume extracted per hour shall not exceed 10 % of the hourly volume of room air exchanged. If this is unknown, the sampling volume extracted per hour shall not exceed 10 % of the room's volume.

Larger particles can contaminate the optical detection system or block the saturator. A pre-separator, usually a cyclone, can be used to remove all particles greater than 2 µm or 3 µm. This limits the upper size range of the device but has an impact on the total number which is much lower than the total uncertainty of the method.

Particle losses in a sampling line by diffusion or impaction or electrostatic charge have to be considered. Impaction losses can usually be neglected for small particles. Other losses can be minimised by

a) keeping sampling lines short,

b) establishing high sample flows, and

c) using electrically conductive materials (e.g. carbon-black filled silicon rubber, stainless steel) for the sampling line.

In most cases, no sampling line is required and sampling can just be performed at the inlet of the instrument. This solution should be selected each time it is possible. For further information, see Reference [21].

8 Measurement strategy

8.1 General

The measurement strategy to be followed when measuring UFPs indoors is largely dependent on the objective of the investigation.

Typical objectives are listed below:

- average room concentration;
- source investigation or identification;
- infiltration from outdoor or connecting rooms;
- measurement in vehicle cabins;

- success control of mitigation measures.

Depending on the respective measuring task, recommendation on planning including measurement location, frequency and time of measurement, duration and frequency of measurement are described in the following subclauses.

Any additional information which is requested to allow a correct interpretation of the final result shall also be measured and included in the report.

Non-exclusive lists of information that are usually reported are:

- the operator, information on the used device, time and day of sampling;
- room characteristics (fixed installations, such as, floor covering, wall cladding, also size, window type, room textiles, air conditioning systems and heating source);
- main equipment/sources (e.g. refrigerators, stoves, TV sets, computers, printers, toasters, vacuum cleaners, fireplaces) present in the room specifying operation status;
- possible sources in adjacent rooms;
- a plan of the room and adjacent rooms if useful with the location of the sampling points and of the measuring device;
- room conditioning (air tightness of the building envelope);
- the actual air ventilation arrangement; the usage and ventilation conditions can be documented through concurrent measurements of CO_2 concentration; the impact of doors and windows opening is not critical except if creating important air flow (wind); indeed classical building envelop do not stop infiltration of UFPs;
- the number of people present in the room and their activities;
- the presence of specific punctual activities (cleaning, cooking, smoking, printing, candle burning, etc.);
- indoor air conditions (e.g. temperature, pressure, humidity);
- outdoor conditions (e.g. wind direction and strength, temperature, humidity, solar radiation, precipitation); UFP parallel outdoor measurements are always recommended;
- the location of the building and presence of outdoors anthropogenic sources (e.g. road, rail, ship and air traffic, industry, commerce, agriculture, barbecue, smoking) or natural sources (e.g. photochemical particle formation, forest fire).

8.2 Average room concentration

8.2.1 General

Regarding spatial average room concentration, it is sometime necessary to run more than one measurement to be representative of the entire room. If more than one measurement is performed, all results should be reported separately and the average value should be used for any further assessment.

Regarding time average room concentration, three different operational states can be specified:

a) resting state without activity: no occupants and no activities; all equipment present in the room with possible impact to the measurement are switched off or inactivated;

b) resting state with equipment activity: no occupants and activities, but with operation of all fixed and/or constantly operated equipment (e.g. ventilation system, gas heating, refrigerators, servers);

c) active state: occupants present in the room and activities and equipment operations under investigation are taking place.

Information related to the current operational state and any changes occurred during the investigation shall be included in the report.

8.2.2 Resting state without activity

As a minimum, a one hour' measurement should be performed in the centre of each room investigated. If more than one point is measured in the same room, a lower sampling time, down to 15 min, is allowed at each location, but the sampling times of all points investigated in the same room shall at least sum up to one hour.

8.2.3 Resting state with equipment activity

If the purpose is to characterise the room as a whole, the same procedure as for the resting state without activity applies (see 8.2.2). All equipment should be put in normal operation mode and care should be taken to avoid any specific unwanted interference. If some activities are cyclical, the minimal sampling period of one hour should be extended to include an entire number of cycles.

If the purpose is to highlight the impact of specific equipment, two separate samples should be taken, keeping all other room parameters constant in between (see 8.3). Example measurements are shown in Annex A.

8.2.4 Active state

The number of sampling events, their localization and the minimal sampling time depend on the usage. Most of the time, multiple measurements are performed to highlight the impact of a specific activity or sources in the investigated room.

8.3 Source investigation/identification

Indoor sources of UFPs are diverse. ISO 16000-34 describes the procedure to assign and evaluate individual indoor sources. Quantities and positions of sampling points are also specified in this document, considering the type of room and expected activities of potential aerosol sources.

This document focuses only on the measurement of the total number concentration of particles in the size range of the CPC as a standalone measuring instrument. Most indoor sources of airborne particles emit particles in size ranges which will not be detected by CPCs.

A basic source investigation can be performed by slowly moving the CPC around the considered room. Usually the concentration increases the closer to the source the measurement takes place. For a complete source investigation, the use of additional suitable techniques described in ISO 16000-32[47] is often necessary.

When a specific source has been identified and if determining the relative impact of this particular source on the total room concentration is the objective, a specific measurement using a CPC should take place in the vicinity of the source. Measurements with and without this specific source in operation should be performed, trying to keep all other sources and parameters constantly in between. Each separate measurement should have a minimal duration of one hour. If the studied source cannot be maintained in operation during one hour, the sampling period can be extended in a way to have in total a period of one hour of source activity. Periods of inactivity can then be removed when doing the data treatment. For intermittent sources that cannot be measured in operation during one hour because of their low occurrence within the same working day, lower sampling time is allowed, but users should take extra care when interpreting the results. In any case, all periods sampled should be reported.

Maintaining stable conditions in the room during the measurements requires particular care. Removing other sources to achieve this stability is not recommended as cross interactions are possible and part of the investigation. While indoor sources can be switched on and off this is not possible for outdoor aerosol contributions. For this reason, outside measurements in parallel are always recommended to ensure a certain level of stability.

If the beginning and end of the particle release can be determined exactly (e.g. when equipment is switched on), the measurement should be started in advance (e.g. 15 min to 30 min) in order to record the idle state. In order to be able to estimate the decay behaviour of the particle number concentrations after the particle release has ended, the measurement should be continued for enough time until no change in the concentration can be detected. When using electrical equipment, the particle release can continue until the equipment has cooled down completely.

It is recommended to repeat the measurement to ensure the reliability and reproducibility of the results. In case of multiple measurements, each result should be reported separately and the average value used for particle number concentration assessment.

8.4 Infiltration from outdoor or connecting rooms

Road traffic or neighbouring industrial plants can contribute to high UFP concentrations indoors. High emitters (e.g. cooking, heating system, printing facilities) in rooms sharing air exchange can also influence the UFP concentrations in the investigated room.

Building envelopes do not necessarily stop UFP infiltration, but the relationship is often complex, especially when mechanical ventilation is present. Measurements are required to quantify the influence of this important source.

When investigating outdoor input, simultaneous measurement of indoor and outdoor air is mandatory as outdoor UFPs are often unstable and directly affected by wind or other parameters.[21] When investigating input from another room and if the concentration in this room is stable enough, simultaneous measurements are recommended, but not compulsory.

Two equivalent CPCs shall be used to perform this simultaneous measurement (same mark and model). Prior parallel measurements are required in a way to ensure comparative results between instruments. Both CPCs are placed close to each other indoor in the investigated room during a minimum of 15 min. The average concentration of both systems is then determined. The systems should be checked if the difference is greater than the specified measurement uncertainty for the operating mode used.

It should also be noted that rapid changes in the outside air concentration or in the connecting rooms are not always simultaneously and to the same extent reflected in the investigated room, and thus the obtained results should be interpreted with care.

If a sampling line is used for outdoor measurement (i.e. for leaving the CPC indoors), particle losses in the line can result in important underestimation of the real concentration and should thus be taken into account when comparing results with indoor measurement. Losses should be roughly estimated by a comparative test and taken into account in the uncertainty budget. A prior measurement during 15 min in the investigating room with and without connecting the CPC is usually sufficient.

The sampling location for the outside air should be as close as possible to the measurement location indoors, or to the place where the outdoor air is sucked if this location can be easily identified (i.e. inlet of a mechanical ventilation system), so that the outside air infiltrating the interior under consideration can be investigated and evaluated. A distance of about 1 m to the building should be kept to avoid wall influences. When using sampling lines, ensure that the device specific characteristics are not changed. (e.g. pressure drop, separation, electrostatics). The sampling location in the connecting room should be representative of the mean concentration of the room but should remain the same point during the entire measuring period.

If the measuring rooms are not located on the ground floor, outdoor measurement should take place at the same altitude, if possible. This point is really important if the room investigated is located on the street side of the building, but is also recommended for rooms located towards the courtyard or the garden. In case of a larger office building, outdoor air measurements can be carried out on representative areas of the building façade.

The outside air measurement is directly influenced by the weather conditions. The weather conditions shall be recorded and the measurement campaign shall be postponed in case of rain.

8.5 Measurement in vehicle cabins

Traffic is a major source of UFP emissions. A vehicle cabin does not prevent exposure. Time spent in a car or public transport can represent a high-exposure period compared to other daily activities, especially in metropolitan areas.

The instruments should be fit for operation in a vehicle cabin. The CPC shall be firmly fixed to the vehicle. Special care should be taken to avoid any risk of damage to the car or injury to the occupants, even in case of shocks or accident. Care should be taken to avoid any risk of working fluid leakage (such as during a tight turn, a speed bump, etc.).

The placement of the inlet should be reported. Using a reduced operating flow rate can be necessary to reduce the pump size and noise and make the CPC more portable. The sampling line should be as short as possible and of conductive material to avoid losses. This point is important as losses in the line increase at lower flow rates.

Using a high sampling rate (i.e. 1 Hz) is recommended as a way to be able to follow more precisely potential quick variations in concentration during the journey.

The sampling duration depends on the measurement purpose. Usually, the duration should be long enough to cover several situations. In case of intermittent events which can significantly influence the results, these episodes should be studied separately during data assessment. Repeating the measurement several times is always good practice to ensure a correct value.

It is recommended to record the position of the vehicle via GPS to be able to link high episode measurements with a specific situation (i.e. traffic jam, red light). Writing down an event report or using a dash cam can also be useful.

8.6 Success of control and mitigation measures

In a way to highlight the efficiency of a reduction measure, specific campaigns are often organised. Two different scenarios are possible: the first one corresponds to some reduction measures which can be switched on or off easily (i.e. air conditioning system with HEPA filters); the second one corresponds to permanent infrastructure reduction measures (i.e. building of a wall, use of specific material, shifting in the localisation of a specific source, etc.).

If the mitigation measures can be easily switched off, quantification should be done with and without this mitigation measure in operation and the procedure followed is the same as the one applied in 8.2. An initial investigation shall be performed before executing permanent mitigation measures (i.e. fix infrastructure) and compared to the result obtained after their implementation. Both measurements should have been performed using the same protocol and according to 8.1.

Particular care is needed to keep as constant as possible every parameter and source (i.e. CPC performance, activities, presence of sources, outside condition) between the two measurements. In practice, this ideal situation can never be obtained and thus particular care should be used when interpreting the results.

9 Quality assurance and uncertainty evaluation

9.1 General

Clause 9 sets out the performance criteria for the CPC and the measurement setup (e.g. sample line, sampling flow rate and resulting sampling loses) which influence the result.

The measurement uncertainties are affected, not only by the counting instrument, but also by possible losses in the sampling system. Relevant factors affecting the measurement uncertainties are listed above in this document (e.g. see 7.3, 8.3, 8.4).

The uncertainty evaluation resulting from manufacturer's calibration or third-party calibration should be reported.

9.2 Instrument parameters

Proper functioning of the CPC components shall be verified by instrument indicators and status messages. These will in most cases be documented automatically along with the data in log files, generated by the instrument's software. The CPC sample flow rate is the most influential parameter for a particle number concentration measurement. The CPC's flow control system should be calibrated and traceable to the International System of Units (SI) following ISO 27891 recommendations.

Several CPC flow control systems consider standard flows rather than volumetric flows. A standard flow always refers to standard conditions of the flow sensor (T_{std}, P_{std}), which are not uniformly defined among sensor manufacturers and which can deviate considerably from actual meteorological conditions. The volumetric flow is the actual sampling flow passing through the CPC inlet at the actual meteorological conditions, T and P.

The manufacturer's manual should be consulted to check whether the sample flow indicated by the CPC is given as volumetric or standard flow. In the latter case, calculation of the actual sample flow at the sampling site and corrections to measured data using Formula (1) is mandatory. All sample flow conversion calculations which have been applied shall be documented in the report. Formula (1) shows the conversion between standard and volumetric flow rate.

$$Q_{\text{vol}} = Q_{\text{std}} \left(\frac{T_{\text{room}}}{T_{\text{std}}} \right) \left(\frac{P_{\text{std}}}{P_{\text{room}}} \right) \tag{1}$$

where

Q_{vol}	is the volumetric flow rate;
Q_{std}	is the standard flow rate;
T_{room}	is the temperature of the gas in the CPC inlet;
P_{room}	is the pressure of the gas in the CPC inlet;
T_{std}	is the standard temperature of the CPC (see manual);
P_{std}	is the standard pressure of the CPC (see manual).

9.3 CPC's settings check

The CPC settings, especially the sample flow rate, shall be checked and their recording during measurement ensured. An externally calibrated flowmeter should be applied before a measurement to verify, if the intended sample flow in the sampling line is established by the CPC.

If the CPC allows for a change of saturator or condenser temperatures by the user, these changes shall be documented.

9.4 Performance check, zero check or leak check

A performance test of the CPC should be done before each measurement and documented in a protocol. In case of a malfunction, the instrument cannot be used until the instrument's full operational capability has been checked and re-established. If feasible, the instrument's data record should be checked for error warnings after each measurement. It is advisable to have a record of the meteorological conditions during the measurements and to check the data for large temporal changes that can have an impact on the result. The following two performance checks are suggested.

a) Check that the CPC can detect particles by sampling room air. If the number concentration obtain is lower than 500 cm^{-3}, aerosols from other sources (e.g. ambient outdoor aerosol, smoking, candles) which provide sufficiently high number concentrations should also be used for this test.

b) Attach a high efficiency particulate air filter (HEPA) or ultra-low penetration air filter (ULPA; >99,99 % efficiency) to the CPC inlet (an additional filter in series can be necessary to achieve extremely low concentrations). Run the CPC for a minimum of 5 min and record the concentration values with a 1 s reading interval and a 1 s averaging time. After any leaks are eliminated, the measured arithmetic mean concentration shall be <0,1 cm^{-3}. Higher values indicate malfunctioning of the CPC.

If one of these checks is unsuccessful, the CPC is not ready for use and seeking advice from the manufacturer's service is recommended.

9.5 Uncertainty

The uncertainty of a measurement of the particle number concentration with a CPC-standalone instrument is influenced by the shape of the CPC's particle detection efficiency. The detection efficiency follows a sigmoidal curve that goes from zero to a maximum, called the plateau efficiency. The normalized plateau efficiency of a properly working CPC can reach 100 %. The particle diameter at 50 % of the normalized detection efficiency, D_{50}, is called "lower detection limit". In the same logic, D_{90} depicts the diameter for which the normalized efficiency reaches 90 %. These characteristic quantities are however dependent on the shape and chemistry of the particles; for example, metallic and organic particles with the same size are counted with different efficiencies. Most manufacturers provide efficiency curves or at least D_{50} and D_{90} values as a result of a calibration with a metallic or organic test aerosol (e.g. Ag, emery oil, polystyrol, PAO, soot). Real indoor air sample contain a mixture of particles with various shapes and compositions, resulting in an uncertainty on the detection efficiency of the smallest particles. Coarse particle fractions above the upper size limit of the CPC are also not counted.

The involved systematic contributions to the measurement uncertainty cannot be quantified without a good estimate of the minimum and maximum particle size in the aerosol to be measured. Special care shall therefore be taken if results from CPCs of different type or brand are compared, as arising differences are not always solely be due to the particle sources observed but also due to the different CPC performance characteristics.

Excluded from the above effects, the total particle number concentration measurement of a properly calibrated CPC is expected to have a relative uncertainty of about ±10 % in the size range of the plateau counting efficiency and operating in single count or correction mode. The D_{50} is expected to be reproducible within ±1 nm to the nominal value.

Most manufacturers specify concentration ranges for which these modes apply and quantify the respective accuracies as relative errors. For measurements in the photometric mode, the measurement uncertainty is much higher. It is worth noting that the upward and downward transitions between coincidence correction mode and photometric mode can follow a hysteresis loop rather than a sharp sudden change. Therefore, in the border area of both modes, the quantification of the relative accuracy needs a case-by-case assessment.

10 Evaluation and reporting of the results

Measurement results shall be expressed as (time dependent) particle number concentration $C_N(t)$ in $1/cm^3$ (or alternatively cm^{-3}). It has to be stated whether any correction to the instrument read out has been applied, for example, due to losses in the sampling line, effects of temperature, or pressure or humidity in the sample flow.

Temperature, pressure and humidity at the location of the measurement have to be recorded.

Data can be averaged over time, depending on the measurement purpose (see Clause 8). All data treatment, such as time averaging and correction should be documented comprehensively.

In order to derive a suitable measurement strategy, an inspection of the measurement scenario in accordance with ISO 16000-34 shall be carried out and documented. Clause 8 gives the minimal list of information which should be investigated. Further information is given in Annex D.

The type of CPC used for the measurement and its basic characteristics (mark and model, working fluid, D_{50} and saturator temperature) shall be reported.

Annex A
(informative)

Examples of particle number concentrations encountered during room user activities

A.1 General

This annex describes the measurement of particle number concentration for the purpose of assessing indoor air quality. In order to complement this description, this annex gives a non-exhaustive list of references allowing an empirical overview of the range of concentration which can be obtained indoors depending on expected activities or source location. Table A.1 identifies few situations which can significantly influence the final result of air quality.

Table A.1 — Factors influencing the indoor air quality in different situations

Indoor situation	Concentration depends in particular on
Dwellings	Number of persons present in the room and respective activity
Schools, day nurseries	
Offices	
Smoking	Number/quantity
Using a vacuum cleaner	Degree of pollution, filtration performance
Cooking/preparing hot water	Duration and intensity
Stove/fireplace	Fireplace/stove construction, heating material, chimney

A.2 Observed values of typical concentration ranges

The references for observed values of typical concentration ranges are:

- for dwellings, see References [22] and [23];
- for schools, see References [24] to [26];
- for offices, see Reference [27];
- for smoking, see References [28] to [30];
- for using a vacuum cleaner, see References [31] and [32];
- for cooking/preparing hot water, see References [33] to [35];
- for stove/fireplace, see References [36] to [38];
- for indoor aerosols, see References [39] to [41].

Annex B
(informative)

Determination of the particle number size distribution of indoor aerosol using a differential mobility aerosol spectrometer

B.1 General

The DMAS is a combination of a DEMC[42] with a CPC. It is also known as MPSS or as SMPS. This system allows the determination of the particle number size distribution in the size range of around 10 nm to about 800 nm.

ISO 15900[43] provides guidance for calibration of particle sizing and a methodology for quality control while CEN/TS 17434[24] specifies performance criteria and its use for atmospheric monitoring.

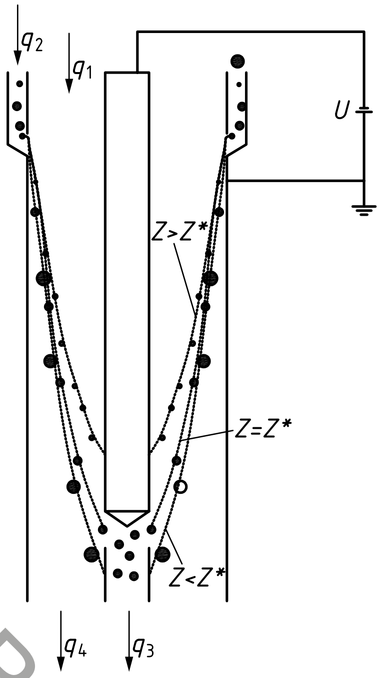
B.2 System configuration

The following components are part of a DMAS.

- Pre-conditioner: This typically includes reducing the sample humidity for example by using a diffusion dryer based on silica or a membrane dryer. Please note that heating is not recommended as this can change the aerosol by evaporating semi-volatile components above 40 °C. Pre-conditioning can also include removing large particles by using an impactor[45] or diluting the sample to reduce the concentration.
- Particle charge conditioner: Before size classification, the aerosol particles need to be brought to a bipolar charge equilibrium. This can be achieved by using radioactive sources such as ^{85}Kr, ^{63}Ni, ^{241}Am or ^{210}Po, as well as soft X-ray or electrical charge conditioners. These all continuously produce positive and negative ions that transfer their charges by collision with the aerosol particles.
- Differential electrical mobility classifier (DEMC): The DEMC is usually built in the shape of a cylindrical capacitor (see Figure B.1). The basic operating principle is electrical mobility discrimination by particle migration perpendicular to a laminar sheath flow. The migration is determined by an external electrical force and the counteracting particle drag forces in the laminar sheath flow. Measuring a particle size distribution is achieved by changing the voltage.
- System controller: The system controller monitors operating parameters, sets the voltages for the size distribution scan, controls the sheath air and reads the particle number data from the CPC. It further performs the data inversion and presents, stores or exports the resulting particle size distributions.
- Aerosol particle detector: For the purpose of this document, the particle detector will always be a CPC. The CPC is connected to the aerosol outlet of the DEMC and thus detects the classified aerosol particles only.

B.3 Principle of measurement

Figure B.1 shows how DEMC is classifying the aerosol particles by their size. The charged polydisperse aerosol particles are injected at a flow rate, q_2, through an annular slit by the outer electrode into the DEMC. They then merge with the particle-free sheath air flow, q_1, such that there is no turbulence. All flows have to be strictly laminar. By applying a voltage between the inner and outer electrodes, the charged aerosol particles move perpendicular to the air flow either to the inner or the outer electrode, depending on their net charge. A small fraction of the charged particles enters the thin circumferential slit near the bottom of the inner electrode, this is the classified fraction for a specific voltage setting. These particles, q_3, are then counted by the CPC. Uncharged particles follow the flow, q_4.



Key

q_1	flow rate without particles
q_2	flow rate with particles
q_3	fraction of charged particles
q_4	uncharged particles
U	voltage
Z	electrical mobility of a charged particle
Z^*	electrical mobility value which allows the classified fraction to pass

SOURCE Reproduced from ISO 15900.

Figure B.1 — Working principle of a coaxial cylindrical DEMC

The electrical mobility Z of a particle depends on its size and its electric charge. It is given by:

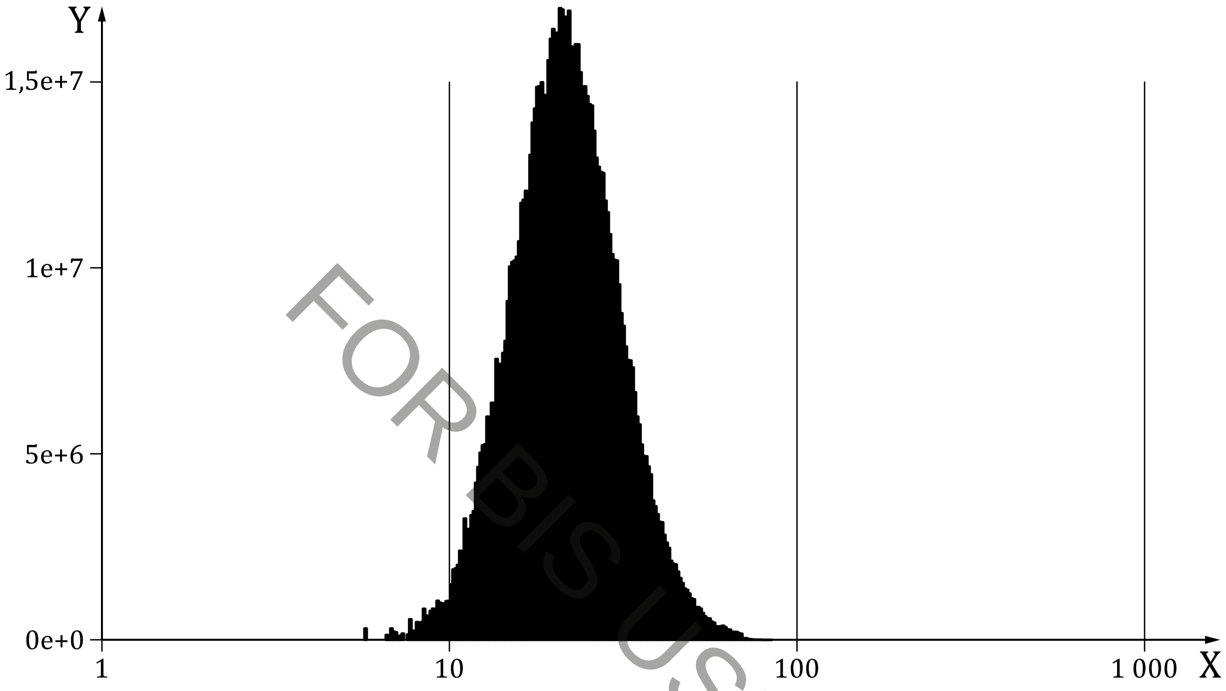
$$Z = \frac{n \cdot e \cdot C\left(D_p\right)}{3\pi \cdot \eta \cdot D_p}$$

where

Z	is the electrical mobility of a charged particle;
n	is the number of elementary charges carried by the particle;
e	is the elementary charge ($e = 1{,}602 * 10^{-19}$ C);
$C(D_\mathrm{p})$	is the Cunningham slip correction factor;
η	is the dynamic gas viscosity;
D_p	is the particle diameter.

Next, by changing the voltage, another particle size will exit the DEMC and be counted by the CPC. By stepwise increasing the voltage for example from a few volts to 10 kV a particle size range from 10 nm to 800 nm can be measured. Figure B.2 shows an example of a particle size distribution.

Since particles can carry more than one elementary charge, particles of different sizes can have the same electrical mobility. This is accounted for in the system controller by applying a data inversion process that applies size-dependent charging probabilities. Typically, the system controller also corrects for particle losses caused by diffusion.



Key

X diameter (nm)

Y number of particles (dN/dlogDp)

Figure B.2 — Particle size distribution of generated NaCl aerosol measured with a DMAS

Annex C
(informative)

Water-CPCs

C.1 General

"Water-CPCs" are condensation particle counters that use water as the working fluid instead of alcohol as described in Clause 7. Water-CPCs can be used in inhabited places and have seen an increased use in indoor settings. Water overcomes the disadvantages of butanol, such as olfactory nuisance, toxicity, flammability and affecting VOC measurements.

While earlier water-CPCs already showed matching results in ambient aerosol measurements, they also showed material dependent counting efficiencies for nonpolar particle materials.[17] Latest development have led to water-CPCs that provide similar counting efficiency measurement results compared to alcohol CPCs even for nonpolar materials such as, for example, Ag[46] (see Figure C.1).

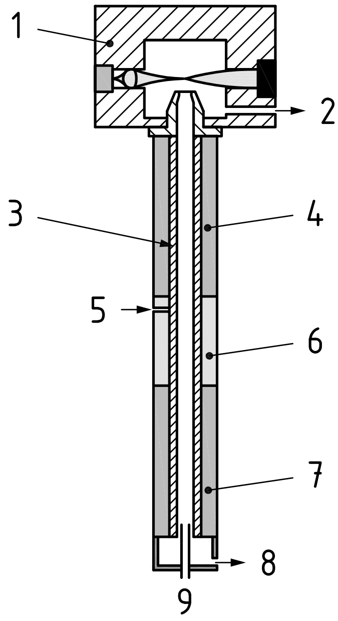
C.2 Principle of measurement

CPCs detect very small particles by vaporizing water, bringing the water vapour in contact with the aerosol and creating a supersaturation. This supersaturation leads to the water vapour condensing onto the aerosol particles and growing into droplets. These droplets are then detected using scattered light. However, since the diffusion of water vapour is faster than the heat transport, supersaturation in a water-CPC cannot be induced by wall cooling. Therefore, the aerosol is pre-conditioned and then introduced into a heated section with moist walls.

Figure C.1 shows the schematic of a water-CPC. The condensing section consists of a cylindrical section divided into three temperature sections. The inside of the cylinder contains a replaceable porous channel, which has the task of separating the water-vapour and liquid phases. The three temperature sections are called conditioner, initiator and moderator. The temperature difference between conditioner and initiator determine the lower detection limit of the particle size.

In this section with likewise humid walls, when the aerosol enters the CPC and first passes through the cooled conditioner, the aerosol is brought to 100 % relative humidity in order to better define the state of the aerosol and improve the counting efficiency. In the subsequent saturator/initiator, the water is injected. Water vapour diffuses from the warm walls into the cooler aerosol stream and supersaturates. This causes the water vapour to condense onto the particles. Droplet growth continues in the cooled moderator. In addition, excess water vapour is condensed and absorbed on the walls of the porous cylinder.

The aerosol particles, which have grown to droplets, are then counted in the optics via light scattering. The optics also detects the amplitude of the pulses. The percentage of particles with sufficient pulse height is evaluated as a measure of the quality of the measurement and used as a status diagnostic.



Key

1	optical particle detector
2	vacuum pump
3	porous media
4	moderator
5	water fill
6	initiator
7	conditioner
8	excess water + excess air
9	aerosol inlet

Figure C.1 — Schematic of the water-CPC

Annex D
(informative)

Checklist to collect information useful for interpreting indoor measurement of particle number concentration

No.	Information	Note
1	**Details of the measurement**	
	Job or sample number	
	Name of the lab/operator	
	Start of measurement/sampling (date/time)	
	End of measurement/sampling (date/time)	
2	**Sampling equipment**	
	Equipment type/manufacturer	
	Working fluid of the CPCs (including origin and lot number)	
	D_{50} of the CPCs	
	Saturator temperature	
	Date of last (re-)calibration of the measuring device	
	Additional monitors type/manufacturer used for outdoor assessment	
	Date of last (re-)calibration of these additional monitors	
3	**Reason for the measurement (Clause 8)**	
	Compliance with specified assessment values (average room concentration)	
	Source investigation/identification	
	Infiltration from outdoor or connecting rooms	
	Measurement in vehicle cabins	
	Success control of mitigation measures	
	Other	
4	**Location of the premise**	
	Complete address of the premise	
	Complete contact information	
	Building type/use (residential, school, preschool, office, sport hall, hospital, business premise, retail premise, workshop, restaurant, airport ...)	
	Other building – which?	
5	**Construction/maintenance/renovation**	
	Date of construction of the building	
	Date of last remedial maintenances/renovations	
	Works carried out	
6	**Building's environment (<1 km)**	
	Rural/urban (centre) /urban (suburb)	
	Low traffic/heavy traffic	
	Distance to nearest street in metres	
	Commercial/industrial zone (type of commerce/industry)	

	Bulk storage site/waste tip/composting facility	
	Exhaust air or exhaust fume outlets on neighbouring buildings (<50 m)	
7	**Position of room(s) in the building, with a sketch (when possible provide a plan)**	
	Floor	
	Window direction(s) (by compass points)	
	Room without windows	
	Windows to street	
	Windows to inner courtyard/garden	
	Doors to street	
	Doors to inner courtyard/garden	
	Description of adjacent room	
8	**Room’s use**	
	Dwelling/private room	
	Kitchen	
	Cooker powered by...	
	Living room	
	Bedroom	
	Children’s room	
	Office	
	Classroom	
	Other room – which?	
9	**Set-up of the sampling/measuring devices in the room (prepare a sketch)**	
	Closest distance to a wall	
	Position of the ambient air measurement point with a sketch	
	Height above floor	
10	**Heating system**	
	Central heating	
	Under-floor heating	
	Space heating	
	Cookers	
	Type of fuel (coal, oil, gas, wood)	
	Open fireplace (position, with a sketch)	
11	**Room users and their activities — Dwelling**	
	Usual room occupancy: ... persons	
	... persons were present in the room during sampling	
	Tobacco smoke	
	Non-smoker dwelling/smoker dwelling	
	Non-smoker room/smoker room – mean daily quantity of tobacco consumed in the room: ... cigarettes /cigars/pipes (time interval before the measurement in hours)	
	Cooking (time interval before the measurement in hours)	
	Burning candles (time interval before the measurement in hours)	
	Vacuum cleaning (time interval before the measurement in hours)	
	Other activities (time interval before the measurement in hours)	

	Operating electric and electronic appliances (television set(s), computer(s), printer(s) – time interval before the measurement in hours)	
	No activity	
12	**Room users and their activities — office**	
	Usual room occupancy: ... persons	
	... persons were present in the room during sampling	
	Operating electric and electronic appliances [copiers, computer(s), printer(s) – time interval before the measurement in hours]	
13	**Room users and their activities — School/preschool**	
	Usual room occupancy: ... persons	
	... persons were present in the room during sampling	
	Normal physical activity during sampling/measurement	
	Above-normal physical activity during sampling/measurement	
	Operating electric and electronic appliances [television set(s), film projector(s), computer(s), printer(s) – time interval before the measurement in hours]	
14	**Room users and their activities — Vehicle cabin**	
	Number of passengers and their position	
	Widows open/close	
	Air conditioning (on/off)	
	Ventilation (on/off/recycling)	
	Specific activities (smoking, using spray)	
	Journey during measurement (provide a map)	
15	**Sealing level of the window and the building envelope (estimated by the sampling/measuring technician)**	
	Very high (e.g. passive house standard)	
	High (e.g. insulated glazing or thermal insulation standard)	
	Moderate or low (e.g. single glazing or not sealed built-in insulating windows)	
16	**State of ventilation before the measurement**	
	Room intensively ventilated (duration in minutes)	
	Windows and doors kept closed (duration in hours)	
19	**Room with air conditioning**	
	Unit in operation for the past ... hours	
	Unit not in operation for the past ... hours	
	Details of the air-conditioning unit	
	Position of the ambient air intake	
	Air quantity or air exchange rate in the room	
	Operation with humidification	
	Operation without humidification	
	The unit is operated with ... % air circulation	
	Last servicing and hygiene inspection of the unit	
20	**Room's climatic and ventilation conditions during sampling/measurement**	
	Room with window ventilation	
	Presence of natural ventilation (opening, windows opening)	
	Windows open/close	

	Doors open/close to other room	
	Doors open/close to outside	
	The room users' usual ventilation habits	
	Mechanical ventilation	
	Unit in operation	
	Unit not in operation	
21	**Cleaning and hygiene status**	
	Visible dust deposits on the floor and furnishings	
	Black discolouration on the wall and ceiling surfaces (the black dwelling phenomenon)	
22	**Cleaning procedures**	
	Cleaning intervals per week	
	Moisture	
	With vacuum cleaner	
	Last cleaning before the measurement/sampling	
23	**Additional recorded parameters**	
	Room temperature	
	Room relative humidity	
	Atmospheric pressure in the room	
	CO_2 content of the room air (only for measurements in occupied rooms to have an indicator of the ventilation rate)	
	Temperature of ambient air (outdoor assessment)	
	Relative humidity of ambient air (outdoor assessment)	
	Wind speed/wind direction (outdoor assessment)	
25	**Reasons for deviating from the measurement protocol's specifications**	

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