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Zunanji zrak - Določevanje številčne koncentracije delcev atmosferskih aerosolov

Ambient air - Determination of the particle number concentration of atmospheric aerosol

Außenluft - Bestimmung der Partikelanzahlkonzentration des atmosphärischen Aerosols

Air ambient Détermination de la concentration en nombre de particules de l'aérosol atmosphérique

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Contents	Page
European foreword	4
Introduction	5
1 Scope.....	6
2 Normative references.....	6
3 Terms and definitions.....	6
3.1 Aerosol properties.....	6
3.2 Instrument performance	7
3.3 Flow rates	7
4 Atmospheric aerosol.....	8
5 Description of the method	8
5.1 Sampling and conditioning.....	8
5.1.1 Sampling.....	8
5.1.2 Drying.....	10
5.1.3 Dilution.....	10
5.2 Determination of the number concentration with a CPC	10
5.2.1 Condensation growth	10
5.2.2 Optical detection	12
6 CPC performance criteria and test procedures.....	13
6.1 General.....	13
6.2 General requirements for the CPC.....	13
6.3 Test conditions	14
6.4 Performance characteristics and criteria.....	14
6.5 Test procedures.....	15
6.5.1 Calibrated flow rate	15
6.5.2 Number concentration measurement range	15
6.5.3 Number concentration detection limit	15
6.5.4 Calibration factor.....	15
6.5.5 Instrument-specific assessment of linearity and slope of response	16
6.5.6 Detection efficiency curve at low particle size.....	16
6.5.7 Upper particle size detection limit.....	17
6.5.8 Zero count rate	17
6.5.9 Response time.....	17
6.5.10 Dependence of flow rate on supply voltage.....	17
6.5.11 Accuracy of temperature and pressure sensor calibration.....	17
6.5.12 Effect of failure of mains voltage	17
7 Performance criteria and test procedures for the sampling and conditioning system	18
7.1 General requirements.....	18
7.2 Performance characteristics and criteria.....	18
7.3 Diffusion losses.....	18
7.4 Relative humidity.....	19
7.5 Dilution.....	19
7.5.1 Dilution factor	19

7.5.2	General criteria for dilution systems	19
7.6	Primary sampling flow	20
8	Measurement procedure	20
8.1	Measurement planning.....	20
8.2	Environmental operating conditions	20
8.3	Initial installation.....	20
8.4	Initial checks on site.....	21
8.5	Data processing and reporting	21
9	Quality control, quality assurance and measurement uncertainty.....	21
9.1	General	21
9.2	Frequency of calibrations, checks and maintenance.....	22
9.2.1	General	22
9.2.2	Maintenance of CPC.....	22
9.2.3	Calibration of linearity	22
9.2.4	CPC zero check.....	23
9.2.5	Number concentration check.....	23
9.2.6	Check of the actual flow rate.....	23
9.2.7	Temperature and pressure sensor calibration	23
9.2.8	CPC internal diagnostics.....	23
9.2.9	Sample system maintenance	23
9.2.10	Relative humidity sensor.....	24
9.2.11	Dilution factor (where applicable).....	24
9.2.12	Leak check.....	24
9.3	Measurement uncertainty	24
9.3.1	General	24
9.3.2	CPC plateau detection efficiency	25
9.3.3	CPC detection efficiency drift	25
9.3.4	Flow determination	25
9.3.5	Correction to standard temperature and pressure.....	25
9.3.6	Diffusion losses in the sampling system.....	25
9.3.7	Dilution factor (where applicable).....	26
9.3.8	Calculation of overall uncertainty	26
	Annex A (normative) Determination of diffusion losses in sampling lines.....	27
	Annex B (informative) Example of the calculation of diffusion losses in a sampling system	29
	Annex C (informative) Data reporting	32
	Annex D (informative) Uncertainty calculation (example).....	34
	Annex E (informative) Atmospheric aerosols	36
	Annex F (informative) Dilution systems.....	39
	Annex G (informative) Laminar flow.....	46
	Annex H (informative) Coincidence correction	47
	Annex I (informative) Results of an experimental comparison of different CPCs	49
	Bibliography	54

prEN 16976:2023 (E)**European foreword**

This document (prEN 16976:2023) has been prepared by Technical Committee CEN/TC 264 “Air quality”, the secretariat of which is held by DIN.

This document is currently submitted to the CEN Enquiry.

This document will supersede CEN/TS 16976:2016.

In comparison with the previous edition, the following technical modifications have been made:

- 1: The lower limit of the measured particle size range is set to be 10 nm and thus identical to MPSS (Mobility Particle Size Spectrometers) measurements (see CEN/TS 17434). In air quality monitoring networks where MPSS will be used for determining the particle size distribution a CPC may be used for QA purposes for the MPSS data.
- 3: The parameter “calibration factor” was introduced and defined. The terms and definitions for the various flow rates were revised and rearranged.
- 5.1.2: Aerosol diffusion dryer based on silica is excluded, because diffusion losses are too high with this type of dryer.
- 6.2: Coincidence correction shall be applied. No other correction factors shall be applied unless a correction for the analysed flow rate is necessary.
- 6.3: All tests are carried out only at one temperature (between 20 °C and 30 °C).
- 6.4: Table 1: Criteria for several performance characteristics were changed, the performance characteristic “calibration factor” was included.
- 6.5: Some of the test procedures have been revised, a test procedure for the calibration factor was added.
- 7.2: Two dilution factors are necessary: one for reducing the concentration, an additional one for drying.
- 7.5: The method of using tracer gas for the determination of the dilution factor of a dilution system has been removed. General criteria for dilution systems were added.
- 9.2: The test “Determination of low size cut-off” was removed, the “Number concentration check” was substantially revised.
- Annex E: The ambient particle number concentration values were updated.
- Annex F: An example of the design of a dilution system and an example for the calculation of the uncertainty of the dilution factor have been added.
- Annex H: The new Annex “Coincidence correction” was added.
- Annex I: The new Annex “Results of an experimental comparison of different CPCs” was added.

Introduction

There is a growing awareness of the significance of aerosol particles with diameters of $D < 1 \mu\text{m}$ for human health as well as for their climatic impact. To assess air quality, it appears necessary to supplement gravimetrically determined mass concentrations such as PM_{2,5} and PM₁₀ with a measurement of the particle number concentration. Since ultrafine particles with diameters of $D < 0,1 \mu\text{m}$ make an almost insignificant contribution to the mass of atmospheric aerosol particles, they can best be detected with counting measuring methods of sufficient sensitivity.

As particle measurement instrumentation allows determining either the particle number concentration or the particle number size distribution two documents are established:

- one dealing with the determination of the single parameter number concentration (a measure of “total” number concentration, this document)
- one dealing with the determination of number concentration within a limited number of size ranges (CEN/TS 17434).

Clauses 5 and 6 contain general information about the method and the expected properties of the aerosol to be measured.

Clause 7 sets out the performance criteria for CPCs. Specifically, these are the relevant performance characteristics of CPC instruments (without any sampling system), the respective criteria that shall be met, and a description of how the tests shall be carried out. In general, these tests are expected to be carried out by test houses or CPC manufacturers rather than users and could form the basis for type testing of CPCs in future.

Clause 8 sets out the performance criteria and test procedures for the sampling and conditioning system (e.g. dilution). These may be applied by manufacturers of sampling systems, test houses or users (network operators).

Clause 9 sets out requirements for the installation, initial checks and calibrations, and operation of a CPC and sampling system at a monitoring site, including routine maintenance, data processing (including use of QA/QC data) and reporting. In general, these will be the responsibility of users (network operators), though calibrations requiring test aerosols shall only be carried out by suitably qualified laboratories.

Clause 10 sets out Quality Assurance and Quality Control procedures, i.e. the ongoing checks and calibrations that are required on the CPC and sampling system during operation at a monitoring site. It is expected that these will be the responsibility of users (network operators), though calibrations requiring test aerosols shall only be carried out by suitably qualified laboratories. The main sources of measurement uncertainty are described.

1 Scope

This document describes a standard method for determining the particle number concentration in ambient air in a range up to about 10^7 cm^{-3} for averaging times equal to or larger than 1 min. The standard method is based on a Condensation Particle Counter (CPC) operated in the counting mode and an appropriate dilution system for concentrations exceeding the counting mode range. It also defines the performance characteristics and the minimum requirements of the instruments to be used. The lower and upper sizes considered within this document are 10 nm and a few micrometres, respectively. This document describes sampling, operation, data processing and QA/QC procedures including calibration parameters.

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 27891:2015, *Aerosol particle number concentration — Calibration of 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:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1 Aerosol properties

3.1.1

particle

small piece of matter with 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, modified]

3.1.2

aerosol

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

3.1.3

number size distribution

frequency distribution of the particle number concentration represented as a function of particle size

3.1.4

particle number concentration

number of particles related to the unit volume of the carrier gas

Note 1 to entry: For the exact particle number concentration indication, information on the gaseous condition (temperature and pressure) or the reference to a standard volume indication is necessary.

[SOURCE: ISO 27891:2015]

3.2 Instrument performance

3.2.1

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 size of sensing zone.

3.2.2

detection efficiency

ratio of the particle number concentration determined by the measuring instrument to the reference particle number concentration of the aerosol at the instrument's inlet

Note 1 to entry: The detection efficiency depends on particle size and may depend on particle number concentration.

3.2.3

calibration factor

model- or instrument-specific ratio between the reference FCAE reading and the CPC count rate, both converted to particle number concentration

3.3 Flow rates

3.3.1

actual flow rate

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

3.3.2

nominal flow rate

volumetric flow rate which a specific CPC model is designed for and which is indicated on the instrument specification sheet by the manufacturer

Note 1 to entry: The actual flow rate of individual instruments may differ from the nominal flow due to manufacturing tolerances.

3.3.3

calibrated flow rate

actual flow rate at the time of calibration documented on a calibration certificate

3.3.4

analysed flow rate

volumetric flow rate which is used for instrument internal calculation of the particle number concentration

4 Atmospheric aerosol

Atmospheric aerosols are strongly dependent on their local and regional sources. Especially, the size distribution in number and mass, as well as the size-resolved chemical composition are highly variable. Aerosol particles are either emitted directly (primary aerosols) or formed by nucleation and condensation from pre-cursor gases (secondary aerosol). Combustion processes lead to both primary and secondary aerosols.

Mass-wise, the global direct emission of aerosol particles is dominated by sea salt, biological material as well as by desert and volcanic dust. These particles are generally larger than 1 μm . Anthropogenic emissions in this size range play a minor role on a global scale. Submicrometer natural aerosols consist mainly of marine sulfate, biogenic organics, and wildfire carbonaceous particles. Submicrometer anthropogenic aerosols are complex mixtures of primary and secondary particles, consisting mainly of sulfate, nitrate, organics, and elemental carbon.

Particle number concentrations of atmospheric aerosols cover several orders of magnitude. While remote marine or free tropospheric aerosols have number concentrations as low as tens or a few hundred per cubic centimetre, anthropogenically influenced aerosols can contain a few thousand up to one million particles per cubic centimetre. The number concentration of the anthropogenic aerosol over land, especially in urban areas is dominated by particles in the size range smaller than 0,1 μm . Major sources for high number concentrations in this size range are regional new particle formation and local combustion processes. Average background concentrations in an urban area are several thousands of particles per cubic centimetre.

For details see Annex E.

5 Description of the method

5.1 Sampling and conditioning

5.1.1 Sampling

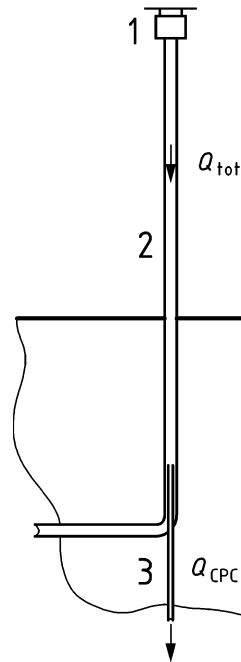
The measurement of atmospheric aerosols will always necessitate sampling and the transport of the sample to the measuring instrument. Moreover, in certain cases the sample has to be processed in terms of temperature, relative humidity, and particle concentration in order to adapt the aerosol to the measuring instrument's permissible operating conditions.

The information given on this issue in this document refers to stationary ambient monitoring sites. For mobile applications (e.g. measurements from aircraft), additional considerations have to be taken into account.

The measuring instruments shall be accommodated in a protected environment in controlled conditions (temperature 20 °C to 30 °C).

The sampling location depends on the measurement task. If the undisturbed atmospheric aerosol is to be measured, air intake should take place 5 m to 10 m above the ground level. Buildings, vegetation, or the topography of the terrain may make an even higher sampling point necessary. By contrast, the measurement of aerosols close to the source (e.g. traffic) calls for much lower sampling points (1,5 m to 4 m above the ground, see Directive 2008/50/EC [1]).

The design of the intake port should permit representative sampling regardless of the direction of the wind for a broad range of wind velocities. However, this is not a critical condition for the small particles measured by the CPC. Steps shall be taken to avoid soiling of the sampling lines by particles larger than 10 μm . For this purpose, a PM10 or PM2,5 inlet can be used (see Figure 1). An inlet that removes particles in the measurement range of the CPC (e.g. a commercial PM1 inlet) shall be avoided.



Key

- 1 PM sampling inlet
- 2 Primary sampling tube
- 3 Secondary sampling tube

Figure 1 — Basic design of the aerosol intake port

The sample should ideally be fed via a vertical primary sampling tube without bends to the measuring instruments. Since gas measuring methods have fundamentally different requirements regarding sampling, gas and aerosol sampling should be conducted independently of each other.

To reduce diffusion loss, it is necessary to intake aerosol with the aid of a pump at a primary flow rate (Q_{tot}) much higher than the secondary flow rate (Q_{CPC}). The CPC should sample isoaxially in the central area from this volumetric flow via a secondary sampling tube that is as short as possible. Flow in the primary sampling tube should be laminar in order to prevent additional particle loss due to turbulence. Ideally, a Reynolds number of $Re \leq 2000$ shall be aimed for (see 7.2).

The diffusion losses in the sampling system for smallest relevant particle size of 10 nm shall be less than 25 % (see 7.2).

The intake port and lines shall be made of a conductive, corrosion-resistant material with a low surface roughness (e.g. stainless steel) and electrically earthed. This prevents chemical changes to the aerosol and particle losses due to electrostatic effects. Flexible tubing of electrically conductive material may also be used for small connections or short distances. The length of flexible tubing should be below 50 cm.

The inlet and the flow-splitter of the sampling system shall be checked regularly to detect obstructions, e.g. by insects, and cleaned, if necessary.

prEN 16976:2023 (E)**5.1.2 Drying**

Aerosols with a high relative humidity (mist in extreme cases) should be dried, as the size of particles of hygroscopic materials is strongly influenced by humidity. The requirement is to keep the relative humidity of the primary flow at the CPC inlet lower than 40 % (see 7.2). The relative humidity at the inlet of the CPC shall be monitored.

With respect to the temperature conditions three cases are to be distinguished:

- In case the room temperature is higher than 22 °C no aerosol dryer is needed if the ambient dew point temperature never exceeds 10 °C.
- If the dew point temperature is between 10 °C and the room temperature, the secondary flow shall be dried.
- In case that the dew point temperature is above the room temperature, the primary flow shall be dried before entering the room. Additional drying of the secondary flow may be necessary.

There are two recommended methods to dry the aerosol:

- Membrane dryer; preferably used to dry the secondary sampling flow.
- Dilution with dry particle-free air (see 5.1.3); preferably used to dry the primary sampling flow. In this case the exact dilution ratio shall be known in order to calculate the correct concentrations.

5.1.3 Dilution

Dilution is applied either to reduce the number concentration of the ambient aerosol to the limits of the CPC's measuring range or to reduce the humidity of the ambient aerosol. In both cases the dilution step may introduce a high uncertainty which shall be estimated and specified in the report. Where dilution is not required this step should be avoided. The minimum requirement with respect to accuracy of the dilution factor for both cases is given in 7.2.

Preferably the CPC selected to measure at any particular site will have a concentration range in counting mode that covers the expected concentrations. When this is not possible the sample shall be diluted with particle-free air. In this case the secondary sampling flow is diluted. Operation principles of suitable dilution systems for this purpose are presented in Annex F.

If dilution is applied to dry the aerosol, then the dilution system has to be part of the primary sampling line outside of the air-conditioned environment to avoid water condensation in that part of the sampling system. A dilution system specially designed for that purpose is presented in Annex F.4. Its operating parameters are discussed in detail.

5.2 Determination of the number concentration with a CPC**5.2.1 Condensation growth**

In a CPC, particles are enlarged by condensation growth and then subjected to optical detection by scattered light.

To incite the condensation growth of particles of a given diameter, a certain minimum saturation ratio with respect to a condensable vapour must be present in accordance with the Kelvin Formula (1):

$$S = \exp\left(\frac{4 \cdot \sigma \cdot M}{\rho \cdot R \cdot T \cdot d}\right) \quad (1)$$

Where

- S is the saturation ratio (ratio of current vapour pressure to saturation vapour pressure);
- σ is the surface tension of the vapour substance;
- M is the molar mass of the vapour substance (relative molecular mass);
- ρ is the density of the vapour substance in its condensed state;
- R is the general gas constant;
- T is the absolute temperature;
- d is the Kelvin equivalent diameter.

Particle shape, surface structure and affinity of the particle material to the vapour phase are important factors influencing the Kelvin equivalent diameter.

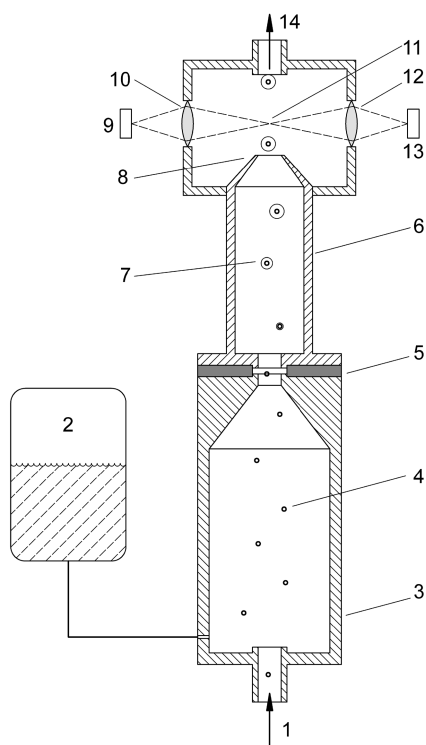
NOTE The Kelvin equivalent diameter (with respect to the vapour substance) of an aerosol particle is defined as the diameter of a pure vapour substance drop that would start to grow at the same supersaturation as the particle in question.

Figure 2 shows the principle of a continuous flow CPC. The aerosol enters a heated saturator (3) in which it is saturated with the vapour substance at a constant temperature. Typical vapour substances used in CPCs are alcohols, e.g. n-butanol. It then flows into a cooled condenser (6) where the vapour condenses on the particles forming spherical droplets that consist mainly of the vapour substance and have a diameter of typically a few micrometres. These droplets can be easily detected and counted optically.

The temperatures of the saturator and the condenser are important operating parameters that influence the smallest detectable particle size.

[oSIST prEN 16976:2023](https://standards.iteh.ai/catalog/standards/sist/32d86f69-e958-4649-ac53-7a5c7a6c85d9/osist-pren-16976-2023)

<https://standards.iteh.ai/catalog/standards/sist/32d86f69-e958-4649-ac53-7a5c7a6c85d9/osist-pren-16976-2023>

**Key**

1	Aerosol inlet	8	Nozzle
2	Vapour substance reservoir	9	Light source
3	Heated saturator	10	Illumination optics
4	Nanoparticle (not true to scale)	11	Measuring volume
5	Thermoelectric cooling and heating device	12	Receiving optics
6	Condenser	13	Photodetector
7	Droplet (not true to scale)	14	Aerosol outlet

Figure 2 — Principle of a continuous flow CPC (cf. ISO 27891:2015)

5.2.2 Optical detection

The droplet aerosol produced by the condensation process is transported via a nozzle (8) through the measuring volume of the instrument, where the droplets are illuminated by a light beam. The light scattered by the droplets is collected by a receiving optics (12) under a defined solid angle (receiver aperture) and guided onto a photodetector (13) (e.g. photodiode).

The measurement volume in most instruments is defined by the intersection of the aerosol stream and the light beam (full flow instrument). In order to implement a very small measurement volume some instruments do not count the droplets in the total cross-section of the aerosol flow. They instead confine a smaller measurement volume within the aerosol stream using a special optical arrangement with apertures in both the illumination optics and the receiving optics. The analysed flow rate for this type of instrument is smaller than the actual flow rate at its inlet because the droplets are only counted in a fraction of the actual flow. The analysed flow rate in this case shall be determined from the dimensions of the measurement volume and the flow velocity of the aerosol stream inside the measuring volume.

If the particle number concentration is low enough, the droplets cross the light beam one after the other, thus producing single electrical pulses at the detector output. From the count rate of these pulses and the analysed flow rate and the sampling time the total number concentration of the droplets can be

determined. If there are no transport losses of droplets, this number concentration 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.

For higher particle number concentrations more than one particle may be present in the measuring volume at the same time (coincidence). This results in the coincidence error, which leads to a measured value lower than the actual concentration. The coincidence error can be described statistically and corrected for within certain limits (see Annex H).

For even higher concentrations the detector cannot distinguish single pulses but measures the light scattered by the whole population of particles in the sensing volume as an analogue signal (photometric mode). 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 which can be determined by calibration. On the other hand, very high particle number concentrations lead 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 for particle size.

The use of the photometric mode is not allowed in the standard method.

6 CPC performance criteria and test procedures

6.1 General

This clause sets out the performance criteria for the CPC. In general, the tests described in 6.3 are expected to be carried out by test houses or CPC manufacturers to validate an instrument design, and could form the basis for type approval of CPCs in future.

6.2 General requirements for the CPC

- 1) The performance criteria all refer to the counting mode of the CPC.
- 2) Coincidence correction and the calibration factor shall be applied.
- 3) The CPC shall have no internal flow splitting, which is not accessible to an external flow rate check, or internal dilution to avoid unnecessary sources of measurement uncertainty.
- 4) The working fluid shall be n-butanol.

NOTE: Adequate data from long-term studies in ambient air for other working fluids are currently not available.

- 5) The instrument shall produce concentration data averaged over a data reporting interval of 1 min.
- 6) The instrument's internal clock shall be externally synchronizable.
- 7) 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
 - Analysed flow rate
 - Raw concentration (count rate divided by the analysed flow rate), in cm^{-3}
 - Concentration with internal coincidence correction (based on the analysed flow rate), in cm^{-3}

prEN 16976:2023 (E)

- Saturator temperature, in K
- Condenser temperature, in K
- Temperature and absolute pressure at the point of flow rate measurement
- Warning and error flags:
 - Signal quality out of tolerance
 - Concentration exceeding maximum single count range
 - Flow problems
 - Saturator or condenser temperature out of range
 - Butanol liquid level too low
 - Light source malfunction

6.3 Test conditions

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.

During the laboratory tests for each individual performance characteristic, the temperature of the air surrounding the instrument shall be between 20 °C and 30 °C.

6.4 Performance characteristics and criteria

Table 1 lists the performance criteria of the CPC which shall be met in the performance tests specified in 6.5.

Table 1 — CPC performance criteria

	Performance characteristic	Criteria	Clause
1	Calibrated flow rate	$\leq \pm 10\%$ difference to the nominal flow rate	6.5.1
2	Number concentration measurement range Lower limit Upper limit Dynamic range	$\leq 100 \text{ cm}^{-3}$ (based on at least 1500 particle counts) $\geq 10\,000 \text{ cm}^{-3}$ (including coincidence correction) at least 3 orders of magnitude	6.5.2
3	Number concentration detection limit	< lower limit of number concentration measurement range	6.5.3
4	Calibration factor	$1,0 < k < 1,1$	6.5.4
5	Concentration response Slope (instrument-specific) Linearity	$1,00 \pm 0,05$ (after calibration factor has been applied) all residuals < 4 % of the measured value	6.5.5
6	Detection efficiency at low particle size	$D_{50} = 10 \text{ nm} \pm 1,0 \text{ nm}$	6.5.6

	Performance characteristic	Criteria	Clause
		$D_{90} < 20 \text{ nm}$	
7	Detection efficiency (at intermediate particle sizes)	$> 95 \%$ at $(40 \pm 10) \text{ nm}$	6.5.5
8	Upper particle size detection limit	$> 90 \%$ detection efficiency at $1000 \text{ nm} \pm 100 \text{ nm}$	6.5.7
9	Zero count rate	$< 1 \text{ min}^{-1}$	6.5.8
10	Response time	$t_{\text{rise}} < 5 \text{ s}$ $t_{\text{fall}} < 5 \text{ s}$ $\left \frac{t_{\text{rise}} - t_{\text{fall}}}{t_{\text{rise}}} \right < 10 \%$ or $< 0,5 \text{ s}$	6.5.9
11	Dependence of flow rate on supply voltage	$\leq 5 \%$	6.5.10
12	Accuracy of temperature and pressure sensor calibration	$T \leq 3 \text{ K}$ $P \leq 1 \text{ kPa}$	6.5.11
13	Effect of failure of mains voltage	Instrument parameters shall be secured against loss. On return of mains voltage, the instrument shall automatically resume functioning.	6.5.12

6.5 Test procedures

6.5.1 Calibrated flow rate

The calibrated flow rate shall be measured using a calibrated reference flow meter at atmospheric pressure.

The reference flow meter shall measure with an accuracy of $\leq 2 \%$ at the controlled flow rate. At least 10 consecutive measurements shall be taken. The mean of the measurement results shall be compared with the nominal flow rate and the relative difference shall meet the criterion in Table 1.

6.5.2 Number concentration measurement range

The instrument shall demonstrably cover the range given in Table 1 within its counting mode (with or without coincidence correction).

6.5.3 Number concentration detection limit

The detection limit for the number concentration is the value that can be distinguished with a statistical certainty of 95 % from the concentration indicated on the basis of the instrument's zero count rate. The zero count rate states the number of indicated count events per unit of time that are not caused by particles. The detection limit shall be lower than the lower limit of the number concentration measurement range given in Table 1.

6.5.4 Calibration factor

Comparing the particle number concentration determined by a CPC with the reference number concentration determined from the current of a calibrated Faraday Cup Aerosol Electrometer (FCAE) (corrected for multiply charged particles) can give CPC particle number concentrations that are slightly too low (5 % to 10 %). This shall be corrected for by applying a model- or instrument-specific calibration factor to the particle number concentrations determined by the CPC. A model-specific calibration factor,