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Indoor air —

Part 34: Strategies for the measurement of airborne particles

Air intérieur —

Partie 34: Stratégie pour la mesure des particules en suspension

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

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

Airborne particulate matter (colloquially known as “fine dust”) plays a role not only outdoors, but is also significant in terms of hygiene, especially indoors. People in industrialized countries spend most of the day indoors. Particles are either transported into indoor air from outdoor environments or the particles directly result from indoor sources, such as smoking, housework and do-it-yourself (DIY), burning candles, residential wood burning, cooking and using printers. The concentration, composition and size distribution of airborne particulate matter in indoor environments strongly depend on parameters such as the sources present in the room, room size, relative humidity, air exchange rate, air flow conditions and sink effects on surfaces (e.g. walls, ceilings, floor coverings, soft furnishings). In addition, particles already deposited can be re-entrained through various activities and subsequently inhaled. Depending on the particular case, all this can result in highly variable levels of indoor fine dust pollution that are not easily ascertained or assessed in terms of their impact on health.

In the ISO 16000 series, the following rooms are understood to constitute indoor spaces: dwellings with living rooms, bedrooms, work rooms, sport rooms, cellars, kitchens and bathrooms; work spaces or workstations in buildings not subject to controls under industrial safety legislation in terms of airborne pollution (e.g. offices, shops); public buildings (e.g. restaurants, theatres, cinemas, other function rooms); and the passenger compartments of vehicles and all public transport systems (e.g. buses, trains, aircraft).

Epidemiological and toxicological findings suggest that health effects are more strongly related to sub-micron particles[33]. Indeed, ultrafine particles (UFP), due to their small size, can deeply penetrate into the body and contribute to adverse health effects.

This document describes the general strategies for the measurement of airborne particles, including PM_{10}, $PM_{2,5}$, PM_1 and UFP. The different technologies available equipment are presented and compared in a way that allows the user to select the best technique depending on the monitoring objective. Sampling requirements are presented together with key factors that users should take into account.

Indoor air —

Part 34:
Strategies for the measurement of airborne particles

1 Scope

This document specifies the general strategies for determining the concentration of airborne particles indoors and covers the size range from approximately 1 nm to 100 µm.

In addition, this document describes methods for identifying typical indoor particle sources and gives general recommendations for obtaining a representative sample.

The main sources of indoor particulate matter are described in this document, together with indoor particle dynamics. Various measurement methods are described, along with their advantages, disadvantages and areas of application, as well as some general sampling recommendations. Measurement strategies for determining airborne particles indoors are discussed, including reference case studies with more specific sampling recommendations.

Additional documents in the ISO 16000 series will focus on each fraction of airborne particulate matter and give specific recommendations for these measurements.

The determination of measurement uncertainty and minimum reporting requirements are also part of this document.

This document does not apply to the determination of bioaerosols or the chemical characterization of particles. For the measurement and assessment of dust composition, see the relevant part in the ISO 16000 series.

This document does not apply to the measurement of airborne particles in vehicle passenger compartments and public transport systems.

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 16000-1:2004, *Indoor air — Part 1: General aspects of sampling strategy*

3 Terms and definitions

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

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

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

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

3.1
particle
small discrete mass of solid or liquid matter

[SOURCE: ISO 29464:2017, 3.2.111]

3.2
aerosol
suspension in a gaseous medium of solid *particles* (3.1), liquid particles or solid and liquid particles having a negligible falling velocity

[SOURCE: ISO 23210:2009, 3.1.9]

3.3
equivalent diameter
diameter of a spherical *particle* (3.1) which will impart geometric, optical, electrical or aerodynamic behaviour identical to that of the particle being examined

Note 1 to entry: Depending on the measurement method applied, various equivalent diameters could be defined for the same particle. These different diameters are only indirectly comparable since different particle properties are being measured, e.g. geometric diameter, diameter according to dielectric mobility, diameter according to light scattering properties. Nevertheless, the generic term "particle diameter" is often used for all of them.

[SOURCE: ISO 4225:1994, 3.35, modified — Note 1 to entry has been added.]

3.4
aerodynamic diameter
diameter of a sphere of density 1 g cm^{-3} with the same terminal velocity due to gravitational force in calm air as the *particle* (3.1), under the prevailing conditions of temperature, pressure and relative humidity

Note 1 to entry: The aerodynamic diameter is calculated using the formula:

$$D_a = D_p \sqrt{\frac{1}{\chi}} \sqrt{\frac{\rho_p}{\rho_o}}$$

where

D_a is the aerodynamic diameter;

D_p is the particle diameter;

ρ_p is the density of the particle;

ρ_0 is the standard density;

χ is the form factor.

Note 2 to entry: The form factor describes by how much the resisting force of an irregularly shaped particle is greater than that of a sphere with the same volume[26].

Note 3 to entry: The aerodynamic diameter determines the sedimentation and the separation properties of particles in impactors. It is also of particular importance for penetrative behaviour and the retention of particles in the human body.

[SOURCE: ISO 7708:1995, 2.2, modified — "particle" has been removed from the term and Note 1 to entry has been replaced by Notes 1 to 3 to entry.]

3.5
fine dust
fraction of airborne *particles* (3.1) with an *aerodynamic diameter* (3.4) below 10 µm

[SOURCE: EN 15445:2008, 3.5]

3.6
coarse mode particle
particle (3.1) larger than 2,5 µm in diameter

Note 1 to entry: Coarse mode particles are formed by mechanical abrasion and the swirl-up of sediment and floor dust.

3.7
fine mode particle
particle (3.1) with a diameter below 2,5 µm

Note 1 to entry: Fine mode particles are formed primarily from gases or secondarily through nucleation and condensation.

3.8
ultrafine particle
UFP
particle (3.1) with a diameter of 100 nm or less

[SOURCE: ISO/TR 19601:2017, 3.34, modified — The definition has been shortened and Note 1 to entry has been deleted.]

3.9
cut-off diameter
aerodynamic diameter (3.4) at which the impactor stage has a separation efficiency of 50 %

[SOURCE: ISO 23210:2009, 3.1.2, modified — The definition has been changed from "where the separation efficiency of the impactor stage is 50 %".]

3.10
$PM_{2,5}$
fraction of the airborne *particles* (3.1) that passes a size-selective sampling head with a separation efficiency of 50 % with an *aerodynamic diameter* (3.4) of 2,5 µm

[SOURCE: EN 12341:2014, 3.1.14]

3.11
PM_{10}
fraction of the airborne *particles* (3.1) that passes a size-selective sampling head with a separation efficiency of 50 % with an *aerodynamic diameter* (3.4) of 10 µm

[SOURCE: EN 12341:2014, 3.1.14]

3.12
mass concentration
c
ratio of the mass *m* of the measured component and the gas volume *V*, as shown by:

$$c = \frac{m}{V}$$

[SOURCE: EN 15259:2007, 3.26]

3.13
number concentration
number of *particles* (3.1) per volume element of carrier gas (air)

3.14
lung-deposited surface area
LDSA
particle (3.1) surface area concentration per unit volume of air, weighted by the deposition probability in the lung

Note 1 to entry: Due to lung deposition efficiency during inhalation, only a fraction of the particles will effectively deposit in the human lung. LDSA is thus strongly related to the potential particles health impact.

[SOURCE: Reference [22], modified — Note 1 to entry has been added.]

3.15
particle volume concentration
total volume of all dispersed *particles* (3.1) per unit volume of the carrier gas

4 Origin, properties and health implications of airborne particles

4.1 Origin and properties

Airborne solid and liquid particles (e.g. in the form of dust, smoke, mist and fog) have always been a component of the atmosphere. Together they are referred to as aerosol. Natural sources that contribute to the release of primary particles into the air include oceans, deserts, plants, volcanic eruptions, erosion and fire. In addition, atmospheric photochemistry involving biogenic volatile organic compounds (known as precursor gases, such as isoprene and monoterpenes) leads to the generation of secondary particles. Since the industrial revolution, in particular, primary or secondary anthropogenic particles have been making up a growing proportion of the atmospheric particle spectrum. Large amounts of carbon dioxide, carbon monoxide, nitrogen oxides, sulfur dioxide, organic and elementary carbon, plus other gaseous and particulate substances, reach the troposphere via industrial processes and the combustion of fossil oil products, black coal, brown coal and biomass. According to the World Health Organization (WHO), particular sources of high concentrations of anthropogenic airborne particles include combustion processes and photochemical reactions from anthropogenic precursor gases.[40] Abrasion and re-entrainment processes (e.g. those involving bulk freight, industry, agriculture, the construction industry) can also contribute to fine dust pollution, especially with the coarse mode fraction.

The interaction between natural and anthropogenic aerosols from local, regional and remote sources results in ambient aerosol, in which composition undergoes pronounced spatial and temporal fluctuations. In towns, ambient aerosol is often referred to as urban aerosol.

Ambient aerosol is made up of various particle sizes, i.e. ultrafine, fine and coarse particles. The chemical composition can vary greatly, depending on the source and transport conditions.[35] Elevated concentrations are measured in the vicinity of industrial facilities. Particles with a diameter less than 50 nm are essentially composed of low-volatility organic compounds.

The dynamic behaviour of an aerosol always depends on the properties of the aerosol particles themselves and on those of the surrounding medium, including potential sinks. This is a dynamic system, subject to constant changes caused by various physical and chemical processes, which are also characteristic of different size fractions of the total aerosol. Nucleation gives rise to particles with diameters of a few nanometres (nucleation mode). Condensation and coagulation result in further growth processes taking place (accumulation mode). Abrasion and re-entrainment processes generate in particular particles in the coarse mode (see ISO 4225 and ISO 16000-37).

Airborne particles are thus a cluster of various pollutant species with high variation in shape, size, chemical composition and physical properties.

4.2 Health implications

Based on epidemiological studies, it has been assumed for many years that fine dust pollution of the ambient air can cause health problems, without relevant threshold values having been found thus

far, see ISO 20988. In general, a linear dose-effect relationship is assumed. With the EU Air Quality Directive (1999/30/EC) that came into force in 2005, this issue has become a focus of attention for the wider public. This Directive envisages limits for the daily and annual means of PM_{10} in ambient air. For the $PM_{2,5}$ fraction, the amendment of this Directive (2008/50/EC) specifies an annual mean of 25 µg m^{-3} as a target value from 2010 and as a limit from 2015, and which from 2020 is to be lowered to 20 µg m^{-3}. The PM_{10} limits remain unchanged in the 2008 revision of this Directive (24 h mean: 50 µg m^{-3}, which may be exceeded 35 times per year; annual mean: 40 µg m^{-3}). The limit set by the EU Air Quality Directive for PM_{10} represents, in terms of type, level and measurement strategy, a convention for limiting the health risks caused by fine dust in the ambient air.

In principle, the global interim and target values proposed by WHO in 2006 for fine dust in ambient air can also be used for indoor situations.[40] However, this WHO proposal relates primarily to particles emitted by combustion sources; these are mostly particles belonging to the $PM_{2,5}$ fraction.

Epidemiological studies show that high concentrations of fine dust in the ambient air are associated with health consequences, such as damage to the cardiovascular system and the respiratory tract, and with increased morbidity and mortality.[21] A summarizing analysis of European time-series and panel studies on the effects of particles from the ambient air, carried out in 2004 for WHO, demonstrated statistically significant elevated risk associated with total mortality, mortality caused by respiratory tract and cardiovascular diseases in all age groups and hospital admissions of elderly patients.[16] Accordingly, limits have been developed for ambient air concentration of fine dust. Compared with the number of studies that describe the effect of ambient air aerosols on human health, so far there exist few studies dealing with indoor air[23].

For fine dust indoors, WHO recommends that levels should be minimized. An assessment in terms of health is currently difficult.

Considering these aspects, the following statements on the health implications of fine dust in indoor air can be made.

— Neither the particulate matter limits of the EU Directive 1999/30/EC, nor the annual or daily means for particulate matter in the ambient air proposed by WHO[40], can be used as assessment values for indoor air.

— In the absence of specific internal dust sources, the concentrations of $PM_{2,5}$ inside dwellings are principally due to fine dust from ambient air and resuspension.[38] It seems reasonable, therefore, to use the $PM_{2,5}$ daily mean derived by WHO for dwellings without specific internal sources for guidance.

— In other indoor spaces, such as kitchens, basements, rooms where handicraft activities and hobbies are pursued or community facilities (e.g. office, school, retail centres, medical centres) with specific internal sources (e.g. combustion sources, printing facilities, chemical products), the aforementioned WHO evaluation standard cannot be extended meaningfully.

— The current absence of suitable evaluation standards applicable to all indoor spaces and all particle sizes does not mean that fine dust in indoor air shall be rated as “harmless to health”. Provided no valid assessment in the form of guide or limit values is possible, the conventional procedures for improving indoor air quality shall be implemented on precautionary grounds. In many cases, suitable ventilation procedures shall also contribute to alleviating the problem of fine dust.

When considering the health implications of indoor particle pollution, not only particle size but also particle chemical composition and morphology shall be taken into account. This document does not discuss the determination of these parameters.

5 Sources of indoor particulate matter and particle dynamics indoors

5.1 General

Fine dust concentrations indoors can originate from continuous (e.g. ambient air, heating) and from intermittent (e.g. cooking, smoking, burning candles, printers) sources. As a result of these different source locations and dynamics, the size distribution and composition of indoor particles vary markedly. The processes mentioned below are of special importance. All processes together induce and determine the dynamics of the indoor particle spectrum[29] (see Figure 1).

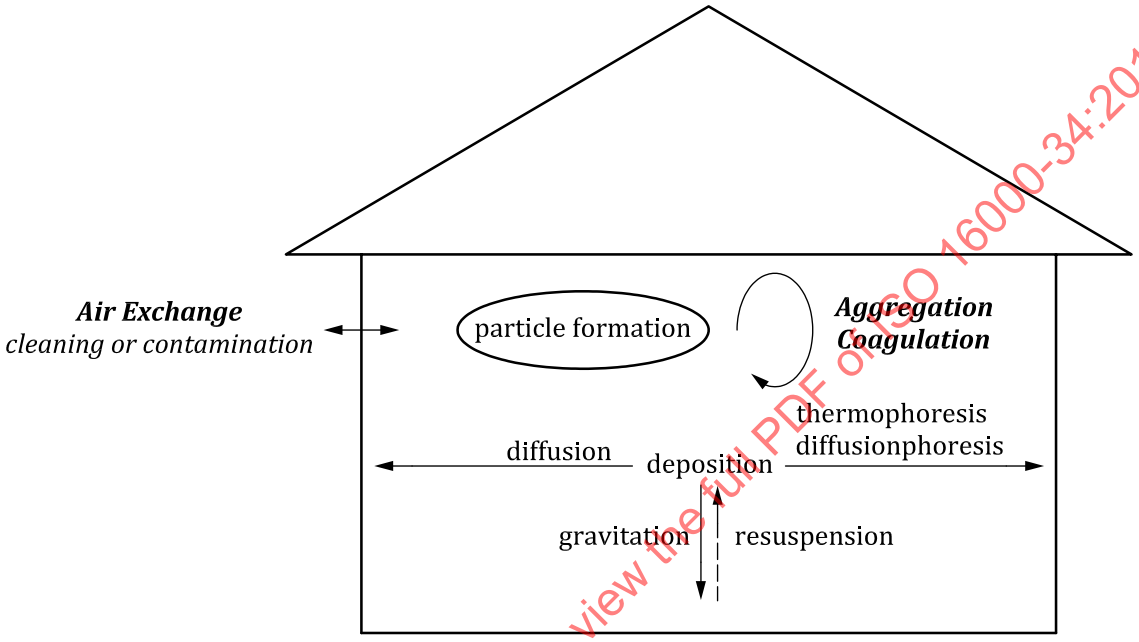

Figure 1 — Particle formation and particle dynamics indoors

5.2 Sources of indoor particulate matter

5.2.1 Typical indoor sources

The major particle sources in indoor environments are as follows.

— Infiltration of outdoor aerosol through windows, doors and the building envelope. In the case of high levels of air exchange, the likelihood of particles from the ambient air entering the building is very high; it drops with decreasing air exchange.[30] The presence of an air-conditioner and related air-filtration system has a huge impact. The fraction of the ambient aerosol found indoors (even with closed windows) depends on particle size, and is highest for particles around 0,3 µm[23].

— Combustion processes, such as smoking, burning candles, open fires, fireplaces and incense sticks.

— Activities, such as cooking, cleaning, hobbies, DIY activities, textile abrasion, and using household and office appliances.

— Humans and domestic animals (skin flakes and hair particles), microorganisms (moulds, bacteria, cell fragments, etc.), pollen and other allergens.

— Particle reformation through physicochemical reactions of volatile organic compounds (VOC), e.g. ozone-terpene reaction.

— Resuspension of deposited particles. Various activities may cause the re-suspension of particles from room surfaces.

5.2.2 Influence of the premises

The indoor sources of particulate matter are diverse. If the premises are in use, the indoor aerosol is often affected by indoor sources, which may be located either in the investigated room itself or in adjacent rooms. A non-exhaustive list of case studies is given in the Bibliography, see References [42] to [77], which can be a good source of inspiration for users, depending on the intended purpose. Typical sources found in different types of premises and which should be taken into consideration are listed below.

a) The typical sources in living rooms include:

   1) cooking, heating, smoking, candles, fireplaces and fragrant oil burners;
   2) body care and cleaning materials (e.g. sprays);
   3) electric appliances (e.g. refrigerators, vacuum cleaners);
   4) people and domestic animals;
   5) abrasion of textiles and textile floor coverings.

b) The typical sources in an office include:

   1) office machines (e.g. printers, copiers, computers);
   2) air-conditioning units;
   3) people;
   4) external inputs (e.g. smoking, adjoining manufacturing premises);
   5) abrasion of textiles and textile floor coverings.

c) The typical sources in kindergartens and schools include:

   1) human and external inputs brought in with clothing (e.g. animal hairs);
   2) activities (e.g. cooking, art, crafts);
   3) electric appliances (e.g. printers, copiers, computers);
   4) soft furnishings;
   5) air-conditioning units where relevant.

5.2.3 Particle size range generated by typical sources

Indoor airborne particles cover a large size range from a few nanometres up to 100 µm. Particle size is deeply influenced by origin, but also by chemical or physical reaction following generation. A non-exhaustive list of typical sources of indoor airborne particles with their typical size ranges is presented in Figure 2.

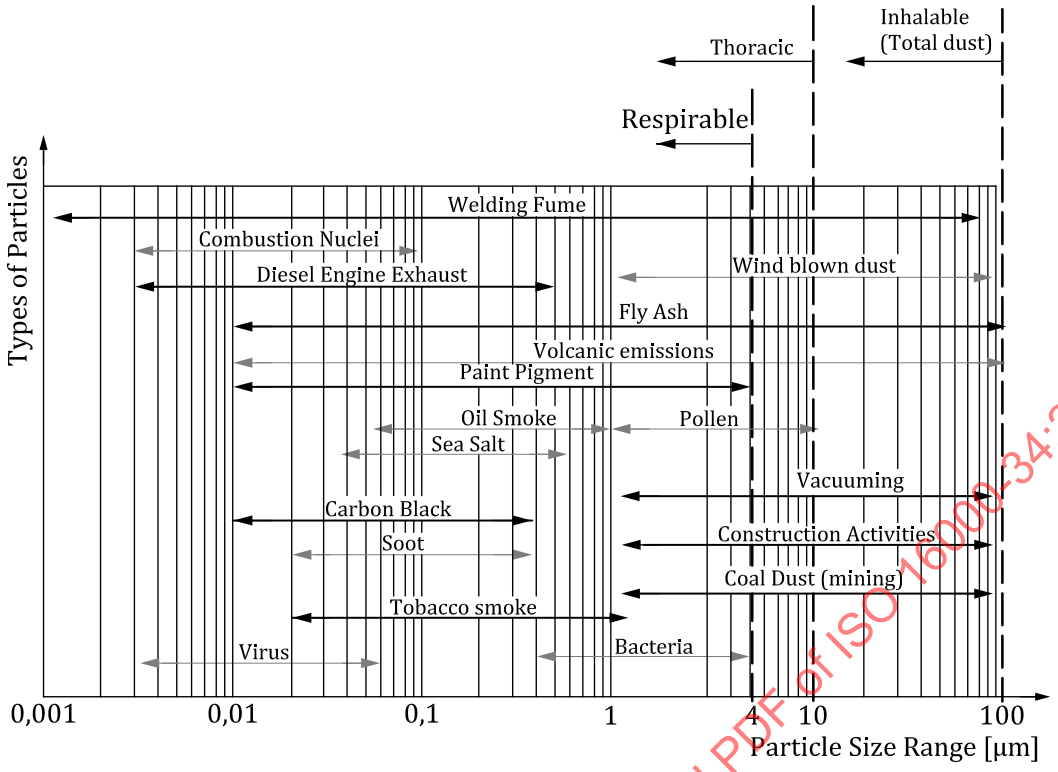

Figure 2 — Typical sources of airborne particles and size ranges

The calculated concentration depends on many factors, such as the intensity of the source, the type, nature, intensity and frequency of use, the distance between the source and the measuring equipment and on specific properties of the room, especially the ventilation rate. Therefore, it is difficult to give empirical ranges of possible concentration values through indoor air measurements of residential premises. Drawing conclusions about hygiene risks associated with the measured particle numbers and mass concentrations is also difficult and should only be done if all parameters have been taken into account. There are several sources dealing with specific activities or specific investigation purposes and some examples are listed in References [42] to [77]. Values obtained during these studies can help experts and/or measuring institutes during future fine dust measurements to select the effective range of the measurement method correctly.

5.3 Particle dynamics indoors

5.3.1 Major particle sinks

Particles that are around 0,1 µm in diameter have the lowest deposition rates on indoor surfaces, whereas smaller and especially larger particles have significantly higher deposition rates. This process depends greatly on, for example, air movements in the room, the room's furnishings and the nature of the surfaces.[37] It is important to distinguish between the processes of sedimentation, impaction and diffusion.[39] These processes decrease the number, mass, volume and surface area concentration.

Building design and construction, as well as climatic conditions, can result in a decrease in the concentration of particles in indoor air through their deposition on surfaces (the sink effect). The cause for this lies in dynamic aerosol processes referred to as thermophoresis, electrophoresis[30], diffusion, dilution, filtration, coagulation, ventilation, deposition, resuspension and others[30].

5.3.2 Variations of the particle spectrum

Physical and chemical reaction after particle emission for their source will occur and have a large impact on the particle size. The accretion of smaller particles on the surfaces of larger ones and the

coalescing of smaller particles into larger ones (coagulation) can decrease the number concentration without changing the total mass concentration. If such growth processes create particles above the cut-off diameter of the mass fraction being measured (e.g. in the case of $PM_{2,5}$, particles larger than 2,5 µm), this also leads to a decrease in the mass concentration of this fraction. The accretion of low-volatility compounds on particles does not change the number concentration.

In addition, secondary particle formation from precursor gases is observed. Thus, the particle spectrum is influenced by the distance between the source and the measuring, and also by the presence of other sources in the room due to cross reaction between the different emitted compounds.

5.3.3 Effect of air conditioning

Air-conditioning units affect indoor particle concentration and dynamics, for example via the air duct, filtration, flow and exit speed of the air. Improperly installed and maintained systems can lead to elevated particle input to the room.

5.3.4 Conditions of room use

The indoor fine dust inputs, which are mostly intermittent and usage-dependent, can be divided into two groups. On the one hand, they include concretely classifiable sources resulting from the use of individual appliances or furnishings. On the other hand, there are diffuse sources caused by the users themselves. Typically, these include fine dust brought in by humans/users and their clothing. The sum of these sources determines the fine dust concentration in the air measured at a particular time.

The sources and their highly variable inputs to the fine dust concentration in the indoor air do not allow a consistent specification of the measurement conditions. The measurement procedure, therefore, should be derived and justified based on the task and situation. This justification shall be recorded in the test report, together with the chosen measurement and sampling conditions (as described in ISO 16000-1:2004, Clause 4). Other parameters, e.g. those relating to ventilation, should be taken into consideration. No standard scenario can be defined.

6 Measurement methods for airborne particles indoors

6.1 General

A variety of complementary measurement methods are available for measuring airborne particles indoors[22][23].

Using the various methods, the following measured variables are determined, either as integral or as size-resolved quantities:

— particle mass concentration;

— particle number concentration;

— particle surface area concentration;

— particle lung-deposited surface area (LDSA) concentration;

— particle volume concentration.

These variables are either measured directly or calculated from the measured values. In the latter case (e.g. when calculating surface area concentration from the number concentration for the various particle size fractions), it is necessary to check whether the calculation method used is plausible for the intended task.

NOTE Estimating the mass concentration from the number concentration is possible only if the spatial particle size distribution and the density of the particles are known (see Clause 7). The same is true for conversions for other quantities (surface area, volume, etc.).

Particles less than 1 µm in diameter can be characterized by the number or surface area concentration more accurately than by mass concentration. Particles larger than 1 µm can be characterized by mass concentration usually, but in some cases number concentration might also be relevant.

Particles can be divided into different class sizes using different physical principles (e.g. optical diameter, aerodynamic diameter or electric mobility of the particles). Results obtained with various instruments based on different techniques will thus be different by principle and particular care should be taken when comparing results obtained with different measuring methods.

In order to capture the full size range of airborne particles, typically instruments need to be combined. Instruments are often based on different physical principles and thus often result in different equivalent diameters. This means that data do not necessarily merge in a common size range.

6.2 Established method description

6.2.1 General

Figure 3 gives a summary of the established methods most commonly used for indoor measurements and can help in selecting the best technique depending on the application.

This selection is based on the size of interest, and also on the volumetric flow rate, the requested lower limit of detection and time resolution.

NOTE Single particle measurements are more sensitive and are an asset for measurement at low concentration or if a fast response time is requested. For other instruments, particles are accumulated before being able to be detected. Some measurement techniques allow a near real-time result or measure within a small period of time (i.e. typically less than 1 s for a LSAS, 5 min to 10 min for a DMAS). Other techniques require accumulation of particles during a long period, generally 24 h, and therefore only give information over a large integrated period of time. Generally, techniques that require a long period of time for collection are less sensitive and require sampling of a higher volume than the other ones.

The principles of each method listed in Figure 3, along with their capabilities and their limits are described briefly in 6.2.2 to 6.2.15. Before using an instrument, detailed method descriptions shall be consulted in the respective guidelines, if they exist. Specific International Standards in the ISO 16000 series describe some of the listed techniques in detail.

Figure 3 gives general information about common instruments available on the market. Users shall refer to specific instrument manuals for exact values.

Equivalent Diameter (µm): no sizing / Electrical Mobility / Inertia / Optical / Aerodynamic Mobility; 0,001 0,01 0,1 1 10 100			Measurand	Lower limit	Upper limit	Sample flow	Typical time resolution	Traceability	Standards						
									ISO 27891	ISO 15900	ISO 21501-1	ISO 29904 TR 27628	ISO 11801	ISO TR 25597 ISO TR 13271	EN 12341
Physical particle size separator	Fine particles	Cyclone	SD	1 µg/m³	< 100 mg/m³	1 - 20 l/min									
		Impactor	SD	0,1 µg/m³	< 2,5 mg/m³	< 30 l/min		X				X		X	X
	Fine and ultrafine particles	LPI	SD	0,1 µg/m³	< 2,5 mg/m³	< 30 l/min									
		MOI	SD	0,1 µg/m³	< 2,5 mg/m³	≈ 30 l/min									
		DMA	SD	< 100 cm⁻³	E7 cm⁻³	> 10 l/min		X	X	X					
		AMS	SD	< 100 cm⁻³	E7 cm⁻³	> 5 l/min									
Collection on media (Low time resolution)	Gravemetry	AMM	MC	0,1 µg/m³	< 100 mg/m³ [b]	≈ 1 - 3 m³/h	1 h - 24 h	X							
		OMB	MC	0,1 µg/m³	< 100 mg/m³	≈ 3 l/min	1 h - 24 h	X				X	X		
	attenuation	BRA	MC	0,1 µg/m³	< 1 mg/m³	≈ 20 l/min	1 h - 24 h	X					X		
	microscopy	OM	SD	0,1 µg/m³	< 100 mg/m³	≈ 1 - 3 m³/h	1 h - 24 h								
		SEM	SD	0,1 µg/m³	< 100 mg/m³	≈ 1 - 3 m³/h	1 h - 24 h								
		TEM	SD	0,1 µg/m³	< 100 mg/m³	≈ 1 - 3 m³/h	1 h - 24 h								
High time resolution aerosol measurement	Individual particle analysis	LSAS	NC, SD	> 1 cm⁻³	E7 cm⁻³	< 5 l/min	> 5 s	X			X				
		TOF AS	NC, SD	> 1 cm⁻³	E7 cm⁻³	< 1 l/min	> 1 s								
		CPC	NC	0,1 cm⁻³	E5 cm⁻³	< 1,5 l/min	1 s	X	X	X					
		UF CPC	NC	0,1 cm⁻³	E5 cm⁻³	< 1,5 l/min	1 s	X	X	X					
		CPC with SES	NC	0,1 cm⁻³	E5 cm⁻³	< 1,5 l/min	2 s		X	X					
		LSAS+DMA+CPC	NC, SD	> 1 cm⁻³	E7 cm⁻³	< 1,5 l/min	> 5 s		X	X	X				
	Integral or accumulative particle analysis	CPC photometric mode	NC	0,1 cm⁻³	E8 cm⁻³	< 1,5 l/min	1 s								
		FCAE	NC	≈ 375 cm⁻³ [a]	≈ E7 cm⁻³ [a]	< 5 l/min	1 s	X	X						
		DMA+CPC	NC, SD	< 100 cm⁻³	E7 cm⁻³	< 1,5 l/min	≈ 60 s	X	X	X					
		DMA+FCAE	NC, SD	≈ 1 000 cm⁻³	E7 cm⁻³	< 5 l/min	≈ 60 s	X	X						
		AMS+CPC	NC, SD	< 100 cm⁻³	E7 cm⁻³	≈ 1,5 l/min	> 1 s								
		AMS+FCAE	NC, SD	≈ 1 000 cm⁻³	E7 cm⁻³	≈ 1,5 l/min	≈ 60 s								
		FRAS	NC, SD	< 100 cm⁻³	E7 cm⁻³	≈ 10 l/min	1 s								
		LPI+E	NC, SD	≈ 375 cm⁻³ [a]	≈ E7 cm⁻³ [a]	< 10 l/min	1 s								
		MOI+OMB	NC, SD	≈ 40 µg/m³	< 2,5 mg/m³	≈ 10 l/min	5 min								

Measurands

NC particle number concentration

SD particle size distribution (based on mass or number)

MC particle mass concentration

a The particle number concentration measured by a FCAE is calculated from its primary measurands electrical current or electrical charge concentration. Upper and lower limits of NC depend on electrical charge distribution on particles and sample flow. For example, an electrical current of 1 fA with a sample flow of 1 l/min corresponds to a singly charged particle number concentration of ~375 cm^{-3}.

b Time resolution depends on situational conditions, such as the time needed for sampling of the minimum analyte quantity.

Acronyms	Description		Synonyms[c]
Cyclone		6.2.1	
Impactor	impactor/cascade impactor	6.2.2	
LPI	low-pressure impactor	6.2.2	Berner low pressure impactor (BLPI) Dekati® low pressure impactor (DLPI)
MOI	micro orifice impactor	6.2.2	micro-orifice uniform deposit impactor (MOUDI™)
DMA	differential mobility analyser	6.2.3	
AMS	aerosol mass spectrometer	6.2.4	centrifugal particle mass analyser (CPMA) aerodynamic aerosol classifier (AAC) aerosol particle mass analyser (APM)

AMM	aerosol mass monitor	6.2.5	air sampler PM monitor personal sampler personal impactor
OMB	oscillating microbalance	6.2.6	quartz crystal microbalance (QCM) tapered element oscillating microbalance (TEOM)
BRA	beta radiation attenuation	6.2.7	beta attenuation monitor (BAM)
OM	optical microscope	6.2.8	
SEM	scanning electron microscope	6.2.8	
TEM	transmission electron microscope	6.2.8	
LSAS	light scattering aerosol spectrometer	6.2.9	optical particle counter (OPC) optical particle size spectrometer (OPSS)
TOF-AS	time-of-flight aerosol spectrometer	6.2.10	aerodynamic particle sizer (APS)
CPC	condensation particle counter	6.2.11	butanol based condensation particle counter (BCPC) water based condensation particle counter (WCPC)
UF CPC	condensation particle counter optimized for the small size range	6.2.11	UF-CPC
CPC with SES	condensation particle counter with size enhancer stage	6.2.11	nano-CPC
CPC photometric mode	condensation particle counter in photometric mode	6.2.11	
FCAE	faraday cup aerosol electrometer	6.2.12	Faraday (FC cup) eFilter
DMA + CPC DMA + FCAE	differential mobility aerosol spectrometer (DMAS)		scanning mobility particle sizer (SMPS)
DMA + FCAE			mobility particle size spectrometer (MPSS)
LSAS+DMA+CPC			wide range aerosol spectrometer (WRAS) wide range particle spectrometer (WPS)
AMS + CPC AMS + FCAE	aerosol mass spectrometer analyser (AMSA)		
FRAS	fast response aerosol spectrometer	6.2.13	fast mobility particle sizer (FMPS) electrical aerosol spectrometry (EAS) fast particle analyser (FPA) differential mobility spectrometer (DMS)
LPI + E	low pressure impactor with electric detection	6.2.14	electrical low-pressure impactor (ELPI)
MOI + OMB			quartz crystal microbalance micro-orifice uniform deposit impactor (QCM-MOUDI)

[c] Column "Synonyms" contains trademarks. This section is non exhaustive.

Figure 3 — Overview of particle measurement methods

6.2.2 Cyclone

6.2.2.1 Principle

In a cyclone, the air sampled enters a conical cyclone chamber tangentially, where it forms a vortex. The formed vortex causes particles with sufficient inertia to impact onto the chamber walls, from where they drop into a collection cup while smaller ones follow the air stream.

Depending on the measurement task, both particles collected by the cyclone and the ones passing through the system are further available for the measurement.

6.2.2.2 Capabilities of the method

The main advantage of the technique is that it can be used at high concentration.

Several cyclones can be used in cascade (generally limited to two cyclones) to collect different fractions (i.e. PM_{10} and $PM_{2,5}$).

Most of the time, this technique is used as a pre-separator to remove the coarse fraction before analysis of the fine fraction by another technique.

6.2.2.3 Limits of the method

Due to the difficulties of collecting dust from the cap without losing particles or contamination, this technique is generally used only for high concentration. It induces a higher uncertainty compared to an impactor, for example.

Cut-off size is generally limited to 1 µm for physical reasons and this method is thus not used for ultrafine particles.

6.2.3 Impactors (impactor – cascade impactor – LPI – MOI)

6.2.3.1 Principle

Impactors are a subtype of inertial classifiers where particles are selected by impinging on a flat plate.

a) Single-stage impactor: The sample flow is first led through a nozzle to achieve a certain flow velocity. After the nozzle, the air flow is turned sharply in front of a collection plate. Particles larger than cut-off size (e.g. PM_{10} or $PM_{2,5}$) of the impactor cannot follow the flow stream lines but are impacted onto the collection plate. Smaller particles follow the flow and are not collected.

b) Cascade impactor: By using multiple impactor stages with progressively smaller cut sizes in series, the sample can be separated into several size fractions (typically 3 to 15) and therefore cascade impactors can be used for determination of the particle size distribution.

c) LPI: The cut-off size of the conventional impactor is limited by the diameter of the nozzle and the pressure drop through the impactor. The lower cut-off diameter limit of the conventional impactor is approximately 0,3 µm.

   The cut-off diameter can be reduced down to a few nanometres by operating the impactor at a low pressure. By use of a vacuum pump, a lower pressure (as low as 0,03 atm) is created downstream of the nozzle and the air is thus drawn through the nozzle at a high flow rate (as high as ultrasonic).

d) MOI: Another way to decrease the cut-off diameter of a conventional impactor is to use an MOI. In this system, the nozzle diameter is decreased to a very low size to enable the collection of particles as small as a few nanometres. To avoid pressure drop and maintain the total sampling velocity, a large number (up to several thousands) of very small nozzles (as low as a few µm) are necessary. In practice, a plate containing a large number of very small orifices is used. By rotating this impaction plate, particle bounce and re-entrainment can be limited and the deposition on the collection filter is nearly uniform.

6.2.3.2 Capabilities of the method

Collected particles can be measured by different techniques depending of the purpose of the measurement (e.g. gravimetric, optical, electric). Impactors are thus mainly used in combination with other detection instruments for providing information related to the particle size distribution.

Since the sample is collected on a substrate, the investigation of specified particle size fractions is also possible to a limited extent. By using powerful identification methods [e.g. SEM, infrared (IR), microprobe methods, microscopic and chemical analytical methods], the composition or other identifying features, possibly including those of individual fine dust particles, can be detected on the dust-loaded substrates.

6.2.3.3 Limits of the method

The known limitations of impactors include the problem of particle bounce and re-entrainment[28]. The impaction surface will usually be coated with an adhesive collection substrate (e.g. greased aluminium foil, suitable fibre filter) to eliminate the particle bounce and re-entrainment. For cascade impactors, greased collection substrates are often not compatible with the applied detection techniques and can thus not be used.

Since the particles are deposited inside the samplers, they shall be cleaned regularly, in particular after sampling in highly polluted environments.

6.2.4 Differential mobility analyser (DMA)

6.2.4.1 Principle

A DMA is a device that separates charged aerosol particles according to their mobility in an electric field. A neutralizer, typically radioactive or soft X-ray neutralizer, is used to charge the particles with a known charge distribution before entering the DMA. The DMA can be described as an assembly of two concentrically cylindrical electrodes with an air gap in between. An electric field is applied between the inner and outer electrodes. Within the system, a laminate clean sheath air flow is created. Aerosol air flow enters from one end and exits the other end. When a charged particle suspended in a gaseous medium is placed in an electric field, the particle experiences a force which is dependent on its charge and the strength of the electric field. As the sheath flow is constant and laminar, each particle follows the gas stream, but is also moved in the perpendicular direction under the effect of the electric field depending of its electrical mobility. Particles with the same electrical mobility are collected at the exit at a certain fixed distance from the electrode through a very small slit. Particles with a different electrical mobility do not reach the slit and are removed. By changing the electric field apply to the electrode, particles with different electrical mobilities can be selected in a monodisperse way.

6.2.4.2 Capabilities of the method

The DMA is one of the most commonly used devices for classifying and measuring nanometer-sized aerosol particles between 1 nm to 1 µm in diameter, based on their electrical mobility.

The DMA is usually combined with a counting device, typically a CPC (see 6.2.12) or a FCAE (see 6.2.13) to form a differential mobility aerosol spectrometer (see ISO 15900). This method allows the fine and ultrafine spectrum to be determined with a high time resolution (typically 1 min to 5 min).

6.2.4.3 Limits of the method

The presence of multiple charged particles has the potential to affect the results for the larger particles in the measured size range, even when applying a multiple charge correction function.

In addition to the multiple charging issues, several reasons, including particle diffusion and turbulence, mean that the output of a DMA is not always completely monodisperse, but more a distribution with a narrow dispersion of mobilities. This distribution is referred to as the transfer function of the DMA, and must be known to obtain accurate particle number concentrations from DMA scans.

For spherical particles mobility, diameter is equivalent to volumetric diameter. However, this is not the case for non-spherical particles. For aggregate particles which have a fractal nature, the mobility diameter may be significantly larger than the volume equivalent diameter of the material present.

Diffusion losses are important with small particles within the sampling system and the DMA. Charging probability also decreases with the size. As a result, only a fraction of the particles present in the air sampler eventually exit from the system. Correction should be applied if a detection device is used downstream. If the SMPS provides a diffusion loss correction, users should enable this for more accurate particle number concentration results. The real concentration could also be theoretically recalculated.

A radioactive source is often used when adjusting the system for a defined charge distribution. This source normally requires a specific authorization and specific precaution for storage, transport and operation, as well as precautions against vandalism and theft. Soft X-ray neutralizers are also available and do not require a transport licence. These, however, often have a more limited lifetime and are not recommended for 24/7 measurements. Non-radioactive corona-jet chargers are also available. These, however, could affect the result as the charging distribution is different.

SMPS systems measure particles size distributions discontinuously in time intervals of typically 1 min to 5 min. This shall be taken into consideration when evaluating the results of particle counts with upstream particle size classification, especially where the particle size composition of the investigated aerosol varies rapidly compared with the time needed to measure the particle size range of interest. Where the measured signal varies rapidly, using the FRAS (see 6.2.14), which allows the size distribution of ultrafine particles to be measured with a high time resolution (1 s), may be helpful.

6.2.5 Aerosol mass spectrometer (AMS)

6.2.5.1 Principle

An AMS classifies particles based on their charge to mass ratio. The instrument consists basically of two cylindrical electrodes co-rotating about a common axis at the same angular speed. A voltage is applied between the inner and outer cylinder. Charged particles enter the instrument through the annular gap rotating at the same speed as the cylinders. The particles experience directly opposing centrifugal and electrostatic forces. Rotational speed and voltage are adjusted to balance these forces for particles of a specific charge to mass ratio. These particles traverse through the AMS and can be counted downstream.

6.2.5.2 Capabilities of the method

The separation technique is not dependent on particle size, shape factor, orientation or properties of the carrier gas.

6.2.5.3 Limits of the method

For the calculation of the transferred particle's diameter, their density must be assumed as well as their size dependent charge state. An AMS works with the particle fraction of either positive or negative net charge in an aerosol and, hence, a known charge distribution must be generated with a particle charger. Charging is not very effective for small and very small particles and the majority of them do not traverse through the instrument. Hence, size dependent losses and diffusion losses as well as multiple charge corrections must be calculated based on available theory. When operated, the instrument is very loud and is, therefore, typically not used in populated spaces.

6.2.6 Aerosol mass monitor (AMM)

6.2.6.1 Principle

AMM is a generic term for a system that allows the collection of aerosols on a substrate suitable for post gravimetric analysis. The system collects at constant flow rate a known volume of air. It also takes into account all parameters influencing the collected volume and flow rate (e.g. temperature, pressure).

The weight of the substrate is determined before and after the measurement. The difference yields the deposited particulate mass. Mass concentration is then calculated by combining collected mass and sampled volume. In most cases, impactors are used to collect desired mass fractions, but some designs also use an inlet cyclone or no pre-separator if total mass information is targeted.

Systems are usually split in two categories.

a) The first category includes high flow fix instruments of typically several m^3/h, which are used to determine local concentrations of PM. In ambient air, the gravimetric method is the reference method for measuring particle mass concentrations (PM_{10}, $PM_{2,5}$; see EN 12341). In indoor air, the gravimetric method is also the reference method for measuring particle mass concentration of $PM_{2,5}$ (see ISO 16000-37). Appropriately standardized measuring devices are available commercially.

b) The second category includes instruments that are usually worn by people during indoor activities to determine their personal exposure levels. They are known as personal samplers or personal impactors. A constant air flow of typically 1 l/min to 2 l/min is pulled through the monitor using a small, battery-operated sample pump. Particles are deposited on a substrate that is placed on one or more impaction stages.

6.2.6.2 Capabilities of the method

The measurement is representative of mean particle mass concentration or personal exposure level. For quantitative gravimetric analysis, typically only one desired mass fraction (e.g. inhalable, $PM_{2,5}$, PM_{10}) is collected. The collected particle samples can further be analysed chemically or microscopically.

EN 12341 describes traceable, validated methods for determining particle mass concentrations. Assuming a measurement period of 24 h and a volume flow of 2,3 m^3/h, particle mass concentrations or mass concentrations of particle fractions can be determined quantitatively from approximately 3 $\mu g/m^3$. (According to EN 12341, the detection limit of the standard measurement method is 1 $\mu g/m^3$.) Data on measurement errors shall be obtained from EN 12341.

6.2.6.3 Limits of the method

Due to the relatively high uncertainty, weighing is not suitable for ultrafine particles as it is not possible to collect sufficient mass of the sample. Other detection methods (e.g. optical, electric) are thus used for the ultrafine fraction.

The gravimetric method is a time-integrating method. Within the sampling time-interval (mostly 8 h, 24 h or more), no conclusions can be drawn about temporal changes in the mass concentration. A known and constant volume flow through the monitor needs to be maintained and the flow needs to be verified regularly with an external reference flow meter.

Gravimetric measurement methods are not noiseless, since usually several cubic metres of air are drawn via a pump. In residential premises, therefore, often acceptance problems arise on the part of the room's user if the equipment runs for a lengthy period. The high sampling extract can also impact the particle concentration in small rooms.

6.2.7 Oscillating microbalance (OMB)

6.2.7.1 Principle

An OMB consists of a sub-millimetre-sized wafer cut from a single quartz crystal. Electrodes are placed on each side of the wafer to excite and measure the resonant vibration frequency of the crystal. The base of the crystal cannot move, but the tip is free to vibrate at its natural frequency (in a similar way to a tuning fork). If particles are deposited on the wafer, the natural frequency of the oscillating quartz decreases. The frequency shift is proportional to the deposited mass, which is directly measured by the electronics at a 1 Hz rate.

6.2.7.2 Capabilities of the method

The main advantage of oscillating balance samplers is that it is directly measuring the mass of the collected sample and thus does not require a correction factor to move from another metric (e.g. number, volume, surface) to mass. The system also runs continuously and is quite sensitive. It provides information on the PM concentrations on a very short time base. Depending on the pre-separator used, this instrument can be used for $PM_{2,5}$, PM_{10} or total suspended particles, and also for the submicron range.

6.2.7.3 Limits of the method

Volatile particulates that were collected can evaporate from the sensor filter due to the heating in the inlet creating underestimation in the measurement. Newer versions of OMB are thus equipped with a system that aims to limit the impact of this phenomena and allow a better correlation with reference mass sampling. The instrument is sensitive to vibration and is designed for long-term measurements. Measurement method is sensitive to the decoupling of collected particle matter (particles only loosely attach to the surface or are liquid/semiliquid), particle bounce and particle re-entrainment (particles detach from the collecting surface after initial deposition, normally due to overloading). Since the particles are deposited on the impactor stages, the device shall be cleaned regularly.

6.2.8 Beta radiation attenuation (BRA) monitor

6.2.8.1 Principle

A BRA monitor uses beta ray attenuation to calculate collected particle mass concentrations in units of $\mu g/m^3$. The sampled air passes usually through a size-selective inlet (cyclone or impactor) at a controlled flow rate. The relevant PM fraction is collected on a sample support (substrate or filter tape). A beta source (e.g. a 14C element with +/−250 MBq) emits a constant source of low-energy electrons, also known as beta particles, which is used for the deposit determination. The beta rays are attenuated as they collide with particles collected on the filter tape. A low level of beta radiation is passed through the sample support. The increase in PM load causes a decrease in the radiation level measured by the detector. The decrease is proportional to the increase in the mass of PM. All BRA monitors use some sort of heating of the inlet. This prevents water vapour from condensing on the filter tape.

6.2.8.2 Capabilities of the method

Due to the high resolution of beta ray radiation detectors, the signal is often very stable even for a very low dust concentration. BRA is often used for the routine measurement of $PM_{2,5}$ and PM_{10} in ambient air monitoring networks.

6.2.8.3 Limits of the method

As sufficient particles need to be accumulated to reach the minimal detection limit, a BRA monitor measures and records minimum hourly particulate mass concentration. For the same reason, this detection method is not suitable for ultrafine particles as it is not possible to collect sufficient mass of sample.

The heating probe used to remove vapour is known to be the cause of losses of some volatile particulate matter. The way the heating is physically set up within each instrument type and regulated by the set up in the monitor are related to these losses of particulate matter. There are also small differences between instruments (e.g. for beta radiation reading while sampling, sampling modes, zeroing procedures).

This type of instrument also normally requires a specific authorization due to the presence of a nuclear beta source and specific precautions for storage, transport, operation and protection against vandalism and theft.

6.2.9 Microscopy (OM – SEM – TEM)

6.2.9.1 Principle

a) OM: A type of microscope, often referred to as the "light microscope", which uses visible light and a system of lenses to magnify images of small samples. Microscopes with a CCD camera are available and this allows a direct examination of the sample on a computer screen and informatics treatment of the image.

b) SEM: An electron beam is focused into a small probe and is rastered across the surface of a specimen. The electrons interact with atoms at the surface of the sample, producing the emission of electrons or photons from the examined material. These emitted elementary particles can be collected with the appropriate detector to yield valuable information about the material, including the shape of the sample.

c) TEM: A microscopy technique in which a beam of highly focused electrons is transmitted through an ultra-thin sample (< 200 nm). These highly energetic incident electrons interact with the atoms in the sample, producing characteristic radiation and providing information for the characterization of materials. Information is obtained from both deflected and non-deflected transmitted electrons, backscattered and secondary electrons, and emitted photons.

6.2.9.2 Capabilities of the method

a) OM: Direct imaging with no need for sample pre-treatment. The only microscopy for real colour imaging. Fast and adaptable to all kinds of sample systems, from gas to liquid and to solid sample systems, in any shapes or geometries. It is readily integrated with digital camera systems for data storage and analysis.

b) SEM: The method is based on surface interaction and thus does not require an electron-transparent sample. Almost all kinds of samples can be used. For non-conducting samples, a stain coating is needed. 3D imaging of the particle is possible.

c) TEM: High resolution, as small as 0,2 nm, can be reached. It is the only available technique to measure particles below 1 nm. Direct imaging of a crystalline lattice is possible. The method also delineates the defects inside the sample. No metallic stain-coating is needed, thus it is convenient for structural imaging of organic materials.

6.2.9.3 Limits of the method

In practice, the inspection of the entire area is often limited to a few particles and thus it is non-representative of the collected sample except in case of mono-disperse dust.

a) OM: The resolution of this method is quite low, usually down to only sub-micron or a few hundreds of nanometres, mainly due to the light diffraction limit.

b) SEM: The resolution is usually limited to a few tens of nanometres. Sample preparation is time-consuming and usually requires surface stain-coating with metals for electron conducting.

c) TEM: The preparation of an electron-transparent sample is difficult. The method is time-consuming and each particle collected on the substrate requires a separate analysis.

6.2.10 Light scattering aerosol spectrometer (LSAS)

6.2.10.1 Principle

The operating principle of a LSAS relies on particles being guided individually through an intensely illuminated volume (see ISO 21501-1). The intensity of light scattered by the particles in a fixed angular region (typical scattering angles lie in the range between 50° and 90°) is a measure for the particle size. Depending on the equipment used, the effective range of an optical aerosol spectrometer can lie

at optical particle diameters between 0,06 µm and 100 µm; usually, at least the range between 0,3 µm and 30 µm is covered. Given a known sample volume flow and a defined measurement period, the particle number concentration is inferred from the number of scattered light pulses counted. The light sources used for optical aerosol spectrometers include monochromatic (e.g. laser diodes, lasers) and polychromatic sources (e.g. white light diodes).

6.2.10.2 Capabilities of the method

Optical aerosol spectrometers enable the measurement of particle number and particle size distributions continuously and with high time resolution. They also allow the determination of the particle number in separate size fractions.

The equipment available commercially mostly also allows, by using evaluation software, an estimate of the mass concentrations.

By adding a downstream filter, some types permit dust sampling and further analysis. However, the instruments do not separate airborne particles in a separate fraction, but just collect all particles on a filter. The equipment is silent and low-maintenance. Scattered light photometry permits high time resolution, which is desirable, e.g. for determining peak concentrations or in the case of intermittent emission sources (printers, toasters, etc.).

6.2.10.3 Limits of the method

The level of the scattered light pulse depends on the size, the optical properties and the shape of the particles. Calibration is required, and is usually done with the help of latex particles of defined size as a test aerosol. Comparison with other metrics should nevertheless always be done carefully, as ultimately what is determined with LSAS is an optical equivalent diameter defined by calibration with monodisperse spherical latex particles.

Since the particles' mass is derived from particle number and particle size, the results depend on the assumptions made as to the physical properties of the particles and on the algorithms used by the evaluation software. Usually, an ideal spherical form of the particles is assumed, and converted to mass using an assumed density.

A prerequisite for using this continuously counting measurement principle is that always only one particle must be present in the examined volume. The lower detection limit depends greatly on particle size: the larger the particles, the lower the detectable concentration. As a result the range of concentration of such instrument is always limited.

6.2.11 Time-of-flight spectrometer (TOF-AS)

6.2.11.1 Principle

A TOF-AS determines the aerodynamic diameter of particles by accelerating particles in a nozzle and then measuring the time of flight of each particle individually in the airflow. Due to the inertia of larger particles, they are accelerated more slowly than smaller ones. The time of flight is determined with two laser beams in series. The particle size range covered by this method comprises aerodynamic diameters from 0,5 µm to 20 µm.

6.2.11.2 Capabilities of the method

This method determines the aerodynamic diameter of airborne particles with a high sizing resolution in real time. The method is suitable to complement gravimetric measurements in order to determine short-term temporal changes in particle concentration. Particles exhibiting the same airborne behaviour have the same aerodynamic diameter, regardless of their physical size, shape, density or composition.

6.2.11.2.1 Limits of the method

The effective range is limited to particle diameters larger than approximately 0,5 µm.

6.2.12 Condensation particle counter (CPC – UF CPC – CPC with SES – CPC photometric mode)

6.2.12.1 Principle

Optical techniques are limited by being unable to detect particles smaller than a few hundred nm, and are also susceptible to sizing errors resulting from variations in particle shape and refractive index.

In a CPC, particles that are too small for direct optical counting are grown under controlled conditions by vaporizing a working fluid (isopropanol, butanol or water) that supersaturates and condenses onto the particles. The particles effectively grow to larger, optically detectable sizes of a few µm and do not contain the size information of the original particles anymore. CPCs measure the total particle number concentration of ultrafine particles with diameters from around 10 nm up to several µm[25][17].

CPCs optimized for the small size range (UF CPC) employ the same technique to count particles as conventional CPCs. They are optimized for a lower particle size down to 2 nm to 10 nm. Diffusion losses are minimized by using higher inlet flows and adding sheath air to confine the aerosol flow path near the centreline of the condenser. This design also exposes particles to the region of highest supersaturation and uniformity of working fluid vapour.

To extend the detectable size range of a CPC down to 1 nm, a SES is used upstream. The minimum diameter of a particle on which supersaturated vapour will condense is dependent of the working fluid used and its supersaturation ratio. The smaller the particle, the higher is the supersaturation ratio of the working fluid, needed for growth. A SES increases the supersaturation ratio by controlling saturator and condenser temperatures and optimizing the flow scheme. Further, by using diethylene glycol (DEG), a low vapour pressure and high surface tension working fluid, instead of butanol or water, particles down to 1 nm in size can be effectively grown to larger droplets. These larger droplets are then further grown by the attached conventional CPC and counted.

Single particles can be counted up to a concentration limit depending on type and manufacturer, usually up to 10^6 particles/cm^3. Above that limit, particles cannot be physically separated anymore within the resolution time of the instrument. The light scattered back from all particles that are illuminated at the same time in the sensing region can then be detected as an electric signal (CPC photometric mode) proportional to the concentration.

6.2.12.2 Capabilities of the method

CPCs offer high time resolution and very low-number concentrations can be determined accurately (< 1 particles/cm^3). The photometric mode is less accurate but increases the measureable concentration to about 10^8 particles/cm^3.

The SES extends the size range of aerosol instruments down to ~1 nm in mobility equivalent diameter and thus enables the study of, for example, gas to particle conversion, engineered nanoparticle synthesis, particle nucleation and growth, as well as aerosol reaction kinetics in the environment.

6.2.12.3 Limits of the method

If used indoors, butanol can present an odour nuisance and may affect VOC measurements, while isopropanol or water does not. The working fluid used can influence the result (i.e. water in the case of hydrophobic particles).

Coarse particles can clog the system. As they are usually negligible compared to the smallest fraction in terms of number, a pre-separator, usually a cyclone, is used to remove all particles above 2 µm or 3 µm. As a result, the upper size range of the instrument is limited.

Special care shall be taken to optimize the sampling location and sampling system. High losses can be indeed expected if using long and/or non-conductive sampling lines.

Photometric detection requires frequent calibrations to be correlated with the number concentration. The optical properties of the individual particles considerably affect the measured values. Calibration with the help of test aerosols having similar optical properties needs to be carried out.

The growth efficiency in a SES is slightly material dependent.

6.2.13 Faraday cup aerosol electrometer (FCAE)

6.2.13.1 Principle

The measured physical variable in this method is the electric charge of the aerosol particles following a defined charging process. Within the scope of this guideline, aerosol electrometers are used as detection units in combination with size separation or collection units. They can be connected downstream of a DMA (see 6.2.4) or integrated as particle detectors into FRAS (see 6.2.14).

6.2.13.2 Capabilities of the method

As the measurement of current is a primary physical quantity, an accurate and certified measurement principle can be achieved. The diffusion charging method is insensitive to the particle properties (density, material). The electrical detection method has a lower detection limit than gravimetrical measurement because of higher sensitivity.

6.2.13.3 Limits of the method

Since particle charge is strongly dependent on particle size, total particle number or mass concentration can be inferred only for known particle size distributions or by correlating the result to a parallel primary measurement. The electrometer can be linked to a particle size separating method, e.g. LPI, DMA (see ISO 15900) or AMS.

6.2.14 Fast response aerosol spectrometer (FRAS)

6.2.14.1 Principle

A FRAS measures particle size and number distributions by sizing the particles by their electrical mobility and counting them with a set of FCAE. Particles pass a two-stage corona charge conditioner, which sets a defined electrical charge distribution on them before they enter the sizing section. The sample flow is directed through a serial stack of electrometers (stack of concentrical ring electrodes around a centre electrode) each held at distinct voltages to detect particles of different electrical mobilities. The particles impact at the electrometer's surfaces and induce small electrical currents in each of the stages. These signals are inverted into a number based size distribution. Due to the quasi-simultaneous measurements at the electrodes and the fast flow through the sizing section, only small travel-time corrections are needed and even fluctuating size spectra in the sub-1 µm size range can be measured in real time. The high sample flow, e.g. 10 l/min, minimizes diffusion losses.

6.2.14.2 Capabilities of the method

The method allows a real-time measurement of sub-1 µm particle number concentration with a sufficient size resolution (e.g. 32 log-spaced size bins) and short time resolution (e.g. 1 s). Neither radioactive substances as charge conditioners nor working fluids are required. The instruments are typically easy to transport, setup and operate.

6.2.14.3 Limits of the method

Due to the inherent noise level of the electrometers, low concentrations are not easy to measure. The method doesn't allow a direct measurement of particle mass and is not suitable for measuring

particle sizes above 1 µm. The sample flow is rather high compared to traditional applications using a DMA or an AMS.

6.2.15 Low pressure impactor with electric detection (LPI+E)

6.2.15.1 Principle

The LPI+E operating principle can be divided into three major parts: particle charging in a unipolar corona charger, size classification in a cascade low-pressure impactor, and electrical detection with sensitive electrometers. The particles are first charged to a known charge level in the corona charger. After charging, the particles enter a cascade low-pressure impactor with electrically insulated collection stages. The particles are collected in the different impactor stages depending on their aerodynamic diameter, and the electric charge carried by particles into each impactor stage is measured in real time by sensitive electrometers. This measured current signal is directly proportional to particle number concentration and size. Thus, the system gives particle number concentration and size distribution in real time.

6.2.15.2 Capabilities of the method

The LPI+E can measure particles in real time with wide size range (from 7 nm to 10 µm) and high time resolution (10 Hz sample frequency), which allows a very good understanding of time-resolved measurement. The use of an electrometer for detecting the particles allows a more sensitive detection limit than traditional gravimetric measurement. Detection limit is a function of the particle size: 0,1 to 240 particles/cm^3 (0,000 2 µg/m^3 to 11 µg/m^3). The size resolution varies from 15 channels to 500 channels for the measurement range (5/decade to app. 160/decade) depending on the instrument model.

As particles are collected and can be measured gravimetrically, the LPI+E signal can be directly calibrated to the mass.

6.2.15.3 Limits of the method

LPI+E needs a vacuum pump. When using the pump, the user shall prevent the oil mist escaping in the pump exhaust. Use of a scroll pump with filtered exhaust is recommended.

Instrument flow rate is quite high compared to other techniques, which can be a problem for small rooms. Pump noise can be avoided by placing it outdoors when possible.

7 General sampling recommendations

7.1 Instrumentation and sampling system

Particular care should be taken to ensure that measurements remain within the specificities of the instruments, both in type and linearity. Instruments should be correctly calibrated and checked before use as recommended by the manufacturer or an existing International Standard.

The time response of the measurement system is a combination of the instrument time response and the sampling system time response. The effect of any sampling system configuration (sampling line, mixing chambers, dilution system, etc.) on the time response of the measurement system in total should be taken into account when planning and evaluating the time response of the measurement system. The effect of the sampling line should be either calculated before the measurement or determined during the measurement using a controlled particle source operated in step function (on-off).

Generally, it is advisable to use sampling systems with short sampling lines that have the smallest possible volume to avoid adding unwanted delays due to mixing or delays in the sampling. This also helps to minimize the particle losses.

The time constant in the sampling line should be in the order of the time response of the measurement instruments or less.

7.2 Measurement location

The measurement usually takes place in the centre of the room at approximately 1,5 m height (see ISO 16000-1). The distance to walls or large pieces of furniture can have an important impact.

A plan of the building premises, including the exact sampling location, should be added to the report (see Clause 11).

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

When using high time-resolving instruments, it is also possible to either make a time-resolved measurement plan, comprised of an array of sequential sampling spots, or to move the measuring instrument in order to quickly map out a much wider area. However, it is very important to compensate any sampling artefacts due to moving systems and to take account of any local changes compared to any changes in the whole source system. (All sources must be stable as a function of time. This often requires an additional time-resolved measurement reference.)

7.3 Measurement time and duration

The time at which the measurement is performed depends essentially on the potential source and its input. If one can specify exactly the beginning and end of particle release (e.g. for vacuum cleaning) and if a continuous measurement method is used, the measurement should start shortly before that (e.g. 1 h) in order to record the background state. Measurements should then be taken during the entire particle release phase and then for a follow-up time (also e.g. 1 h). It has been shown that after the end of active particle release by a source, it can take some time before particle concentrations in the air return to their starting level. During vacuum cleaning, for example, the process also swirls up sedimented particles and it can take one to two hours after the end of vacuuming before they settle again on the floor. In the case of electric appliances (printers, etc.), particle release may persist until the equipment has cooled down completely.

If no information is available about the time-resolved emission of a specific source, the timescale of the phenomena should be estimated by performing preliminary measurements with a method of sufficient time resolution.

As the determination of a sufficient timescale is subject to several independent factors, such as source, measurement method, environmental conditions and physical constraints, a single definite suggestion for time resolution cannot be given. Requirements for the time-resolved measurements are further complicated by the unfortunate fact that it is relatively uncommon for critical parameters of the source emission to be known prior to measurement. In practice, it is often necessary to make test-run measurements for as long as possible in order to establish the base parameters. The required timescale is also affected by the transient or periodical nature of the measured quantity.

If no information on the source or general variation of the measured parameter is available, it is advisable to use the highest time-resolution method possible. For most practical purposes, due to mixing and airflow, the highest time resolution achievable is in the order of a few seconds.

If the time-resolved measurement cannot be made in real time, it is advisable to make a discrete sampling plan based on the source emission timing properties. The sampling frequency should be at least double the estimated emission signal frequency.

7.4 Estimated concentration scale (minimum and maximum accuracy)

Estimation of the concentration scale is necessary to determine the suitable instrumentation and necessary sample conditioning (e.g. diluting or concentrating the sample). As the time-resolved

phenomena can be relatively short-scaled, this should be carefully considered in order not to exceed the instrument capabilities. Again, for unknown sources, this can be difficult to estimate before measurement.

For unknown situations, it is advisable to use the widest possible concentration scale method. For this purpose, it is possible to pre-condition the sample (with dilution or concentrator) in order to achieve a wider dynamic measurement range but the issues of sample loss, transportation and representativeness need be considered (see 7.7). Sample conditioning can only be used if the interference caused by it is fully understood.

The use of a high time-resolved method is also recommended in the explanatory phase and the results obtained can be used to prepare the longer timescale sampling, especially for the estimation of the collection time needed for gravimetrical methods.

7.5 Background concentration

Background measurements can be defined as the concentration present in the room in the absence of the specific investigated source.

Depending on the final purpose of the investigation, different background situations can thus be defined and do not necessarily correspond to an absence of particles in the room. Background results shall always be provided with an exact room activity description.

Background measurements provide important information, which should be reported. The difference between measurement and background should be high enough to highlight the impact of the investigated source or group of sources. Users should prove that the difference remains within the capability of the measurement method.

In case of assessment of limit value, no background measurement is required.

7.6 Impact of outdoor air quality

The outdoor (ambient air) concentration level of airborne particles can also have an impact on the indoor concentration levels due to possible input through transport between the indoor and outdoor environments.

Exact knowledge about the outdoor pollution level during the time of the indoor measurement campaign requires measurements both indoors and outdoors. For this reason, if outdoor air is expected to be the determining source of the indoor aerosol, parallel measurements are recommended (see 8.5.3).

In all other cases, the impact of outdoor fine dust pollution on indoor fine dust pollution should be assessed. General knowledge about the outdoor pollution level can be estimated from investigating available suitable ambient air monitoring data from regulatory monitoring stations in the vicinity of the measurement site, as well as by assessment of the local conditions with respect to topography, orography and potential sources (e.g. traffic, domestic burning, natural sources), as well as meteorological conditions.

Weather conditions have a direct effect on outdoor air quality. Rainfall and other precipitation wash out particles, thus decreasing concentrations in the air. For these reasons, weather conditions observed (e.g. presence of rain, sun, strong wind) shall be documented (see Annex A). It is also recommended to record outside temperature, humidity, wind speed and wind direction during the measurement. It should also be noted that rapid changes in ambient air concentration are not mirrored immediately indoors.

Quality of the building envelope (e.g. quality of window seals, building insulation) influence the air exchange rate and thus also the impact of outdoor air quality on indoor air concentration. For this reason, a visual description of the building envelope should be documented (see Annex A).

The chosen approach of estimating the influence of outdoor (ambient air) concentration should be described and justified. Estimations of the influence of outdoor (ambient air) concentration should be reported whatever the purpose of the investigation.

7.7 Impact of room conditions

When attributing fine dust particles indoors to particular sources and estimating the intensity of these sources, it should be borne in mind that the air/fine dust system is a dynamic one (see 5.1). The composition, the concentration and, to some extent, the state of matter of the fine dust change constantly. In the case of measurement methods that rely on determining particle sizes, it needs to be considered that, depending on relative air humidity, the particle size distribution may change as a result of water condensation on the particles present.

Room conditions (e.g. temperature, atmospheric pressure, relative humidity) during the measurement shall be recorded and reported.

The user's normal ventilation arrangements are usually maintained. The usage and ventilation conditions can be documented through concurrent measurements of CO_2 concentration. Basic information about the ventilation arrangement (e.g. windows open or closed, ventilation system on or off) shall be specified in the report (see Clause 11).

Hygiene status (e.g. presence of dust, moisture), room materials (e.g. floor, wall and ceiling material) and furniture present in the room (e.g. sofa fabric) is important information, which shall be reported (see Annex A). Construction materials can also emit some particles. The date and type of the latest renovation work should be specified.

7.8 Impact of the measurement itself

As stated above, the measurement instrument itself can induce a modification in the room being studied (e.g. wind created by a pump, exhaust of VOC in the room). The measurement procedure should take this aspect into account when selecting the technique and try to reduce this impact to the minimum.

Incorrect use of a method or losses in the sampling system can result in underestimating the real concentration of the room.

The main particle loss mechanisms that can affect the measurement are diffusion, electrostatic deposition, thermophoresis, sedimentation and inertial losses.

Sedimentation losses only affect particles above 2,5 µm. The losses are directly related to the length of the horizontal section and velocity in the sampling line. The easiest way to increase velocity and thus reduce sedimentation losses is to reduce the diameter of the tubing.

Inertial losses only affect particles above 1 µm and impact increases with diameter. Sharp curves and bends in sampling line should be avoided.

Thermophoretic losses can be considered to be neglected in indoor air measurements as long as the sampling system used is already at room temperature when performing the analysis.

Electrostatic losses should be eliminated by using earthed conductive material for the sampling lines and by using the shortest possible transport line.

Diffusion loss of particles drastically affects the fine fraction, which collapses on the wall due to Brownian motion. The magnitude of diffusion losses is highly dependent on particle size. For particles larger than 100 nm, diffusion losses can be neglected, but particular attention should be paid to smaller particles. Correction of the result to include theoretical losses is usually performed for particles smaller than 50 nm.

8 Measurement strategy for determining airborne particles indoors

8.1 General

This clause describes best practices for indoor aerosol measurement. The criteria below should be considered in planning, performing and evaluating aerosol source identification in a room. They may also be useful for reporting and comparing results.

8.2 Preliminary work — Definition of the measurement objective and list of basic information

8.2.1 General

Before performing measurements, the objectives of the measurement campaign should be discussed. The purpose of the measurement, room configuration, expected type and number of sources, specific uses of the room, rate of use of the room, etc., are factors that deeply influence the results and the measurement strategy.

This information is generally collected by telephone with the customer or by asking the customer to fill in a questionnaire, including a list of typical elements of interest.

The factors described in 8.2.2 to 8.2.5 should be taken into consideration. The decision should be justified in the report.

8.2.2 Statement on the purpose of the measurement

Give a concise description of the purpose. This could be regulatory, instrument test, emission test, scientific, etc.

Depending on the purpose, various goals can be relevant to the measurement. This could be peak emission determination, source appointment, dynamic source logging, understanding the emission process, quality assurance of longer timescale measurement, etc.

The purpose and list of objectives and restrictions will help to define an effective measurement plan later.

8.2.3 List of main expected sources

The indoor sources of particulate matter are diverse. The measurement strategy for source identification should be adjusted to the characteristics of the presumed source. Different particle numbers may be obtained by using measuring equipment where the effective range does not correspond to that used in the cited investigations. For this reason, the choice of the appropriate technique (see Clause 6) is critical.

If the premises are in use, the indoor aerosol is often affected by indoor sources, which may be located either in the investigated room itself or in adjacent rooms. Depending on the type of sources and on the objective of the study, combining different techniques could be necessary for a detailed room characterization.

The purpose of this preliminary list is to determine the range in size and number of particles that should be measured, and to make a realistic estimate of the number of sampling days required for the requested measurement, rather than to make a non-exhaustive list of the sources. This can also help to determine if an instrument should be used in the screening procedure (see 8.3) and the best device for this purpose.

8.2.4 Temporal effects

Particle concentration in indoor air can exhibit significant short-term variations. Particle release can last for long periods, especially where ambient air inputs dominate or exist only for a short time, e.g. during vacuum cleaning, frying or printing.

High-resolution measurements allow for a better understanding of the phenomena, but are not always possible depending on user objectives and available measurement techniques.

Individual measurement results, even where they encompass a whole day (24 h), are snapshots and contain insufficient information to describe the usage situation of a room adequately, taking into account ambient air and climatic conditions. On the other hand, for reasons of cost, measurements cannot be repeated in any arbitrary number that would be suitable to account for all the external effects. The following strategies are possible in order to record possible variations over time.

— Regular monthly measurements in order to record seasonal effects.

— Regular daily or weekly measurements in order to record effects caused by the user or when it is known that ambient air effects are present during a particular time.

Furthermore, three different operational states are defined.

— Resting state without equipment activity: The resting state without equipment activity is characterized by the absence of users and user activities and by switching off all fixed equipment (e.g. ventilation systems, gas heating, refrigerators, servers).

— Resting state with equipment activity: The resting state with equipment activity is characterized by the absence of users and user activities, but with operation of all fixed and/or constantly operated equipment.

— Active use state: The active use state is characterized by usage activities of the relevant persons and by the operation of all fixed and/or constantly operated equipment.

8.2.5 Description of the indoor compartment

A description of the indoor compartment should comprise:

— dimensions and volume;

— volume-to-surface ratio;

— existing links to other compartments;

— air conditioning and climate;

— air flow and ventilation:

  — Spatio-temporal variation may be caused by meandering of an aerosol plume in the surrounding, stagnant clean air. Room aerosol concentration gradients can be reduced by turbulence created by the ventilation system. This is important if local aerosol sources are to be measured. Hence, the following factors should be specified:

    — air exchange rate;

    — outdoor aerosol intake rate;

    — clean air intake rate;

    — air speed (shear flow);

— air flow direction;

— situational factors: moving persons, opening of doors and windows, rapid climate changes, etc., can change measuring conditions and have a strong impact on results. It is strongly recommended to record any obvious changes during measurements.

8.3 Visual room inspection — Definition of the measurement planning and strategy

In order to assign and evaluate individual indoor sources and sinks, the following circumstances, in particular, should be clarified through a visual inspection of the premises. Annex A shall be used and completed during the visual room inspection. Annex A shall be added to the final report as it provides important information for result interpretation.

A continuous measurement method with high time resolutions (see Clause 6) could also be used during this investigation step. This first measurement overview can indeed support expert judgement and help in the determination of the correct instrument choice and measurement planning.

At the end of this visual inspection of the premise, the purpose of the task, list of sources to characterize, type of instrument used for the measurement and measurement planning should be agreed with the customer.

The investigation should also take into account the following parameters:

a) Indoors:

1) the room's properties (fixed equipment, e.g. floor coverings, wall coverings, window type, soft furnishings, ventilation systems, heating sources);

2) the room's equipment (mobile appliances, e.g. refrigerators, cookers, television sets, computers, printers, toasters, vacuum cleaners);

3) the room's configuration (the building envelope's air tightness, especially windows, doors, the black dwelling phenomenon[24][25]);

4) the user's behaviour [activities, e.g. ventilation arrangements, movements, playing, cleaning, smoking, burning candles/incense sticks, keeping domestic animals, using household chemicals, fragrances (potential particle precursor substances)].

b) Outdoor air:

1) anthropogenic sources (e.g. road traffic, railways, shipping and air traffic, industry, commerce, agriculture, leisure facilities);

2) natural sources:

i) chemical sources (e.g. salt spray, particle reformation on high-insolation days);

ii) biological sources (e.g. agriculture, compost);

iii) physical sources (e.g. swirl-up of sand, biogenic particles);

3) external climatic conditions (e.g. wind direction and force, air humidity, insolation).

Source identification requires differentiation between the procedures chosen for different room types.

8.4 Preliminary measurements

Preliminary measurements are generally performed during the visual room inspection and using a fast-track investigation instrument (LSAS, CPC, etc.). Preliminary measurements are used with a view to enabling an objective expert judgement and selection of the correct instrument device.

Preliminary measurement sampling periods are generally short and can thus be deeply influenced by specific room circumstances. As a result, no direct conclusion can be drawn from preliminary measurement results without combining them with expert observation. It is recommended to document expert observations to avoid any misunderstanding. For the same reason, it is recommended that the user in charge of the preliminary measurements also perform the measurement campaign.

It is important to understand which parameters are needed or which parameters best delineate the task at hand. It is important to choose parameters which are representative for the goals defined. Sometimes it is necessary to select several parameters to form a definite picture of the source or emission processes. Parameters may include the physical properties of aerosols (mass, number, surface area, composition, structure, density, etc.). It is also sometimes necessary to include parameters for the time-dependent emission phenomena (duration, frequency, repeatability, etc.).

At the end of this visual inspection of the premises, the purpose of the task, the list of sources to characterize, the type of instrument used for the measurement and measurement planning should be agreed with the customer.

8.5 Measurement procedures

8.5.1 General

It is not possible to describe all particular cases, and measurement procedures are greatly influenced by the measurement objectives or tasks.

Furthermore, depending on the selected measuring device, specific additional recommendations arise. Additional techniques and recommendations can be found in other parts of the ISO 16000 series.

Each instrument should be correctly calibrated and checked before use, as recommended by the manufacturer or existing standard.

A non-exhaustive list of five main objectives, covering some usual measurement objectives or tasks, is described in this document.

8.5.2 Procedure for the determination of the background

8.5.2.1 Instrumentation and measurands

Background levels should be determined using the same instrument as the one used for conducting the measurement campaign. It is recommended to perform background measurements before each series of measurements and to repeat them several times, if possible.

Particular care should be taken to ensure the linearity of the instruments during the measurement step.

8.5.2.2 Measurement procedure

All important sources should be turned off well in advance of the measurement. Particle concentration decreases slowly and users should ensure that there is no impact any more.

The positioning of the instrument should be the same during the tests and background measurements. Except for the absence of the investigated sources, the room characteristics and parameters should remain as fixed as possible to allow for high comparability.

Instrument settings (e.g. ranges, time resolution) should be kept constant between background and final measurement to allow for high comparability.

8.5.2.3 Measurement planning and setup

Background sampling duration should be adapted to cover all possible background variations. If possible, a sampling duration equal to the future test period should be selected. Due to the potential

impact of external sources (outdoor, etc.), the background sampling period should be selected so that conditions are as close as possible to those observed during the future test measurements.

8.5.2.4 Evaluation

High average values generally indicate that important sources of pollution are present in the room. Users should ensure that future measurements remain in the accepted concentration range of the instrument.

Strong variation in the concentration is observed during background measurement indicates that a non-continuous source is present.

This source should be eliminated and investigated separately, if possible and depending on the purpose of the measurement.

8.5.3 Procedure for the estimation of the influence of outdoor (ambient air) concentration

8.5.3.1 Instrumentation and measurands

Indoor and outdoor measurements should be performed with two instruments of the same type to allow for parallel measurements. Device responses should be compared prior the measurement, by placing both instruments indoors in the same vicinity.

Furthermore, particular care should be taken to ensure the general suitability of the instrument for measuring outdoors, especially with respect to weather protection and sample conditioning (possible impact of relative humidity on the measured results).

8.5.3.2 Measurement procedure

Parallel measurements with one instrument indoors and one instrument outdoors shall be performed. Particular care should be taken to apply the same settings (e.g. ranges, time resolution) to the instruments to allow for high comparability. Furthermore, the instruments' clocks should be time-synchronized.

8.5.3.3 Measurement planning and setup

The positioning of the instrument measuring outdoor air should be selected carefully in terms of representativeness. The sampling point should be as close as possible to the main interface between outdoor and indoor air (e.g. outside an opened window, close to a ventilation air inlet) without suffering from possible interferences. A minimal distance of approximately 1 m from the building should be maintained in order to avoid wall effects.

If the investigated rooms are located on the street side, the fine dust content of the ambient air should be determined, as far as possible, at the same floor level and also on the building's street side. If the investigated rooms are located towards the courtyard or garden, the fine dust content of the ambient air should be determined, as far as possible from the street, at the same floor level and on that side of the building. In the case of a large office building, ambient air measurements can be conducted at representative parts of the building's façade. Ambient air measurements at ground level are not suitable for recording the effect of the ambient air on offices located on upper floors.

The duration of the outdoor measurement should cover the entire measurement time of the indoor measurement in order to be able to investigate trends and possible correlations over time.

8.5.3.4 Evaluation

The course of time of the parallel indoor and outdoor measurements is plotted and investigated.

If events and trends can be seen in both measurements, the contribution of outdoor pollution to indoor air quality should be taken into account as one major source of indoor air pollution and can be separately

reported depending on the purpose of the measurement. In case of low or no correlation, the influence of outdoor (ambient air) concentration can only be estimated with higher uncertainties and is usually simply integrated in the reported indoor concentration level.

8.5.4 Procedure for the identification of main sources present in a room

8.5.4.1 General

This procedure can assist in developing strategies for the identification of individual known or unknown sources under varying conditions. While every source can be characterized by its typical strength, the related impairment of the indoor air quality is situational. Identification of an indoor aerosol source can be understood as the clear (unambiguous) temporal and quantitative assignment of a local activity to the aerosol.

8.5.4.2 Instrumentation and measurands

In some cases, it is possible to infer the properties of an aerosol source to be measured (e.g. size distribution, size range, mass concentration, number concentration, composition) and choose adequate measurands and instrumentation beforehand. In the majority of cases, the aerosol source diverges considerably from those assumptions and a combination of instruments that covers a wide particle size range is often required. If that is technically not feasible or not intended, exclusion criteria should be mentioned and explicitly justified in the report.

Source identification requires instrumentation with good time resolution, which should in all cases be better than one scan per minute and if possible around one scan per few seconds, in order to identify onset and end of the source's emission activities. Usually, total particle number or total particle mass concentrations are appropriate measurands for a quick identification. Additional source information (size, etc.) will be obtained if required in a second step by an extensive investigation into each of the identified sources.

The lower and upper limits in size range and concentration of the instruments affect the visibility of a source. Instruments with overlapping size ranges avoid gaps in the detection size range. Verification or falsification of sources with emissions outside instruments' limits is not possible.

8.5.4.3 Measurement procedure

The measuring instrument is moved slowly to map out the entire area of the room. An increase in concentration indicates that a source is approaching. Measurement results are usually easily correlated with visual observations. Nevertheless, in complex situations, where several sources coexist and respective emissions mix together, source determination is sometimes more difficult. In such situations, it is recommended, if possible, to remove temporarily the impact of the sources already identified.

It is essential to compensate any sampling artefacts due to moving systems and to take account of any local changes compared to any changes in the whole source system. (All sources must be stable as a function of time, often requiring an additional time-resolved measurement reference.)

8.5.4.4 Measurement planning and setup

Prepare a time schedule for the measurement. Position the instrument sampling inlets in the room at a defined spot with good ventilation, e.g. the centre. Make sure that:

— the air speed at that spot does not interfere with instrument sampling;

— losses in sampling tubes are minimal. This is particularly important for particles in the lower nanometre range. Losses can be predicted theoretically and corrected.

Activate sources in slow succession with enough time in between to observe either a stable low concentration level or the onset of the concentration decay. A remote source activation from outside is preferable. If that is not feasible, take the measurement with an assistant in the compartment manually

activating the source(s). Make sure that the possible impact of the assistant on the results is clarified beforehand.

Record details of sources activation (e.g. onset, duration).

Check the instrument's readiness. Document all details of the setup, especially:

— number and character of sources (e.g. open fire, cooker, fan);

— horizontal and vertical distances of sources to the sampling spot;

— dimension of sources;

— technical details of sources (e.g. materials used, operation temperature, device type).

8.5.4.5 Evaluation

The sources can be identified by their temporal coincidence with the onsets of particle emissions. This is, however, a semi-quantitative method. Quantification and comparison of individual source strengths require a careful deconvolution of the mutual influences of all involved sources, also considering agglomeration, coagulation and particle losses. Source strengths can be quantified more easily by applying the procedure with one active source only. In this case, the aerosol should be observed until it reaches the background level again in order to gain sufficient data for indoor aerosol modelling.

8.5.5 Procedure for the measurement of the average and the time-resolved emission of a specific source

8.5.5.1 General

As the temporal variation of some emission sources can vary significantly, it is often useful or necessary to determine the emissions in much shorter timescales than that used for determining the average impact of the source. The reason for the time-resolved measurement can be the determination of the maximum concentration or peak emission, better understanding of the variation or dynamic situation of the source, determination of the source(s) or quality assurance of the measurement process itself.

However, the need for the time-resolved measurement brings some additional requirements to the measurement procedure (see 8.2.4).

8.5.5.2 Instrumentation and measurands

Any instrument with high time resolution covering the same range of size and magnitude can be used for this purpose. The easiest way is to use the same instrument as the one used for determining the average emission of the source. Nevertheless, if for practical or regulatory reasons, the average mass should be determined by an instrument with low time-resolved characteristics, an additional device may be used.

As the time-resolved methods can often generate vast amounts of data, a definition of the necessary amount of data, sampling sequences and number of source emission incidents (if possible) must be considered. This is to maximize the reachable information and to minimize the work needed to process the data, which may be considerable compared to the single-shot measurement data processing.

8.5.5.3 Measurement procedure

— Case 1: The same instrument is used for time-resolved emissions and average emissions of the source.

  The instrument is used with the higher time resolution. Particular care should be taken in the selection of the time resolution to avoid use of the instrument close to its detection limit. The average emission of the source is then calculated by mathematically averaging the recorded data.

— Case 2: Different instruments are used for time-resolved emissions and average emissions of the source.

  Both instruments are placed in the same vicinity and are run simultaneously during the whole test period to allow a correct comparison.

8.5.5.4 Measurement planning and setup

If no information on the source or general variation of the measured parameter is available, it is advisable to use the highest possible time-resolution method. For most practical purposes due to mixing and airflow, the lowest time resolution achievable is in the order of a few seconds.

Time-resolved measurement actions are similar to longer timescale measurements but some specific points need be considered, especially if external factors are likely to change significantly during the measurement period.

Difference in the time response of the two measuring system could affect the result and shall thus be taken into account.

In case of cyclic variation of the particle concentration (presence of high peak, very limited impact of one source in time, etc.), the total sampling period should be long enough to cover an entire number of cycles, in order to be representative.

8.5.5.5 Evaluation

Measurement results are usually presented in the form of a chart showing the concentration (mass or number concentration) as a function of time.

— Case 1: The same instrument is used for time-resolved emissions and average emissions of the source.

  The average emission of the source is calculated by mathematically averaging the data. Part of the data set can be selected or ignored depending on the measurement purpose (peak determination, resting period). Whatever the procedure followed, average results should always be interpreted in the light of the time-resolved emission effect.

— Case 2: Different instruments are used for time-resolved emissions and average emissions of the source

  Average results obtained by the continuous instruments should always be interpreted in the light of the time-resolved emission chart. In the case of cycling emissions of some sources, it is recommended to cover an entire number of cycles and to sample during a minimum of two cycles. Depending on the measurement purpose, some average measurement results should be rejected if they do not cover the right period of time (absence of particular emission during the investigated period of time, unexpected interference of another source when the investigated source is inactive, etc.).

8.5.6 Procedure for the estimation of the efficiency of an abatement techniques (i.e. filtration by air conditioning system

8.5.6.1 General

When measuring indoor particle concentrations, one result can be that the particle concentration is higher than desired. In this case, different abatement techniques with the aim of decreasing the particle concentration to which people are exposed can be employed, such as:

— removing an identified source;

— enclosing a source and using filters in the air exchange;

— changing the behaviour (forced fresh air exchange);

— actively filtering the air using an air conditioning system.

In order to determine the efficiency of an abatement technique, one measurement should be taken before the technique is employed, followed by a second measurement after giving enough time for the abatement technique to be effective.

8.5.6.2 Instrumentation and measurands

The same instrument should be used for both measurements. Measurements should be performed successively if possible. Instrument settings (e.g. ranges, time resolution) should be kept constant between both measurements to allow for high comparability.

8.5.6.3 Measurement procedure

It is important to use the same instrumentation and measurement location to conduct the measurements. The abatement technique should be applied well in advance. The particle concentration decrease indeed slowly and users should ensure that the stability has been reached before starting the measurement. A minimal sampling time of one hour is recommended.

8.5.6.4 Measurement planning and setup

Any changes to the room/environment besides the abatement technique should be avoided. If the room was populated during the first measurement, the same population and activity level should be ensured for the second measurement.

As the outdoor concentration can change between measurements and can influence the indoor measurement result significantly, it is essential to complement the indoor measurement with a parallel outdoor measurement.

8.5.6.5 Evaluation

Abatement efficiency can only roughly be estimated by applying this procedure and usually results in the determination of a simplified yield factor, such as the ratio between the average accumulated (total) particle number concentration levels before and after applying the abatement technique. The efficiency of air-conditioning systems, i.e. the air cleaning effect, may vary drastically with particle size. For broad particle size distributions, it is therefore advisable to do size-resolved measurements and to calculate individual abatement efficiencies for each of the measured particle size bins.

9 Uncertainty evaluation

The evaluation of the measurement uncertainty is an essential component of any air quality measurement. Any statement on whether measurement results are equal or distinct can only be made on the basis of an uncertainty evaluation. The measurement uncertainty is the combination of the uncertainties of the measuring device and any other unavoidable identified or unidentified sources, such as randomly fluctuating measurement conditions. Manufacturers usually provide information about instrument uncertainties, but in many cases the contributions from other sources cannot be described mathematically and the overall measurement uncertainty must be estimated experimentally. It is advisable in these cases to apply a Type A evaluation of the standard uncertainty. It assumes random variations within repeated measurement of a quantity q_k (e.g. the particle number concentration) under

conditions kept as constant as possible. The best approximation of its true value is then given by its arithmetic mean value, as shown by Formula (1):

$$\bar{q} = \frac{1}{n} \sum_{k=1}^{n} q_k \tag{1}$$

The result of a measurement should then conveniently be reported as shown by Formula (2):

$$q = \bar{q} \pm U \tag{2}$$

where U is the expanded uncertainty which is obtained by multiplying the combined standard uncertainty $u_c(q)$ by a coverage factor k. The combined Type A standard uncertainty is calculated by Formula (3):

$$u_c(q) = \sqrt[2]{\frac{s^2(q_k)}{n}} \tag{3}$$

with the experimental standard deviation $s(q_k)$of the measured values q_k. It can be assumed that taking $k = 2$ or $k = 3$ produces levels of confidence of approximately 95 % or 99 %, respectively. Several concepts for uncertainty evaluations are described in ISO/IEC Guide 98-3.

Additional information can also be found in ISO/IEC Guide 98-3 and ISO 20988.

10 Evaluation and reporting of results

Evaluation and reporting of the measurement results should be performed. Specified technical regulations can apply for each particular measurement method.

11 Documentation

A complete test report should include the following information.

— Detailed and clear description of the reason for conducting the measurements, the measurement objective and the derived measurement strategy.

— Description of the measurement method and of primary measurands. Description of the calculation principles and calculated measurands (e.g. when converting particle counting results into mass, surface area). Description of the measuring devices used and their detection and measurement limits.

— Description of the prevailing conditions in accordance with the sampling protocol (see Annex A).

— Full description of the location of the measuring point, sampling period, operators and instrumentation.

— Visual observation of the weather conditions (i.e. raining or not). Outdoor weather can have a strong influence on the results if outdoor input is important.

— Measurement results.

— Estimate of measurement uncertainties in accordance with ISO 20988.

— Detection limits and measurement limits.

— Any deviation from the provisions of this document and the reasons for doing so.

12 Quality assurance

12.1 Performance specifications

Quality assurance should be performed according to the specified technical standard for each particular measurement method.

Typical relevant specifications are as follows.

— Measurement uncertainty.

Temporal fluctuations and shifts of an instrument's reading may be due to the limited stability of the instrument in use or may be affected by fluctuations of situational factors, such as air exchange. They can also reflect actual changes in the investigated aerosol and its sources. Observed variable readings below the specified measurement uncertainty of the instrument should be considered as artefacts rather than as significant. The selection of instruments with sufficiently low measurement uncertainty is part of the measurement strategy.

Users shall refer to specific International Standards or guideline or instrument manuals to determine how to assess their measurement uncertainty. Figure 3 provides a non-exhaustive list of International Standards describing some of the listed techniques in detail and providing information regarding typical measurement uncertainty.

— Electronic noise.

The measurement noise may be correlated to instrument settings, such as data sampling frequency, time resolution and signal processing time. As with measurement uncertainty, it shall be checked beforehand that the instrument's noise level is sufficiently low. This is especially important for instruments using electrometers as sensors.

— Dynamic concentration range (lowest detection limit, maximum concentration).

The measured particle concentration may vary drastically with time and may temporally exceed or fall below detection limits of the instrument. If not indicated by instrument error messages, the measured data shall be carefully checked for these events.

— Particle size detection range.

Previous knowledge or assumptions about the expected particle distribution may be useful to select instruments with an appropriate size range in order to meet the set goals for the measurement. The unexpected occurrence of particles with sizes outside the instrument's size detection range shall always been taken into consideration and a combination of instruments with complementary size ranges may be necessary. A combined presentation of particle size distributions or a comparison of size spectra from different instruments shall always use normalized data (dW/dlogdp), where the measured or calculated weight (W) — number, surface, volume or mass — is normalized to the width of the size bins.

— Time resolution.

It shall be considered that the sampling rate often quoted on instrument specifications is not necessarily the same as the actual time resolution. For example, size scanning instruments, such as the DMAS, use fast particle counters but may, due to the durations of scanning intervals, not be able to record quick changes in size distribution and/or concentration of an aerosol.

— Interference factors.

Possible instrument response interference factors to be considered for time-resolved measurement are: gas interference, gas to particle formation, volatility of particles, effect of volatility during sampling and measurement, effect of humidity and temperature as function of time. Instrument and measurement conditions shall be matched so that the interference of external factors can be eliminated or they are minimized to insignificant level.

If particles partly or completely consist of volatile components, losses due to evaporation may occur inside measuring instruments and sampling lines. Also, very high levels of humidity (condensing conditions) can be disturbing. It is advisable to periodically check the potential effect of volatility for example by changing the sample line temperature or using a drying unit as part of the sample conditioning.

12.2 Quality assurance when determining particle number concentrations

12.2.1 General

When measuring particle number concentrations, the conditions specified in ISO 16000-1 shall be observed. Special attention should be paid to the aspects listed in 12.2.2 to 12.2.3.

12.2.2 Sampling volume flow

The sampling volume flow is an essential variable in aerosol metrology. A user may apply calibrated volume or mass flow measuring devices to check for a correct volume flow. The measurement uncertainty of the flow meter used should be better than that of the equipment's own volume flow measurement. It is important to ensure that the pressure drop caused by the reference device does not unduly affect the volume flow of the equipment being tested. Care shall be taken to correct for the effects of gas temperature and pressure on the instrument readings.

12.2.3 Checking the equipment's parameters

Instrument manufacturers provide factory calibration certificates for their instruments, which provide sufficient information on measurement uncertainties in many cases. For some types of aerosol instruments (DMAS and CPCs), independent periodic calibrations based on International Standards (e.g. ISO 27891 and ISO 15900) with specific test aerosols are feasible.

The instrument status (e.g. date and result of internal or external calibration, date of last maintenance) should be thoroughly checked and documented beforehand.

12.3 Quality assurance when determining particle mass concentrations

12.3.1 Mass concentration calculation based on measured number concentration

Mass concentration calculation from number concentration data induces high uncertainty and is based on several assumptions (spherical particles, absence of aggregation, assumed particle density, etc.). Particle sizing uses different principles (aerodynamic mobility, electric mobility, light scattering, etc.), which provide different information on particle diameters.

For outdoor aerosols, EN 12341 describes a proof of equivalence procedure for an optical particle size spectrometer (OPSS), which is used for mass concentration measurements. This procedure is not directly applicable to indoor aerosol mass concentration measurements with an OPSS, as the indoor particle density distribution can, depending on the case, differ substantially from that of typical outdoor aerosols.

12.3.2 Gravimetric mass concentration measurement

12.3.2.1 General

Systematic errors and measurement uncertainties associated with gravimetry are influenced, firstly by the accuracy of the scales and the quality of weighing (i.e. by the ratio of the deposited particle mass to the filter's weight), secondly by filter handling (change of mass by evaporation losses and change of humidity), and thirdly by the quality of the sampling volume measurement as a reference volume.