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Indoor air —

Part 5: Sampling strategy for volatile organic compounds (VOCs)

Air intérieur —

Partie 5: Stratégie d'échantillonnage pour les composés organiques volatils (COV)

Reference number
ISO 16000-5:2007(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16000-5 was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 6, *Indoor air* and by Technical Committee CEN/TC 264, *Air quality* in collaboration.

ISO 16000 consists of the following parts, under the general title *Indoor air*:

— *Part 1: General aspects of sampling strategy*

— *Part 2: Sampling strategy for formaldehyde*

— *Part 3: Determination of formaldehyde and other carbonyl compounds — Active sampling method*

— *Part 4: Determination of formaldehyde — Diffusive sampling method*

— *Part 5: Sampling strategy for volatile organic compounds (VOCs)*

— *Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas chromatography using MS/FID*

— *Part 7: Sampling strategy for determination of airborne asbestos fibre concentrations*

— *Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions*

— *Part 9: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test chamber method*

— *Part 10: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test cell method*

— *Part 11: Determination of the emission of volatile organic compounds from building products and furnishing — Sampling, storage of samples and preparation of test specimens*

— *Part 12: Sampling strategy for polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polycyclic aromatic hydrocarbons (PAHs)*

— *Part 13: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls and polychlorinated dibenzo-p-dioxins/dibenzofurans — Collection on sorbent-backed filters*

— *Part 15: Sampling strategy for nitrogen dioxide (NO_2)*

— *Part 16: Detection and enumeration of moulds — Sampling by filtration*

— *Part 17: Detection and enumeration of moulds — Culture-based method*

The following parts are under preparation:

— *Part 14: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls and polychlorinated dibenzo-p-dioxins/dibenzofurans — Extraction, clean-up and analysis by high-resolution gas chromatography/mass spectrometry*

— *Part 18: Detection and enumeration of moulds — Sampling of moulds by impaction*

Furthermore, ISO 16017-1 and ISO 16017-2 deal with VOC measurements.

Introduction

In ISO 16000-1, general requirements relating to the measurement of indoor air pollutants and the important conditions to be observed before or during the sampling of individual pollutants or groups of pollutants are described.

This part of ISO 16000 describes basic aspects to be considered when working out a sampling strategy for the measurements of volatile organic compounds (VOCs) in indoor air. It is intended to be a link between

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

— the analytical procedures described in ISO 16000-6, *Indoor air, Determination of volatile organic compounds in indoor air and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas chromatography using MS/FID*, and

— the more generic ISO 16017-1, *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 1: Pumped sampling and* ISO 16017-2, *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 2: Diffusive sampling*.

This part of ISO 16000 presupposes knowledge of ISO 16000-1.

The sampling strategy procedure described in this part of ISO 16000 is based on Guideline VDI 4300 Part 6 [1].

Indoor air —

Part 5:
Sampling strategy for volatile organic compounds (VOCs)

1 Scope

This part of ISO 16000 is intended as an aid to planning volatile organic compound (VOC) indoor pollution measurements. In the case of indoor air measurements, the careful planning of sampling and the entire measurement strategy are of particular significance since the result of the measurement may have far-reaching consequences, for example, with regard to the need for remedial action or the success of such an action.

An inappropriate measurement strategy may contribute to the complete uncertainty of the measurement result in a larger extent than the measurement procedure itself.

This part of ISO 16000 uses the definition for indoor environment defined in ISO 16000-1.

2 Normative references

The following referenced documents are indispensable for the application 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 — General aspects of sampling strategy*

ISO 16000-6, *Indoor air — Part 6: Determination of volatile organic compounds in indoor air and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas chromatography using MS/FID*

ISO 16000-8, *Indoor air — Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions*

ISO 16017-1, *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 1: Pumped sampling*

ISO 16017-2, *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 2: Diffusive sampling*

3 Definition of volatile organic compounds (VOCs)

Numerous organic compounds are present in indoor environments. Depending on volatility, these are present in the gas phase or are bound to suspended particulate matter or deposited dust. A working group of the World Health Organization WHO [2] classified organic compounds based on boiling point (see Table 1).

Table 1 — Classification of organic pollutants of indoor air [2]

Description	Abbreviation [a]	Boiling point range		Saturation vapour pressures	Examples of sampling media [a]
		from °C	to °C	kPa	
Very volatile organic compounds	VVOC	< 0	50 to 100	> 15	Activated carbon, cooled sampling media, molecular sieves, canister method
Volatile organic compounds	VOC	50 to 100	240 to 260	$> 10^{-2}$	Tenax® 1), graphitized carbon or activated carbon
Semi-volatile organic compounds	SVOC	240 to 260	380 to 400	10^{-2} to 10^{-8}	PUF [b] or XAD-2® 1)
Particulate organic matter	POM	> 380			Filters

[a] The WHO information has been supplemented.

[b] Polyurethane foam.

This classification, based primarily on the boiling point, takes into account aspects of the analysis, especially gas chromatography. Since the transition points are fluid here, it is not useful to specify sharp limits for the boiling point ranges and the sampling media to be selected.

NOTE 1 Boiling points of some compounds are difficult or impossible to determine because they decompose before they boil at atmospheric pressure. Vapour pressure is another criterion for classification of compound volatility that may be used for classification of organic chemicals [3].

NOTE 2 TVOC (total volatile organic compounds) is defined in ISO 16000-6.

4 Sources and occurrence

Several hundred VOCs have been detected in indoor air, stemming from various sources. These sources may be present in the room continuously or intermittently. The most important continuous sources are all kinds of building products, furniture, and room textiles. Intermittent sources include household products and products for renovation, as well as the occupants and a number of their activities, such as smoking and hobby work. Ambient air shall also be considered as a source although its contribution to indoor air pollution by VOCs is generally less important.

The various types of sources mentioned in the preceding paragraph emit a wide range of different VOCs into the indoor air. They also have different emission profiles. As the goal of most indoor air analyses is to provide as representative information as possible on the air pollution status of a room, taking into account the emission characteristics, it is important to develop a sound measurement strategy. In addition, it shall be considered that VOC concentrations in indoor air vary from room to room and are also subject to change over time.

It is difficult to establish a comprehensive list of which VOCs are emitted from which sources because of the ongoing variation in the production of products and the resulting change in the composition of the mixture of VOCs emitted. The VOCs listed in Annex A represent an overview of VOCs that are frequently found in indoor

1) The sorbents listed in Table 1 and elsewhere in this International Standard are those known to perform as specified under this part of ISO 16000. Each sorbent or product that is identified by a trademarked name is unique and has a sole manufacturer; however, they are widely available from many different suppliers. This information is given for the convenience of users of this part of ISO 16000 and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

air. A good overview of the VOC concentrations in indoor air of many countries are given in Reference [4]. The compounds mostly belong to one of the following chemical classes: aliphatic hydrocarbons such as alkanes and cycloalkanes, aromatic hydrocarbons, terpenes, aldehydes, ketones, alcohols, alkoxyalcohols, esters, ethers, and halocarbons.

This listing does not include a number of groups of compounds such as carboxylic acids, isocyanates or amines. Although these VOC may be present in the air of a room they will not readily be detected with the analytical methods routinely applied for VOC. Correct determination of these “special” VOCs, which may also include a number of polar compounds, requires more complex analytical work.

NOTE Sampling and analysis method for formaldehyde and other low boiling aldehydes are given in ISO 16000-3 [5] and ISO 16000-4 [6].

5 Measurement technique

5.1 General

The methods for determining VOCs in indoor air may be divided into short-term and long-term measurement methods, herewith assuming that determination of individual VOCs is considered. The basics of sampling and analysis methods used for VOC analysis are described in ISO 16017-1 and ISO 16017-2. When using active sampling for VOCs from indoor air, ISO 16000-6 shall be used. (A protocol for recording activities and boundary conditions during sampling is given in Annex B.)

5.2 Short-term measurements

Short-term measurements are generally understood to involve a sampling period from less than one hour to a few hours depending on the purpose of the measurement.

The VOCs are concentrated in the sampling medium by air being drawn through the sorbent using suction pumps (active sampling).

The sampling flow rate and the final sampling volume shall be selected as a function of the breakthrough volumes of single VOCs (see ISO 16017-1).

5.3 Long-term measurements

Although it is possible to perform long-term measurements using active sampling with low air flow rate, for this application, sampling using diffusive samplers is the method of choice [7] to [18]. Passive samplers, from here on called “diffusive samplers”, predominantly work according to the diffusion principle and give an integrated measurement value as a mean over the selected exposure period (usually from a few days to several days or weeks). In this method, short-term peak concentrations contribute towards the longer-term mean value given by ISO 16017-2.

6 Sampling and measurement planning

6.1 General

When carrying out indoor air analysis, the procedure depends on the measurement purpose and the emission characteristics of possible sources. Since sources that emit continuously and over long periods are typically the most important, the following subclauses specifically target these types of sources.

6.2 Measurement objective and environmental conditions

6.2.1 General

Before indoor air measurements are carried out, the objective of such measurements shall be clearly defined. Also, independently of the objectives listed below, it shall be made clear in advance whether it is wished to determine the concentration of a single organic compound, or a relatively small number of predetermined VOCs or to record and evaluate the entire VOC profile. If necessary, the measurement strategy shall be orientated accordingly.

Depending on the objective, different environmental conditions shall be maintained or recorded before and during measurements. These environmental conditions principally relate to the ventilation condition, the room temperature and the relative humidity.

6.2.2 Clarification of the reasons for complaints from room occupants, possibly in association with checking compliance of guideline values for indoor air using short-term measurements

6.2.2.1 General

In many cases, indoor air analyses are initiated by various types of complaints expressed by the room occupants. Complaints of this type can range, e.g. from the perception of unknown and frequently unpleasant odours, to headaches, nausea or irritation of the nose, throat or eyes. If VOC guideline values exist and these are time-related, the measuring or sampling period shall correspond to the specified time interval. VOC measurement is carried out under the conditions described below.

6.2.2.2 Naturally ventilated rooms (rooms without mechanical ventilation)

After intensive ventilation for 15 min, doors and windows of naturally ventilated rooms are kept closed for about 8 h (optimally overnight) prior to measurement, without additional sealing measures such as taping over window and door gaps. Sampling is then performed (see ISO 16000-6) with the room still closed off.

To obtain information on the effectiveness of hourly intensive ventilation, the room is ventilated intensively after sampling by opening doors and windows for 5 min. Doors and windows are reclosed and after a waiting time of 1 h a further sample is taken.

6.2.2.3 Rooms with mechanical ventilation

When rooms which are ventilated by mechanical ventilation or air conditioning (VAC) systems are investigated, the system shall be operated according to the building codes or other normative guidelines and the required ventilation shall be in operation at least for 3 h before the sampling is started.

The functioning of the ventilation system should be recorded or measured (see ISO 16000-8).

Rooms operated according to specified ventilation instructions (for example, schools and kindergartens where windows have to be opened after specified time periods), one complete and typical operating cycle has to be carried out prior to measurement.

If room occupants make complaints during unusual conditions, for clarification, measurements should also be performed under these conditions. The functioning of the ventilation system shall be recorded or measured (see ISO 16000-8).

The investigated spaces should preferably be operated according to the building codes or design guidelines and especially in complaint cases any deviation shall be the reported.

The VOC concentration level depends, if conditions are otherwise constant, on the indoor air temperature to a large extent, and possibly also on the relative humidity. To obtain meaningful indoor air VOC concentrations, it is therefore essential to perform the measurement under the climate conditions under which the room being investigated is usually used. If these conditions are outside the comfort zone, then it shall be indicated that complying with these conditions should take precedence over other measures for reducing the VOC concentration.

6.2.3 Determination of the average concentration over a relatively long time period (exposure studies)

To carry out long-term measurements, diffusive samplers are generally used. In these cases, the room does not need to be prepared if the measurement period exceeds 24 h. Usually the sampling period does not exceed one month. In each case, the decisive factor is the performance of the sampler used with respect to stability of the sampling medium and the VOC collected.

In the case of long-term monitoring, the room occupants should continue their usual ventilation behaviour and other activities. The common activities shall be clarified and documented before the examination. It is of particular importance here to obtain knowledge of the activity of intermittent sources. If deviations therefrom occur during the sampling period, these shall also be documented.

NOTE Annex D of ISO 16000-1:2004 gives guidelines for information to be recorded during indoor air measurement.

6.2.4 Determination of the concentration occurring under special conditions

In some cases, it can also be of interest to obtain information on the level of VOC concentrations under special conditions. Such special conditions may occur, firstly, if a room is used under unfavourable climatic conditions, for example, at temperatures or relative humidity outside the comfort region without the room occupants being able to alter this. Secondly, the emission of VOCs from sources which emit temporarily, for example, when a solvent is used, can also be an unusual situation of this type. Accordingly, a short-term measurement is performed under the conditions which are expected to give rise to elevated VOC concentrations.

NOTE The conditions for thermal comfort of temperate climate are described in ISO 7730 [19]. In the case of extreme climatic conditions, ISO 7243 [20], ISO 7933 [21] or ISO/TR 11079 [22] are available.

6.2.5 Identification of sources

If unusual concentrations of VOCs occur, it is of interest to identify the source. The potential sources, such as building materials, interior furnishings, office materials or cleaning agents often have typical emissions reflected in the indoor air. Therefore, it is important to know the emission characteristics of materials and products. The following procedures are suitable for tracing of material sources:

— odour;

— comparison between the results of air measurements in the centre of the room and in the vicinity of the potential source;

— in building-related sources, the emission is measured directly from the suspected structure using a transportable emission test cell, which can be set up on flat surfaces (see ISO 16000-10 [23] and Reference [24]). Alternatively, in some cases samples of materials may be removed for laboratory testing.

Source identification measurements are performed using short-term sampling (ISO 16000-6).

If continuous sources are to be monitored in isolation of other sources, the influence of intermittent sources shall be excluded or minimized (see Table 2).

6.2.6 Checking the success of remedial activities

Measurements are made before and after completion of remedial activities. The indoor air conditions shall be selected here to ensure comparability with the initial measurements. Attention shall be paid as to whether new substances have been introduced into the interior as a result of the remediation measures chosen.

NOTE When new materials such as flooring materials are introduced into an interior space, the indoor air VOC concentrations are high during the first two to twelve months depending of the ventilation efficiency of the space.

6.3 Time of sampling

The sampling time is determined by the measurement purpose. When the results of measurement are interpreted, one shall take into account the concentration variations that occur during relatively large time periods. For example, changes in concentration may occur due to seasonal variations and short-term effects such as changes in source strength and ventilation. *Cigarette smoking or the use of chemicals (e.g. for cleaning) shall be forbidden during air sampling, if there is no intention to take these pollutants into account for the evaluation of the measurement results.* Table 2 gives an overview of important VOC sources and their emission characteristics.

When the change in VOC concentration with time is being considered, two categories of sources may be differentiated: continuous sources which are active over relatively long time periods (months, years) and intermittent sources which are only active over shorter periods (days, hours). More detailed consideration of the emission profile results in further differentiation: each of the two main categories may be subdivided into two groups, those in which the pattern is constant and those in which it is variable with time.

6.4 Duration of sampling and frequency of measurement

The sampling duration is determined first by the measurement purpose and second by the characteristics of the analytical method chosen, for example by the detection limit and the breakthrough volume expected in association with the sorbent chosen.

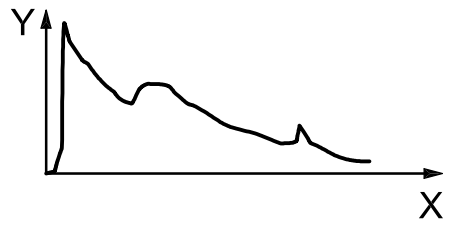
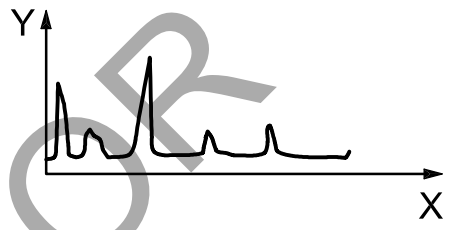
Particular attention shall be paid to the sampling duration in measurement planning if complaints are the reason for the measurements. Thus, for example, it shall be taken into account that short-term measurements only rarely permit conclusions to be drawn with respect to a mean value valid for longer time periods. On the other hand, long-term sampling leads to a loss of information with respect to the variation with time of the VOC concentrations and particularly with respect to the frequency of the occurrence and the magnitude of peak concentrations.

The frequency of measurements shall be incorporated into the measurement plan in accordance with the measurement purpose and should also be based on the measurement uncertainty.

Table 2 — Emission characteristics of VOC sources

Emission characteristics and indoor air concentration	Example of source	Example of emitting VOCs
Continuous	Building products	
– active over a long period		
– uniform, short term changes in emission rates are low	– PVC	plasticizers, viscosity modifiers, solvent residues, antioxidants, stabilizers
	– linoleum	linseed oil and oxidation products as process residues
	– cork	binders, thermal degradation products
	– parquets and wooden furniture	wood extractives, solvent from varnishes, surface treatment oils and waxes
X time Y concentration		

Table 2 (*continued*)

Emission characteristics and indoor air concentration	Example of source	Example of emitting VOCs
Continuous – irregular, decaying  X time Y concentration	Paints, adhesives	Organic solvents, coalescing solvents, film forming reaction products, film degradation products
Intermittent – active in the short term – uniform – periodic time pattern  X time Y concentration	Cooking Smoking	combustion products, fats and oils, VOCs from spices hundreds of VOCs typical for incomplete combustion
Intermittent – irregular – variable time pattern  X time Y concentration	Cleaning and maintenance agents Hobby products	wood oils, essential oils, fragrants, co-solvents solvents, plasticizers
Ambient sources Indoor concentrations depend on ventilation, distance from the source, building characteristics and meteorological conditions	Traffic, industrial sources, contaminated sites	Large variety of source-dependent VOCs

6.5 Sampling location

It is generally not necessary to investigate every room in a large building or apartment complex. Prior to initiating the monitoring program, appropriate rooms shall be identified for VOC sampling. The criteria for selection are typically the room usage or the occurrence of complaints. Rooms that are occupied for long periods such as living rooms and bedrooms, classrooms and kindergartens, and offices, may be of particular interest.

The sampling location within a room can also influence the result of the measurement. Frequently, higher concentrations are observed in the immediate vicinity of an emission source than anywhere else in the room.

To identify source(s), the measurements can be performed close to the suspected source(s) and at a further distance from those source(s) within a room.

When the compliance with a guideline value is being checked, a procedure should be followed such that sampling is performed at a minimum distance from the walls of 1 m to 2 m and at about the same height above the ground as the sampling point in the room. In that case, one sampling point per room is generally sufficient.

For particular purposes, it can be useful to determine the ambient air concentration for comparison with the indoor air. The ambient air should, if possible, be measured at least 2 m from the building wall at about the same height above ground as the sampling point in the room.

NOTE Sometimes, depending on the pressure differences between spaces, it is possible that pollutants from neighbouring spaces such as stair cases are transported to room investigated.

In the case of buildings fitted with air-conditioning, the ambient air measurement shall be carried out in the vicinity of the ambient air supply inlet.

6.6 Presentation of results and measurement uncertainty

6.6.1 Presentation of results for individual VOC components and TVOC concentration

During measurement planning, the relevant parameters shall be specified. The used parameters shall be notified in the report and the measurement uncertainty shall be specified.

The results of a determination including gas chromatographic separation of VOCs are reported in the form of the concentrations of the individual compounds.

When passive samplers are used, the conversion formulae used to calculate the result, including the diffusion coefficients or absorption rates, shall be specified.

To assess the overall situation, frequently a single concentration value is used as a basis, which is intended to characterize the total VOC concentration (TVOC concentration).

It shall be stated that not all of the VOCs present in the indoor air are included in a TVOC concentration determined in this manner. Low-molecular-mass aldehydes, amines and highly polar VOCs, especially, may not be determined meaningfully using a method which is currently common for gas chromatographic determination of VOCs in air, and shall be determined separately using suitable methods.

6.6.2 Measurement uncertainties

Measurement uncertainties are unavoidable. The overall uncertainty of the measurement is determined by the number of measurements made and by the individual uncertainties in the sampling and analytical methods used. An example of the effect of the number of samples on the uncertainty of the reported result is given in ISO 16000-2:2004[29], Annex D. The representative nature of the result of each single measurement is influenced, in addition, by concentration changes in time and space.

The measurement report shall include, in addition to a reference to the analytical method used, a description of the performance characteristics valid at the time the measurements are made, especially the limits of detection and determination.

In the measurement results, the numerical data are usually reported so that the last decimal place (significant place) represents the order of magnitude of the measurement uncertainty at the same time.

6.7 Quality assurance

The measurement plan shall specify what measures to be taken to meet the quality requirements specified by the client.

It is advisable to carry out replicate sampling. One or more of the samples may be archived for later analysis if desired. The recovery rates shall be documented.

The criteria for selection of a contractor or laboratory to perform VOC measurements should include the following criteria:

— Does the contractor (laboratory) have a documented quality assurance system?

— What calibration methods will be carried out, with what frequency and to what extent?

— Which methods will be used to identify the VOCs

— Are duplicate measurements or comparative measurements (for example, with other laboratories) to be carried out?

— How will the measurement uncertainties be determined?

— In which interlaboratory tests has the contractor (laboratory) participated, and with what results?

Annex A
(informative)

Examples of organic chemicals detected in indoor air

Table A.1 — Examples of some organic chemicals [25] that may be measurable by ISO 16000-6

Chemical compound	CAS number	Boiling point °C [a]	Vapour pressure kPa (25 °C)
Aromatic hydrocarbons			
Benzene	71-43-2	80	10,1
Toluene	108-88-3	110	2,9
Ethylbenzene	100-41-4	136	0,93
m/p-Xylene	108-38-3 / 106-42-3	139 / 138	0,67 to 0,87
o-Xylene	95-47-6	144	0,7
n-Propylbenzene	103-65-1	159	0,3
1,2,4-Trimethylbenzene 1,3,5-Trimethylbenzene	95-63-6 108-67-8	169 165	0,15 to 0,2
2-Ethyltoluene	611-14-3	165	0,4
Styrene	100-42-5	145	0,88
Naphthalene	91-20-3	218	0,01
4-Phenylcyclohexene	31017-40-0	251	
Aliphatic hydrocarbons			
***n*-C_6 to *n*-C_{16}**			
n-Hexane	110-54-3	69	20,1
n-Heptane	142-82-5	98	4,7
n-Octane *n*-Nonane	111-65-9 111-84-2	126 151	1,4 0,5
n-Decane *n*-Undecane	124-18-5 1120-21-4	174 196	0,13 0,14
n-Dodecane	112-40-3	216	0,04
n-Tridecane *n*-Tetradecane	629-50-5 629-59-4	235 253	0,003 4 0,001 3
n-Pentadecane	629-62-9	270	
n-Hexadecane 2-Methylpentane	544-76-3 107-83-5	287 60	0,000 9 [26] 16
3-Methylpentane	96-14-0	63	Ca.16
1-Octene	111-66-0	121	2,3 [27]
1-Decene	872-05-9	170	0,22 [27]
Isobutene	115-11-7	−7	257 (20 °C)
Cycloalkanes			
Methylcyclopentane	96-37-7		18,3
Cyclohexane	110-82-7	81	12,7 (20 °C)
Methylcyclohexane	108-87-2	101	5,73
Terpenes			
3-Carene	13466-78-9	167	
α-Pinene	80-56-8	156	5 [27]
β-Pinene	18172-67-3	164	< 5
Limonene	138-86-3	170	0,19

Table A.1 (*continued*)

Chemical compound	CAS number	Boiling point °C [a]	Vapour pressure kPa (25 °C)
Alcohols			
2-Propanol	67-63-0	82	32 (20 °C) [27]
1-Butanol	71-36-3	118	4,4 [27]
2-Ethyl-1-hexanol	104-76-7	182	0,11 (20 °C) [27]
Benzyl alcohol	100-51-6	205	0,3 (20 °C) [27]
Glycols / Glycol ethers			
2-Methoxyethanol	109-86-4	124 to 125	0,8
2-Ethoxyethanol	110-80-5	135	0,51
2-Butoxyethanol	111-76-2	171	0,1
1-Methoxy-2-propanol	107-98-2	118	1,2 (20 °C)
2-Butoxyethoxyethanol	112-34-5	231	0,003 (20 °C)
2-Phenoxyethanol	122-99-6	245	0,001 (20 °C)
Aldehydes			
Butanal	123-72-8	76	12,2 (20 °C)
Pentanal	110-62-3	103	3,4 (20 °C)
Hexanal	66-25-1	129	3,5 (20 °C)
Nonanal	124-19-6	190 to 192	0,048
Benzaldehyde	100-52-7	179	0,13 (20 °C)
Ketones			
Methylethylketone	78-93-3	80	10,3
Methylisobutylketone	108-10-1	117	0,8
Cyclohexanone	108-94-1	156	0,45
Acetophenone	98-86-2	202	0,13 (15 °C)
Halocarbons			
Trichloroethene	79-01-6	87	2,7
Tetrachloroethene	127-18-4	121	1,87
1,1,1-Trichloroethane	71-55-6	74	2,7
1,4-Dichlorobenzene	106-46-7	173	1,2
Esters			
Ethyl acetate	141-78-6	77	9,7
Butyl acetate	123-86-4	126	1,9
Isopropyl acetate	108-21-4	85	6,3
Methoxypropyl acetate	108-65-6	145 to 146	
2-Ethoxyethyl acetate	111-15-9	156	0,16
Dimethyl phthalate	131-11-3	284	0,001 3 [28]
2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	25265-77-4	244	
2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	6846-50-0	280	
Other			
2-Pentylfuran	3777-69-3	> 120	
THF (Tetrahydrofuran)	109-99-9	67	19,3 (20 °C)

[a] Depending on the literature used, the boiling points reported may vary by a few degrees Celsius for some compounds.

Annex B
(informative)

Protocol for recording activities and boundary conditions during sampling

During typical use of rooms, temporary emissions may occur owing to activities or behaviour of the occupants. In order to interpret the analytical results, the activities of the occupants, the ventilation conditions and the climatic conditions during sampling shall be determined and documented. During long-term measurements, the participation of the occupants is also necessary. The measurement institute should inform the occupants that activities deviating from customary use can affect the measurement result. For this reason, all activities deviating from customary use should be noted in a protocol. Since many rooms are only used at specific times or are used by different groups of people, in practice, it has proved to be helpful if the activities and boundary conditions are recorded by occupants at the end of a period of use or at the end of a day. The protocols can be collected and be made available to the measurement institute for evaluation at the end of the sampling period.

The final version of the protocol should be established during the appropriate measurement planning. General guidelines concerning information to be recorded during indoor air measurement are given in ISO 16000-1:2004, Annex D.

In the case of long-term sampling, it is advisable, in addition to the information to be obtained in indoor air studies, to record other information listed in Annex D of ISO 16000-1:2004.

When diffusive samplers are used for long-term sampling, the way in which the samplers are attached and the position and height of attachment of the passive samplers in the room shall be documented, if necessary, using a sketch.

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ISO 16000-6

Third edition
2021-08

Indoor air —

Part 6: Determination of organic compounds (VVOC, VOC, SVOC) in indoor and test chamber air by active sampling on sorbent tubes, thermal desorption and gas chromatography using MS or MS FID

Air intérieur —

Partie 6: Dosage des composés organiques (COTV, COV, COSV) dans l'air intérieur et l'air de chambre d'essai par prélèvement actif sur tubes à sorbant, désorption thermique et chromatographie en phase gazeuse avec détection MS ou MS-FID

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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*.

This third edition cancels and replaces the second edition (ISO 16000-6:2011), which has been technically revised. The main changes compared to the previous edition are as follows:

— other sorbents than Tenax TA® are allowed to be used;

— descriptions of VVOC and SVOC measurements are included in the mandatory part of the document.

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

ISO 16000-1 establishes general requirements relating to the measurement of indoor air pollutants and the important conditions to be observed before or during the sampling of individual pollutants or groups of pollutants. Aspects of the determination (sampling and analysis) and the sampling strategy of specific pollutants or groups of pollutants are specified in the subsequent parts of ISO 16000 (see Foreword).

ISO 16000-5 (dealing with VOC sampling strategy) is a link between ISO 16000-1 (a generic standard establishing the principles) and this part of ISO 16000, which deals with sampling and analytical measurements.

ISO 16017 (see Clause 2 and Reference [8]) and ISO 12219 [3]-[7] also focus on measuring vapour-phase organic chemicals in air.

This document can be applied to measure vapour phase organic compounds in indoor environments that include buildings with varying designs and purposes and cabins for different modes of transport, as well as measurement in product emission test chambers. These measurements can be for a range of purposes as described in ISO 16000-1 and ISO 16000-5, therefore the requirement for the measurement may be well defined by the task descriptor or may be quite open. For example, the task may be to determine a specific list of target chemicals with a defined sampling time and sensitivity of measurement or it may be to investigate the cause of a reported and poorly understood indoor air quality problem. Depending upon the task of measurement the user of this document should select the most appropriate sampling and analytical instrumentation and conditions. This document provides that information in the normative part combined with informative guidance. Figure 1 refers to the most critical parts of the standard with regard to selection of the most appropriate methodology for the task to be undertaken. Tenax TA®[1)] only or multisorbents can be used to capture ranges of vapour phase organic compounds. Multisorbents are used for wider ranges and may improve recovery of compounds.

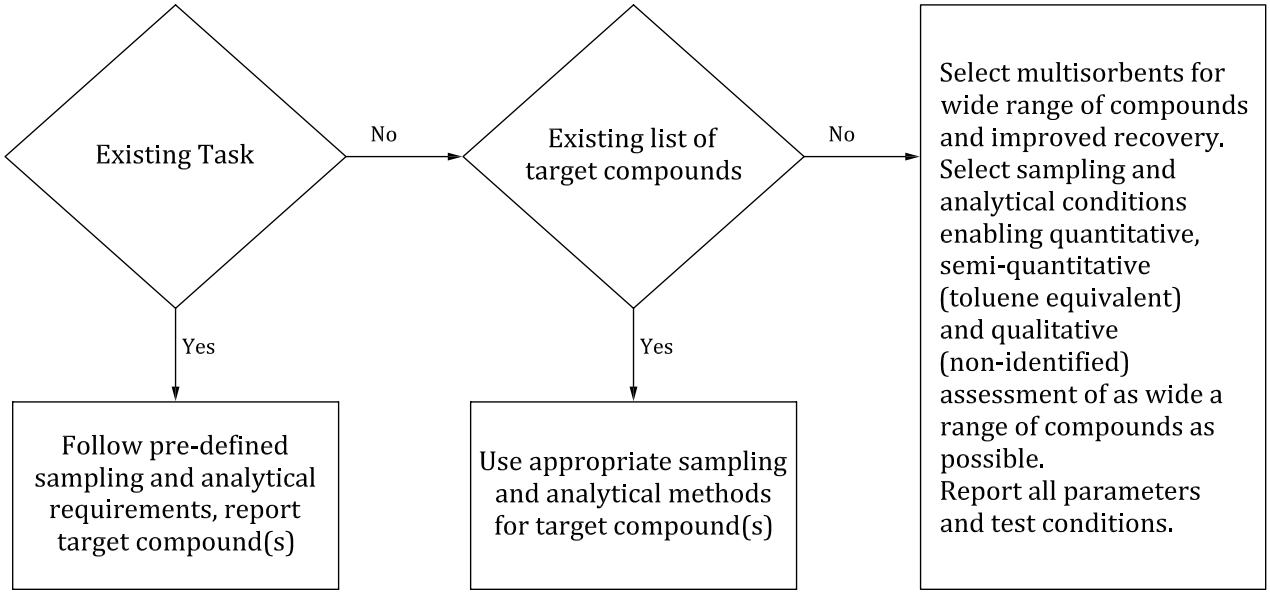

Figure 1 — Measurement scheme showing different ways of analysing air samples depending on the respective task including target compounds

1) Tenax TA® is a trade name of a product supplied by Buchem. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used, if they can be shown to lead to the same results.

Indoor air —

Part 6: Determination of organic compounds (VVOC, VOC, SVOC) in indoor and test chamber air by active sampling on sorbent tubes, thermal desorption and gas chromatography using MS or MS FID

1 Scope

This document specifies a method for determination of volatile organic compounds (VOC) in indoor air and in air sampled for the determination of the emission from products or materials used in indoor environments (according to ISO 16000-1) using test chambers and test cells. The method uses sorbent sampling tubes with subsequent thermal desorption (TD) and gas chromatographic (GC) analysis employing a capillary column and a mass spectrometric (MS) detector with or without an additional flame ionisation detector (FID)[13].

The method is applicable to the measurement of most GC-compatible vapour-phase organic compounds at concentrations ranging from micrograms per cubic metre to several milligrams per cubic metre. Many very volatile organic compounds (VVOC) and semi-volatile organic compounds (SVOC) can be analysed depending on the sorbents used.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

EN 13137, *Workplace atmospheres – Pumps for personal sampling of chemical and biological agents – Requirements and test methods*

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 https://www.electropedia.org/

3.1
semi-volatile organic compound
SVOC
organic compound eluting after n-hexadecane on a gas chromatographic column specified as a 5 % phenyl 95 % methyl polysiloxane phase capillary gas chromatographic column

Note 1 to entry: The vapour-fraction of SVOC ranging in volatility to n-C_{44} can also be analysed by thermal desorption GC-MS but requires specific sampling and analytical conditions for optimum performance [22,25].

3.2
volatile organic compound
VOC
organic compound eluting between and including n-hexane and n-hexadecane on a gas chromatographic column specified as a 5 % phenyl 95 % methyl polysiloxane phase capillary gas chromatographic column

3.3
very volatile organic compound
VVOC
organic compound eluting before n-hexane on a gas chromatographic column specified as 5 % phenyl 95 % methyl polysiloxane phase capillary gas chromatographic column

3.4
total volatile organic compounds
TVOC
sum of the concentration of the identified and unidentified *volatile organic compounds* (3.2) calculated as detailed in Annex A

3.5
total semi-volatile organic compounds
TSVOC
sum of the concentrations of identified and unidentified *semi-volatile organic compounds* (3.1) and calculated as detailed in Annex A

Note 1 to entry: The limit of volatility of SVOCs included in the TSVOC sum may be defined by the specific task list.

3.6
target compound
individual vapour phase compound in indoor air with a concentration determined quantitatively and reported as a result of this method

3.7
task list
specific list of requirements for sampling and analysis defined prior to testing and reflected in the reporting of the results

Note 1 to entry: The requirements may include a specific target list with or without associated limit criteria, and/or require investigations of unknowns. They may also include particular control of aspects such as the location, duration and frequency of sampling.

3.8
laboratory blank
conditioned sorbent tube from the batch selected for each sampling exercise, retained in the laboratory, sealed with long term storage caps throughout the sampling exercise to be used as a blank tube

Note 1 to entry: These tubes are analysed with the sampled tubes.

3.9
field blank
conditioned sorbent tube from the batch used for the sampling exercise, subjected to the same handling procedure in the field as the sample tubes, including removal and replacement of storage caps, but not used for sample collection

3.10
internal standard
compound of known concentration added to a sample to facilitate the qualitative identification and/or quantitative determination of the sample components

4 Abbreviated terms

For the purpose of this document, the following abbreviated terms apply:

FID	flame ionisation detector
GC	gas chromatograph
MS	mass spectrometer
SVOC	semi-volatile organic compounds
TD	thermal desorption
TIC	total ion chromatogram
TSVOC	total semi-volatile organic compounds
TVOC	total volatile organic compounds
VOC	volatile organic compounds
VVOC	very volatile organic compounds

5 Principle

A measured volume of sample air is actively collected from indoor air, vehicle interior air, an emission test chamber (see ISO 16000-9, ISO 12219-4, ISO 12219-6) or an emission test cell (see ISO 16000-10) by drawing through one (or more) sorbent tubes. VOC, VVOC and SVOC are retained by the sorbent tube, and the compounds are subsequently analysed in the laboratory to determine the identity, retained mass and associated air concentration of as many individual compounds as required by the specific test. Depending upon the range of target compounds the most appropriate sorbent tube(s), sampling and analytical conditions are applied. The collected compounds are desorbed by heat and transferred under inert carrier gas via a focussing trap into a gas chromatograph equipped with a capillary column and a mass spectrometer, with or without an additional flame ionisation detector (FID).

6 Reagents and materials

6.1 Organic compounds for calibration of chromatographic quality

6.2 Dilution solvent for preparing calibration blend solution for liquid spiking. Shall be of chromatographic quality, free from compounds co-eluting with the compound(s) of interest (6.1)

6.3 Sorbents

6.3.1 General

Multiple sorbents, suitable for thermal desorption, are commercially available. They range in strength from very retentive sorbents required to retain and release VVOC to very weak sorbents suitable for quantitative sampling and release of SVOC. For particulate sorbents, the relevant particle size is 0,18 mm to 0,60 mm (80 mesh – 30 mesh). For a detailed list of sorbents see Annex D.

6.3.2 Quartz wool or glass/quartz beads, clean (i.e. do not produce analytically significant artefacts) and not prone to particle formation.

6.3.3 Porous Polymers, i.e. Tenax TA® particle size approx. 0,25 mm to approx.0,6 mm (60 mesh to 30 mesh). Tenax TA® is a porous polymer based on 2,6-diphenyleneoxide. Manufactured Tenax TA® contains quantities of impurities, which shall be removed before using it for air sampling.

6.3.4 "Carbon black" sorbents, such as Carbopack X®[2] or Carbograph 5 TD®[3], particle size 0,25 mm to 0,5 mm (60 mesh to 40 mesh). Hydrophobic carbon sorbents suitable for VOC and VVOC with vapour pressures below those typical for C_4 hydrocarbons.

6.3.5 Carbon molecular sieve (very strong) sorbents can also be used at the non-sampling end of the tube for trapping VVOC with vapour pressures above those typical for C_4 hydrocarbons. However, note that these sorbents are not completely hydrophobic. Therefore, if such sorbents are included, the tube needs to be dry purged in the sampling direction before analysis.

6.4 Preparing calibration standards on sorbent tubes

As many identified substances as possible, or as required, should be calibrated using original reference compounds. Standards should be introduced to the sampling end of conditioned sorbent tubes using either liquid or gas phase standards.

6.4.1 Gas-phase standards

Standard atmospheres of known concentrations of the compound(s) of interest, shall be prepared by a recognized procedure such as ISO 6141[1] or ISO 6145[2]. Typical concentrations are around 100 µg/m^3 but levels will vary depending on test requirements. Alternatively, gas standards of appropriate quality and concentration shall be sourced commercially.

If the concentrations in any prepared standard atmosphere are not traceable to primary standards and/or if the inertness and stability of the atmospheres generated cannot be guaranteed, the concentration shall be confirmed using an independent procedure.

NOTE Producing gas phase standards of reactive and/or high boiling compounds can be particularly difficult. Frequent monitoring of the standard is needed.

6.4.2 Loading sorbent tubes with gas-phase standards

Pass a known volume of standard atmosphere or gas standard through a conditioned sorbent tube from the sampling end, e.g. by means of a pump operating at 50 ml/min.

The volume of gas-phase standard sampled shall not exceed the breakthrough volume of sorbent tube for any of the compounds of interest.

After loading disconnect and seal the tube. Prepare fresh standards with each batch of samples. For indoor air and emission test chamber studies, load sorbent tubes with e.g. 100 ml, 200 ml, 400 ml, 1 l, 2 l, 4 l or 10 l of the 100 µg/m^3 standard atmosphere selected.

6.4.3 Calibration blend solution for liquid spiking

Standard solution concentrations will vary depending on test requirements. The selected compound(s) shall be prepared or obtained as a liquid standard in chromatographic-grade solvent (e.g. in methanol) at an appropriate level – typically between 10 ng/µl and 1000 ng/µl – depending on system sensitivity and the analytical conditions selected, for example split ratios. A suitably precise micro-syringe shall

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2) Carbopack X® is a trade name of Supelco. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

3) Carbograph 5 TD® is a trade name of Lara. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used, if they can be shown to lead the the same results.

be used to introduce 1 µl aliquots of the standard solution onto the sampling end of sorbent tubes in a stream of inert gas as described in 6.4.4. 1 µl is the suggested volume unless solvent can be selectively and efficiently purged without jeopardising breakthrough of the most volatile compound(s) of interest.

The stability and safe storage times of calibration blend solutions shall be determined. Fresh standard solutions shall be prepared accordingly or if there is evidence of deterioration, e.g. reactions between alcohols and ketones.

6.4.4 Loading sorbent tubes with liquid standards

The sampling end of a sorbent tube is fitted to the unheated injection unit of the gas chromatograph (GC) (see 7.6) through which inert purge gas is passed at 100 ± 10 ml/min, and a maximum 1 µl aliquot of an appropriate standard solution is injected through the septum. After 5 min, the tube is disconnected and sealed. Prepare fresh standard tubes with each batch of samples.

NOTE 1 It is more difficult to selectively purge solvent from multi-sorbent tubes, particularly those containing strong sorbents. Smaller injection volumes are recommended for stronger sorbents and multi-sorbent tubes.

Introducing liquid standards onto sorbent tubes via a GC injector is considered the optimum approach to liquid standard introduction, as components reach the sorbent bed in the vapour phase.

Calibration mixtures should be prepared in controlled ambient temperature conditions. Before use, temper the solutions accordingly.

NOTE 2 When preparing standard tubes from liquid standards containing SVOC analytes, efficient transfer is enhanced if the configuration of the injector allows the tip of the syringe to make gentle contact with the sorbent retaining mechanism (e.g. gauze or frit) at the sampling end of the tube.

NOTE 3 It is important to keep liquid standard injection volumes to 1 µl or less unless the solvent can be selectively purged from the tube prior to analysis. Using small injection volumes minimises the difference between standards and samples during analysis thus minimising uncertainty.

NOTE 4 Standard tubes containing VVOC are more typically prepared either from standard atmospheres (see 6.4.1 and 6.4.5) or from concentrated gas standards sourced commercially. It is appropriate for concentrated gas standards to be introduced to the sampling end of sorbent tubes in a stream of carrier gas via an unheated GC injector or similar device.

An internal standard can be added by mixing with the calibration solution or by spiking separately.

NOTE 5 If standard tubes are being prepared by introducing aliquots from more than one standard solution or gas, it is appropriate to first introduce the standard containing higher boiling components and to introduce the most volatile organic compounds last. This minimizes risk of analyte breakthrough during the standard tube loading process.

The purity of the inert carrier gas used to purge sorbent tubes during standard introduction (e.g. He, Ar, N2) should permit the detection of an injection of 0,5 ng toluene. The quality of the carrier gas is of great importance, as any contaminants contained in the gas are enriched on the sorbent together with the substances to be analysed.

Other techniques such as direct liquid spiking onto the sorbent bed without gas stream applied are also possible. In this case it is important to use tubes where the syringe needle can directly reach the sorbent bed.

6.4.5 Commercial, pre-loaded standard tubes

Certified pre-loaded standard tubes are available and can be used for establishing analytical quality control and for routine calibration.

7 Apparatus

Ordinary laboratory apparatus and in particular the following:

7.1 Sorbent tubes of stainless steel or glass,

7.1.1 General

Tubes with outside diameter of 6,4 mm (0,25 inch), inside diameter of 5 mm, and of length 89 mm (3,5 inch) fulfil the requirement and are used in many commercial thermal desorbers. Use deactivated glass wool or other suitable mechanism, e.g. stainless-steel frit, to retain the sorbent in the tube. Conditioned and sampled sorbent tubes shall be effectively sealed, e.g. with metal screw caps and combined polytetrafluoroethene (PTFE) ferrules. Alternative tube dimensions may be applied if appropriate performance data concerning trapping and recovery of target compounds is available as well as information on safe sampling volumes (SSV).

NOTE 1 The unit inch is not allowed in ISO documents; inch equivalents are given for information only.

Pre-packed sorbent tubes are available commercially. Alternatively, sorbent tubes can be filled in the laboratory as follows.

Weigh the appropriate amount of each adsorbent in turn into the tube and tap it down gently to settle, assisted by suction if desired. Place an additional plug or gauze after each sorbent to prevent sorbent mixing and retain the sorbents in the tube.

NOTE 2 The determination of breakthrough volume is specified in ISO 16017-1:2000 Annex B. Breakthrough volumes are used as a measure of sorbent strength (affinity) for organic vapours. They are dependent on temperature and are proportional to the dimensions of the sampling tube and quantity of sorbent. Typically, the SSV is set at 2/3 of the breakthrough volume. As an approximate measure, doubling the bed length while tube diameter is kept constant doubles the breakthrough volume. Similarly, as an approximate measure, a rise of 10 °C in the temperature of the tube during sampling, halves the breakthrough volume. Note that most breakthrough volume and safe volume data (e.g. in Annex E and in ISO 16017-1:2000) are reported at 20 °C. Note also that the breakthrough volume of some sorbents is adversily affected by high humidity (see ISO 16017-1).

When filling sorbent(s) into tubes, care shall be taken to ensure that the position of the sorbent(s) within the tube corresponds to the position of the tube heater of the instrument used. This ensures direct heating of the sorbent(s), minimising carryover. Contact the instrument manufacturer for details.

7.1.2 Sorbent tubes — Combinations and options

See Annexes C and D for more information.

Tubes of the dimensions described in 7.1.1 may contain up to 3 sorbents as well as quartz (or glass wool), arranged in order, from least retentive to most retentive, from the sampling end. This maximises the target analyte volatility range.

A mass of about 200 mg Tenax TA® is suitable for sampling VOC and some higher boiling compounds, e.g. those boiling up to n-C_{22}.

NOTE 1 The density of Tenax TA® is variable. However, 200 mg of Tenax TA® normally occupies ~40 mm depth in a 5 mm bore metal tube and ~60 mm depth in a 4 mm bore glass tube.

The recovery of semi-volatiles (particularly those less volatile than n-C_{22}) is facilitated by inserting a short (5 mm to 10 mm) bed of loosely packed quartz wool in front of the 200 ng of Tenax TA®.

Quantitative sampling and analysis of VVOC can be achieved by adding a 20 mm bed of a suitable stronger sorbent after the Tenax TA®.

NOTE 2 Selection of Carbopack X® or Carbograph 5 TD® as stronger sorbent facilitates quantitative retention and analysis of compounds as volatile as 1,3-butadiene, but without significant retention of water.

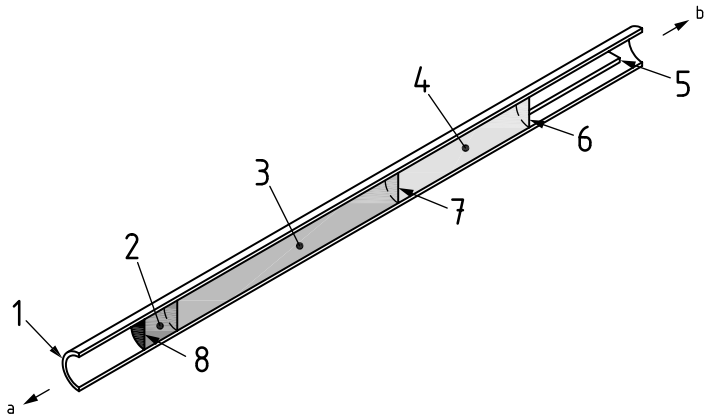
NOTE 3 Alternatively, even stronger sorbents are available (e.g. carbon molecular sieves) which allow ultra-volatile compounds such as C_3 hydrocarbons and vinyl chloride to be trapped. However, tubes packed with such very strong sorbents are prone to some water retention (see ISO 16017-1) and normally require an additional dry purge step prior to TD-GC-MS(FID) analysis.

NOTE 4 Stainless steel or coated stainless steel (metal) tubes of bore 5 mm have capacity for both 200 mg of Tenax TA® and 20 mm of a stronger sorbent.

NOTE 5 A useful example sorbent combination comprises: quartz wool (5 mm); Tenax TA® (175 mg, ~35 mm); and 15–20 mm of Carbograph 5 TD® or Carbopack X® - suitable for compounds ranging in volatility from 1,3-butadiene to n-C_{30} or more depending on the capability of the thermal desorption instrument selected.

All sorbents shall be held within the central (typically 60 mm) portion of the tube, i.e. the portion that is in direct contact with the tube desorption oven of the apparatus (see Figure 2).

All sorbent tubes should be desorbed with the flow of carrier gas in the reverse direction to the flow of air during sampling (see Figure 2).



Key

1 stainless steel or coated steel tube
2 5 mm quartz wool
3 ~35 mm, 175 mg Tenax TA®
4 20 mm stronger sorbent, e.g. Carbograph 5 TD® or Carbopack X®
5 gauze retaining spring
6 sorbent retaining gauze
7 sorbent retaining gauze or 0,5 mm quartz wool
8 sorbent retaining gauze
a Desorption gas flow.
b Sampling air flow.

Figure 2 — Example of a metal tube packed with multiple sorbents for extending the target volatility range from 1,3 butadiene to n-C_{30}

NOTE 6 Optimum pump flow rates for multi-sorbent tubes of the dimensions described are in the range 20 ml/min to 200 ml/min.

NOTE 7 Inert-coated stainless steel or glass tubes are preferred for monitoring reactive, odorous compounds.

Sorbents with significantly different maximum temperatures should not normally be combined in a single tube or it can be difficult to completely condition one without overheating and degrading the other.

An alternative approach is to use tubes containing single sorbents of increasing strength connected together in series using inert unions (7.2) with the tube containing the weakest sorbent first in line. However, this is an inefficient approach with regard to the resources required for sampling and analysis.

Pre-packed as well as pre-packed and pre-conditioned sorbent tubes are available commercially. Alternatively, sorbent tubes can be filled in the laboratory as specified in 7.1.1.

7.2 Sorbent tube unions

For sampling onto an assembly of two (or more) tubes in series. The sampling end of a secondary (back-up) tube can be connected to the non-sampling end of a primary sorbent tube using metal screw-couplings fitted with combined PTFE ferrules. Besides the metal screw couplings fitted with PTFE ferrules, fluorocarbon resin joints (unions) with Taper-Swaging Seal mechanism are also applicable to connecting sampling tubes. Two identical tubes can be connected in series – for example, as a check on the breakthrough of volatile compounds (9.1). Tubes containing different sorbents can also be connected in series (7.1.2).

7.3 Precision syringes, readable to at least 0,1 µl.

7.4 Calibrated sampling system for pumping air through the sorbent tubes. Shall fulfil the requirements of EN 13137.

7.5 Tubing, of polyethylene (PE) or PTFE, of appropriate diameter used to ensure a leak-proof fit to both pump and sample tube.

Sampling tubes shall be used with inert tubing upstream of the sorbent. Interferences from the tubing can introduce contaminants.

7.6 Gas chromatographic system (GC), fitted with a mass spectrometer (optional FID) capable of detecting an injection of at least 1 ng of toluene with a signal-to-noise ratio of at least 5 to 1.

7.7 Capillary column. A GC capillary column of 5 % phenyl 95 % methyl polysiloxane phase is selected. Bonded columns of 30 m to 60 m, internal diameter 0,25 mm to 0,32 mm and phase thickness 0,25 µm to 0,5 µm are examples of columns proven to be suitable for VOC analysis. Simultaneous analysis of VVOC, VOC and SVOC requires more care with respect to column selection, it is dependent on the target list.

7.8 Thermal desorption apparatus, for two-stage thermal desorption of the sorbent tubes and transfer of desorbed vapours via an inert gas flow into the GC analytical column.

7.8.1 Types of thermal desorber

Two-stage thermal desorbers typically fall into two main categories depending on the type of secondary focusing device:

a) small, electrically-cooled sorbent traps desorbed in a reverse flow of carrier gas (i.e. with carrier gas flowing in the opposite direction to that used during focusing) and

b) focusing mechanisms which are desorbed with a forward flow of carrier gas (i.e. with the gas flowing in the same direction as that used during focusing).

7.8.2 General requirements

The following apply to all types of thermal desorption apparatus:

— Tube seals or 'analytical' caps shall be leak tight to protect sampled and desorbed tubes from analyte loss and contaminant ingress while they are on the analytical system. This is particularly critical for automated operation where tubes may be in situ for extended periods.

— When tubes are sealed into the carrier gas (sample) flow path ready for primary (tube) desorption, these seals shall be leak tested before desorption and without compromising the sample, to prevent analyte loss and misreporting.

— The mechanism for sealing tubes into the sample flow path shall also exclude artefacts from outer tube surfaces to prevent contamination.

— Air shall be pre-purged from the tubes to vent before primary (tube) desorption to prevent sorbent or analyte oxidation and to extend the life of the GC column and detector.

— Tubes shall be desorbed with carrier gas flowing in the reverse direction to the flow of air during sampling. This optimises the release of retained compounds and extends the volatility range of compounds which can be analysed simultaneously.

— Desorption conditions of temperature, time and carrier gas flow rate shall be adjustable.

— The rate of compound release from the focussing device during secondary (trap) desorption shall be sufficiently fast for compatibility with high resolution capillary chromatography.

— The two-stage desorption process shall enable quantitative splitting of the sample during secondary desorption to extend the compatible concentration range.

NOTE 1 Some apparatus also incorporates additional features such as automatic sample-tube loading, the addition of gas-phase internal standard onto the sampling end of tubes (or focusing traps) immediately before each tube is desorbed, dry purging of tubes (in the sampling direction) before primary desorption, sample splitting during primary (tube) desorption and quantitative re-collection of sample split flow for repeat analysis and validation of compound recovery.

NOTE 2 The addition of gas phase internal standard onto the sampling end of sorbent tubes (or onto the focusing trap) immediately before primary (tube) desorption, provides a valuable check on the integrity of the analytical caps (or other means of sealing tubes) while tubes are awaiting desorption during automated operation. It allows users to distinguish between detector drift and analyte loss if there is any apparent loss of signal during a sequence (see 10.1.1.2).

Tube dry purging can be required prior to desorption if sample tubes containing very strong (water retentive) sorbents (see Note 3 of 7.1.2) have been used to sample humid air. This minimises analytical interference and measurement uncertainty.

7.9 Injection facility

The injection facility is required if standard tubes are being prepared by liquid spiking (optional). A conventional gas chromatographic injection unit or equivalent device may be used for preparing calibration standard tubes. This can be used in situ, or it can be mounted separately. The injector should be unheated to eliminate risk of heat transfer to the tube and associated risk of analyte breakthrough. The back of the injection unit should be adapted if necessary, to fit the sample tube. This can be done conveniently by means of compression coupling with an O-ring seal.

7.10 Mass spectrometer, for identification of target compounds and investigation of unknowns. It is also used for quantification.

NOTE Optional Flame ionisation detector (FID): While the retention time of a GC peak using FID cannot, on its own, be used as confirmation of compound identity, it increases confidence in peak identification (assignment) by GCMS, if the peak retention time also corresponds to that of the respective standard on FID.

FID responses are typically stable and linear over many orders of magnitude making them suitable for quantification. However using FID in conjunction with MS in dual detector format, may compromise the sensitivity of the method. It is also difficult to accurately quantify unresolved (overlapping) chromatographic peaks using FID alone.

8 Conditioning and storage of sorbent tubes

8.1 Conditioning

Prior to each sampling use, condition the pre-cleaned sorbent tubes using more stringent conditions than those required for analysis (temperatures and flows), but taking care not to exceed the maximum temperature of the least stable sorbent in the tube. Analyse a representative number of conditioned tubes using routine analytical parameters, to ensure that the thermal desorption blank is sufficiently

small. The sorbent tube blank level is acceptable if interfering artefact peaks do not exceed 2 ng for each of the target analytes. If the method requires summation of VOC or SVOC (TVOC or TSVOC – see Annex A) then any TVOC or TSVOC levels in the blank should not exceed 20 ng. If the blank is unacceptable, recondition the tubes by repeating the conditioning procedure. If after repeated conditioning the blank is still unacceptable, the tubes shall be re-packed or replaced (see procedure in 7.1.1).

Do not exceed the maximum temperature of the sorbent during tube conditioning or analysis.

NOTE Generation of benzaldehyde and acetophenone from Tenax TA® might be increased by ozone in the sampling air.

8.2 Storage of conditioned sorbent tubes before sampling

Seal conditioned sorbent tubes with metal screw-cap fittings with combined PTFE ferrules and store in a sealed container at room temperature. The container shall be clean and low emission such that the levels of artefacts introduced onto sealed tubes during storage does not cause them to exceed the requirements of 8.1. Use conditioned sampling tubes within four weeks. Recondition tubes stored for more than four weeks before sampling.

One or two of the conditioned tubes from the batch selected for each sampling exercise shall be retained as laboratory blank tubes (3.8). These are noted. They shall be analysed with the sampled tubes and shown to meet the performance specification detailed in 8.1.

9 Sampling

9.1 Air sampling

If more than one sorbent tube is being used as a check on analyte breakthrough, prepare a tube assembly by joining two identical tubes in series with a union (7.2). Connect the sampling end of the sorbent tube or tube assembly to the sampling line (if applicable) and attach the pump to the non-sampling end of the sorbent tube or tube assembly using low emission tubing (7.5). Start the pump and note and record the sampling flow rate, starting time, temperature and, if necessary, for calculation, also atmospheric pressure. An appropriate sampling flow rate for the broadest volatility range of vapour-phase organic compounds is in the range of 20 ml/min to 200 ml/min. At the end of the sampling period, note and record the flow rate, turn the pump off, and note and record the time, temperature and, if necessary, atmospheric pressure. Disconnect the sampling tube or tube assembly from the sampling line and seal both ends using screw-cap fittings with PTFE ferrules.

In order to minimize risk of condensation when sampling humid environments, the temperature of the sorbent tube should not be lower than the sampled air.

NOTE Depending on circumstances it can be useful to record relative humidity.

9.2 Sampling volumes

Safe sampling volumes (SSV), i.e. amounts of gas that can be sampled without breakthrough of possible target compounds, are listed in Annex E. Typical sampling volumes when sampling VOCs from non-industrial indoor air are 3 l to 20 l. In material emission measurements, the material type and age, loading factor and air exchange rate in the chamber determine suitable sampling volumes. Sampling volumes should be adjusted to concentration range, boiling point of target compounds and sorbents.

NOTE 1 For a broader study on using sorbent tubes and TD-GC-MS for the analysis of a range of semi-volatiles, including polycyclic aromatic hydrocarbons, polychlorinated biphenyls (PCB), phthalate esters and certain pesticides, see[22].

NOTE 2 When using Tenax TA® as a single sorbent a maximum sampling volume of 5 l is widely applied to prevent breakthrough of benzene on Tenax TA®.

The sampling volume should be adjusted to the expected concentrations. When sampling unknown concentrations, it is recommended that at least two parallel samples be taken with different sampling volumes. If the analytical result of the parallel samples is not dependent on the sampling volume, no breakthrough of the analytes has occurred.

9.3 Storage of loaded samples

To avoid possible changes, the sample should be analysed as soon as possible and preferably within four weeks after collection and with validated calibration. Loaded sampling tubes shall be tightly sealed using the caps described in 8.2 and stored in a low emission container at ambient room temperature (single sorbents) or under refrigerated conditions (multi-sorbent tubes).

NOTE 1 The effect of storage on loaded VVOC, VOC and SVOC from indoor or chamber air is not known for every sorbent and compound combination, although some data suggests that VOC may be stable over several months at room temperature (see ISO 16017[23],[24],[11],).

Long-term storage caps on refrigerated sample tubes should be retightened once the sample has reached its minimum storage temperature.

Refrigerated sample tubes should be allowed to re-equilibrate with room temperature before they are opened for analysis.

NOTE 2 Information on recovery of VOC from sorbent tubes after storage is given in Annex F and in ISO 16017-1.

In the case of long-term emission chamber tests, it is possible to store the sampling tubes and measure all tubes with one calibration. However, certain substance groups (e.g. aldehydes, monoterpenes and thiols) may start to degrade on the sorbent within a few days. In such case the analysis for the loaded tubes should be performed in a timely manner.

9.4 Field blanks

Field blanks (3.9) shall be marked, stored and analysed in sequence with the actual samples. In a measurement campaign, about 10 % of the samples analysed shall be field blanks. If only a few measurements are performed, at least one field blank shall be undertaken and analysed as part of each study.

10 Analysis

10.1 Determination of VOC, VVOC and SVOC

10.1.1 Analytical System

10.1.1.1 Checks on analytical system performance

Routine system calibration processes (multi- and single-level) allow analytical performance to be evaluated in respect of sample tube integrity, dynamic range, linearity, repeatability and sensitivity. Relevant performance criteria are listed below.

Analyte recovery through the two-stage thermal desorption process is validated by repeating the multi-level TD-GC-MS (and/or optional FID) calibration procedure using liquid injection and comparing the two curves (see ISO 16017-1 and other methods). An alternative method is e.g. to load the sorbent with the highest calibration level and desorb the tube twice. The second desorption should show analyte concentration less than 5 % of the first desorption. Alternatively, thermal desorbers allow quantitative re-collection of the split portion of TD samples, either pre or post column. In this case, subsequent analysis of the re-collected sample allows simple identification of any compounds with lower recovery

than expected – i.e. proportionally lower than other compounds in the standard and/or lower than that predicted from the split ratio.

NOTE 1 Poor recovery of compounds through the thermal desorption process might be due to incomplete desorption or to condensation or degradation within the system flow path.

Other chromatographic performance criteria shall be evaluated using a suitable 'reference standard' prepared using a check material. This shall be used when the method is first set up, whenever there is a modification to the system and at least once a quarter (every three months) or with higher frequency if analytically required. It shall also be used whenever routine GC data from samples or standards indicates that system performance is deteriorating. A 'check material' is a chromatographic test mix containing analytes that are representative of the range of compounds of interest.

NOTE 2 An example check material is described in EN 16516.

Records of routine chromatographic checks using this reference standard shall be maintained for each analytical system (detailed in 10.1.1.2, 10.1.1.4, 10.1.3 and Clause 14).

10.1.1.2 Analytical system performance criteria

The following analytical system performance criteria shall be demonstrated:

a) sensitivity of the apparatus: this should meet the requirements set for quantification (see 10.1.4);

b) Chromatographic resolution: this shall be sufficient to allow the analytes to be separately quantified. This may be demonstrated if the resolution is sufficient to separate cyclohexanone and o-xylene; e.g. as described in Figure 3 at least to the extent that the two apexes (tops of the peaks) can be observed.

If using hydrogen carrier gas all relevant safety precautions should be adhered to.

NOTE 1 Other indicators for good chromatographic resolution are achieving separation between methyl methacrylate (CAS 80-62-6) and methyl cyclohexane (CAS 108-87-2) or butylhydroxyltoluene (CAS 128-37-0) and dodecanoic acid methyl ester (CAS 111-82-0).

NOTE 2 Deterioration of the shape of the phenol peak (e.g. increased tailing) is another good indicator of the deterioration of the analytical system performance.

NOTE 3 If appropriate quality helium (or hydrogen) carrier gas is used (minimum 99,999 % pure), ideally with an oxygen trap fitted, it is usually possible to maintain TD-GC-MS system chromatographic performance between routine annual maintenance visits, depending on sample throughput. However, if chromatographic performance deteriorates and these critiera cannot be met, consider checking the status of:

— all connections in the sample flow path;

— the thermal desorption focusing trap;

— the GC capillary column.

The focusing trap may need repacking or replacing. The first 30 cm of the column may need to be removed or the capillary column may need replacing.

c) Linearity: The linear regression coefficient should be above 0,99 for toluene across the calibration range.

d) System and sample stability during batch analysis: Mid-range single level standards shall be interspersed between samples at a frequency of e.g. one standard every 10 samples. If the analytical TD-GC-MS process is being automated, the standard tubes shall be loaded onto the system at the same time as the samples. The response of the standards shall be monitored to check for loss of signal over the duration of the sequence. All compounds in repeated single level calibrations should meet the performance criteria given in 10.1.3 and Clause 14.

NOTE 4 Loss of signal, if it does occur can be the result of detector drift or loss of analyte caused by inadequate sealing with tubes awaiting desorption (e.g. on an autosampler). The stability of data from gas phase internal standards introduced immediately prior to the desorption of each tube (see Note 2 of 7.8.2) can be compared to the stability of results from the series of mid-range-single-level standards run with each batch of samples in order to distinguish the cause of any drift – be it changing detector response or loss of analyte from tubes waiting for automatic analysis.

e) Long-term system stability: this should be checked by plotting a control chart with the response of all the compounds in the check material every time it is analysed. The control chart of each analytical system should be kept until the instrument is decommissioned. An acceptance limit of two times the standard deviation shall be applied along with the following assessment criteria:

   - o if one control measurement is outside ± 3 standard deviations this means that the acceptance criterion is exceeded;
   - o if the second consecutive measurement is on the same side outside ± 2 standard deviations, this means that the acceptance criterion is exceeded.

f) Dynamic range: It shall be possible to quantify peaks at levels which are at least 100 times above their respective lower limit of quantification.

g) Repeatability: Sample and standard repeatability requirements are detailed in Clause 14.

10.1.1.3 Tune requirements for the mass spectrometer

The mass range scanned is typically 29 amu to 550 amu. The mass spectrometer should be tuned whenever the vacuum has been broken (e.g. to change the column or to install or clean the source). The tune needs to be repeated if the quality of mass spectral matches for compounds in the calibration standard or check material begin to deteriorate.

NOTE When scanning from 29 amu, interference from O_2 and N_2 from leakage might occur in the mass spectrum. This might disturb matching with the mass spectra library and would result in a lower spectral match.

10.1.1.4 Laboratory proficiency testing schemes and participation in round-robin exercises

Relevant laboratory proficiency testing (PT) schemes are available and participation is strongly recommended. In this case thermal desorption tubes pre-loaded with relevant target components are distributed for evaluation and reporting by participating laboratories. Participation in material emission and indoor air testing round-robin exercises is also strongly recommended. In this case, either suitable (homogenous and stable) example construction products or in case of indoor air, tubes used by the reference laboratory to sample a given atmosphere, are typically distributed for evaluation and reporting by participating laboratories.

10.1.2 Identification of target compounds

Chromatographic peaks shall be identified by retention time and comparison with spectra obtained from standards or from commercial libraries. The identification of a compound is confirmed if a reliable spectral match is made (typically equal or better than 80 %) and if the retention times match. A lower match quality can be used for identification only if there is additional, independent evidence to confirm compound identity (for example, the presence of known isomers, typical contaminants, typical emission profiles of similar products, presence of the compound at another testing time). Otherwise the substance shall be marked as not identified.

If hydrogen is used as carrier gas, analytical conditions may need to be adjusted for optimum performance and calibration, and all QC tests must be performed with hydrogen carrier gas.[30] Note that guidance should be taken from the GC/MS manufacturer to determine if any other aspects of library matching need to be considered.

NOTE The choice of baseline substraction method, spectral deconvolution approach, library search algorithm, spectral database and mass spectral tuning criteria are all factors in obtaining a reliable compound match.

10.1.3 Quantification of target compounds and compounds according to task list

For quantification by MS, chromatographic peaks shall be integrated using quantifier and qualifier mass ions extracted from the TIC signal. The choice of quantifier and qualifier ions for each compound shall be documented and available in the laboratory and shall be reported if requested. Where possible, quantifier and qualifier ions shall be selected that are not present in neighbouring peaks and that are major fragments of the compound in question. Using the total ion signal of the mass spectrometer is a poor estimate of the integrated mass.

NOTE 1 Using extracted ions for quantification improves selectivity and signal to noise ratios.

Extracted ion data, including sub-unit mass data (where available), shall be used to resolve co-eluting peaks or clusters of peaks and identify/quantify individual compounds as accurately as possible.

NOTE 2 Alternatively, if spectral deconvolution software is available, it can be used to define, identify and quantify individual compounds in both co-eluting peaks and peaks which appear as unresolved clusters in the TIC.

If co-eluting peaks remain unresolved, all major components shall be identified and the entire affected chromatographic area quantified by dropping perpendiculars to baseline in the valleys between the major components (Figure 3). For interpretation and quantification of complex chromatograms that show clusters of peaks that cannot be resolved, these clusters should not be separated into solitary peaks, but the total area of the whole agglomerate should be calculated and quantified using the most appropriate authentic response factor (for a group of target compounds) or the TIC response factor for toluene. Typical clusters could originate from technical mixtures such as hydrocarbons or glycols (Figure 4). Clusters that span over hexadecane (as VOC/SVOC-border) shall be split into a VOC- and an SVOC-part with a perpendicular to the baseline at the retention time of n-hexadecane.

During initial system set-up, the analytical system shall be quantified using a minimum five-point multi-level calibration over a range of at least 20 (i.e. the factor between the lowest and highest mass in the range shall be at least 20). Data from this initial calibration phase should be used to determine a relative response factor (RRF) for each compound of interest, relative to an internal standard such as toluene D8. At least one appropriate (e.g. mid-level) standard, containing toluene and the expected target compounds (or at least a set of compounds that is representative of the volatility and polarity range of the relevant target compounds), shall be run at the start of each batch of samples and be interspersed with the sample tubes – e.g. every 10th sample – as a check on relative response factor stability. The multi-level calibration for one or more specific compounds of interest shall be repeated whenever the single level calibration for that type of compound shows unacceptable drift in actual or relative response factors since the previous multi-level calibration. See also 14.

NOTE 3 The set of compounds that is representative of the volatility and polarity range of target compounds could be the same as those contained in the check material.

NOTE 4 Use of an internal standard (e.g. toluene D8 or cyclodecane) can be used to ensure accuracy and as a further check on analytical system stability.

Identified target compounds shall be quantified using the actual response factor for each compound. Identified non-target compounds shall be quantified using the TIC relative response factor for toluene (i.e. in ‘toluene equivalents’).

NOTE 5 Additional use of the actual response factors for quantifying identified non-target compounds can provide useful supplemental information.

NOTE 6 Determining VOC using 'toluene equivalents' is necessary for non-identified compounds (and for non-target compounds under some test protocols). This determination is semiquantitative since the individual compounds in the mixture may have actual response factors which differ widely from the toluene response factor.

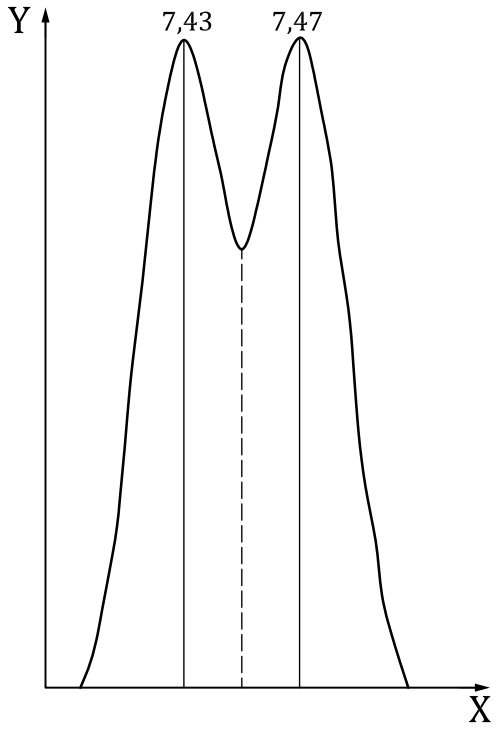


Figure 3 — Depiction of a suitable integration method for chromatographical compounds which do not fully resolve

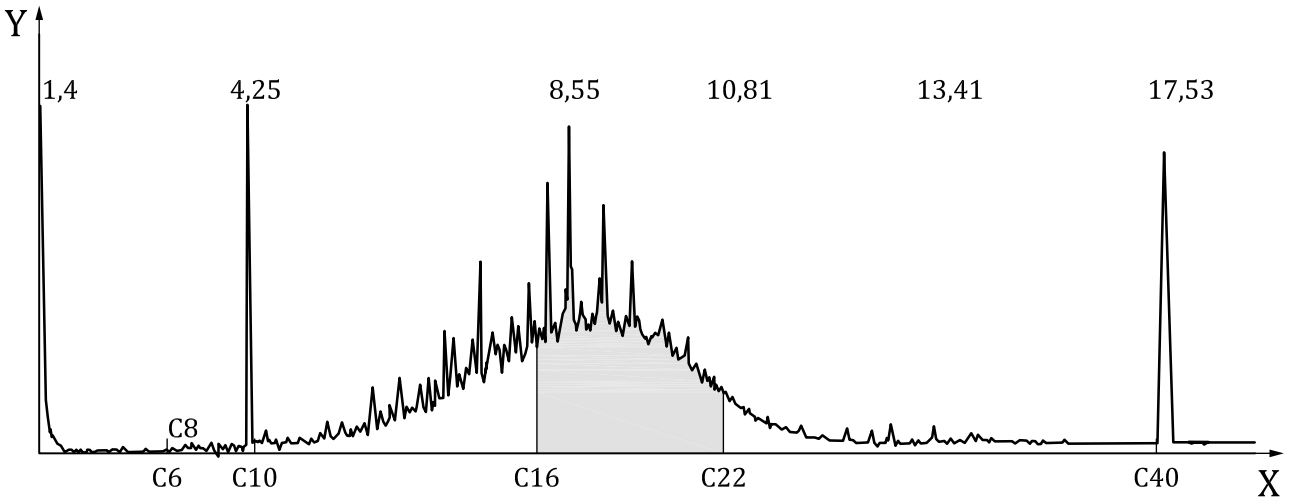


Figure 4 — Depiction of a suitable integration method for complex mixtures of chemical homologues which do not fully resolve

NOTE 7 For quantification by FID such as the reporting of $TVOC_{FID}$ (see Annex A) then the quantification procedure should follow a similar procedure to that described in 10.1.3 but applying the respective FID response factor for each individual compound. $TVOC_{FID}$ concentrations can also be calculated by applying the FID response factor for toluene to the entire peak area eluting between n-hexane to n-hexadecane inclusively.

10.1.4 Determining the lower limit of quantification

The quantification limit is defined as equal to 10 times the standard deviation of the results for a series of at least 12 replicate tubes spiked with the compounds of interest from the check material at levels at or near the quantification limit. The quantification limit shall be below 5 ng for the compounds in the check material except phenol. A limit of 5 ng on tube is equivalent to 1 µg/m^3 in the sampled air,

assuming a 5 l air sample volume. The quantification limit for phenol shall be below 25 ng which is equivalent to 5 µg/m^3 in the sampled air assuming a 5 l air sample volume. For the relevant carcinogenic compounds (see EN 16516[13]), the quantification limit shall be below 5 ng on tube or 1 µg/m^3 (assuming a 5 l air sample volume) in the air as far as feasible. The actual quantification limit for any compound which fails these criteria shall be reported.

If any check material compounds fail to meet these quantification limits, consider possible causes.

The quantification limit of any target vapour-phase organic compounds shall be 1 µg/m^3 if feasible or as low as possible.

10.2 Identified non-target compounds and unidentified compounds

Those compounds not listed in the target list shall be identified by mass spectra, if required.

For identification and quantification of single, non-target and unidentified VOC, analyse the samples with MS operating in the scan mode. Identify single compounds detected in the sample using the mass spectrometer total ion chromatogram and the retention time of the compound. Compare the total ion chromatogram with either the mass spectra of pure compounds or commercially available compilations (libraries) of mass spectra. User-generated libraries may also be used. Correspondence of retention time with a retention time of a compound used for calibration on a single column should not on its own be regarded as proof of identity.

Identify as many compounds as possible according to the task. Commonly reported are those representing the 10 highest peaks and those present at concentrations above 2 µg/m^3, quantified as toluene equivalent. A list of VOC which, according to experience at the time of publication, are frequently encountered in indoor air and emitted from materials is given in Annex B. A satisfactory level of identification has been achieved if the chromatographic peak areas of identified VOC when summed correspond to at least two-thirds of the total area of all the peaks in the chromatogram.

For quantification of identified non-target compounds a chemically similar component can be used, if available. Unidentified compounds should be quantified as toluene equivalent.

11 Concentration of analytes in the sampled air

The peak area of each individual organic compound is proportional to the mass of compound injected. For each compound, the relationship between the mass of analyte injected and the corresponding peak area is determined by Formula (1). The slope of the calibration curve over the linear range is the response factor of the compound studied.

$$A_{St} = b_{St} * m_{St} + c_{St} \quad (1)$$

where

A_{St} is the analyte peak area, in area units, in the chromatogram of the standard;

b_{St} is the slope of the calibration curve;

m_{St} is the mass, in nanograms, of the analyte in the standard;

c_{St} is the ordinate intersect of the calibration curve – if the calibration curve passes through the origin, $c_{St} = 0$.

The mass of analyte, m_A, in nanograms, present in the sample is calculated from the detector peak area using the response factor of the analyte given in Formula (2):

$$m_A = \frac{A_A - c_{St}}{b_{St}} \quad (2)$$

where

A_A is the peak area, in area units, of analyte in the chromatogram of the sample;

b_{St} is the slope of the calibration curve;

c_{St} is the ordinate intersect of the calibration curve — if the calibration curve passes through the origin, $c_{St} = 0$.

The mass concentration, ρ_A, in micrograms per cubic metre, of organic compounds identified in the air sampled is calculated by means of Formula (3):

$$\rho_A = \frac{m_A - m_{A0}}{V} \quad (3)$$

where

m_A is the mass, in nanograms, of analyte present in the sampling tube;

m_{A0} is the mass, in nanograms, of analyte present in the blank tube;

V is the sampling volume, in litres.

If necessary, the volumes are converted to other temperatures and pressures (reference conditions).

If necessary, the concentrations are adjusted to other temperatures x and 101,3 kPa see Formula (4):

$$\rho_{A;101,3;x} = \rho_A \frac{101,3}{p} \frac{(t+273)}{x} \quad (4)$$

where

p is the actual pressure, in kilopascals, of the air sampled;

t is the actual temperature, in Kelvin, of the air sampled.

NOTE Concentrations resulting from the conversion of the sampling volume do not reflect the concentration at real test conditions or concentrations resulting at the reference conditions.

12 Performance characteristics

Before this method is used, its performance characteristics should be determined in accordance with ISO/IEC Guide 98-3.[9] This determination should include, as a minimum, the estimation of uncertainty components from the following sources:

a) sampling:

1) volume

2) temperature

3) sampling efficiency

b) sampling integrity:

1) measure and stability

2) blank stability

c) desorption efficiency

d) calibration

1) standards

2) lack-of-fit of calibration function

e) analysis

1) repeatability

2) blank level

f) environmental influences

1) temperature at sampling

2) humidity at sampling

3) interferents

g) field repeatability

The accuracy and repeatability of the measuring method are important factors, which shall be determined in order to evaluate the results and the suitability of the method for the intended purposes. The accuracy of the measurement method can be determined if atmospheres of known level (micrograms per cubic metre) can be reliably produced. This is relatively difficult and therefore most researchers only determine the repeatability of their measuring method by repeated sampling from a constant atmosphere.

In a study of chlorinated butadiene's in indoor air, the uncertainty of the measurement results was assessed based on the principles of ISO/IEC Guide 98-3.[9] The combined relative uncertainty for the measurement of hexachlorobutadiene at a volume fraction level of $0{,}6 \times 10^{-9}$ was ±12 % and the expanded relative uncertainty (at the 95 % confidence level) was ±23 %[26].

The repeatability of sampling of non-polar hydrocarbons from cylinder atmospheres containing six VOCs has been reported. For 2 l samples, the repeatability for Tenex TA® was less than 10 %, and for 0,5 l samples it was 12 %[16].

NOTE In material emission testing, interlaboratory comparisons have been organized to assess the agreement between laboratories undertaking tests to characterize the emissions from VOC from indoor materials and products. The results of these intercomparison have been published[17],[18].

13 Test report

The test report shall contain at least the following information:

a) list of measurement tasks;

b) description of the sampling location, if the task requires it;

c) time and date of the sampling;

d) sampling conditions (temperature, relative humidity; atmospheric pressure);

e) reference to this document (i.e. ISO 16000-6);

f) full description of the sampling procedure;

g) full description of the analytical procedure;

h) quantification limits of the analytical method;

i) field blanks shall be reported, if the task requires it;

j) concentrations of identified compounds (target compounds and target sum parameters), provided with CAS numbers, and non-identified compounds including calculation and calibration principles used;

k) uncertainty of the reported results.

NOTE Typically test results are reported with not more than two significant figures if below 10 µg/m^3, report only one significant figure. This rule reflects the degree of precision that can be achieved by this testing method. Examples:

— 4,5 and 5,4 both are expressed as 5;

— 52,5 and 53,4 both are expressed as 53;

— 255,0 and 264,9 both are expressed as 260;

— 2550 and 2649 both are expressed as 2600.

14 Quality control

An appropriate level of quality control shall be employed and documented. See also 10.1. Important checks include:

a) Single level standards interspersed with a batch of samples (10.1.1.1). These shall be compared with each other and with the most recent multi-level calibration (10.1.3). Single level standard results should not deviate more than ± 15 % of their mean and not more than ± 15 % of the values given by the most recent multi-level calibration for at least 90 % of compounds. If unacceptable, a new multi-level calibration shall be undertaken.

b) Each sampling exercise shall include at least one duplicate sampling event (9.1). The compound concentration determined from duplicate air samples should not deviate more than ± 15 % of their mean, after taking the air sample volume into account. If there is any greater disparity, only the higher concentration shall be reported unless there is a good technical reason (e.g. artefact or contamination) why the higher value should be discounted. This should be documented.

c) Notified and accredited laboratories should verify the performance of the whole method by participating in relevant proficiency testing schemes and round-robin exercises, by using certified reference materials and samples as regularly as possible and by following the quality control requirements of ISO 16000-9:2006 and ISO 16000-11:2006 (see 10.1.1.4).

d) Field blanks are prepared in accordance with 9.4. Background levels are acceptable if levels of target compounds or interfering artefacts do not exceed 2 ng.

e) Desorption efficiency (10.1.1.1) shall be better than 95 % for all reported compounds.

f) Sample collection efficiency shall be determined by using back-up tubes or taking samples of different sampling volumes in parallel (9.1). Breakthrough levels are satisfactory if subsequent analysis of the back-up tube shows less than 5 % of any compound of interest, compared to the primary tube.

Annex A
(informative)

Total volatile organic compounds (TVOC) and total semi-volatile organic compounds (TSVOC)

A.1 Total volatile organic compounds (TVOC)

A TVOC measurement comprises the concentration (mass per unit air volume) of identified and unidentified volatile organic compounds, as defined in 3.4.

There are three ways of determining the TVOC, which lead to three different versions of the TVOC parameter:

1) **Calculation of TVOC based on TIC/FID ($TVOC_{TIC/FID}$):** The concentration determined from the sum of all compounds masses eluting in a defined section of the chromatogram, quantified using either the FID response factor for toluene or the TIC response factor for toluene, after correcting for blank values of the respective compounds quantified in the same way.

2) **Calculation of TVOC based on identified and not identified compounds ($TVOC_{ID}$):** The concentration determined from the sum of all identified target compounds (see 3.6) (quantified using authentic standards) plus all identified non-target compounds and non-identified compounds (quantified using the TIC response factor for toluene) eluting in a defined section of the chromatogram, after correcting for blank values of the respective compounds quantified in the same way. This option could be argued to provide a value that most closely represents the actual total concentration of VOC emitted under the test conditions, but requires a harmonized list of target compounds for consistent results.

3) **Calculation of TVOC based on the sum of integrated peaks quantified as toluene equivalents ($TVOC_{MEQ}$):** The concentration determined from the VOC mass derived from the total area of a defined section of the chromatogram, obtained using a specific column, calculated using the TIC or FID response factor for toluene after substracting the total area of the same section of the equivalent chromatogram.

CAUTION — These parameters all give different values and cannot be used interchangeably.

A.2 Total semi-volatile organic compounds (TSVOC)

A TSVOC measurement (if required) comprises the sum of the concentration of the identified and unidentified semi-volatile organic compounds, as defined in 3.1 and the respective task list. Like the TVOC value, it can be determined in several ways (see A.1).

NOTE For example EN 16516 limits the TSVOC range to n-hexadecane to n-docosane(n-C_{22}).

A.3 Limitations of TVOC and TSVOC values

TVOC and TSVOC values are sum parameters and different calculation methods are used as stated above. TVOC and TSVOC values are also dependent on the choice of sorbents in the sampling tube, sorbents in the focussing trap, and the detector type and will vary from FID to MS and between different types of MS. Therefore, the results can be compared between FID and MS only when using results obtained with compound specific standards.

TVOC and TSVOC emission values comprise an undefined mix of compounds of varying or poorly defined toxicity. They are not reliable indicators of the impact of product emissions or indoor air quality with respect to human health.

Annex B
(informative)

Examples of compounds detected in indoor air and from building products in test chambers

Table B.1 — Examples of compounds detected in indoor air and emitted from building products in test chambers[17],[18]

Chemical compound	CAS No.	Boiling point °C
Aromatic hydrocarbons		
1,2,3-Trimethylbenzene	526-73-8	176
1,2,4,5-Tetramethylbenzene	95-93-2	197
1,2,4-Trimethylbenzene	95-63-6	169
1,3,5-Trimethylbenzene	108-67-8	165
1,3-Diisopropylbenzene	99-62-7	203
1,4-Diisopropylbenzene	100-18-5	203
1-Methyl-2-propylbenzene	1074-17-5	185
1-Methyl-3-propylbenzene	1074-43-7	175
1-Propenylbenzene	637-50-3	175
2-Ethyltoluene	611-14-3	165
3-Ethyltoluene/4-ethyltoluene	620-14-4/622-96-8	162
2-Phenyloctane	777-22-0	123
4-Phenylcyclohexene	4994-16-5	251[a]
5-Phenyldecane	4537-11-5	
5-Phenylundecane	4537-15-9	
α-Methylstyrene	98-83-9	165
Benzene	71-43-2	80
Ethylbenzene	100-41-4	136
Ethylylbenzene/Ethynylbenzene	536-74-3	144
Isopropylbenzene	98-82-8	152
m-/*p*-Methylstyrene	100-80-1/622-97-9	168/169
m-/*p*-Xylene	108-38-3/106-42-3	139/138
Naphthalene	91-20-3	218
n-Butylbenzene	104-51-8	183
n-Propylbenzene	103-65-1	159
o-Methylstyrene	611-15-4	171
o-Xylene	95-47-6	144
Styrene	100-42-5	145
Toluene	108-88-3	111
Aliphatic hydrocarbons *n*-C_6 to *n*-C_{16}		
1-Decene	872-05-9	171
1-Octene	111-66-0	121

Table B.1 *(continued)*

Chemical compound	CAS No.	Boiling point °C
2,2,4,6,6-Pentamethylheptane	13475-82-6	178
2,4,6-Trimethyloctane	62016-37-9	172
2-Methylhexane	591-76-4	90
2-Methylnonane	871-83-0	167
2-Methyloctane	3221-61-2	143
2-Methylpentane	107-83-5	60[b]
3,5-Dimethyloctane	15869-93-9	159
3-Methylhexane	589-34-4	92
3-Methyloctane	2216-33-3	143
3-Methylpentane	96-14-0	63[b]
4-Methyldecane	2847-72-5	189
Isododecane	31807-55-3	216
n-Decane	124-18-5	174
n-Dodecane	112-40-3	216
n-Heptane	142-82-5	98
n-Hexadecane	544-76-3	287
n-Hexane	110-54-3	69
n-Nonane	111-84-2	151
n-Octane	111-65-9	125
n-Pentadecane	629-62-9	271
n-Tetradecane	629-59-4	254
n-Tridecane	629-50-5	235
n-Undecane	1120-21-4	196
Cycloalkanes		
1,4-Dimethylcyclohexane	589-90-2	124
1-Methyl-4-methylethylcyclohexane (*cis*/*trans*)	6069-98-3/1678-82-6	167
Cyclohexane	110-82-7	81
Methylcyclohexane	108-87-2	101
Methylcyclopentane	96-37-7	72
Terpenes		
ß-Caryophyllene	87-44-5	275
α-Pinene	80-56-8	156
ß-Pinene	18172-67-3	164
3-Carene	13466-78-9	167
α-Cedrene	469-61-4	262
Camphene	79-92-5	158
Limonene	138-86-3	176
Longifolene	475-20-7	254
Turpentine	8006-64-2	150 to 180
Alcohols		
1-Butanol	71-36-3	118
1-Hexanol	111-27-3	158

Table B.1 *(continued)*

Chemical compound	CAS No.	Boiling point °C
1-Octanol	111-87-5	194
1-Pentanol	71-41-0	137
1-Propanol	71-23-8	97
2-Ethyl-1-hexanol	104-76-7	182
2-Methyl-1-propanol (isobutanol)	78-83-1	108
2-Methyl-2-propanol	75-65-0	82
2-Propanol	67-63-0	82
2,6-Di-*tert*-butyl-4-methylphenol (BHT)	128-37-0	265
Cyclohexanol	108-93-0	161
Phenol	108-95-2	182
2,2,4-Trimethyl-1,3-pentanediol isobutyrate	25265-77-4	254
Glycols and glycol ethers		
1-Methoxy-2-propanol	107-98-2	118
2-Butoxyethanol	111-76-2	171
2-Butoxyethoxyethanol	112-34-5	231
2-Ethoxyethanol	110-80-5	136
2-Methoxyethanol	109-86-4	125
2-Phenoxyethanol	122-99-6	245
3-Phenyl-1-propanol	6180-61-6	235
2-(2-Butoxyethoxy)ethanol	112-34-5	230
Dimethoxyethane	110-71-4	85
Dimethoxymethane	109-87-5	42[b]
Propylene glycol	57-55-6	189
Aldehydes		
2-Butenal	123-73-9	104
2-Decenal	2497-25-8	78 to 80
2-Ethylhexanal	123-05-7	163
2-Furancarboxaldehyde	98-01-1	162
2-Heptenal (*cis*/*trans*)	57266-86-1/18829-55-5	90 to 91 at 50 mmHg
2-Nonenal	2463-53-8	100 to 102 at 16 mmHg
2-Pentenal	1576-87-0	115 to 125
2-Undecenal	1337-83-3	244 to 245
Acetaldehyde	75-07-0	21[b]
Benzaldehyde	100-52-7	179
Butanal	123-72-8	76
Decanal	112-31-2	208
Heptanal	111-71-7	153
Hexanal	66-25-1	129
Nonanal	124-19-6	190
Octanal	124-13-0	171
Pentanal	110-62-3	103
Propanal	123-38-6	49[b]

Table B.1 *(continued)*

Chemical compound	CAS No.	Boiling point °C
Ketones		
2-Butanone (methyl ethyl ketone)	78-93-3	80
2-Methylcyclohexanone	583-60-8	163
2-Methylcyclopentanone	1120-72-5	139
3-Methyl-2-butanone	563-80-4	95
4-Methyl-2-pentanone (methyl isobutyl ketone)	108-10-1	117
3,5,5-Trimethylcyclohex-2-enone	78-59-1	214
Acetone	67-64-1	56[b]
Acetophenone	98-86-2	202
Cyclohexanone	108-94-1	155
Cyclopentanone	120-92-3	130
Halocarbons		
1,1,1,2-Tetrachloroethane	630-20-6	130
1,1,2,2-Tetrachloroethane	79-34-5	146
1,1,1-Trichloroethane	71-55-6	74
1,1,2-Trichloroethane	79-00-5	114
1,2-Dichloroethane	107-06-2	84
1,4-Dichlorobenzene	106-46-7	173
Carbon tetrachloride	56-23-5	76
Chlorobenzene	108-90-7	131
Dichloromethane	75-09-2	40[b]
Tetrachloroethene	127-18-4	121
Trichloroethene	79-01-6	87
Acids		
2,2-Dimethylpropanoic acid	75-98-9	164
Acetic acid	64-19-7	118
Butyric acid	107-92-6	163
Heptanoic acid	111-14-8	223
Hexadecanoic acid	57-10-3	350
Hexanoic acid	142-62-1	202
Isobutyric acid	79-31-2	153
Octanoic acid	124-07-2	240
Pentanoic acid	109-52-4	186
Propanoic acid	79-09-4	141
Esters		
2-Ethoxyethyl acetate	111-15-9	156
2-Ethylhexyl acetate	103-09-3	198
2-Methoxyethyl acetate	110-49-6	145
Butoxyethyl acetate	112-07-2	192
Butyl acetate	123-86-4	126
Butyl formate	592-84-7	107
Ethyl acetate	141-78-6	77

Table B.1 *(continued)*

Chemical compound	CAS No.	Boiling point °C
Ethyl acrylate	140-88-5	100
Isobutyl acetate	110-19-0	118
Isopropyl acetate	108-21-4	90
Linalool acetate	115-95-7	220
Methyl acrylate	96-33-3	81
Methyl methacrylate	80-62-6	100
Propyl acetate	109-60-4	102
2,2,4-Trimethylpentanediol diisobutyrate	6846-50-0	281
Vinyl acetate	108-05-4	72[b]
Dibutyl phthalate	84-74-2	340
Dimethyl phthalate	131-11-3	284
Other		
1,4-Dioxane	123-91-1	101
1-Methyl-2-pyrrolidinone	872-50-4	202
2-Pentylfuran	3777-69-3	>120
Aniline	62-53-3	184
Caprolactam	105-60-2	267
Indene	95-13-6	182
Nitrobenzene	98-95-3	211
Pyridine	110-86-1	116
Tetrahydrofuran	109-99-9	67[b]

NOTE 1 Safe sampling volumes for organic vapours are given in Annex E.

NOTE 2 When analysing VOC eluting before *n*-hexane, the complementary sorbents given in ISO 16017-1 can be used.

NOTE 3 For some compounds the boiling points are not known.

[a] Value of 1-phenylcyclohexene.

[b] Compounds with boiling points below that of hexane are not retained quantitatively by Tenax TA® when using the sampling tube size and sampling volumes recommended in this part of ISO 16000.

Annex C
(informative)

Description of sorbents

Table C.1 — List of sorbents

Sorbent	Type
Carbotrap	Graphitized carbon
Carbopack	Graphitized carbon
Carbograph TD-1	Graphitized carbon
Carbosieve S-III	Carbon molecular sieve
Carboxen 569	Carbon molecular sieve
Carboxen 1000	Carbon molecular sieve
Chromosorb 102	Styrene/divinylbenzene
Chromosorb 106	Polystyrene
Porapak N	Vinylpyrrolidone
Porapak Q	Ethylvinylbenzene/divinylbenzene
Sherocarb	Carbon molecular sieve
Tenax TA	Poly(diphenyl oxide)
Tenax GR	Graphitized poly (diphenyl oxide)

NOTE All sorbents given here are trademarks of different manufactures. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the products named. Equivalent products may be used if they can be shown to lead to the same results.

Annex D
(informative)

Guide on sorbent usage

Tubes containing Tenax TA® can generate low levels of benzene artefacts over time, even if the tube was shown to be free of benzene immediately after conditioning. False-positive results may impair the determination in the low µg/m^3 range of benzene. It is therefore recommended to verify any such low benzene values with an independent second test using sorbent tubes packed with alternative sorbents such as carbon blacks (see EN 14662-1[12]).

Table D.1 — Sorbent usage

Type	Sorbent	Analyte range	Conditioning at max. (°C)	Desorption max. (°C)	Hydrophobic	Notes
Polydimethyl-siloxane PDMS	3 % OV-101	Semi-volatiles – compounds less volatile than n-C_{16}				working on gas-liquid chromatographic principles, this adsorbent is more commonly used as a GC stationary phase, but has been found suitable for very high boiling air pollutants
	10 % OV-101					
	Various suppliers					
very weak graphitized carbon black	Carbopack C	n-C_8 to n-C_{20}	400	360	Yes	artefacts per tube: individual VOC < 1 ng, friable, recommended mesh size: 40/60, some activity for labile compounds, desorption efficiency: medium, (some band broadening), typical surface area: 10 m^2/g
	Carbotrap C		400	360	Yes	
	Carbograph 2 TD		400	360	Yes	
	Anasorb GCB 1		400	360	Yes	
	Carbopack F		400	360	Yes	
	Carbotrap F		400	360	Yes	
	Carbopack Y		400	360	Yes	
	Carbotrap Y		400	360	Yes	
Weak porous polymer	Tenax TA™	n-C_6 to n-C_{22}	320	280	Yes	artefacts per tube: 1-2 ng of some VOC (incl. benzene). very inert; desorption efficiency good (narrow peaks); typical surface area: 30 m^2/g; recommended mesh size: 35/60
	Tenax GBR		320	280	Yes	
Weak to medium graphitized carbon black	Carbopack B	n-C_5 to n-C_{14}	400	360	Yes	
	Carbotrap		400	360	Yes	
	Carbograph 1 TD		400	360	Yes	
	Carbograph 4 TD		400	360	Yes	
	Anasorb GCB2		400	360	Yes	

Table D.1 *(continued)*

Type	Sorbent	Analyte range	Conditioning at max. (°C)	Desorption max. (°C)	Hydrophobic	Notes
Various medium strength porous polymer sorbents	Chromosorb Century series	Varies within range n-C_5 to n-C_{14}. Some of these sorbents are very specific for a given polarity or compound group			Yes	low desorption temperatures (range: 180-200 °C) – preclude use in multi-bed tubes; hydrophobic artefacts per tube: individual VOC< 10ng; use of these sorbents is reducing due to supply issues, high background and high batch-to-batch variability.
	102			180-200	Yes	
	106 Porapaks			180-200	Yes	
	Porapak Q			180-200	Yes	
	Porapak N			180-200	Yes	
Medium to strong graphitized carbon black	Carbopack X	1,4-butadiene to benzene	400	360	Yes	artefacts < 1 ng, friable; recommended mesh size 40/60; some activity for labile compounds, desorption efficiency poor (band broadening), typical surface area: 240 m^2/g
	Carbograph 5 TD		400	360	Yes	
	Carbograph 4 TD		400	360	Yes	
Carbon molecular sieve	Carboxen 1003	n-$C_{2/3}$ to n-$C_{5/6}$	350	330	No	artefacts < 1ng per tube; recommended mesh size: 40/60; desorption efficiency poor (band broadening); typical surface area: 400-1000 m^2/g, retention volumes reduced significantly when > 80 % RH
	Carboxen 569		350	330	No	
	Sulficarb (formerly Unicarb or Spherocarb)		350	330	No	
	Carbosieve SIII		350	330	No	
	Anasorb CMS		350	330	No	
	Carboxen 1000		350	330	No	
	Carboxen 56		350	330	No	
Others	Quartz wool	~C_{30}	Na	na	Yes	
	Glass wool		Na	Na	Yes	
	Glass beads		na	Na	Yes	

Annex E
(informative)

Safe sampling volumes for selected organic vapours

Table E.1 provides data on extrapolated retention volumes and SSVs for organic vapours sampled on a 200 mg Tenax TA® sorbent tube at 20 °C[14],[21],[27],[28]. CAS numbers of the compounds are listed in Table B.1.

Table E.1 — Safe sampling volumes for organic vapours sampled on Tenax TA®

Organic compound	Boiling point °C	Vapour pressure kPa (25 °C)	Retention volume l	SSV l	SSV per gram l/g	Desorption temperature °C
Hydrocarbons						
Hexane	69	16	6,4	3,2	16	110
Heptane	98	4,7	34	17	85	130
Octane	125	1,4	160	80	390	140
Nonane	151	0,5	1 400	700	3 500	150
Decane	174	0,13	4 200	2 100	$1,0 \times 10^4$	160
Undecane	196	0,14	$2,5 \times 10^4$	$1,2 \times 10^4$	$6,0 \times 10^4$	170
Dodecane	216	0,04	$1,26 \times 10^5$	$6,3 \times 10^4$	$3,0 \times 10^5$	180
Benzene	80	10,1	13	6,2	31	120
Toluene	111	2,9	76	38	190	140
Xylene	138 to 144	0,67 to 0,87	600	300	1 500	140
Ethylbenzene	136	0,93	360	180	900	145
Propylbenzene	159	0,3	1 700	850	4 000	160
Isopropyl-benzene	152	0,4	960	480	2 400	160
Ethyltoluene	162	—	2 000	1 000	5 000	160
Trimethyl-benzene	165 to 176	0,15 to 0,2	3 600	1 800	8 900	170
Styrene	145	0,88	600	300	1 500	160
Methylstyrene	167	0,3	2 400	1 200	6 000	170
Chlorinated hydrocarbons						
Carbon tetra-chloride	76	12	12	6,2	31	120
1,2-Di-chloro-ethane	84	8,4	11	5,4	27	120
1,1,1-Trichloro-ethane	74	2,7	Not recommended on Tenax TA®			
1,1,2-Trichloro-ethane	114	2,5	68	34	170	120
1,1,1,2-Tetra-chloro-ethane	130	0,6 to 0,7	160	78	390	150
1,1,2,2-Tetra-chlo-roethane	146	0,67	340	170	850	150

Table E.1 *(continued)*

Organic compound	Boiling point °C	Vapour pressure kPa (25 °C)	Retention volume l	SSV l	SSV per gram l/g	Desorption temperature °C
Trichloro-ethylene	87	2,7	11,2	5,6	28	120
Tetra-chloro-ethylene	121	1,87	96	48	240	150
Chloro–benzene	131	1,2	52	26	130	140
Esters and glycol ethers						
Ethyl acetate	71	9,7	7,2	3,6	18	120
Propyl acetate	102	3,3	36	18	92	140
Isopropyl acetate	90	6,3	12	6	31	120
Butyl acetate	126	1,9	170	85	420	150
Isobutyl acetate	115	2,7	265	130	650	130
tert-Butyl acetate	98	—	Not recommended on Tenax TA®			
Methyl acrylate	81	9 to 11	13	6,5	32	120
Ethyl acrylate	100	3,9	48	24	120	120
Methyl methacrylate	100	3,7	55	27	130	120
Methoxy-ethanol	125	0,8	6	3	15	120
Ethoxy-ethanol	136	0,51	10	5	25	130
Butoxy-ethanol	170	0,1	70	35	170	140
Methoxy-propanol	118	1,2 (20 °C)	27	13	65	115
Methoxy-ethyl acetate	145	0,27	16	8	40	120
Ethoxyethyl acetate	156	0,16	30	15	75	140
Butoxyethyl acetate	192	0,04	300	150	750	160
Aldehydes and ketones						
2-Butanone (methyl ethyl ketone)	80	10,3	6,4	3,2	16	120
Methyl isobutyl ketone	118	0,8	52	26	130	140
Cyclo-hexanone	155	0,45	340	170	850	150
3,5,5-Trimethyl-cyclohex-2-enone	214	0,05	11 000	5 600	28 000	90
Furfural	162	0,5	600	300	1 500	200

Table E.1 *(continued)*

Organic compound	Boiling point °C	Vapour pressure kPa (25 °C)	Retention volume l	SSV l	SSV per gram l/g	Desorption temperature °C
Alcohols						
n-Butanol	118	0,67	10	5	25	120
Isobutanol	108	1,6	5,6	2,8	14	120
tert-Butanol	83	1,17	Not recommended on Tenax TA®			
Octanol	180	< 0,1	2 800	1 400	7 000	160
Phenol	182	0,03	480	240	1 200	190
Others						
Pyridine	116	16	8	40	150	—
Aniline	184	0,09	440	220	1 100	190
Nitrobenzene	211	0,02	28 000	14 000	70 000	200

Annex F
(informative)

Storage recovery of solvents on sorbent tubes

Table F.1. provides data on storage recovery of solvents on Tenax TA® sorbent tubes (ISO 16017-1). The CAS numbers of the compounds are listed in Table B.1.

Table F.1 — Solvent recovery after storage on Tenax TA® sorbent tubes

Organic compound	Loading	Storage time 5 months		Storage time 11 months	
		Mean recovery[a]	Precision (coefficient of variation)	Mean recovery[a]	Precision (coefficient of variation)
	µg	%	%	%	%
Hydrocarbons					
Hexane	7,8	93,6	17,9	100,8	26,1
Heptane	8,4	99,5	2,1	100,0	1,3
Octane	8,6	100,1	1,8	100,0	0,5
Nonane	12,0	Nd	Nd	101,0	0,4
Decane	9,2	100,4	1,5	100,2	0,5
Undecane	9,1	100,7	1,5	100,2	0,2
Dodecane	9,9	101,8	1,5	101,5	0,4
Benzene	11,0	98,7	2,0	98,6	0,8
Toluene	10,9	(100,0)	1,8	(100,0)	0,6
p-Xylene	5,3	99,9	1,7	99,8	0,7
o-Xylene	11,0	100,0	1,7	98,8	0,7
Ethylbenzene	10,0	99,6	0,4	97,9	1,3
Propylbenzene	10,5	99,7	1,5	98,5	0,7
Isopropylbenzene	10,9	98,9	1,8	97,2	1,3
m+*p*-Ethyltoluene	10,5	98,8	1,7	96,9	1,2
o-Ethyltoluene	5,4	100,1	1,6	98,9	0,7
1,2,4-Trimethylbenzene	10,8	100,1	1,3	99,1	0,5
1,3,5-Trimethylbenzene	10,7	100,0	1,5	99,1	0,5
Trimethylbenzene	10,2	101,6	0,5	101,3	0,8
Esters and glycol ethers					
Ethyl acetate	10,3	97,6	1,0	100,0	2,5
Propyl acetate	10,9	100,5	1,7	99,1	0,8
Isopropyl acetate	9,4	97,0	0,4	100,0	1,4
Butyl acetate	10,8	100,3	1,6	99,9	0,6
Isobutyl acetate	10,7	100,2	1,4	99,8	0,7
Methoxyethanol	8,9	87,3	5,7	93,1	1,6
Ethoxyethanol	10,4	97,6	2,5	97,2	3,3
Butoxyethanol	10,0	100,6	4,1	100,1	3,0
Methoxypropanol	10,4	95,3	3,6	99,0	1,2

[a] Normalized to toluene = 100.

Table F.1 *(continued)*

Organic compound	Loading	Storage time 5 months		Storage time 11 months	
		Mean recovery[a]	Precision (coefficient of variation)	Mean recovery[a]	Precision (coefficient of variation)
	µg	%	%	%	%
Methoxyethyl acetate	12,5	100,6	1,4	98,9	1,4
Ethoxyethyl acetate	11,4	99,8	2,2	98,7	2,6
Butoxyethyl acetate	11,5	101,3	1,3	99,9	1,1
Aldehydes and ketones					
2-Butanone (methyl ethyl ketone)	9,2	97,4	0,8	99,1	0,6
Methyl isobutyl ketone	9,3	100,7	0,6	100,7	0,5
Cyclohexanone	10,9	102,4	1,2	100,7	0,6
2-Methylcyclohexanone	10,7	101,1	0,5	101,1	1,3
3-Methylcyclohexanone	10,5	103,6	1,0	103,0	0,7
4-Methylcyclohexanone	10,6	103,6	1,4	102,7	0,6
3,5,5-Trimethylcyclohex-2-enone	10,6	101,4	0,9	97,7	1,2
Alcohols					
Butanol	9,0	94,8	3,0	96,9	1,2
Isobutanol	8,9	93,6	3,5	96,4	1,0

[a] Normalized to toluene = 100.

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INTERNATIONAL STANDARD

ISO 16000-7

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2007-08-01

Indoor air —

Part 7: Sampling strategy for determination of airborne asbestos fibre concentrations

Air intérieur —

Partie 7: Stratégie d'échantillonnage pour la détermination des concentrations en fibres d'amiante en suspension dans l'air

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take Part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16000-7 was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 6, *Indoor air*.

ISO 16000 consists of the following parts, under the general title *Indoor air* :

— *Part 1: General aspects of sampling strategy*

— *Part 2: Sampling strategy for formaldehyde*

— *Part 3: Determination of formaldehyde and other carbonyl compounds — Active sampling method*

— *Part 4: Determination of formaldehyde — Diffusive sampling method*

— *Part 5: Sampling strategy for volatile organic compounds (VOCs)*

— *Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas-chromatography using MS/FID*

— *Part 7: Sampling strategy for determination of airborne asbestos fibre concentrations*

— *Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions*

— *Part 9: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test chamber method*

— *Part 10: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test cell method*

— *Part 11: Determination of the emission of volatile organic compounds from building products and furnishing —Sampling, storage of samples and preparation of test specimens*

— *Part 12: Sampling strategy for polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polycyclic aromatic hydrocarbons (PAHs)*

— *Part 13: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDDs/PCDFs) — Collection on sorbent-backed filters*

— *Part 14: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDDs/PCDFs) — Extraction, clean-up and analysis by high-resolution gas chromatography/mass spectrometry*

— *Part 15: Sampling strategy for nitrogen dioxide (NO_2)*

— *Part 16: Detection and enumeration of moulds — Sampling by filtration*

— *Part 17: Detection and enumeration of moulds — Culture-based method*

The following parts are under preparation:

— *Part 18: Detection and enumeration of moulds — Sampling by impaction*

— *Part 23: Performance test for evaluating the reduction of formaldehyde concentrations by sorptive building materials*

— *Part 24: Performance test for evaluating the concentration reduction of volatile organic compounds and carbonyl compounds except formaldehyde by sorptive building materials*

— *Part 25: Determination of the emission of semi volatile organic compounds for building products — Micro chamber method*

The following parts are planned:

— *Part 19: Sampling strategy for moulds*

— *Part 20: Detection and enumeration of moulds — Sampling from house dust*

— *Part 21: Detection and enumeration of moulds — Sampling from materials*

— *Part 22: Detection and enumeration of moulds — Molecular methods*

— *Part 26: Road vehicle interior test stand — Determination of VOC, SVOC and carbonyls including formaldehyde in car interiors*

Furthermore, two International Standards, ISO 16017-1 on pumped sampling and ISO 16017-2 on diffusive sampling, focus on volatile organic compound (VOC) measurements.

Introduction

Measurements of airborne asbestos fibre concentrations in indoor atmospheres are made for several reasons related to short-term or long-term exposure of building occupants to asbestos. One application of such measurements is to ensure that airborne asbestos fibres dispersed in areas of a building that are undergoing asbestos abatement do not result in unacceptable exposures of occupants in other areas of the building. After asbestos abatement is completed, measurements are made prior to removal of containment barriers and before safety precautions are discontinued to determine whether any residual asbestos that may remain in the abated area could give rise to unacceptable airborne asbestos exposures when the areas are re-occupied.

The characterization and assessment of ambient air at a fixed position, whether in a building or outside, is normally based on a series of measurements made over a long period of time, generally months or years. However, the release of asbestos fibres into ambient air is not constant and human, or in some cases animal, activity will result in short-term release episodes. Maintenance activity in particular will disturb asbestos-containing materials and settled dust in buildings. Control and monitoring of these activities will determine the long-term exposure levels [1][2]. Workplace atmospheres are also assessed by a series of repeated measurements, the number of measurements depending on the difference between the measured value and the control limit.

In contrast to the strategy used for assessment of long-term asbestos fibre concentrations and personal exposures, the assessment of asbestos fibre concentrations in connection with asbestos abatement measures is nearly always based on a set of measurements made at one time. This special situation needs to be taken into account, both when planning the measurements, and during collection of the air samples. It is not possible to predict long-term changes of airborne asbestos fibre concentrations resulting from any deterioration of asbestos-containing material or the type of usage of the rooms. However, through the use of an appropriate sampling strategy and sampling technique, and by taking extreme, but realistic, conditions into consideration, it is possible to simulate and estimate the short-term maximum asbestos fibre concentrations that can occur.

The sampling strategy described in this part of ISO 16000 is based on VDI 3492 [3].

Indoor air —

Part 7: Sampling strategy for determination of airborne asbestos fibre concentrations

1 Scope

This part of ISO 16000 specifies procedures to be used in planning of air measurements to determine the concentrations of asbestos in indoor atmospheres. Careful planning of the measurement strategy is important, because the results can become the basis of recommendations for major building renovations, or for the return of a building to normal occupancy status after removal of asbestos-containing materials.

This part of ISO 16000 uses the following definition for indoor environments as specified in ISO 16000-1:

— dwellings having living rooms, bedrooms, do-it-yourself (DIY) rooms, recreation rooms, cellars, kitchens and bathrooms;

— workrooms or workplaces in buildings which are not subject to health and safety inspections in regard to air pollutants (for example, offices and sales premises);

— public and commercial buildings (for example, hospitals, schools, kindergartens, sports halls, libraries, restaurants and bars, theatres and other function rooms);

— cabins of vehicles and public transport.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Sources and occurrence

Airborne fibres in building atmospheres can originate from various sources within or outside the building. Many of the fibres are organic, such as cotton or synthetic fibres released from upholstery fabrics or the clothing of the occupants, or cellulose fibres dispersed during manipulation of paper. Other organic fibres originating from vegetation can infiltrate the building from outside, or can be dispersed from potted plants. Inorganic fibres, such as asbestos, glass fibres, mineral wool fibres and gypsum can be released from various building materials. Release of airborne fibres from building materials can occur intermittently, particularly during disturbances of the materials during maintenance activities. Fragments of the materials can become detached when the materials are contacted, and, if not removed, these fragments can be pulverized by subsequent activities to form dust that can be dispersed into the atmosphere.

4 Terms and definitions

For the purposes of this part of ISO 16000, the following definitions apply.

4.1
abatement
activity undertaken to control the potential emission of asbestos fibres from an asbestos-containing building material by removing, enclosing or encapsulating the material, or by repairing damaged material

4.2
abatement containment area
space within which an asbestos abatement activity is performed and which is separated from the remainder of the building by a containment barrier

4.3
ambient sampling
air sampling to determine the airborne asbestos fibre concentration in the immediate vicinity of the building exterior

4.4
analytical sensitivity
calculated airborne asbestos fibre concentration, equivalent to counting of one asbestos fibre in the analysis

4.5
asbestos
term applied to a group of silicate minerals belonging to the serpentine and amphibole groups which have crystallized in the asbestiform habit, causing them to be easily separated into long, thin, flexible, strong fibres when crushed or processed.

NOTE NOTE The Chemical Abstracts Service Registry Numbers of the most common asbestos varieties are: chrysotile (12001-29-5), crocidolite (12001-28-4), grunerite asbestos (amosite) (12172-73-5), anthophyllite asbestos (77536-67-5), tremolite asbestos (77536-68-6) and actinolite asbestos (77536-66-4).

4.6
asbestos structure
term applied to an individual asbestos fibre, or any connected or overlapping grouping of asbestos fibres or bundles of asbestos fibres, with or without other particles

4.7
aspect ratio
ratio of length to width of a particle

4.8
background sampling
air sampling performed to determine the short-term asbestos fibre concentration in the air of occupied spaces during normal usage before an activity that can disturb asbestos

4.9
blank
unused filter submitted for analysis as a control

4.10
clearance sampling
air sampling performed following an asbestos abatement activity with the purpose of determining whether airborne levels of asbestos are below a specified level at which re-occupancy of an asbestos abatement area is permitted

4.11
cluster
structure in which two or more asbestos fibres, or bundles of asbestos fibres, are randomly oriented in a connected grouping

4.12
containment barrier
impervious barrier enclosing the asbestos abatement containment area

4.13
containment clearance
air sampling performed within the asbestos abatement containment area with the purpose of determining whether airborne levels of asbestos are below a specified level at which the containment barrier can be removed

4.14
electron diffraction
technique in electron microscopy in which the crystal structure of a small area of a sample is examined

4.15
energy-dispersive X-ray analysis
determination of elemental composition through measurement of the energies and intensities of X-rays by use of a solid state detector and multi-channel analyzer system

4.16
field blank
filter cassette which has been taken to the sampling site, opened, and then closed

NOTE Field blanks are used to determine whether contamination can have occurred during field handling of the cassettes.

4.17
fibre
elongated particle, with a minimum length to width ratio of 3:1

NOTE The dimensional parameters used to define a fibre are specific to the analytical method used, and are separately defined in each analytical method.

4.18
fibre bundle
structure composed of parallel, smaller-width fibres attached along their lengths

NOTE A fibre bundle can exhibit diverging fibres at one or both ends.

4.19
fibrous structure
fibre, or connected grouping of fibres, with or without other particles

4.20
HEPA filter
High Efficiency Particulate Absolute filter

NOTE Specifications for an HEPA filter (class H13) require that it has a collection efficiency of 99,95 % for the most penetrating particle size (MPPS) according to EN 1822 [4]. Filters with higher efficiency may be used.

4.21
indoor baseline concentration
long-term asbestos fibre concentration measured in a building during normal usage

4.22
interim corrective actions
any simple measures, short of full asbestos abatement, used to alleviate emissions of airborne asbestos fibres from building materials

4.23
investigative sampling
air sampling performed to determine the impact of an occurrence or a simulated activity on airborne asbestos fibre concentrations

4.24
leakage sampling
air sampling performed around the perimeter of an asbestos abatement containment area for the purposes of determining whether leakage of airborne asbestos fibres from the containment area has occurred or is occurring

4.25
limit of detection
numerical asbestos fibre concentration that will not be exceeded at a probability of 95 % by the actual asbestos fibre concentration, if no asbestos fibres are detected during analysis

4.26
long-term
period of time exceeding 24 h

4.27
matrix
structure in which one or more asbestos fibres, or bundles of asbestos fibres, touch, are attached to, or partially concealed by, a single particle or connected group of non-fibrous particles

4.28
negative pressure
pressure differential between an asbestos abatement containment area and its surroundings when the asbestos abatement containment area is maintained at a pressure lower than that of its surroundings

NOTE The expression is frequently loosely applied to the pressure in the asbestos abatement containment area.

4.29
negative pressure ventilation unit
device used to exhaust air from an asbestos abatement containment area in order to establish a negative pressure differential between the asbestos abatement containment area and its surroundings

NOTE Typically, the air is exhausted through an HEPA filter, or a filter of higher efficiency, to minimize the escape of airborne asbestos fibres from the asbestos abatement containment area to its surroundings.

4.30
outdoor baseline concentration
long-term asbestos fibre concentration measured outdoors and sufficiently close to a building to be representative of air drawn into the building

4.31
PCM-equivalent fibre
asbestos fibre of aspect ratio greater than or equal to 3:1, longer than 5 µm, and which has a width between 0,2 µm and 3,0 µm

4.32
PCM-equivalent structure
fibrous structure of aspect ratio greater than or equal to 3:1, longer than 5 µm, and which has a width between 0,2 µm and 3,0 µm

NOTE A PCM-equivalent structure does not necessarily contain any fibres longer than 5 µm, and can consist of a grouping of parallel asbestos fibres, all of which are shorter than 5 µm.

4.33
personal sampling
air sampling performed in the breathing zone of an individual in order to determine that individual's potential exposure to airborne asbestos fibres

4.34
phase contrast optical microscopy
microscopy technique in which the differential phase shift of the energy passing through a sample is converted into an amplitude effect.

NOTE In asbestos fibre monitoring, this technique is implemented on the light microscope and is widely accepted for monitoring asbestos exposure in a workplace.

4.35
pre-activity (background) concentration
short-term asbestos fibre concentration measured immediately before an activity

4.36
prevalent level sampling
air sampling performed within an area to determine asbestos fibre concentrations during normal occupancy of, and during normal activities in, that area

4.37
procedure validation sampling
air sampling to determine the impact on prevalent levels resulting from maintenance or other activities in a building in which asbestos-containing materials are installed

4.38
replicate sample
one or more air samples collected in close proximity to another air sample, such that the analytical results from the samples are expected to be consistent

4.39
room unit
room that has a maximum floor area of 100 m^2 and a maximum length of 15 m

NOTE In special situations, up to four smaller rooms, for which the total floor area does not exceed 100 m^2, can be considered as a single room unit, provided that there is efficient air exchange between the rooms. Otherwise, a small, individual room is considered as a single room unit.

4.40
short-term
period of time less than or equal to 24 h

4.41
simulation
activity designed to replicate specific activities performed under controlled conditions in order to test the impact of these activities on airborne asbestos fibre concentrations

4.42
small room
room of area of less than 10 m^2

4.43
structure
single fibre, fibre bundle, cluster or matrix

4.44
stratified sampling
air sampling conducted according to a defined strategy in which the samples are grouped on the basis of detailed knowledge of the building characteristics

5 Symbols and abbreviations

5.1 Symbols

n_{RU} the number of room units

A the area of a room in square metres, m^2

L_{LCL} factor by which a PCM fibre concentration shall be multiplied to obtain the lower 95 % confidence limit

L_{UCL} factor by which a PCM fibre concentration shall be multiplied to obtain the upper 95 % confidence limit

s_R the subjective component of the interlaboratory coefficient of variation for PCM fibre counts

x the number of fibres counted

x_{LCL} the lower 95% confidence limit of a fibre count made by either SEM or TEM

x_{UCL} the upper 95% confidence limit of a fibre count made by either SEM or TEM

α statistical significance level

D_1 for a fibre count of x, the value of the χ^2 distribution with $2x$ degrees of freedom and a significance level of $(1 - \alpha/2)$

D_2 for a fibre count of x, the value of the χ^2 distribution with $2(x + 1)$ degrees of freedom and a significance level of $\alpha/2$

E limit of detection

z standard normal deviate

5.2 Abbreviations

ED Electron diffraction

EDXA Energy dispersive X-ray analysis

HEPA High efficiency particle absolute

MEC Mixed esters of cellulose

PC Polycarbonate

PCM Phase contrast optical microscopy

SAED Selected area electron diffraction

SEM Scanning electron microscopy

TEM Transmission electron microscopy

TSP Total suspended particulate

6 Measurement strategy

6.1 Planning of measurements

6.1.1 General

Depending on the applicable regulations, phase contrast optical microscopy (PCM), scanning electron microscopy (SEM) or transmission electron microscopy (TEM) may be specified for the analysis of air samples. The air sampling parameters depend on the objective of the measurements, the regulatory control limit and the method of analysis. It should be noted that the analytical capabilities of the methods above are different, and that results obtained from PCM, SEM or TEM may not be comparable.

Some regulations specify that the interpretation of indoor asbestos fibre concentrations be based on a comparison with simultaneous measurements made outside. Weather conditions can restrict the ability to collect satisfactory air samples in the outdoor environment. Whenever possible, sampling should be carried out in low-wind, low-humidity conditions. Detailed records of the weather conditions, wind speed and direction during the sampling period should be made. Collect all air samples at a height between 1,2 m and 1,5 m from the floor, with the filter cassette facing downwards at an angle of approximately 45°. All available information concerning local topography, and the types and positions of sources should be recorded.

All sampling data that may be of significance for later analysis shall be carefully recorded. The location of the sampling apparatus shall be documented in the form of a sketch and, if possible, a photograph.

6.1.2 Measurement objectives

The objectives of indoor air monitoring for asbestos are as follows.

1) To determine the asbestos fibre concentrations during normal occupancy and usage of an area within a building for diagnostic purposes; such monitoring may be performed periodically to verify the long-term effectiveness of an abatement activity. This is known as “prevalent level sampling”.

2) To determine the short-term asbestos fibre concentration in occupied spaces during normal usage before an activity that can disturb asbestos. This is known as “background sampling”.

3) To determine the impact on airborne asbestos fibre concentrations resulting from routine maintenance activities in a building in which asbestos-containing materials are installed. This is known as “procedure validation sampling”.

4) To determine changes of airborne asbestos concentrations which can result from a simulated activity, changes of building usage, or as a consequence of inadvertent damage to asbestos-containing materials. This is known as “investigative sampling”.

5) To establish whether the airborne asbestos fibre concentration is below a specified level at which time containment barriers can be removed or safety precautions discontinued, and occupancy of an abated area can be resumed, after either interim corrective actions to reduce the asbestos fibre exposure risk have been taken, or after an asbestos abatement activity has been completed. This is known as “clearance sampling”.

6) To establish whether, during abatement work, leakage of contaminated air from the containment area into the local environment has occurred or is occurring. This is known as “leakage sampling”.

7) To determine the exposure of an individual to airborne asbestos fibres; air sampling for this purpose is performed in the breathing zone of the individual. This is known as “personal sampling”.

These objectives are described in more detail in Table 1.

Table 1 — Types of indoor air monitoring and simulation of the conditions of use

Question	Objective of measurement	Sampling conditions (see 6.2)
How high is the airborne asbestos fibre concentration during normal use of the room?	To establish the long-term prevalent asbestos fibre concentrations in indoor air for diagnostic purposes or to verify the effectiveness of asbestos abatement [prevalent level sampling, 6.1.2 (1)].	No simulation is required. Collect air samples during normal building occupancy and usage.
What is the base-line asbestos fibre concentration against which the effects of an activity are to be compared?	To determine the short-term background asbestos fibre concentration in occupied spaces during normal usage before an activity that can disturb asbestos [background sampling, 6.1.2 (2)].	No simulation is required. Collect air samples during normal occupancy and usage shortly before the planned activity.
What are the asbestos fibre concentrations in a room when activities such as changing light bulbs, cleaning of walls and floors, or replacing ceiling tiles take place?	To determine whether unacceptable airborne asbestos fibre concentrations result from routine maintenance activities [procedure validation sampling, 6.1.2 (3)].	No simulation is required. Collect static and personal air samples during the operations or maintenance activity.
Are interim corrective actions necessary if the room is to be used for other purposes?	To determine whether airborne asbestos fibre concentrations are acceptable if usage of a room is changed [investigative sampling, 6.1.2 (4)].	Disturb surfaces, produce air movements and vibrations typical of those that will occur under the proposed conditions of occupancy.
Has the airborne asbestos fibre concentration been reduced to an acceptable value such that safety precautions can be discontinued? Were the interim corrective actions successful?	To confirm, after interim corrective actions have been taken, and prior to discontinuation of safety precautions, that representative activities in the area do not generate unacceptable concentrations of airborne asbestos fibres [clearance sampling, 6.1.2 (5)].	Disturb surfaces, produce air movements and vibrations typical of those that will occur under the proposed conditions of occupancy.
After completion of asbestos abatement conducted in a containment, is the asbestos fibre concentration under extreme disturbance conditions below a specified permissible limit value?	Final clearance air monitoring to determine whether the area within the containment has been cleaned sufficiently so that containment barriers can be removed and the area of the building re-occupied [clearance sampling, 6.1.2 (5)].	Produce air movements exceeding those that will occur during normal building use. Use various vibration methods and surface disturbances with air mixing to simulate extreme conditions.
Are containment barriers, negative pressure and other protective precautions effective in preventing release of asbestos fibre contamination into areas outside the work area? Has the area outside the work area been contaminated with asbestos fibres?	Air monitoring to assure that all protective precautions are effective during abatement activities [leakage sampling, 6.1.2 (6)].	Collect air samples around the perimeter of the containment during the work.
Is the asbestos fibre concentration associated with an activity likely to result in an unacceptable personal exposure?	Air monitoring to determine the exposure of an individual [personal sampling, 6.1.2 (7)].	Collect air samples in the breathing zone of the individual during performance of the activity.

6.1.3 Choice of analytical method

Mandatory national standard analytical methods can have been defined for determination of the concentrations of asbestos fibres in indoor atmospheres. If no national standard analytical method has been defined, one of four ISO analytical methods can be selected for use with this sampling strategy. The characteristics of ISO standard methods based on PCM, SEM and direct-transfer TEM and indirect-transfer TEM are described in Annex B.

6.1.4 Number of sample locations

The number of air samples to be collected depends on the number, size and arrangement of the rooms in the building. It is convenient to express the nature of the building in terms of "room units", from which the number of samples to be collected for any particular purpose can be calculated. A minimum of two samples shall be collected for each separate containment area, except for very small rooms of area less than 10 m^2, each of which shall be considered as one room unit. For large rooms, calculate the number of room units using the empirical Equation (1), and round up to the next integer.

$$n_{RU} = \frac{14A}{730 + A} \quad (1)$$

where

n_{RU} is the number of room units;

A is the area of the large room in square metres, m^2.

The numbers of samples that are necessary to evaluate a particular area for prevalent or investigative sampling, and for background, clearance or leakage sampling, are specified in Table 2.

Elevated locations (for example, lighting platforms, crane operator's stands, galleries, work platforms in shafts) shall be assessed separately.

Table 2 — Minimum number of random samples required for evaluation of large buildings

Number of room units under evaluation N [a]	Minimum number of samples required	
	Prevalent or investigative sampling	Background, clearance or leakage sampling
1 to 2	2	2
3 to 4	2	3
5 to 6	3	4
7 to 8	3	5
9 to 11	3	6
12 to 14	3	7
15 to 17	4	8
18 to 20	4	9
21 to 25	5	10
26 to 31	5	11
32 to 38	6	12
39 to 46	6	13
47 to 55	7	14
More than 55	N/8 (Round upwards)	N/4 (Round upwards)

[a] N is the value of n_{RU}, rounded upwards.

6.1.5 Choice of sampling locations

The room units chosen may be selected such that increased weight is given to locations where potential asbestos sources are suspected on the basis of a prior survey and analysis of building materials. Where this is done, the results from such stratified samples shall be clearly separated from samples that are randomly distributed. In buildings with a large number of small individual rooms, or in very large rooms, randomly positioned samples may be taken. Air samplers should generally be located at least 2 m away from walls, with the filter cassette positioned between 1,2 m and 1,5 m above the floor. The positions of air supply diffusers should be taken into account, so that the air samples collected are as representative as possible of the air in the room.

If one or more of the measured asbestos fibre concentrations exceeds the permissible limit value, another cycle of measurements shall be carried out after appropriate corrective actions have been taken to reduce the asbestos fibre concentration.

The subsequent re-determination of the number of random samples shall include both the room units in which the limit value has been exceeded and the room units in which sampling has not yet been carried out.

With several sampling locations in a large room or in several small rooms connected to each other, simulate the conditions of usage over the whole area of the room, and in all rooms that are combined into one room unit.

In definition and selection of room units in the individual stories of a building, or in large rooms, the different usage patterns and the furnishings in the room shall be taken into consideration to ensure that the measurements will accurately represent the designated area. Furthermore, preference shall be given to sampling locations that represent high exposure potential, due to the location, accessibility and the nature of asbestos-containing materials.

In staircases or accessible shafts enabling draught effects at least one sampling location shall be chosen in the upper section of the staircase or the shaft, respectively. Alternatively, sealing all openings can minimize the draught effects in inaccessible shafts or similar rooms. The bottom of the shaft shall then be chosen as the sampling location.

6.1.6 Measurements in return air ducts of air-conditioned buildings

Air samples may be collected in the return air system of an air-conditioned building, at the position immediately before the return air is filtered and re-circulated. The particulate material in the air at this location is generally representative of the average situation in the occupied spaces of the building. The air conditioning system should be operating during the collection of air samples. The air velocities in return air ducts are sufficiently low that, for the range of fibre diameters of interest, isokinetic sampling is not necessary.

6.1.7 Measurement in rooms with low volume

The application of this method of measurement in rooms characterized by low air exchange and low volume may reduce the asbestos fibre concentration during sampling as the sampling device itself functions as an air filter when the emission of asbestos fibres into the air does not continue during the entire period of sampling. This is the case, for example, when the simulation of the conditions of usage is performed. Therefore, the total hourly sampled volume for all samples in a room should not exceed one tenth of the room volume, otherwise the outcome of the sampling can result in underestimation of the actual situation. If sampling is carried out in rooms where this effect is expected, and the sample analyses are to be conducted using direct-transfer analytical methods, it is recommended that filters of 25 mm in diameter be used in order to minimize the sampled air volume requirement.

6.1.8 Sampling conditions in containment areas

The surfaces within the containment area shall be dry before sampling is commenced. If sampling is conducted in a containment area after surfactants or sealants have been used, sampling shall be started only after a sufficiently long period of time has elapsed to ensure that the surfactants or sealants have settled out. If sampling is started too early, the filter surface can become heavily covered with the surfactant or sealant, which can often be only partly removed in the specimen preparation process, depending on the type of surfactant or sealant. The presence of these materials on the sample diminishes the visibility of thin asbestos fibres, reduces the sensitivity of the measurement, and can cause the sample to be rejected.

6.1.9 Effects of high particulate loading on filters

A lower limit of detection for a measurement can, in principle, be achieved by increasing the sampled air volume and the area of the filter examined. When either the sampling period or the volume flow-rate is increased, thus increasing the volume of air sampled, the concentration of non-fibrous particles in the indoor air can result in an increase in the formation of agglomerates on the filter. This can lead to clogging of the filter during sampling, and consequently to an unacceptable pressure drop across the filter such that the flow-rate decreases. The higher filter loadings of non-fibrous particles can also result in obscuration of asbestos fibres, thus introducing a negative bias. Particle loading should not exceed 10 % of the surface area of the filter.

The selection of the appropriate sampling period, the intensity and frequency of simulation and the area of sample to be examined is thus a problem of optimization that shall be resolved at the planning stage with regard to the particular objective of measurement. A pilot study can be useful for determining the optimum sampling conditions needed.

6.1.10 Blank measurements

Filters used for field blanks shall pass through the complete sample preparation procedure. The number of field blanks submitted to the laboratory and analyzed shall be at least 10 % of the number of air samples analyzed, with a minimum of one per site and one per day.

6.1.11 Air sample collection inside buildings

Air samples are often collected inside buildings in which asbestos-containing construction materials are present, in order to determine whether these materials contribute to the asbestos concentration in the building atmosphere. The optimum positions for collection of air samples can be determined only after a complete survey of the building has been conducted to establish the location and type of asbestos-containing materials present, the air movement patterns and activities of the occupants. Multiple samples should be collected in the area where asbestos-containing materials are present, and comparison samples should be collected in an adjacent area where no airborne asbestos fibres would be expected. The external intakes for air conditioning systems are frequently used as the exterior sample collection locations. Whenever possible, static samples should be taken over a period exceeding 4 h during normal activity in the building.

All sampling data that can be of significance for later analysis shall be recorded. The location of the sampling apparatus shall be documented in the form of a sketch and, if possible, a photograph. An example of a suitable sample data form is shown in Annex C.

Do not conduct air sampling if high concentrations of dust or smoke are present in the air, because the sample collection filters can either become overloaded to the point that microscopical examination is not possible, or it will be necessary to terminate sampling prematurely, resulting in a measurement with insufficient analytical sensitivity.

If a decrease in temperature is expected during the period of air sampling, the relative humidity should be less than 70 %. If the temperature falls below the dew point, water droplets can be collected on the filter surface, resulting in increased flow resistance.

6.2 Simulation of the conditions of usage

6.2.1 General

It is well known that asbestos may not be detected in air samples collected under passive conditions, even though substantial amounts of asbestos can exist on surfaces in the area where the air samples were collected. Simulated activity is specified for one of two purposes: 1) to obtain measurements of airborne asbestos fibre concentrations under the conditions of current usage; or 2) to demonstrate that a newly abated area can be released for occupancy by generating the highest possible airborne asbestos concentration. Air sampling may be carried out during normal occupancy and usage, in which case no simulation is necessary.

Prior to conducting any simulated activity, the area should be inspected for the presence of any suspected asbestos-containing dust or debris. Examination of dust and debris samples by polarized light microscopy can provide guidance in determining whether such simulated activity should be carried out.

6.2.1.1 Simulation of current usage conditions

For the purpose of measuring airborne asbestos concentrations that arise under current usage conditions, activities comparable to those that normally take place are simulated [3]. Simulation of the conditions of usage is a process in which any dust that can be on surfaces in a room, possibly containing asbestos fibres, is suspended into the indoor air in a manner comparable to that which would occur during the most active usage when normally occupied. For example, office cleaning is a routine activity that can simulate the most active usage of an office, while bouncing a basketball and running can simulate the most active usage in a sports hall. Simulation is achieved by producing air movements, surface disturbance and/or vibrations. The types of simulation methods are listed in Annex A. The methods in Annex A should be used uniformly throughout the study to aid the comparability of the results. Any departure from the specified methods shall be justified in each individual case.

Other than the type of simulation activity, factors such as the energy or effort used when simulating the activity, when it is first carried out, the duration of the activity, the frequency with which it is repeated and the period over which the air sampling is conducted will all affect the measured airborne asbestos fibre concentration. Given the range of situations that will be encountered, it is not realistic to have rigid protocols, but it is required that the summary report adequately documents the above variables.

This simulation activity is designed to reproduce aerosols generated by normal activity. If asbestos is present in the indoor environment, the simulation can generate an asbestos aerosol in the study area. All persons involved in such studies should use personal protective equipment to avoid possible exposure to a potentially hazardous aerosol. The investigator should carefully consider this potential to create an exposure hazard and should take steps to ensure that no bystanders are exposed during the activity. Precautions such as containment barriers and environmental air controls to guard against expanding a contaminated area during the simulation should also be considered.

6.2.1.2 Simulations for post-abatement clearance

For the purpose of post-abatement clearance, aggressive air sampling is specified, during which surfaces are disturbed to disperse any residual dust and create the highest possible airborne asbestos concentration. Prior to carrying out any simulation activities, carry out a visual inspection of surfaces in the area. If visible asbestos-containing debris is present on surfaces, do not perform any simulation as the area will need to be cleaned.

NOTE A detailed procedure for visual inspection of newly abated areas is provided in Reference [8].

6.2.2 Type of simulation to be used

The type of simulation that shall be used is dependent on the objectives of the measurement, and appropriate methods are specified in Table 1.

The simulation may be omitted partially or completely if the normal conditions themselves result in suspension of asbestos fibres. For example, sports activities in gymnasiums, activities during a school day, or the normal cleaning of rooms with a conventional vacuum-cleaner can be considered sufficient levels of disturbance.

6.2.3 Timing of simulation procedures

Provided that no other regulatory requirements are specified, the simulation procedure shall be carried out directly before air sampling is commenced and can be repeated. It is recommended that the period of time during which the simulation procedure is carried out not exceed 10 % of the overall sampling time.

6.3 Sampling parameters

6.3.1 Number of samples to be collected

For prevalent, investigative, background, clearance or leakage sampling, the number of samples collected shall be in accordance with Table 2.

6.3.2 Prevalent level sampling

To ensure that the sampling is representative of conditions during normal occupancy, the air conditioning shall be on and the following precautions shall be taken:

a) in order to avoid dilution of the asbestos fibre concentration in indoor air, all windows, doors and other similar openings shall be kept closed for a minimum period of 3 h before air sampling is commenced, and also during the period of air sampling;

b) so far as it is practical, activities in the building should continue in their usual manner during the air sampling period.

6.3.3 Background sampling

Background sampling is carried out to establish the short-term asbestos fibre concentration in an occupied space in order to provide a basis for comparison after an activity is carried out. The activity may or may not involve disturbance of asbestos. Collect the samples immediately prior to the activity.

6.3.4 Procedure validation and investigative sampling

Measurements to determine the impact of a single event within a building can be difficult to make, because sources of asbestos fibres can be highly localized and this will result in inhomogeneous aerosols. Since the asbestos fibre concentration observed at a distance from a localized source of airborne asbestos fibres can be diluted to the point that no increase is detected by a single measurement, a large number of samples can be required in order to characterize the situation if no supplementary information as to the sources of the airborne asbestos fibres is available. In other situations, an activity, by its nature, can occur for only a short time, thus limiting the air volume that can be collected during the activity. This can result in an inadequate analytical sensitivity, and it can then be necessary to accumulate the asbestos fibres from a number of repetitions of the activity on to each of the filters being exposed. Consideration of measurement sensitivity is crucial in the experimental design for the study of short-term activities.

6.3.5 Clearance sampling

Mandatory national regulations for clearance sampling should be applied if they exist. In general, post-abatement clearance air monitoring following asbestos abatement activities shall be performed only after the following:

a) all surfaces have been cleaned after completion of the asbestos abatement work;

b) a thorough visual inspection shows that no asbestos residue or visible dust remains in the rooms; if any residue is observed, the criteria for the cleaning procedures have not been met and additional cleaning shall be performed;

c) all surfaces are dry; residual water will result in temporary adhesion of asbestos fibres to surfaces and lead to lower air concentrations than would occur if the surfaces were completely dry;

d) if any sealant has been applied by spraying to adhere residual dust to the surfaces, a sufficient period of time has elapsed to ensure that residual airborne sprayed sealant is no longer present.

Provided that no regulations state otherwise, during clearance sampling inside an asbestos abatement containment area, the negative pressure ventilation units, if installed, shall be turned off.

NOTE Some government regulations can require that the negative pressure ventilation units remain on during the clearance test. Air samples collected under these conditions generally contain suspended particulate material originating from outside the asbestos abatement containment area.

6.3.6 Leakage sampling

Leakage sampling is used to augment frequent, thorough, visual inspections of the containment barrier. A number of sample locations should be considered: for example, near an air-lock (the entry and exit for workers, near a bag-lock (the exit used to remove bags from the containment area), and near the exhausts of negative pressure ventilation units. For this type of testing, it may only be possible to sample for a few minutes, in which case a high flow-rate should be used in order to provide adequate analytical sensitivity for the measurement. The origin of any asbestos fibres resulting in a measurement that is confidently above background levels should be investigated.

6.3.7 Personal sampling

The breathing zone of a worker consists of a hemisphere of 0,3 m radius extending in front of the face, and measured from the mid-point of a line bisecting the ears. The filter holder should point downwards and be fixed to the upper lapel or shoulder of the worker's clothing, as close to the mouth and nose as practicable, and preferably within 0,2 m. Due regard shall be given to localized concentrations: in such cases, the sampling head should be positioned on the side expected to give the higher result. If a respirator is worn, the sampling head should be positioned away from the clean air exhaust.

6.3.8 Ambient sampling

Results from air samples collected outside of buildings under study are often used to provide a baseline against which the results from inside the buildings are compared. Weather conditions often restrict the ability to collect satisfactory air samples in the outdoor environment, and whenever possible, sampling should be carried out in low-wind, low-humidity conditions. Detailed records of the weather conditions, wind-speed and direction during the sampling period should be made. All available information concerning local topography and the types and positions of potential sources of asbestos fibres should be recorded. In studies of air-conditioned buildings in urban locations, the total suspended particulate concentration outside the building can limit the air volume that can be sampled, leading to higher values for the analytical sensitivity than those which can be achieved inside the building. This situation requires careful interpretation if only low numbers of asbestos fibres are observed in the measurements.

6.4 Calculation of results

6.4.1 General

In the interpretation of results, it is important to recognize the limits of detection and the limitations of precision for measurements made by PCM, SEM or TEM.

6.4.2 Limit of detection for PCM analyses

The limit of detection for PCM analyses on lightly-loaded filters is controlled by the background fibre count, which shall be obtained by examination of representative filters from each batch. The limit of detection will increase with an increase of particulate density on the filter, but no firm data on this effect are available.

6.4.3 Limits of detection for SEM and TEM analyses

For measurements made by SEM or TEM, the limit of detection is defined in this sampling strategy as the numerical asbestos fibre concentration below which, with 95 % probability, the real concentration shall lie when no asbestos fibres are detected during the analysis.

The limit of detection depends on

a) the sampled volume which passes through the filter during the sampling period, and

b) the area of filter examined.

The limit of detection is defined as that concentration corresponding to the detection of 2,99 asbestos fibres in the analysis. For example, for an SEM measurement in which an air volume of 1 m^3 was collected per square centimetre (cm^2) of filter area, and an area of 1 mm^2 of the filter surface was examined, the defined limit of detection would be 300 fibres/m^3.

Any asbestos fibre background that may be present on unused filters is not taken into account in the specification of the above limit of detection. Experience, however, has shown that background is negligible for both SEM and TEM measurements of asbestos fibres longer than 5 µm. The presence of low numbers of background asbestos fibres may need to be considered when measurements of all asbestos fibres longer than 0,5 µm are made by TEM.

6.4.4 Interpretation of results and compliance with a fixed concentration value

6.4.4.1 Interpretation of PCM measurements

The coefficient of variation for PCM analyses is a combination of the Poisson variability, errors in the measurement of air volume, and a subjective component. The subjective component is the largest of these effects, and each analytical laboratory can derive a value for its group of analysts. Studies have shown that, for a random group of laboratories, the interlaboratory 90 % confidence interval can be estimated by combining the Poisson variability with a subjective component of 0,45 [7][8][9]. In order to demonstrate compliance with a fixed concentration value, it is necessary to take account of the overall variability. The lower and upper 95 % confidence limits are given by the empirical equations:

$$L_{\mathrm{LCL}} = \frac{2x + 4 - \left[(4+2x)^2 - 4(1-4s_R^2)x^2\right]^{1/2}}{2x(1-4s_R^2)} \tag{2}$$

$$L_{\mathrm{UCL}} = \frac{2x + 2{,}25 + \left[(2{,}25+2x)^2 - 4(1-2{,}25s_R^2)x^2\right]^{1/2}}{2x(1-2{,}25s_R^2)} \tag{3}$$

where

L_{LCL} is the multiplication factor to obtain the lower 95 % confidence limit;

L_{UCL} is the multiplication factor to obtain the upper 95 % confidence limit;

s_R is the subjective component of the interlaboratory coefficient of variation;

x is the total number of fibres counted.

Equation (2) is not valid for values of $s_R \geqslant 0{,}50$. Equation (3) is not valid for values of $s_R \geqslant 0{,}66$.

A group of laboratories or analysts that has collected sufficient data to derive its own value of s_R can use these formulae to derive 95 % confidence limit curves for use by the group. The user of the laboratory data should obtain the value of s_R from the laboratory, or should assume a value of 0,45 for the interpretation of PCM data.

For example, assuming an s_R of 0,45, in order to demonstrate compliance with a 0,01 fibre/ml standard using a single sample on which 100 fibres have been counted, Equation (3) indicates that the measured airborne fibre concentration shall be a factor of 3,13 lower than the 0,01 fibre/ml standard. The measured airborne fibre concentration, therefore, shall not be higher than 0,003 fibre/ml (100 fibres counted) in order to demonstrate compliance with the 0,01 fibre/ml standard at 95 % confidence.

6.4.4.2 Interpretation of SEM and TEM measurements

Background contamination by asbestos fibres longer than 5 µm in either SEM or TEM analyses is generally negligible, but a low background may need to be accounted for if measurements are based on asbestos fibres longer than 0,5 µm.

The precision of SEM and TEM analyses is not usually compromised by subjective effects, and, provided that the overall aerosol deposition on the sample collection filter is uniform, a Poisson distribution of asbestos fibres can be assumed. The 95 % confidence interval of a measurement, as a function of the number of asbestos fibres counted, can be obtained either from Equations (4) and (5) or from Table 3. Equations (4) and (5) are approximations that produce upper and lower 95 % confidence limits correct to within two digits in the second decimal place.

For an asbestos structure or asbestos fibre count of x, the lower 95 % confidence limit is

$$x_{LCL} = x[1-(1/9x)-z(1/9x)^{1/2}]^3 \quad (4)$$

The upper 95 % confidence limit is

$$x_{UCL} = d[1-(1/9d)+z(1/9d)^{1/2}]^3 \quad (5)$$

where $d = (x + 1)$, and $z = 1{,}960$, the standard normal deviate for two-sided limits at the 95 % probability level.

Alternatively, it is possible to compute precisely the values for the upper and lower 95 % confidence limits in a software spreadsheet if the spreadsheet can calculate the χ^2 distribution, and the confidence limits are given by:

$$x_{LCL} = 1/2D_1 \quad (6)$$

$$x_{UCL} = 1/2D_2 \quad (7)$$

where

D_1 is the value of χ^2 with $2\times$ degrees of freedom and a significance level of $(1 - \alpha/2)$;

D_2 is the value of χ^2 with $2(\times + 1)$ degrees of freedom and a significance level of $\alpha/2$.

For 95 % confidence intervals, use $\alpha/2 = 0{,}025$.

In some cases, the asbestos fibres collected on the filter can be present as clusters and matrices, and the asbestos fibre counting criteria used can cause the distribution to deviate from the Poisson distribution. If the deviation from the Poisson distribution is significant, and if a sufficient number of asbestos fibres has been detected, it is a more conservative approach to assume another distribution such as the Gaussian, in which the mean and standard deviation are independent variables.

In general, the distribution of asbestos fibres on the microscope specimen prepared by the indirect-transfer TEM method more closely approaches the Poisson distribution than is the case for the direct-transfer TEM method.

The statistical interpretation of results is common to all of the electron microscopy methods, and is illustrated by the following examples.

EXAMPLE 1 There is an ambient asbestos fibre concentration of 50 fibres/m^3, and measurements of air concentration in a building are made with an analytical sensitivity of 100 fibres/m^3. If the mean asbestos fibre count is $\bar{x}$, the probability of detecting x asbestos fibres during examination can be described using the Poisson distribution:

$$P(x,\bar{x}) = \frac{\bar{x}^{x}\exp(-\bar{x})}{x!} \tag{8}$$

In this example, since $\bar{x} = 0{,}5$, the probability of detecting two asbestos fibres during the sample examination is approximately 15 %. Therefore, although observation of two asbestos fibres in the count would correspond to an asbestos fibre concentration of 200 fibres/m^3, if it were concluded that this concentration was elevated above ambient, there would be a 15 % probability that this conclusion would be incorrect.

This ambiguous situation can often be resolved by increasing the area of the sample examined, i.e. by improving the analytical sensitivity of the measurement. If the area of sample examined were doubled, the analytical sensitivity would be 50 fibres/m^3, and on average four asbestos fibres should be detected. Table 3 shows that the lower 95 % confidence limit for four asbestos fibres is 1,090 asbestos fibres, thus yielding a value of 54,5 fibres/m^3 for the lower 95 % confidence limit of concentration. Doubling of the area of sample examined, in this case, allows a statement, at 97,5 % confidence, that the measured concentration is elevated with respect to the ambient concentration.

EXAMPLE 2 If a concentration was measured as 100 fibres/m^3, and the measurements were made at an analytical sensitivity of 100 fibres/m^3, one asbestos fibre would be detected. In order to demonstrate, with 97,5 % confidence, that the measurement is elevated with respect to an ambient concentration of 50 fibres/m^3, it would be necessary to increase the area examined by a factor of 12. This would yield an analytical sensitivity of 8,333 fibres/m^3 and twelve asbestos fibres would be detected. The lower 95 % confidence limit for a mean of twelve asbestos fibres is found in Table 3 to be 6,201 asbestos fibres, giving a lower 95 % confidence limit for the concentration of 51,7 fibres/m^3, slightly higher than the ambient concentration of 50 fibres/m^3.

Table 3 — Upper and lower limits of the Poisson 95 % confidence interval of a count

Asbestos fibre or structure count	Lower	Upper	Asbestos fibre or structure count	Lower	Upper	Asbestos fibre or structure count	Lower	Upper
0	0	3,689[a]	46	33,678	61,358	92	74,164	112,83
1	0,025	5,572	47	34,534	62,501	93	75,061	113,94
2	0,242	7,225	48	35,392	63,642	94	75,959	115,04
3	0,619	8,767	49	36,251	64,781	95	76,858	116,14
4	1,090	10,242	50	37,112	65,919	96	77,757	117,24
5	1,624	11,669	51	37,973	67,056	97	78,657	118,34
6	2,202	13,060	52	38,837	68,192	98	79,557	119,44
7	2,814	14,423	53	39,701	69,326	99	80,458	120,53
8	3,454	15,764	54	40,567	70,459	100	81,360	121,66
9	4,115	17,085	55	41,433	71,591	110	90,400	132,61
10	4,795	18,391	56	42,301	72,721	120	99,490	143,52
11	5,491	19,683	57	43,171	73,851	130	108,61	154,39
12	6,201	20,962	58	44,041	74,979	140	117,77	165,23
13	6,922	22,231	59	44,912	76,106	150	126,96	176,04
14	7,654	23,490	60	45,785	77,232	160	136,17	186,83
15	8,396	24,741	61	46,658	78,357	170	145,41	197,59
16	9,146	25,983	62	47,533	79,482	180	154,66	208,33
17	9,904	27,219	63	48,409	80,605	190	163,94	219,05
18	10,668	28,448	64	49,286	81,727	200	173,24	229,75
19	11,440	29,671	65	50,164	82,848	210	182,56	240,43
20	12,217	30,889	66	51,042	83,969	220	191,89	251,10
21	13,000	32,101	67	51,922	85,088	230	201,24	261,75
22	13,788	33,309	68	52,803	86,207	240	210,60	272,39
23	14,581	34,512	69	53,685	87,324	250	219,97	283,01
24	15,378	35,711	70	54,567	88,441	260	229,36	293,62
25	16,178	36,905	71	55,451	89,557	270	238,75	304,23
26	16,983	38,097	72	56,335	90,673	280	248,16	314,82
27	17,793	39,284	73	57,220	91,787	290	257,58	325,39
28	18,606	40,468	74	58,106	92,901	300	267,01	335,96
29	19,422	41,649	75	58,993	94,014	310	276,45	346,52
30	20,241	42,827	76	59,880	95,126	320	285,90	357,08
31	21,063	44,002	77	60,768	96,237	330	295,36	367,62
32	21,888	45,175	78	61,657	97,348	340	304,82	378,15
33	22,715	46,345	79	62,547	98,458	350	314,29	388,68
34	23,545	47,512	80	63,437	99,567	360	323,77	399,20
35	24,378	48,677	81	64,328	100,68	370	333,26	409,71
36	25,213	49,840	82	65,219	101,79	380	342,75	420,22
37	26,050	51,000	83	66,111	102,90	390	352,25	430,72
38	26,890	52,158	84	67,003	104,00	400	361,76	441,21
39	27,732	53,315	85	67,897	105,11	410	371,27	451,69
40	28,575	54,469	86	68,790	106,21	420	380,79	462,18
41	29,421	55,622	87	69,684	107,32	430	390,32	472,65
42	30,269	56,772	88	70,579	108,42	440	399,85	483,12
43	31,119	57,921	89	71,474	109,53	450	409,38	493,58
44	31,970	59,068	90	72,370	110,63	460	418,92	504,04
45	32,823	60,214	91	73,267	111,73	470	428,47	514,50

[a] The one-sided upper 95% confidence limit for zero structures is 2,99.

6.4.5 Calculation of volume-weighted mean values

For special applications (e.g. calculation of long-term mean values), the combination of several measured values to calculate a mean value for the asbestos fibre concentration, C, is desired in order to reduce, for example, the variability of the measured result.

If the mean value is to be calculated for a series of measured results that are based on low numbers of counted asbestos fibres, the following mathematical procedure shall be applied in order to obtain a volume-weighted average. The usual calculation of the arithmetic mean would yield a value of the asbestos fibre concentration that does not take the relationship between asbestos fibre count and sampled volume into account.

The measured value is completely determined by two parameters: the evaluation result for the number of asbestos fibres, x, and the evaluated sample air volume, V_{p}. The evaluated sample air volume, V_{p}, alone determines the limit of detection.

Correspondingly, several individual measured values are combined by summation of the number of asbestos fibres, x_i, and the evaluated sample air volumes, V_{p}. Hence:

$$C = \frac{\sum x_i}{\sum V_{\mathrm{p}}} \tag{9}$$

and for the limit of detection, E:

$$E = \frac{2{,}99}{\sum V_{\mathrm{p}}} \tag{10}$$

The 95 % confidence interval due to the random sample-related deviation is calculated analogously on the basis of Σx_i and ΣV_{p}.

In order to make the results traceable, the presentation of the measurements for each sample shall include both the number of asbestos fibres counted and the data to allow calculation of the volume of sampled air examined by the analyst. It is essential that all samples be taken at the same flow-rate.

6.5 Reporting

An example of a summary report form is shown in Annex D, which may be used for any of the measurement objectives, and for measurements made by PCM, SEM, direct-transfer TEM or indirect-transfer TEM.

7 Quality assurance

7.1 General

This clause gives practical information to the user of this standard in order to improve the quality of the measurements. The information provided here relates only to the sampling strategy, and not to the analytical methods themselves, each of which contains quality assurance procedures as an integral component of the method. For evaluation of laboratory performance, refer to ISO/IEC 17025.

7.2 Laboratory quality assurance system

Prior to submission of samples to the analytical laboratory, ensure that the laboratory has a documented quality assurance system, and confirm that the laboratory appears to be applying that system.

7.3 Replicate measurements

It is recommended that approximately 10 % replicate samples be submitted to the laboratory as blind samples. The results obtained for pairs of replicate samples should be consistent, within the statistical limitations of the asbestos fibre sampling and counting procedures.

7.4 Submission of unused filters and field blanks as blind samples

Field blanks and unused filter cassettes should not be identified to the laboratory. Each field blank or unused filter cassette should be assigned an air volume and randomly included in the sequence of samples to be analyzed. This provides an independent control over laboratory and field contamination, and ensures that these control samples are analysed with the same degree of care as the actual samples.

7.5 Interlaboratory analyses

It is recommended that one filter cassette from each study be submitted to a second laboratory for analysis. This provides an independent control over laboratory bias. This may be omitted if the laboratory can provide documentation of consistent performance in an interlaboratory programme.

Annex A
(normative)

Simulation methods

A.1 General

The specified simulation methods are intended to be a practicable compromise between the requirement to re-suspend any dust present on surfaces in the area under study and the requirement that sample collection filters have loadings of particulate material such that they are suitable for analysis.

The basic methods used to re-suspend fibres from surfaces are

a) air movements,

b) vibrations,

c) use of a brush or broom,

d) a combination of a), b) and c).

These methods shall be used unless national standards or regulations specify otherwise. When determining the type of simulation to be used, internal instructions and internal organizational measures in connection with safety precautions shall be taken into consideration. It is also important to ensure that all equipment used in the simulation activities is carefully cleaned to avoid the inadvertent introduction of asbestos fibres into the area to be tested.

A.2 Disturbance of surfaces

With the methods described in this clause, settled asbestos fibres are re-suspended from surfaces and from niches, either using a brush or using a blower directed at the surface from a specified working distance.

In general, the disturbance activities should disturb a minimum of 5 % of the surface area under study. The time of disturbance will be related to the size of the area/enclosure (number of room units). For clearance sampling purposes, the simulated disturbance shall be designed to replicate a substantial disturbance inside the enclosure, and be used to disturb the areas from where the asbestos has been removed, the areas directly underneath where the removal took place and a proportion of the horizontal areas in each of the room units within a 3 m to 5 m radius around the sampling device. Disturbance should take place directly before or from the start of the sampling activity and can be repeated during the sampling period. Mechanical disturbance of dust by brushing the surfaces in a room using a broom or brush is an effective means of suspending dust into the air, when combined with air movements. The brush used shall be new, in order to avoid introducing asbestos fibres into the area originating from previous use of the brush. Fans can be used in the area to disperse the re-suspended dust throughout the volume of the room. If brushes are used, brush the surfaces vigorously prior to sampling. Brushing may be repeated during the sampling period. If blowers are used, approximately 5 % of the surface area under study shall be swept one time with the exhaust of the blower, and at least 5 m^2 of each allocated room unit within a 3 m to 5 m radius around the corresponding sampling device. Aim the air stream directly at the surface.

A.3 Blower performance

The performance of the blower used for simulation of disturbances should be evaluated a minimum of once every three months. The air velocity at the working distance shall be 4 m/s ± 20 %. The velocity of the air stream can be measured by means of an anemometer.

A.4 Producing vibrations

A.4.1 Bouncing a ball

In order to simulate the typical conditions of usage in rooms such as gymnasiums or play-rooms, bounce a basketball 40 times against the floor and the walls within a radius of 5 m around each air sampling device during the sampling period. This activity should represent a minimum of 10 % of the sampling time.

A.4.2 Slamming a door

Asbestos fibres can be released from interior wall panels made of asbestos-containing materials through vibrations and the pumping effects from hollow walls. Slamming the door is an appropriate means to simulate typical conditions of usage and to cause re-suspension of deposited asbestos fibres possibly originating from the panels. Close the door from a right angle position in an accelerating manner so that it slams shut forcefully. Repeat this action five times during the sampling period. If slamming the door cannot simulate the pump effect, press strongly against the panels five times during the sampling period.

A.4.3 Dropping an object

In order to re-suspend asbestos fibres that have possibly been deposited on carpets and wall-to-wall carpeting, drop objects which are typical of the room, such as books or files, on to the carpet. Drop the objects from the height of 1 m such that the broadest side hits the floor within a 5 m radius of each sampling device. Repeat this action five times during the sampling period.

Annex B
(informative)

Choice of analytical method

B.1 General

National standard analytical methods can be specified for determination of airborne asbestos fibres in building atmospheres. If local regulations require the use of these methods, they should be used in combination with this sampling strategy.

If there is no requirement for use of a national standard analytical method, four standard analytical methods are available for measurements of airborne asbestos in building atmospheres, and it is important to recognize the different capabilities of these methods. The characteristics of the four standard methods are summarized in Table B.1. Selection of the appropriate method will depend on the size fraction of asbestos fibres to be measured, how definitive the identification of asbestos is to be, and the requirements specified in regulations or air quality standards.

B.2 ISO 8672, *Air quality — Determination of the number concentration of airborne inorganic fibres by phase contrast optical microscopy — Membrane filter method*

ISO 8672 is a PCM method intended for routine monitoring of personal exposures in workplaces where asbestos is being manipulated or processed. This method does not provide fibre identification, and asbestos fibres thinner than approximately 0,2 µm are below the limit of visibility. The concentrations reported are for all fibres longer than 5 µm and thinner than 3,0 µm that are visible (see also References [5], [6] and [7]).

B.3 ISO 14966, *Ambient air — Determination of numerical concentration of inorganic fibrous particles — Scanning electron microscopy method*

ISO 14966 is a method based on SEM which is designed to measure the concentrations of asbestos fibres longer than 5 µm and between 0,2 µm and 3,0 µm in width. Each fibre is classified in accordance with its chemical composition on the basis of its EDXA spectrum, which permits most non-asbestos fibres to be excluded from the measurement. Numerical concentrations are reported separately for each variety of asbestos. Modern x-ray systems allow discrimination between fibres of all of the asbestos varieties. Because the chemical compositions of talc and anthophyllite are very similar, the method cannot discriminate between these minerals except on the basis of morphological differences. For further information, see Reference [3].

B.4 ISO 10312, *Ambient air — Determination of asbestos fibres — Direct transfer transmission electron microscopy method*

ISO 10312 is a direct-transfer TEM procedure which allows detection of asbestos fibres down to a specified minimum length of 0,5 µm, and lower than 0,01 µm in width. Mineral fibres are identified by a combination of morphology, ED pattern and EDXA. Fibre counting procedures are specified for measurement of asbestos fibres longer than 0,5 µm, asbestos fibres longer than 5 µm, and PCM-equivalent asbestos fibres (asbestos fibres longer than 5 µm and between 0,2 µm and 3,0 µm in width).

B.5 ISO 13794, *Ambient air — Determination of asbestos fibres — Indirect-transfer transmission electron microscopy method*

ISO 13794 is an indirect-transfer TEM procedure that has fibre detection and identification capabilities identical to those of ISO 10312. The advantage of ISO 13794 is that there is no necessity to restrict the loading of particulate material on the sample collection filter, because adjustment of the particle loading can be made in the laboratory during preparation of TEM specimens. It should be recognized that ISO 13794 can produce a different asbestos fibre size distribution during specimen preparation from that yielded by the direct transfer method ISO 10312, and the indirect transfer specimen preparation also often results in a significant increase in the reported concentration of asbestos fibres.

Table B.1 — Comparison of relevant parameters of available ISO methods

Analytical method	Type of micro-scope	Sample preparation	Counting magnification	Definition of countable fibre (length l, width w)	Approximate minimum fibre width visible at counting magnification	Method of fibre identifi-cation	Size of microscope specimen	Analytical sensitivity target values[a]
ISO 8672	PCM	Direct	400-500	l/w: Minimum 3,0 l: > 5,0 µm w: <3,0 µm	0,2 µm	Not possible	Total filter, or at least a quarter filter (0,96 cm^2)	Down to 0,003 f/ml in clean atmospheres with low TSP
ISO 14966	SEM	Direct	2 000	l/w: Minimum 3,0 l: > 5,0 µm w: <3,0 µm	0,2 µm	Chemical composition	Total filter, or at least 1 cm^2	Standard 100 f/m^3
ISO 10312	TEM/EDXA	Direct	20 000	l/w: Minimum 5,0 l: Minimum 0,5 µm	0,01 µm	Crystal structure and chemical composition	3 grids, each of 3 mm diameter	Standard 500 s/m^3
			5 000	l/w: Minimum 3,0 l: Minimum 5,0 µm w: 0,2 µm to 3,0 µm	0,03 µm			Standard 100 f/m^3
ISO 13794	TEM/EDXA	Indirect	20 000	l/w: Minimum 5,0 l: Minimum 0,5 µm	0,01 µm	Crystal structure and chemical composition	3 grids, each of 3 mm diameter	Standard 500 s/m^3
			5 000	l/w: Minimum 3,0 l: Minimum 5,0 µm w: 0,2 µm to 3,0 µm	0,03 µm			Standard 100 f/m^3

[a] Can be increased by examination of a larger filter area.
s fibrous structure (see 4.19)
f fibre

Annex C
(informative)

Example of sample data form

An example of a summary report form is shown in Table C.1. A form similar to this example may be used for any of the measurement objectives, and for measurements made by PCM, SEM, direct-transfer TEM or indirect-transfer TEM.

Table C.1 — Example of air sampling data form

Project:	**No:**
Sampling location:	
Photograph number(s):	
Sampling **Start (date, time) .....** **End (date, time) .....** **Duration (minutes) .....**	
Sampling apparatus (type and number):	
Sampling filter (type):	
Pore size (µm):	**Diameter (mm):**
Effective diameter (mm):	**Effective filter area (mm^2):**
Sampling data	
Volumetric meter reading	
Start (m^3):	**End (m^3):**
Total air volume (m^3):	
Leakage flow (sampling head closed) (l/m):	
Pressure differential at beginning of sampling (kPa) (Optional):	
Volume flow-rate (l/m)	
Start:	**End:**
Indoor climatic conditions (if required)	
Air Temperature (°C):	**Relative Humidity (%):**
Simulation method(s):	
Simulation periods (start and stop times):	
Simulation time as percent of sampling time:	
Remarks:	
Collected by:	**Signature:**
Remarks:	

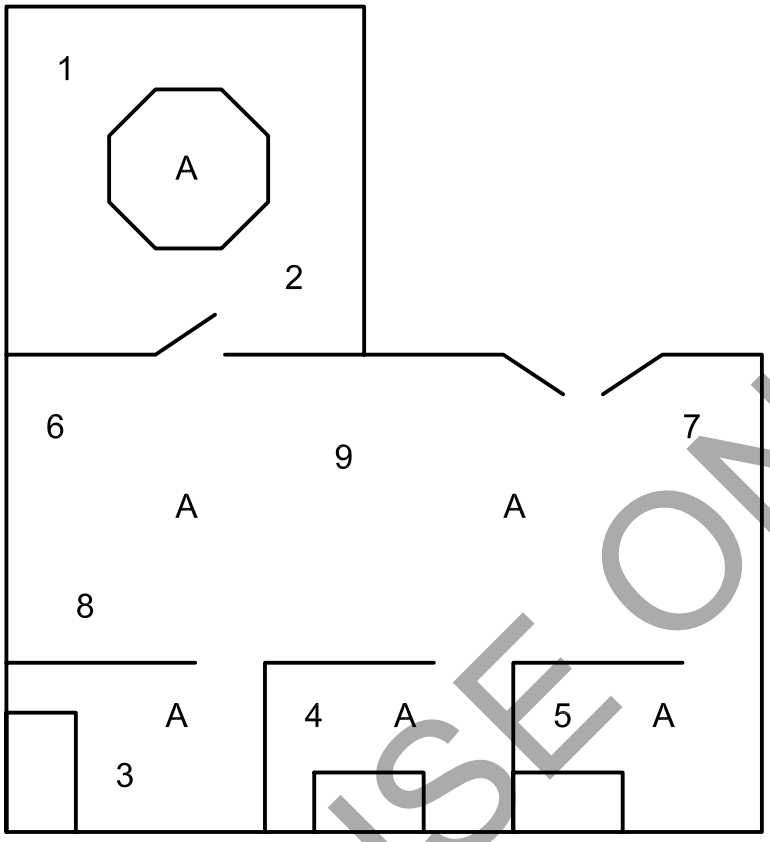
Annex D
(informative)

Example of summary report form

Table D.1 shows an example of a suitable summary form for reporting of results. Figure D.1 shows an example of a suitable drawing to illustrate the locations of air samplers and relevant features such as air supply vents. All items shown in Table D.1 should be reported, along with a drawing of the building on which the sampling locations are annotated, unless there have been deviations from the procedures of this part of ISO 16000. Any deviations from the procedures of this part of ISO 16000 should be reported.

Table D.1 — Example of a summary report form

1.	**Information on the building**			
	Client:			
	Building:			
	Asbestos abatement location (drawing if applicable):			
	Area evaluated (m^2):		**Number of rooms in evaluated area:**	
	Date of measurement:		**Time period of measurement:**	
2.	**Measurement objective**			
	Prevalent air concentration ( )		**Final air clearance ( )**	
	Leakage from containment area ( )		**Occurrence or event investigation ( )**	
	Other (specify)			
3.	**Determination of the number of samples required**			
	Number of room units according to ISO 16000-7:			
	Number of samples specified by ISO 16000-7:			
	Number of samples adjusted to:			
	Reasons for adjustment:			
4.	**Method: ISO 8672 ( )**	**ISO 10312 ( )**	**ISO 13794 ( )**	**ISO 14966 ( )** **Other ( )**
5.	**Simulation method(s):**			
6.	**Simulation time as percent of sampling time:**			
7.	**Results (state units): fibres/ml ( ) structures/l ( ) fibres/m^3 ( )**			
01:		**05:**	**09:**	**13:**
02:		**06:**	**10:**	**14:**
03:		**07:**	**11:**	**15:**
04:		**08:**	**12:**	**16:**
8.Observations				
( ) During sampling, no observations were made which give rise to doubts about the representativeness of the air sample results				
( ) Sampling was not representative, because: **( ) Number of samples too low** **( ) Surfaces were damp** **( ) Other (specify):**				
9.	**Limit values**			
( ) The limit values were complied with **( ) The limit values were exceeded**				
10.	**Additional sampling requirements**			
( ) Additional sampling is not required **( ) Additional sampling at locations ..... required, because the limit value is exceeded** **( ) Additional sampling at locations ..... required, because they are connected to the locations specified in Subclause 7.2 by air exchange** **( ) In accordance with ISO 16000-7, additional sampling is required at ..... locations**				
11.	**Certification of results**			
Signature:		**Date:**		



Numbers represent positions of air samplers

Locations marked "**A**" are air supply vents

Figure D.1 — Example of drawing of air sampling locations

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[7] National Institute of Occupational Safety and Health. *Asbestos and other Fibers by PCM*. NIOSH Method 7400, Issue 2, NIOSH Manual of Analytical Methods, 4th edition, DHHS (NIOSH) Publication 94-113, 16 August, 1994

[8] American Society for Testing and Materials. *Standard practice for visual inspection of asbestos abatement projects*. Practice E1368-00, American Society for Testing and Materials, West Conshohocken, PA

[9] ISO 4225, *Air quality — General aspects — Vocabulary*

[10] ISO 8672, *Air quality — Determination of the number concentration of airborne inorganic fibres by phase contrast optical microscopy — Membrane filter method*

[11] ISO 10312, *Ambient air — Determination of asbestos fibres — Direct transfer transmission electron microscopy method*

[12] ISO 13794, *Ambient air — Determination of asbestos fibres — Indirect-transfer transmission electron microscopy method*

[13] ISO 14966, *Ambient air — Determination of numerical concentration of inorganic fibrous particles — Scanning electron microscopy method*

[14] ISO 16017-1, *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 1: Pumped sampling*

[15] ISO 16017-2, *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 2: Diffusive sampling*

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INTERNATIONAL STANDARD

ISO 16000-8

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Indoor air —

Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions

Air intérieur —

Partie 8: Détermination des âges moyens locaux de l'air dans des bâtiments pour caractériser les conditions de ventilation

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16000-8 was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 6, *Indoor air*.

ISO 16000 consists of the following parts, under the general title *Indoor air* :

— *Part 1: General aspects of sampling strategy*

— *Part 2: Sampling strategy for formaldehyde*

— *Part 3: Determination of formaldehyde and other carbonyl compounds — Active sampling method*

— *Part 4: Determination of formaldehyde — Diffusive sampling method*

— *Part 5: Sampling strategy for volatile organic compounds (VOCs)*

— *Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas chromatography using MS/FID*

— *Part 7: Sampling strategy for determination of airborne asbestos fibre concentrations*

— *Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions*

— *Part 9: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test chamber method*

— *Part 10: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test cell method*

— *Part 11: Determination of the emission of volatile organic compounds from building products and furnishing — Sampling, storage of samples and preparation of test specimens*

— *Part 12: Sampling strategy for polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polycyclic aromatic hydrocarbons (PAHs)*

— *Part 13: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDDs/PCDFs) — Collection on sorbent-backed filters*

— *Part 14: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDDs/PCDFs) — Extraction, clean-up and analysis by high-resolution gas chromatography/mass spectrometry*

— *Part 15: Sampling strategy for nitrogen dioxide (NO_2)*

— *Part 16: Detection and enumeration of moulds — Sampling by filtration*

— *Part 17: Detection and enumeration of moulds — Culture-based method*

— *Part 23: Performance test for evaluating the reduction of formaldehyde concentrations by sorptive building materials*

The following parts are under preparation:

— *Part 18: Detection and enumeration of moulds — Sampling of moulds by impaction*

— *Part 24: Performance test for evaluating the reduction of the concentrations of volatile organic compounds and carbonyl compounds (except formaldehyde) by sorptive building materials*

— *Part 25: Determination of the emission of semi-volatile organic compounds by building products — Micro-chamber method*

Furthermore, the two International Standards, ISO 16017-1 on pumped sampling and ISO 16017-2 on diffusive sampling, focus on volatile organic compound (VOC) measurements.

This corrected version of ISO 16000-8:2007 incorporates the following corrections:

— Equation (D.2) (and the line of text immediately preceding this equation), Equation (D.5) and Equation (D.11) have been corrected.

— In Clause 2, the reference to the ISO/IEC Guide 98 was changed and footnote 1) was added.

— In 7.1.5, 7.2.5, 7.3.4, C.1.1 and D.1, the reference to ISO/IEC Guide 98:1995 was changed to GUM:1995.

— In B.3, footnote 1) was renumbered as footnote 2).

Introduction

An adequate air change is of fundamental importance for indoor air quality. Proper ventilation of all buildings is necessary for the health and comfort of the occupants as well as to protect against damage (e.g. due to excessive atmospheric humidity). However, the present-day use of tightly sealed windows, for example in residential and office buildings, can lead to insufficient ventilation. This situation in turn may lead to an increase in the concentration of substances emitted indoors. Manual ventilation by the occupants or the use of mechanical ventilation systems is thus required. However, excessive ventilation can lead to discomfort and increased energy consumption.

Building regulations make provision for ventilation to control moisture and other pollutants. Measurements of the ventilation conditions allow confirmation of whether these requirements are met in practice. Knowledge of the ventilation conditions is important in order to be able to analyse the possible causes of poor indoor air quality. Thus, ideally, sampling and analysis of contaminants indoors should be accompanied by ventilation measurement, making it possible to estimate the strengths of contaminant sources.

This part of ISO 16000 describes the use of single tracer gas for determining the age of air in a building which is naturally or mechanically ventilated. The age of air is an important factor in assessing the adequacy of ventilation. The concept local mean age of air (and its inverse the local effective air change rate) is used for assessing the ventilation conditions in the building. The mean age of air in a building zone indicates the average time the air in a zone has spent in the building accumulating contaminants. It is closely connected to the time it takes to exchange the air within a zone. The concentration of a contaminant released from continuous indoor sources increases with the length of time the air has spent indoors. The lower the age of air in a space, the lower the concentration. Normally, the ventilation air is supplied at selected parts of the building envelope, and seeks its way to the different building spaces. Thus, before the ventilation air reaches a specific room, a significant portion of the air may have spent time in other rooms, accumulating contaminants. Therefore, the local mean age of air, which describes how long the air in a particular space has spent indoors, needs to be considered in relation to air quality.

The purpose of this part of ISO 16000 is to describe the use of ventilation measurement techniques suitable for air quality studies. For this purpose, the ventilation rate and the air distribution patterns in the building should be measured for representative conditions of interest.

ISO 12569 describes the use of tracer gas dilution for determining the air change rate in a single zone. The procedures for tracer gas dilution include concentration decay, constant injection and constant concentration. ISO 12569 should be used when studying the thermal performance of buildings.

In the case where a zone exchanges air only with the outside (i.e. has no inflow of air from other parts of the building), the tracer gas concentration within the zone can be characterized with a single value, and the ventilation conditions are constant over the measurement period; this part of ISO 16000 and ISO 12569 should, in theory, provide identical results. The methods described in this part of ISO 16000 can, however, be used beyond these conditions, for example in spaces with several zones, which may exchange air with each other, and in cases where the ventilation conditions vary during the measurement period.

Indoor air —

Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions

1 Scope

This part of ISO 16000 describes the use of single tracer gas for determining the local mean age of air as an indicator of ventilation conditions in a building. The procedures include concentration decay and homogeneous constant emission.

The described methods are intended for air quality studies and can be used for

a) checking whether the building ventilation requirements are met,

b) estimating the adequacy of ventilation in buildings with indoor air quality problems, and

c) characterizing the strength and distribution of indoor emission sources.

In principle, the methods can be applied to all indoor spaces, regardless of the type of ventilation used and the state of mixing of air between zones. The prevailing ventilation conditions need not be disturbed by the measurement.

This part of ISO 16000 does not address the details of the analytical methods for tracer gases. The availability of such analysis services should be checked before planning actual field measurements.

2 Normative references

The following referenced documents are indispensable for the application 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 12569, *Thermal performance of buildings — Determination of air change in buildings — Tracer gas dilution method*

Guide to the expression of uncertainty in measurement (GUM), BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1993 [1)]

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12569 and the following apply.

1) Corrected and reprinted in 1995. To be republished as ISO/IEC Guide 98-3.

3.1
homogeneous emission
strategy to inject tracer gas in such a way that the injection rate per unit volume is equal in all parts of ventilated system

3.2
local mean age of air
ventilation parameter, which describes the length of time the air at a specific location has on average spent within the building

NOTE See A.1 for a further explanation of this term.

3.3
ventilated system
the building space, which can exchange air directly or indirectly with the space of interest

NOTE At the border of the ventilated system, there is no other inflow of air than outdoor air.

3.4
zone
space within the building where air mixing is sufficient to create an essentially uniform concentration of a tracer gas released anywhere within that space

NOTE 1 To be considered a zone, the space should not exhibit concentration differences larger than 20 % of the mean.

NOTE 2 A zone can be part of a room, an entire room or even include several rooms.

3.5
zone mean age of air
ventilation parameter, which describes the length of time the air in a zone has on average spent within the building

NOTE In the case of complete mixing within a zone, this is equal to the local mean age of air at any point within the zone.

4 Principles of tracer gas measurements for determining of ventilation conditions

4.1 General principles

Tracer gas techniques for measuring ventilation rely on the possibility of differentiating between air that is already within a space of interest and new air coming into that space. This means that it shall be able either to mark the air already in the space and follow how the marked air is replaced by new ventilation air or, alternatively, to mark the incoming air and measure how this marked ventilation air is distributed through the space.

It should be observed that air flowing into a specified zone from other zones that have a lower or higher concentration of tracer gas would influence the result of the measurement. Therefore, it is important to keep to the prescribed boundary conditions that are different for different tracer gas methods.

If the ventilation condition is to be determined in a zone, which has no inflow of air from other parts of the building (single isolated zone), it is not necessary to inject tracer gas or mark the air in other parts of the building in order to obtain correct results. However, if the zone can exchange air with other parts of the building, which is usually the case, special strategies for tracer gas injection in those connected zones shall be followed in order to avoid ambiguous results. It should also be noted that the closing of doors to a room does not necessarily lead to zero inflow of air from other parts of the building. Such means of restricting a normally occurring airflow will also change the ventilation of a room from that which would otherwise prevail.

4.2 Selected tracer gas methods

4.2.1 General

This part of ISO 16000 describes the strategies for tracer gas injection and measurement in spaces that cannot be regarded as single isolated zones. ISO 12569 presents the tracer gas dilution methods for spaces that can be characterized as a single zone. If the ventilation conditions are constant over the measurement period, and the space of interest can be regarded as a single isolated zone, the methods presented in this part of ISO 16000 and ISO 12569 are, in theory, identical. Under these conditions, the local mean age of air would be the same as the inverse of the air change rate determined using ISO 12569.

4.2.2 Decay method

The principle of the decay method is to mark the air in the ventilated system with tracer gas and determine the rate at which the marked air is replaced with unmarked air.

The zone to be measured and all other zones in the building with which the zone of interest can exchange air directly or indirectly shall be marked with a common initial tracer gas concentration. Such a strategy will prevent air coming from other parts of the building from being regarded as “clean ventilation air” to a greater extent than its actual delivered ventilation power.

The concentration history is recorded as a function of time. The local mean age of air is obtained from the quotient of the integral of the concentration versus time and the initial concentration.

The decay method can generally be used without problems up to air change rate $n = 10\ h^{-1}$.

4.2.3 Active homogeneous emission method

In the active homogeneous emission method, tracer gas is fed at measured constant rates into the zones by a suitable adjustable flow injection device. The injection rates shall be proportional to the zone volumes. The steady state tracer gas concentration of room air is measured using a suitable gas analyser. The local mean age of air is obtained from the quotient of the steady state concentration and the injection rate per unit volume.

The zone to be measured and all other zones in the building with which the pertinent zone can exchange air directly or indirectly shall be equipped with constant homogenous emission of tracer gas.

4.2.4 Passive homogeneous emission method

In the passive homogeneous emission method, tracer gas is emitted at known constant rates into the zones using diffusion sources. The emission rates shall be proportional to the zone volumes. The steady state tracer gas concentration of room air is measured by collecting an integrating sample in a sorbent tube (actively using an air sampling pump or passively using diffusion sampling) and analysing this sample afterwards in an especially equipped laboratory. The local mean age of air is obtained from the quotient of the steady state concentration and the emission rate per unit volume.

The zone to be measured and all other zones in the building with which the zone of interest can exchange air directly or indirectly shall be equipped with constant homogenous emission of tracer gas.

The use of this method requires a special analysis service able to analyse the sample from the sorbent tube in order to determine the amount of the tracer gas in the sample.

5 Measurement planning

5.1 General

Before measurement of the local mean ages of air in a building space, the purpose of the measurement shall be clearly defined. Also, knowledge of the type of building and the particular characteristics of that part of the

building that is to be investigated are essential for the choice of tracer gas technique and the detailed planning of the test.

The ventilation rate and the air distribution patterns in the building should be measured at representative conditions of interest. These conditions should not be disturbed by the measurement, unless it is the purpose of experiment to test the effect of different conditions, of for example door opening, window opening, etc.

The homogenous emission method using sampling on adsorbent tubes is especially suitable for determining the ventilation conditions in the context of air quality studies. Depending on the requirement, short-term (pumped sampling of a few litres of air) or long-term measurements (passive sampling during days to several weeks) can be carried out. In the investigation of indoor air quality (IAQ) problems, the ventilation measurements usually accompany the actual measurement of pollutant. An advantage of this measurement method is the possibility to simultaneously determine the local mean ages of air and the pollutant concentration.

In determination of “air change” (“airflow rate” or “air change rate”), for example using the methods described in ISO 12569, only the total airflow rate to the ventilated system is of concern. Such measurements are therefore restricted to buildings or other enclosures that can be treated as a single zone. In those methods, it shall therefore be ensured that there is complete mixing of air between all spaces within the ventilated system during the measurement.

5.2 Identification of the ventilated system

In planning the test, the “ventilated system” to which the space of interest belongs shall first be identified, because all spaces within the ventilated system shall be tagged with tracer gas. The ventilated system is defined as the building space, which can exchange air directly or indirectly with the space of interest. At the border of the ventilated system, there shall not be any inflow of air other than outdoor air. Thus, a part of a building should only be considered a ventilated system if it has negligible inflow of air from other parts of the building (for example via doorways, air leakage or return air ducts). The location of pollutant sources should also be taken into account to ensure that polluted air is not misinterpreted as outdoor air. In practice, this means, for example that

— for a single family house, all rooms including the cellar (unless there is an airtight door) should be included in the ventilated system, and

— for a flat in an apartment building, all rooms in the studied apartment (and in some cases also the staircase) should be included in the ventilated system.

5.3 Identification of zones

A zone is a space within the ventilated system where it can be assumed that the air mixing is sufficient to ensure a uniform concentration of air tracer gas. Within the ventilated system, there may be several spaces that can be regarded as zones. All such zones should be identified and their volumes measured. The zone-volumes are needed in order to calculate the amount of tracer gas to be injected in the different zones. Small closed spaces with only extract air (e.g. bathrooms), or without any supply of outdoor air (e.g. closets) do not need any tracer gas injection. The volume of small closed spaces, which may receive some supply of outside air should be added to the volume of any connected zone. Large rooms and long corridors may be subdivided into two or more zones.

5.4 Choice of measurement method

5.4.1 General

The choice of the measurement method depends on the type and size of the building, the intended measurement time, the purpose of the measurement, and the availability of equipment and analysis service.

5.4.2 Type of building

5.4.2.1 Simple buildings (e.g. small to moderate-sized dwellings that can be characterized with one to four zones)

When the number of zones is small, it is relatively easy to achieve an initial homogeneous tracer gas concentration within the whole ventilated system. For short-term measurements, the decay method is therefore best suited.

5.4.2.2 Complex buildings (e.g. office buildings and other structures in which the ventilated system comprises several zones)

In this case, it may be very difficult to achieve the necessary condition for the decay method of equal initial tracer gas concentration in all zones. The homogeneous emission method may therefore be better suited than the decay method in this case.

5.4.3 Measurement period

5.4.3.1 Short-term conditions of interest

The decay method is the most practical method to monitor short-term ventilation conditions in simple buildings, while the passive homogeneous emission method with pumped sampling is better suited for complex buildings.

5.4.3.2 Long-term time variation of interest

Though repeated use of the decay method is feasible in buildings with few zones, the most appropriate choice for long-term measurement in all types of buildings is the homogeneous emission method. The purpose may be to monitor the change of ventilation conditions as a function of time, for example in order to investigate the effect of weather conditions or to test the effect of different ventilation strategies. This requires active air sampling using continuous monitoring of tracer gas concentration or repeated sampling using syringes, bags, evacuated gas tubes or pumped collection tubes. The active homogeneous emission method is suitable for measuring time-varying conditions in simple buildings, while passive homogeneous emission with active sampling is better suited for complex buildings.

5.4.3.3 Long-term average conditions of interest

The purpose may be to investigate only the time average of the mean ages of air in different parts of a building. Advantages of this monitoring strategy are that short-term variations in ventilation are levelled out and that the result is directly coupled to the average exposure to contaminants (or dose) generated indoors. The most appropriate choice for monitoring average conditions is the passive homogeneous emission method using passive sampling or integrating sampling using pumps.

5.5 Determination of measurement points

The suitable number and distribution of measurement points are determined from the purpose of the measurement. Air sampling is necessary only in those zones where it is of interest to determine the local mean age of air. If the purpose is to map the distribution patterns of ventilation air within the building, measurements should be performed in several zones, while sampling in only one or a few zones is necessary to get information on local ventilation conditions. Sampling shall be performed at places which are thought to be representative of the zones. It shall not be attempted close to the tracer gas sources (minimum 1 m distance) or close to an air supply terminal. Irrespective of the purpose of the measurement, at minimum of three measurement points should be used in order to gain information of the range of variation. When performing a manual sampling, the sample can advantageously be taken at different positions in the zone. If the purpose is to gain information on the total ventilation flow rate or air exchange efficiency in the building (see E.2), sampling should also be performed close to identifiable air exhaust points.

6 Tracer gases and equipment for determining ventilation conditions

6.1 Choice of tracer gas

Apart from being able to analyse at low concentration with available measurement equipment, tracer gases shall be harmless to health and should fulfil other requirements.

Annex B (informative) provides information on choosing tracer gases based on accepted practice.

6.2 Tracer gas concentration standard

The tracer gas should be used within safe limits for concentration. If the source is pure tracer gas, avoid gas volumes that could create inadvertent hazards. An extremely large pressurized cylinder of pure gas, for example, could momentarily create unsafe concentrations in a small room. Avoid conditions where the amount of tracer gas that may be absorbed onto surfaces and into subordinate enclosures is significant.

Avoid the use of radioactive tracer gases.

The required amount of tracer gas depends on the sensitivity of the detection method, the ventilation rate and the size of the rooms.

6.3 Equipment for feeding the tracer gas

6.3.1 Decay technique

The purpose of tracer gas feeding for the decay technique is to achieve a uniform concentration of tracer gas throughout the ventilated system.

Choose one of the following apparatus for injecting tracer gas.

— **Graduated syringe**, or other container of known volume with a means for controlled release of its content.

— **Compressed tracer gas supply**, with a flow rate measurement and control device.

Choose a technique for creating a uniform initial concentration in the ventilated system from one or more of the following.

a) **Fans** that permit good mixing within and between zones.

b) **Injection lines** that dispense tracer gas via manifolds or switches. All parts of the injection lines shall be clearly labelled “Tracer Gas Only” and shall be keyed to the location that receives the tracer gas.

c) **Swinging doors**. After tracer gas injection in all zones, the doors between zones may be swung back and forth to increase interzonal mixing.

Injection lines should be purged to ensure delivery of known tracer gas volume to a given zone.

All artificial mixing shall be turned off and doors reset to their desired state (open/closed) at the moment of the start of the decay measurement.

NOTE Leaks in injection lines can release tracer gas at unwanted locations and in uncontrolled unwanted concentrations.

6.3.2 Active homogeneous emission technique

The purpose of feeding the tracer gas is to achieve a homogeneous emission rate of the tracer gas within the ventilated system. This means that the constant tracer gas injection rate in each zone of the ventilated system shall be proportional to the zone volume. The following steps are necessary for this:

a) metering the tracer gas emission rate in each zone (This can be performed directly using a pressurized cylinder that is brought into the zone and controlling the gas emission rate via pressure regulator and flow meter, or by using injection lines connecting a remotely located tracer gas source to the zone.);

b) ensuring complete mixing within zones may be necessary in large zones. (This can be achieved by operating one or more fans or by distributing the injection to several points throughout the zone.)

6.3.3 Passive homogeneous emission technique

The purpose of feeding the tracer gas is to achieve a homogeneous emission rate of the tracer gas within the ventilated system. This means that the constant tracer gas injection rate in each zone of the ventilated system is proportional to the zone volume. The following steps are necessary for this:

a) emitting the tracer gas in each zone using diffusion sources with known emission rates;

b) ensuring complete mixing within zones may be necessary in large zones. (This can be achieved by using one or more fans. Multiple diffusion vials with known emission rates may be required for larger zones.)

The fact that the tracer gas emission rate from diffusion sources is strongly temperature dependant, shall be taken into consideration when distributing passive tracer gas sources. The temperature should also be logged at representative locations throughout the measurement period.

6.4 Sampling the tracer gas

6.4.1 Sampling methods

The sampling methods described below are suitable for both decay and homogeneous emission methods, depending on the analytical method used for the tracer gas.

Sampling should be carried out at representative points, and should never be located close to air supplies and windows.

6.4.2 Continuous automatic sampling

The gas analyser is usually connected to the measurement points by one or more inert gas sample tubes through which air is drawn with a pump to the gas analyser. When sampling from several locations, the sampling locations can be chosen via automatically or manually operated multi-port valves. It is important that a sampling tube is flushed with new sample just before introduction into the analysing instrument.

6.4.3 Manual sample collection

With manual sample collection methods, a sample is first collected using a suitable container (syringe, bag or evacuated gas container). The sample is then analysed in the laboratory.

Materials used in manual sample collectors shall be non-absorbent, non-reactive and impermeable for the tracer gas in use. Depending on the tracer gas, the list of suitable materials may include, for example, glass, copper, stainless steel, polypropylene, polyethylene and polyamide.

Care should be taken when collecting manual samples in rooms with a normally closed door. Opening the door and entering the room may introduce a large unwanted amount of air exchange between the two connected zones. An easy and often used practice is to install a tube from the room to the adjacent room through the keyhole, draw one or two syringe samples for purging the tube and take the next sample for analysis.

6.4.4 Solid sorbent samplers

In the active solid sorbent sampling method, room air is drawn (continuously or intermittently) through a solid sorbent suited to the tracer gas in use for the sampling period. After sampling, which shall be performed using a calibrated sampling pump, the loaded samplers are desorbed (using thermal desorption or solvent extraction) to determine the sorbed amount of tracer gas and hence the tracer gas concentration in the sampled air. Pumped sampling using solid sorbent tubes is appropriate for continuous sampling periods of up to a few hours and for intermittent sampling for several days. When using intermittent pumped sampling,

measures should be taken to minimize diffusion of air into the sorbent in between pump periods, e.g. using a capillary restriction.

For long-term sampling, which can extend over one to several weeks, passive sampling using diffusive solid sorption samplers can advantageously be used. The sampling rate of passive samplers shall be carefully calibrated for the type of tracer gas use.

When using the homogeneous emission technique, sample collection points should always be at least 1 m from the nearest tracer gas injection point.

6.5 Determination of tracer gas concentration

From the continuous sample collection system, the tracer gas/air mixture under test is passed directly, or via sample tubes, into a gas analyser to determine its tracer gas content. Manually taken air samples and solid sorbent tubes are usually analysed afterwards in a laboratory. If solid sorbent sample collectors are used, thermal desorption or solvent extraction is necessary in order to introduce the tracer gas sample into the gas analyser.

The gas analyser shall be suitable for the measuring task (sample gas volume, analytical period, cross-sensitivities), the tracer gas used and the tracer gas concentration. The gas analyser accuracy should be known.

For the tracer gases listed in Table B.1, infrared (IR) gas analysers or gas chromatography (GC) are suitable for determination of concentration. GC with an appropriate detector, e.g. ECD (electron capture detector) or MS (mass spectrometry), enables particularly sensitive tracer gas analysis.

7 Measurement methods

7.1 Decay method

7.1.1 Principles of the measurement technique

In the decay method, the tracer gas is injected into the zones and uniformly distributed throughout the whole ventilated system. The local mean age of air, $\bar{\tau}$, is calculated from the decay of tracer gas concentration.

$$\bar{\tau} = \frac{\int_{t_0}^{\infty} \varphi \mathrm{d}t}{\varphi_{t=t_0}} \qquad (1)$$

where

t is the time, in hours (h);

$\varphi_{t=t_0}$ is the initial tracer gas concentration (e.g. in cm^3/m^3) at time $t = t_0$ (start of decay). This should be equal in all zones.

The initial tracer gas concentration, $\varphi_{t=t_0}$, should be chosen to be at least 100 times the detection limit of the analysis system.

The volume v_p of (pure) tracer gas to be injected into a zone (zone volume V_p) is given by Equation (2):

$$v_p = \varphi_{t=t_0} \cdot V_p \qquad (2)$$

7.1.2 Preparations and planning of the test

The planning steps described in Clause 5 are advantageously performed in advance using a plan or sketch of the building space to be investigated.

7.1.3 Measurement procedure

After tracer gas is injected in all zones and mixed to ensure a uniform tracer gas concentration in the ventilated system, sample collection is started using one of the methods mentioned in 6.4. Sample collection is advantageously performed at equal time intervals in each zone of interest. Sample collection should proceed for at least twice the assumed mean age of air (e.g. for a period of 4 h for a normally ventilated dwelling). In order to get satisfactory data for analysis of the decay course, at least seven samples should be collected in each zone of interest during that time. When performing manual sample collection, care should be taken to minimize unnecessary disturbance of air distribution when entering rooms through a normally closed door.

The purpose of the tracer gas injection is to achieve an initial homogeneous concentration of the tracer gas within the ventilated system. In a building with multiple zones, this is best achieved if the injected amounts are proportional to the zone volumes and well distributed into the zone volumes by some mixing devices. Refer to the equipment for tracer gas distribution and mixing described in 6.3.1.

All artificial mixing shall be turned off and doors reset to their desired state (open/close) at the moment of the start of the decay measurement.

Before decay measurement starts, field personnel should, if possible, verify that the tracer gas concentration is equal in all zones of the ventilated system. In the case of a large zone (e.g. room volume greater than 500 m^3 or ceiling heights greater than 4 m), or if it is suspected that there may be pronounced air paths in the room, a uniform initial concentration should be verified by determining the concentration at various points in that room. In such rooms, where incomplete mixing may be suspected, decay measurements at different positions may also be appropriate.

7.1.4 Evaluation and calculation of the results

The integral in Equation (1) is usually evaluated numerically from the measured tracer gas concentration history using a suitable numerical integration technique (e.g. the trapezoid method). When a zone exchanges air with another connected zone, the first part of concentration decay is usually not purely exponential. However, after some time the decay will always approach an exponential decay. It is therefore sufficient to perform the numerical integration to the time t_e when an exponential decay has been ascertained (linear logarithmic plot) and add the area under the "tail" of the decay assuming exponential behaviour.

$$\int_0^{\infty} \varphi_t \mathrm{d}t = \int_{t_0}^{t_e} \varphi_t \mathrm{d}t + \int_{t_e}^{\infty} \varphi_{t=t_e} \cdot \mathrm{e}^{-\lambda_{tail}(t-t_e)} \mathrm{d}t = \Delta t \left(\frac{\varphi_{t_0}}{2} + \varphi_{t_0+1\Delta t} + \ldots + \varphi_{t_0+(n-1)\Delta t} + \frac{\varphi_{t_e}}{2} \right) + \frac{\varphi_{t=t_e}}{\lambda_{tail}} \quad (3)$$

where λ_{tail} is the absolute value of the slope from a plot of the logarithm of concentration as a function of time in the last exponential part of the decay according to Equation (4).

$$\ln \varphi_t = \ln \varphi_{t=t_e} - \lambda_{tail}(t - t_e) \quad (4)$$

First, the logarithm of the tracer gas concentration versus time should be plotted and inspected. If the plot is linear from $t = t_0$, the local mean age of air can be directly evaluated from the inverse of the absolute value of the slope:

$$\bar{\tau} = \frac{1}{\lambda_{linear}} \quad (5)$$

If the logarithmic plot shows curvature, the plot should be inspected for the beginning of the linear segment of the plot. The slope of the linear segment is evaluated and λ_{tail} is set equal to the absolute value of the slope.

Next, choose one of the measurements within the linear part of the plot as the endpoint for the numerical integration (concentration = φ_e at time t_e). Perform the numerical integration from $t = t_0$ to $t = t_e$ and add φ_e/λ_{tail} according to Equation (3) to get an approximation of the concentration integral from $t = t_0$ to $t = \infty$.

Finally, the local mean age of air is calculated from the integral through division by the concentration at the beginning of the decay ($\varphi_{t=t_0}$) according to Equation (1).

7.1.5 Uncertainty

Any calculated value of the local mean age of air determined using the decay technique shall be accompanied by an estimate of its uncertainty. Uncertainty shall be estimated and expressed in harmony with the GUM:1995.

Information on how to estimate the uncertainty of measured local mean ages of air according to this part of ISO 16000 can be found in Annexes C and D.

7.2 Active homogeneous emission method

7.2.1 Principles of the measuring technique

In the homogeneous emission method, a tracer gas stream is continuously injected into the zones in the ventilated system at constant rates that are proportional to the volume of each zone. This establishes a tracer gas concentration in each zone that is dependent on the local mean age of air in each zone.

Like the tracer decay technique, the homogeneous emission technique yields the local mean age of air, $\bar{\tau}$, in a zone as

$$\bar{\tau} = \frac{\varphi}{(q_V / V)} \tag{6}$$

where

φ is the measured tracer gas concentration ($cm^3 \cdot m^{-3}$) in a zone at steady state, in $cm^3 \cdot m^{-3}$;

q_V / V is the constant injection rate ($cm^3 \cdot h^{-1}$) of pure tracer gas per cubic metre (m^3) of space — equal in all zones of the ventilated system (in for example, $cm^3 \cdot h^{-1} \cdot m^{-3}$).

The desired proportionality constant between the injection rate of pure tracer gas q_V ($cm^3 \cdot h^{-1}$) in a zone with volume V is given by Equation (7).

$$q_V = k_V \cdot V \tag{7}$$

where k_V is a constant ($cm^3 \cdot h^{-1} \cdot m^{-3}$) which can be estimated by the product of the anticipated air change rate (ACH in h^{-1}) and the desired tracer gas concentration ($cm^3 \cdot m^{-3}$) at steady state suitable for analysis.

7.2.2 Preparations and planning of the test

The planning steps described in Clause 5 are advantageously performed in advance using a plan or sketch of the building space to be investigated. The zone volumes shall be determined and tracer gas emission rates for each zone shall be calculated. The tracer gas shall be injected uniformly into the zones at a constant flow rate so that good mixing of the tracer gas is established (see 6.3.2). The locations of the injection points shall be planned and necessary equipment (e.g. injection and sample lines) shall be prepared.

7.2.3 Measurement procedure

Sample collection using one of the methods described in 6.4 is started when approaching the equilibrium (or steady state) tracer gas concentration, which requires approximately three to four times the mean age of air.

7.2.4 Evaluation and calculation of the results

The local mean age of air, $\bar{\tau}$, in a zone is determined from the measured tracer gas content at steady state and the tracer gas emission rate per volume unit using Equation (6).

7.2.5 Uncertainty

Any calculated value of the local mean age of air determined using the active homogeneous emission technique shall be accompanied by an estimate of its uncertainty. Uncertainty shall be estimated and expressed in harmony with the GUM:1995.

Information on how to estimate the uncertainty of measured local mean ages of air according to this part of ISO 16000 can be found in Annexes C and D.

7.3 Passive homogeneous emission method

7.3.1 Principles of the measuring technique

The principle of the passive homogeneous emission technique is similar to that of the active homogeneous emission technique (see 7.2.1). However, the tracer gas is emitted from miniature passive tracer gas sources, which can be easily distributed within the ventilated system to yield a homogeneous emission. Due to low tracer gas concentrations, perfluorocarbon tracers (PFT) are used; these can be analysed with extremely high sensitivity.

7.3.2 Measurement procedure

Diffusion sources utilizing capillary diffusion or permeation membranes to control the emission rate of the tracer gas are distributed in the ventilated system in such a way that the tracer gas emission rates are proportional to the zone volumes as described in 6.3.3. After the equilibrium state is reached, the mass concentration of the tracer gas at the selected locations is determined by air sampling using solid sorbent samplers as described in 6.4.4 and subsequent laboratory analysis using gas chromatography.

In the case of short-term measurements, sampling is performed using a pump. For long-term measurements, diffusive sampling is advantageously used in order to obtain the local mean ages of air averaged over the sampling period.

7.3.3 Evaluation and calculation of result

The local mean age of air, $\bar{\tau}$, in a zone is determined from the measured average tracer gas concentration (as evaluated from the tracer gas contents in the sampling tubes) and the tracer gas emission rate per volume unit using Equation (8).

$$\bar{\tau} = \frac{\rho_a}{(q_m / V)} \tag{8}$$

where

$\bar{\tau}$ is the local mean age of air, in hours (h);

(q_m / V) is the constant emission rate of tracer per cubic metre (m^3) of space — equal to the constant k_m in all zones of the ventilated system (in for example, $\mu g \cdot h^{-1} \cdot m^{-3}$); a suitable value of k_m can be estimated from the desired collected amount of tracer;

ρ_a is the time average of the tracer gas concentration in the room air, in micrograms per cubic metre ($\mu g \cdot m^{-3}$).

7.3.4 Uncertainty

Any calculated value of the local mean age of air determined using the passive homogeneous emission technique shall be accompanied by an estimate of its uncertainty. Uncertainty shall be estimated and expressed in harmony with the GUM:1995.

Information on how to estimate the uncertainty of measured local mean ages of air according to this part of ISO 16000 can be found in Annexes C and D.

8 Application of results

The methods described in this part of ISO 16000 can be used for the following purposes.

a) **Checking whether the ventilation requirements are met, both in individual buildings (commissioning) and in broad surveys**

The advantage of these methods is that they can be used while the building is in normal use. The decay method is suitable for short-term measurements of individual buildings. The passive homogeneous emissions method with its simple field equipment is suitable for long-term measurements in broad surveys with hundreds of measurement objects. It takes into account, for example, occupant behaviour and changes in weather conditions. The same method can also be used in **assessing the correlation of ventilation with health and comfort outcomes in epidemiological studies.**

In building regulations and the plans of the ventilation system, the ventilation conditions are usually expressed in ventilation flow rates or specific ventilation flow rates. The interpretation of the local mean age of air into other ventilation parameters requires fulfilment of certain assumptions. This is discussed in more detail in informative Annex E.

b) **Estimating the adequacy of ventilation in buildings with IAQ problems**

Ventilation controls moisture and concentrations of other pollutants and it may have significant role in IAQ problems. This role should be assessed in IAQ problem investigations. Sampling and analysis of contaminants indoors should be accompanied by ventilation measurement, making it possible to determine correct remedial actions. Both short-term and long-term measurements can be used here, and all methods in this part of ISO 16000 are suitable for this. Local mean age of air is the best indicator of ventilation conditions in this case.

c) **Characterizing the strengths and distribution of indoor emission sources**

This may also be needed in IAQ problem investigations. By measuring contaminant concentrations and local ages of air simultaneously, it is possible to identify differences in source strengths between zones. An example of this is given in Annex E. The choice of measurement method depends on the time-scale of the contaminant measurement.

9 Test report

The test report shall contain at least the following information:

a) all details necessary to identify the building tested, and fully characterize the ventilated system, zone divisions and description of the tested zones;

b) a reference to this part of ISO 16000;

c) a summary of test technique, test conditions and apparatus used;

d) a summary of collected data and results including an estimation of the accuracy;

e) the date of the test.

Details for each item can be reported taking into consideration the information in Annexes A to D.

Annex A
(informative)

Explanation of some terms and definitions

NOTE For terms and definitions, see Clause 3.

A.1 Local mean age of air

The local mean age of air is a ventilation parameter, which describes the length of time the air in a specific building space has on average spent within the building.

The concept “local mean age of air” (and its inverse “the local air change rate”) is used for assessing the ventilation condition in the building. The local mean age of air indicates the average time the air in a specific space has spent in the building accumulating contaminants. It is closely connected to the time it takes to exchange the air in that space. The concentration of a contaminant released from continuous indoor sources increases with the length of time the air has spent indoors. The lower the age of air in a space is, the lower the concentration. Normally, the ventilation air is supplied at selected parts of the building envelope, and seeks its way to the different building spaces. Thus, before the ventilation air reaches a specific room, a significant portion of the air may have spent time in other rooms, accumulating contaminants. Therefore, the local mean age of air, which describes the length of time the air in a particular space has spent indoors needs to be considered in relation to air quality.

A.2 Purging flow rate

A pollutant (or a tracer gas) that is injected within one zone (and not any other) will attain a steady state concentration in that zone equal to the quotient of the injection rate and the purging flow rate. For contaminants which are emitted in several zones, or outdoors, the purging flow rate is not a good indicator of air quality. The purging flow rate is a measure of how much outside air is transferred (directly or indirectly) per hour to the zone in question. Its maximum value is equal to the total airflow rate, this occurs for example when there is complete mixing between zones. In most cases, however, some of the air supplied to a building is extracted before it has a possibility to enter a certain zone, a fact that diminishes the purging flow rate in that zone from the maximum possible.

Annex B
(informative)

General requirements of tracer gases, background contents and methods of detection of the most important ones

B.1 General requirements

Apart from being able to be analysed at low concentrations with the available measurement equipment, tracer gases should have the following properties:

a) be non-toxic and non-hazardous to health in the concentration range used;

b) be chemically inert, stable, odourless and tasteless;

c) as far as possible, not be adsorbable by walls, furniture or other surfaces;

d) be non-flammable and non-explosive;

e) not be ordinarily present in the indoor air or outdoor ambient air;

f) if present in ambient air, have concentrations which are significantly lower than those used for tracer gas analysis;

g) be easily transported and handled;

h) be readily miscible with air;

i) have no disadvantageous environmental effects;

j) be inexpensive and readily available from commercial sources.

B.2 Background content and methods of detection

Table B.1 — Background content and methods of detection of the most important tracer gases

Tracer gas	Background volume fraction in air	Method of detection	Measuring range volume fraction in air
Sulfur hexafluoride, SF_6	$(0{,}85 \text{ to } 1{,}5)\cdot10^{-12}$	Gas chromatograph with electron capture detector or mass spectrometer[d]	$5\cdot10^{-12}$ to $200\cdot10^{-9}$
Perfluorocarbons e.g. Hexafluorobenzene (C_6F_6)	$< 1\cdot10^{-12}$	Gas chromatograph with electron capture detector or mass spectrometer [d]	$50\cdot10^{-12}$ to $10\cdot10^{-9}$
Nitrous oxide (laughing gas), N_2O[a]	$315\cdot10^{-9}$	Infrared gas analyser	$1\cdot10^{-6}$ to $200\cdot10^{-6}$
Carbon dioxide, CO_2[b]	$360\cdot10^{-6}$		$1\cdot10^{-6}$ to $5\cdot10^{-3}$
Sulfur hexafluoride, SF_6	$(0{,}85 \text{ to } 1{,}5)\cdot10^{-12}$		$1\cdot10^{-7}$ to $100\cdot10^{-6}$
Nitrous oxide (laughing gas), N_2O[a]	$315\cdot10^{-9}$	Photoacoustic detector	$50\cdot10^{-9}$ [c]
Carbon dioxide, CO_2 [b]	$360\cdot10^{-6}$		$3\cdot10^{-6}$ [c]
Sulfur hexafluoride, SF_6	$(0{,}85 \text{ to } 1{,}5)\cdot10^{-12}$		$5\cdot10^{-9}$ [c]

[a] Use of N_2O requires that water solubility and adsorption effects be taken into account.

[b] CO_2 is suitable only with qualification. The following factors shall be taken into account: the varying content in feed air and exhaust air; and, under some circumstances, the uncertainty of human-related CO_2 release and other possible internal sources. If CO_2 is used as a tracer gas, the CO_2 content of the surrounding air shall be subtracted from the measured CO_2 content.

[c] The upper measuring range is dependent on the calibration.

[d] The instructions of the manufacturers of electron capture detectors shall be considered with respect to radioactivity.

Although radioactive noble gases comply with many of the desired properties of tracer gases, the use of these previously employed tracer gases is now no longer advisable because of radiation-protection reasons.

The tracer gas most frequently used to determine the air change rate is sulfur hexafluoride. When used in buildings, this tracer gas best meets the properties of an ideal tracer gas of the gases listed in Table B.1. However, for sampling on solid sorbents (e.g. for passive tracer gas methods), perfluorocarbons are better suited.

B.3 Health criteria in the use of tracer gases

The use of tracer gases can have adverse effects on the health of the room occupants, depending on the type and chosen concentration of the tracer gas. Health guide values for the indoor air concentration of the most frequently used tracer gases, sulfur hexafluoride and nitrous oxide, have not yet been established. Since, in the detection range, nitrous oxide is close to the MAK value (maximum permissible workplace concentration [2)]; see Tables B.1 and B.2), when air change rate has been determined, all persons not directly participating in the measurements shall leave the room.

2) MAK values are published by the “Senatorial commission for the examination of hazardous working materials (Senatskommission zur Prüfung gesundheitsschädlicher Arbeitsstoffe)” of the German Science Foundation (DFG). The list of MAK values is checked annually and enlarged.

The MAK values tolerated at the workplace apply to the personnel carrying out the measurement. These are intended as 8-h mean values.

Table B.2 — Permissible tracer gas concentrations for the test personnel

Tracer gas	MAK value $mg \cdot m^{-3}$
CO_2	9 100
N_2O	180
SF_6	6 100

Annex C
(informative)

Estimation of uncertainty of measured local mean ages of air

C.1 General

C.1.1 Criteria

The determined values of local mean ages of air shall be given together with estimates of their uncertainty. The uncertainty in a measured quantity is made up of contributions from uncertainties and errors in the factors used to evaluate the quantity. As described in this annex and in the GUM:1995, the uncertainties in the contributing factors can either be obtained from the measurement (type A) or from other existing sources (type B). In Annex D, it is demonstrated how the uncertainty of the determination of the local mean ages of air can be evaluated for some given examples.

The local mean ages of air cannot be measured directly. The determination of the mean age of air relies on tagging the air with tracer gas and measuring the rate of which tagged air is replaced with unmarked air.

In the decay technique, the volume fraction ($\varphi(t)/\varphi_0$) of the initially tagged air (φ_0), which is left after different times t, is measured. It can be shown theoretically that the integral of this fraction from $t = 0$ to $t = \infty$ yields the local mean age of air.

In the homogeneous emission technique, the tracer gas concentration is measured when the removal rate of tracer gas is equal to the injection rate. It can be shown theoretically that this steady state concentration is the product of the local mean age of air and the tracer gas injection rate per volume unit, provided that the tracer gas emission is homogeneously distributed throughout the space.

The uncertainty of the determination of local mean ages of air is therefore connected to the uncertainty of tracer gas concentration, the uncertainty of the calculation of the integral and the uncertainty of tracer gas emission rates and its distribution.

This annex describes how the uncertainty of a measurement can be estimated from individual estimates of uncertainties in the different contributing factors.

These contributing factors can be divided into two groups: one group with the characteristics of the equipment used; and the other which is specific to the measurement situation and its evaluation.

It is here assumed that the characteristics of the used equipment are fully known and documented for use in the particular application.

C.1.2 Examples of necessary knowledge about the equipment performance

C.1.2.1 Analysis instruments

a) Calibrated for the concentrations of concern

b) Standard deviation of analysis investigated at the concentrations of concern

c) Long- and short-term stability documented

C.1.2.2 Tracer gas injection equipment (active)

a) Calibrated flow control devices (e.g. rotameters, mass flow controllers, critical orifices)

b) Standard deviation of flow rate adjustment documented (including precision of pressure regulation)

c) Long- and short-term stability documented

C.1.2.3 Sampling devices (manual)

a) Documented long- and short-term inertness and tightness of sampling syringes, containers or canisters

b) Calibrated air sampling pump for solid sorbent tubes

c) Standard deviation of air sampling rate (volume) documented

d) Documented sorption capacity, suitable sampling flow rate and break-through volume

C.1.2.4 Sampling devices (passive)

a) Calibrated diffusive samplers

b) Standard deviation of equivalent air sampling rate for diffusive samplers

c) Documented performance of diffusive samplers as a function of concentration and exposure time

d) Documented desorption (extraction) efficiency of sorbent sampler

C.1.2.5 Tracer gas injection equipment (passive diffusion devices)

a) Calibrated tracer gas sources

b) Standard deviation of sources documented

c) Temperature dependence of emission rate investigated and documented within temperatures of concern

d) Long-term, short-term and transient behaviour of emission rates known

C.1.3 Examples of factors specific for the measurement situation

The factors influencing the measurement uncertainty that are specific for the measurement occasion shall be evaluated from the circumstances during the measurement and the recorded data.

Such factors are, for example,

a) inability to achieve a uniform initial tracer gas concentration throughout all zones before start of decay,

b) inability to record the initial concentration in all zones,

c) temporal and spatial variation of concentration due to bad mixing within zones, and

d) inability to achieve a homogeneous emission rate throughout all zones in the homogeneous emission technique.

C.2 Decay technique

The normal (relative) uncertainty s of a measurement of a local mean age using the decay technique is made up of contributions from the (relative) standard deviations of determination of the integrated area and the initial concentration

$$s^2 = s_{\text{area}}^2 + s_{\varphi 0}^2 \tag{C.1}$$

where

s_{area}^2 is the variance in calculating the true integral from $t = t_0$ to $t = t_\infty$;

$s_{\varphi 0}^2$ is the variance in estimating the initial concentration.

The relative uncertainty s_{area} of the integrated area can be estimated from the absolute uncertainties $s_{A\text{num}}$ and $s_{A\text{rest}}$ which belong to the numerically integrated part and the extrapolated part, respectively.

$$s_{\text{area}} = \frac{\sqrt{s_{A_{\text{num}}}^2 + s_{A_{\text{rest}}}^2}}{A_{\text{num}} + A_{\text{rest}}} \tag{C.2}$$

s_φ is the relative uncertainty in the initial concentration. It depends not only on the analysis uncertainty, but also on possible spatial variations within and between zones due to inability to achieve a homogeneous initial concentration in the whole ventilated system.

C.3 Homogeneous emission technique

In the homogeneous emission technique, the local mean age of air is computed from the steady state tracer concentration divided by the emission rate per volume unit. The standard relative uncertainty of the local mean age of air is therefore made up of contributions from uncertainties in measurement of concentration s_{meas} and uncertainties in the emission rate per volume s_{distr}.

$$s_\tau^2 = s_{\text{meas}}^2 + s_{\text{distr}}^2 \tag{C.3}$$

In the estimate of the uncertainty in concentration s_{meas}, both random errors of the analysis s_{anal} and uncertainty in the concentration of the calibration mixture s_{cal} should be taken into account.

$$s_{\text{meas}}^2 = s_{\text{cal}}^2 + s_{\text{anal}}^2 \tag{C.4}$$

s_{distr} has two main contributions which have to be accounted for, the uncertainty in the injection rate s_{inject} and the uncertainty due to any known inability to achieve a true homogenous emission rate s_{inhom}.

$$s_{\text{distr}}{}^2 = s_{\text{inject}}^2 + s_{\text{inhom}}^2 \tag{C.5}$$

Examples are given in Annex D of the way in which the different contributions can be estimated for the active and passive homogeneous techniques.

Annex D
(informative)

Examples of measurement procedure, calculation and estimation of uncertainty

D.1 General

In this annex, examples are given of the measurement procedure, calculation and estimation of uncertainty using four different techniques covered in this part of ISO 16000. The input data for the examples are obtained from simulations and measurements.

Examples are given for the following techniques:

a) decay technique using automatic tracer gas injection, sampling and analysis;

b) decay technique using manual tracer gas injection and sampling;

c) homogeneous emission technique using automatic tracer gas injection and analysis;

d) homogeneous emission technique using passive injection and sampling.

The determined values of local mean ages of air shall be given together with estimates of their uncertainty. The uncertainty in a measured quantity is made up of contributions from uncertainties and errors in the factors used to evaluate the quantity. As described in informative Annex C and in the GUM:1995, the uncertainties in the contributing factors can either be obtained from the measurement (type A) or from other existing sources (type B). The examples demonstrate the way in which the uncertainty of the determination of the local mean ages of air can be evaluated.

First, it should be noted that the ventilation condition in a building is not a static matter. Ventilation and air distribution patterns change with wind pressure, outside temperature, window opening, door opening, inside temperature distribution, people's activity, etc., all of which are factors that vary with time. The local mean ages determined at one instant may be different if measured a second time. Such fluctuations are not included in the estimated uncertainty of the measurement. The estimate of uncertainty only indicates the limits within which it is plausible that the true ventilation conditions lie at the time of measurement.

In order to use a short-term measurement for predictive purposes, all factors that may influence the ventilation rate and air distribution shall be known at the instant of measurement. Additionally, a model is required, which describes how the ventilation rate and the air distribution is influenced by those factors. It is beyond the scope of this part of ISO 16000 to discuss ventilation measurements for predictive use.

D.2 Decay technique

D.2.1 Tracer gas injection

D.2.1.1 Automatic injection

For automatic tracer gas injection, there is commercially available doser/analyser equipment that can be programmed to inject tracer gas to a common concentration in up to 12 zones. In order to achieve a uniform distribution in all zones, the injection points should be behind mixing fans.

D.2.1.2 Manual injection

For manual injection, the injection is usually made while walking from zone to zone and injecting tracer gas from a gas cylinder or a syringe. The injected amounts should be proportional to the zone volumes and well distributed into the zone volumes by some mixing devices. After proper injection into all zones, a common initial concentration in all zones shall be secured, preferably using mixing fans that mix the air between zones.

It should be noted that it may be difficult to achieve the necessary equal initial tracer gas concentration in all zones, especially when the number of zones is larger than four to five. Tracer gas distribution should be made quickly enough to avoid decay by ventilation, which may result in significant deviation from the equal concentration distribution.

D.2.2 Tracer gas sampling and analysis

D.2.2.1 Automatic sampling

Automatic sampling is usually performed using a network of tubes through which air is drawn from the different sampling points using a pump. In order to get the correct timing of analysis, it is important to flush the tubes, just before performing the analysis. Sampler equipment is commercially available, which automatically performs flushing of the next sampling tube, while sampling from the preceding one.

The first sample(s) shall be taken at time $t = 0$, just after the mixing fans have been switched off. The subsequent samples should be taken as fast as the sampling and analyser equipment allows, preferably with equal time intervals between sampling at the same position.

With automatic sampling, the tracer gas analysis is usually performed on-line in real time, i.e. with an analysing instrument connected to the sampling device. The most common instruments for online analysis are based on infrared absorption (IR). However, gas chromatography (GC) or mass spectrometry (MS) for field use can also be used.

D.2.2.2 Manual sampling

Manual sampling is usually performed using a syringe, a bag or an evacuated gas container (canister).

As a typical example, medical syringes (e.g. 50 ml plastic syringes) are used for sampling, because they are easy to handle, seal tightly for months, are inexpensive and can be sent for analysis. Because of the relatively low sample volume, sampling with a syringe is especially suitable if SF_6 is used as the tracer gas and analysis is performed by a gas chromatograph (GC) with an electron capture detector (ECD).

In order to be able to evaluate the local mean age of air in buildings where the air is not completely mixed, at least seven samples should be taken during the decay in each zone. The first sample(s) shall be taken at time t = 0, just after the mixing fans have been switched off. The subsequent samples should be taken preferably with equal time intervals during a period that is at least equal to the expected mean age of air in the object (2 h to 3 h for a dwelling).

After sampling, the syringes are capped and sent to a laboratory for analysis using GC/ECD equipment. Tightness, inertness and non-permeation characteristics of the sampling syringes shall be certified before use.

D.2.3 Example of decay technique using on-line sampling and analysis

D.2.3.1 Simulated data

When performing automatic sampling with on-line analysis, the tracer gas concentration as a function of time is usually obtained in the form of a data file. An example is given below of how to evaluate such a file.

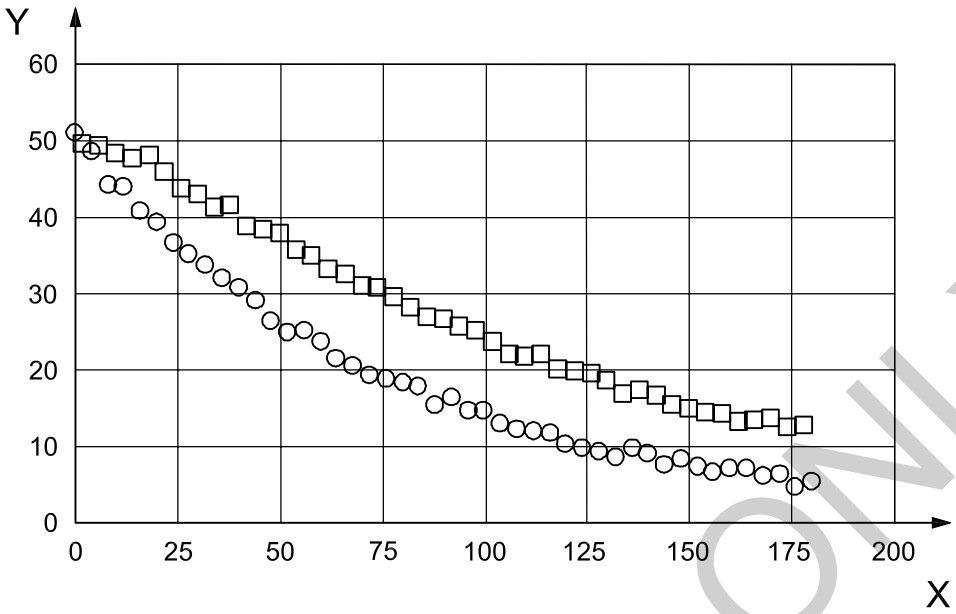
In the simulated example below (see Table D.1), samples were automatically taken and analysed during 3 h at 2-min intervals in the bedroom and the kitchen of a dwelling. The sampling in the bedroom began at time $t = 0$. The dwelling was ventilated with mechanical exhaust in the bathroom and kitchen, while the air inlets were situated in the living room and the bedroom. The bedroom door was closed at the start of the decay.

From the logarithmic plot (see Figure D.2) , it can be seen that the curve for the kitchen is non-linear at the beginning and approaches a linear trend at 100 min. For the bedroom, the curve is linear from the beginning. The sampling could therefore have been interrupted after 100 min.

Table D.1 — Measured tracer gas concentration ($cm^3 \cdot m^{-3}$) during decay

Bedroom			Kitchen		
minute	$cm^3 \cdot m^{-3}$	ln [a]	minute	$cm^3 \cdot m^{-3}$	ln [a]
0	50,9	3,93	2	49,5	3,90
4	48,5	3,88	6	49,4	3,90
8	44,2	3,79	10	48,4	3,88
12	43,9	3,78	14	47,5	3,86
16	40,7	3,71	18	47,9	3,87
20	39,3	3,67	22	45,9	3,83
24	36,5	3,60	26	43,6	3,78
28	35,2	3,56	30	43,0	3,76
32	33,7	3,52	34	41,3	3,72
36	32,0	3,47	38	41,5	3,72
40	30,8	3,43	42	38,9	3,66
44	29,0	3,37	46	38,4	3,65
48	26,3	3,27	50	37,7	3,63
52	24,9	3,22	54	35,7	3,57
56	25,1	3,22	58	35,0	3,55
60	23,7	3,16	62	33,2	3,50
64	21,4	3,06	66	32,5	3,48
68	20,4	3,02	70	30,9	3,43
72	19,2	2,95	74	30,6	3,42
76	18,8	2,94	78	29,4	3,38
80	18,4	2,91	82	28,1	3,34
84	17,7	2,88	86	26,9	3,29
88	15,4	2,74	90	26,5	3,28
92	16,3	2,79	94	25,6	3,24
96	14,7	2,69	98	25,2	3,23

[a] ln denotes the natural logarithm.



Key

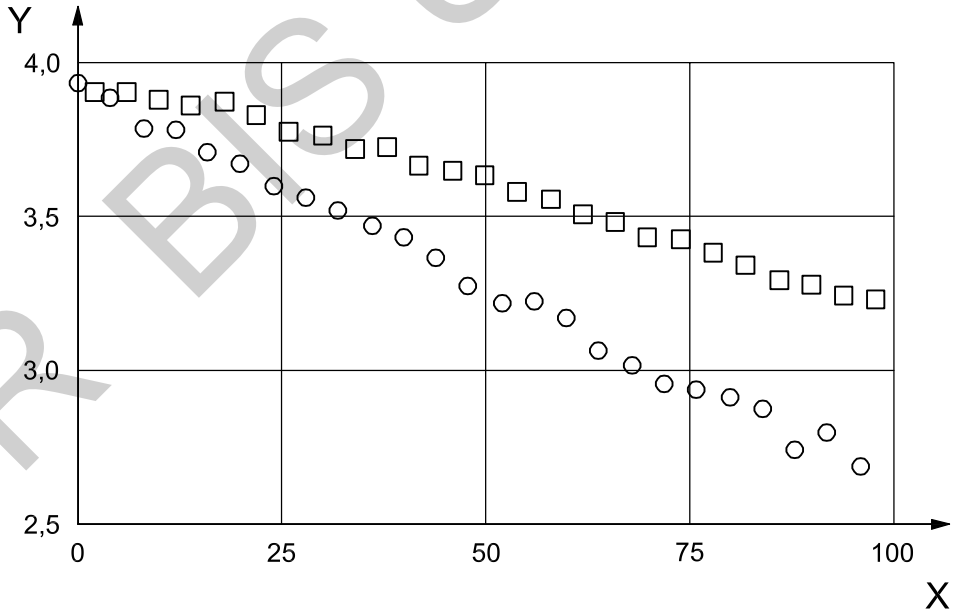
X time, in minutes from the start of decay

Y N_2O, in $cm^3 \cdot m^{-3}$

O bedroom

□ kitchen

Figure D.1 — Plot of tracer gas concentration versus time



Key

X time, in minutes from the start of decay

Y $\ln(\varphi)$, in $cm^3 \cdot m^{-3}$

O bedroom

□ kitchen

Figure D.2 — Plot of log of concentration versus time

D.2.3.2 Steps for calculating local mean ages of air

The calculation of the local mean age of air involves the following steps.

a) Plot the natural logarithm (ln) of tracer gas concentration as a function of time.

It is advantageous if a logarithmic plot can be made in real time, because the sampling can be interrupted when a linear plot is ascertained at all sampling points.

b) Identify the beginning and end of the linear part in the logarithmic plot.

Observe that low concentrations will show large scattering, due to measurement uncertainty and unstable air movements. Do not include the range of excessive scattering.

Sometimes, a logarithmic plot is linear from the beginning of decay. This means that the decay is purely exponential, as in the case of complete mixing between zones. In this case, no numerical integration is needed. The local mean age of air can be calculated from the inverted value of the absolute value of the slope of the logarithmic plot.

c) Calculate the slope ($-\lambda$) of the linear part of the logarithmic plot.

A spreadsheet calculation programme can be advantageously used to calculate the equation of the trend line. Use the absolute value of the correlation coefficient to obtain λ.

d) Make a numerical integration of tracer gas concentration $\varphi(t)$ (e.g. using the trapezoid method) from time $t = t_0$ to a time $t = t_e$ within the linear part of the logarithmic plot.

Usually, sampling at different positions cannot be performed simultaneously. Therefore, only one position can be analysed at $t = t_0$. Samples from the other positions are then analysed with successive time delays. Care should therefore be taken when calculating the area of the first trapezoid from $t = t_0$ to $t = t_{p1}$, where t_{p1} is the time for the first measurement at a position p.

Best practice is to add an area equal to $(t_{p1} - t_0) \cdot [\varphi(t_{p1}) + \varphi(t_0)]/2$ to the calculated integral. $\varphi(t_0)$ is the initial tracer gas concentration at the beginning of decay. This initial concentration should be equal in the whole ventilated system and can be taken as the measured concentration at the location measured at $t = t_0$.

The time t_e can be chosen freely within the linear part of the logarithmic decay.

e) Estimate the total time integral by adding the extrapolated integral $\frac{\varphi_{t=t_e}}{\lambda_{tail}}$ from $t = t_e$ to infinity to the numerically calculated integral.

The value of $\varphi_{t=t_e}$ can be taken as the measured concentration at $t = t_e$. However, a better practice is to use the trend line equation calculated for the logarithmic decay.

The expectation value $\varphi_{t=t_e}$ is obtained from $\varphi_{t=t_e} = e^{\ln\varphi(t_e)}$, where $\ln\varphi(t_e)$ is obtained from the correlation equation with $t = t_e$.

f) Finally, divide the estimated total integral(s) by the common initial tracer gas concentration $\varphi_{t=t_0}$ at time $t = t_0$ to get an estimate of the local mean age of air.

Here, it is very important to get the correct initial concentration. Usually, the concentration measured at the beginning of decay can be used.

D.2.3.3 Evaluation of local mean ages of air in the given example

Below, the actions associated with steps a) to f) in D.2.3.2 are illustrated for the example in Table D.1.

a) The plot of the natural logarithm (ln) of tracer gas concentration as a function of time is shown in Figure D.2.

b) The beginning of the linear part in the logarithmic part plot is identified by inspection to be 40 min for the kitchen. For the bedroom, the curve is linear from the beginning. The end of the linear region is chosen as 100 min, where the scatter around the trend-line is still moderate.

c) With the help of a spreadsheet calculation programme, the least squares trend-line for the kitchen is calculated as $\ln(\varphi) = -0{,}008\,3\ t + 4{,}03$ (using data between 42 min and 98 min) which yields $\lambda = 0{,}008\,3$ min^{-1} or 0,498 h^{-1}. For the bedroom, the whole interval between 0 min and 96 min can be used, which yields the correlation equation, $\ln(\varphi) = -0{,}0129\ t + 3{,}92$. The λ-parameter for the bedroom is thus 0,012 9 min^{-1} (0,774 h^{-1}).

d) Since the decay in the bedroom is exponential from the beginning of the decay, there is no need for a numerical integration. The local mean age of air is directly obtained from the inverted value of λ [Equation (5)], i.e. $\bar{\tau} = 1/\lambda = 1/0{,}774 = 1{,}29$ h.

In the kitchen, a numerical integration from $t = 2$ min to $t = 78$ min (arbitrarily chosen within the linear part of the decay) yields

$$A_{(2\text{-}78)} = 4\left(\frac{\varphi_{t=2}}{2} + \sum_{t=6}^{t=74}\varphi(t) + \frac{\varphi_{t=78}}{2}\right) = 4(24{,}8 + 721{,}4 + 14{,}7) = 4 \times 760{,}8 = 3\,043\ \text{cm}^3\cdot\text{m}^{-3}\cdot\text{min}.$$

Because the analysis did not start at $t = 0$, the missing area from $t = 0$ to $t = 2$ min shall be added.

$$A_{(0\text{-}2)} = 2\left(\frac{\varphi_{t=0}}{2} + \frac{\varphi_{t=2}}{2}\right) = 2\left(\frac{50{,}9}{2} + \frac{49{,}5}{2}\right) = 100\ \text{cm}^3\cdot\text{m}^{-3}\cdot\text{min}$$

e) As the last contribution to the area under the decay curve, the extrapolated area from $t = 78$ to $t = \infty$ is computed,

$$A_{\text{rest}} = \frac{\varphi_{t=t_e}}{\lambda} = \frac{29{,}3}{0{,}008\,3} = 3\,531\ \text{cm}^3\cdot\text{m}^{-3}\cdot\text{min},$$

where $\varphi_{t=t_e} = e^{\ln\varphi(t_e)}$ and $\ln\varphi(t_e)$ are obtained by inserting $t = 78$ min in the correlation equation [see step c)].

The total integrated area, $A_{\text{tot}} = A_{(0\text{-}2)} + A_{(2\text{-}78)} + A_{\text{rest}} = 6\,675$ cm^3·m^{-3}·min.

f) The local mean age of air in the kitchen is calculated from the total integrated area divided by the initial concentration [Equation (1)].

$$\bar{\tau} = \frac{A_{\text{tot}}}{\varphi_{t=t0}} = \frac{6\,674}{50{,}9} = 131\ \text{min} = 2{,}19\ \text{h}$$

D.2.3.4 Estimates of uncertainty

D.2.3.4.1 General

The uncertainty of a local mean age of air obtained using the decay technique with automatic sampling is composed of contributions from uncertainties in the influencing factors.

$$s^2 = s^2_{\text{area}} + s^2_{\varphi_0} \quad \text{(D.1)}$$

where

s^2_{area} is the (relative) variance in calculating the true integral from $t = t_0$ to $t = t_\infty$;

$s^2_{\varphi_0}$ is the (relative) variance in estimating the initial concentration.

It is assumed here that the analysing instrument yields a linear response as a function of concentration from $\varphi = 0$ to the highest measured concentration. Due to the fact that the integral is divided by the measured concentration at $t = t_0$, the instrument does not need to be calibrated in absolute terms.

D.2.3.4.2 Uncertainty of the integral

The integral from $t = t_0$ to $t = t_e$ is approximately $(n - 1)/n$ times the sum of the n concentration measurements during that time, multiplied by the time interval Δt between measurements. The uncertainty of measurement probably depends to a certain extent on the concentration range. If it is assumed here that all measurements have equal absolute uncertainties, the absolute uncertainty of the numerical integration will be equal to the uncertainty $\sqrt{n}s_{\text{meas}}$ in the estimated sum, multiplied by $\Delta t(n-1)/n$. Therefore,

$$s_{A\text{num}} = \sqrt{n}s_{\text{meas}} \cdot \Delta t(n-1)/n = s_{\text{meas}} \cdot \Delta t(n-1)/\sqrt{n} \quad \text{(D.2)}$$

where

$s_{A\text{num}}$ is the absolute standard deviation of the numerical integration;

s_{meas} is the absolute standard deviation of a single measurement;

n is the number of points used in the calculation.

It should be noted that there is an additional error involved when using the trapezoid integration. Due to the fact that the decay curve is concave upwards, the numerical integration will yield an overestimate of the true integral. Depending on the extent of decay between measurements, the overestimate can range from negligible to several tens of percent. If a substantial decay has taken place between measurements, a better approximation of the area between two adjacent measurement points is to assume an exponential decay between them and approximate the area between points i and j according to Equation (D.3) below instead of using the trapezoid rule:

$$A_{ij} = \Delta t_{ij} \frac{(\varphi_i - \varphi_j)}{\ln(\varphi_i) - \ln(\varphi_j)} \quad \text{(D.3)}$$

The uncertainty in the rest area A_{rest} depends on the accuracy of determining φ_e and the exponential decay parameter λ. The λ value is best estimated using a linear least squares fit of $\ln(\varphi)$ as a function of time. The relative standard deviation s_λ of the correlation coefficient ($-\lambda$) and of the estimate s_{φ_e} can be computed using a spreadsheet programme. The absolute standard deviation of the estimate of the tail-area, A_{rest}, can be written

$$s_{\text{rest}} = A_{\text{rest}}\sqrt{s^2_\lambda + s^2_{\varphi_e}} \quad \text{(D.4)}$$

Observe, that the estimate has its smallest standard deviation s_{φ_e} at the time corresponding to the mean of the time values used in the linear correlation.

Lastly, in the computation of the uncertainty of the local mean age of air, one has to consider the uncertainty in the initial concentration. This uncertainty is not only due to uncertainty in analysis, but also due to possible spatial variations of tracer gas distribution at the start of decay. The latter uncertainty has to be based on an

informed guess using information based on the concentration recordings. The injection of tracer gas and mixing before the start of the decay should be performed so that the spatial concentration differences do not exceed 5 %.

D.2.3.4.3 Evaluation of uncertainty in the given example

The uncertainty of the computed area is

$$s_{A_{\text{num}}} = \Delta t(n-1)/\sqrt{n}s_{\text{meas}} \quad \text{(D.5)}$$

s_{meas} is the uncertainty of measuring a concentration. It can be obtained from known performance of sampling and analysis or be calculated from repeated measurement of the same tracer gas concentration. In the present example, s_{meas} is estimated to be 1 $\text{cm}^3\cdot\text{m}^{-3}$. Δt is equal to 4 min and the number of measurements $n = 20$. Therefore, $s_{A_{\text{num}}}$ is estimated to approximately 17 $\text{cm}^3\cdot\text{m}^{-3}\cdot\text{min}$ or 0,5 %, which is quite negligible. The underestimate due to using the trapezoid method can also be shown to yield a negligible error by a simple comparison between the two methods of calculation of areas. The small uncertainty in the computed area is, due to the fact that errors cancel each other when calculating the sum.

The uncertainty in the interpolated area A_{rest} is

$$s_{\text{rest}} = \sqrt{s_{\lambda}^2 + s_{\varphi_e}^2} \quad \text{(D.6)}$$

where the relative standard deviation s_{λ} is computed as 2,2 % using a least squares technique in the range from 42 min to 98 min. s_{φ_e} is only 0,6 %. Therefore, s_{rest} is 2,3 % of A_{rest} or 80 $\text{cm}^3\cdot\text{m}^{-3}\cdot\text{min}$.

The relative uncertainty of the area under the curve is computed as

$$s_{\text{area}} = \frac{\sqrt{s_{A_{\text{num}}}^2 + s_{A_{\text{rest}}}^2}}{A_{\text{num}} + A_{\text{rest}}} = \frac{\sqrt{17^2 + 80^2}}{6\,674} = 1{,}2\,\% \quad \text{(D.7)}$$

The dominating component contributing to the uncertainty in determination of the local mean age of air in this case may be the uncertainty in the initial concentration s_{φ_0}. Assuming this to be 3 %, it is calculated according to Equation D.8.

$$s_{\text{total}} = \sqrt{0{,}012^2 + 0{,}03^2} = 3{,}2\,\% \quad \text{(D.8)}$$

D.2.4 Example of decay technique using manual injection and manual sampling

D.2.4.1 Experimental

In this example, tracer gas is distributed to the different zones of the ventilated system using a graduated syringe filled with SF_6 (sulfur hexafluoride) gas or SF_6/inert gas mixture. In each zone, a portion of the tracer gas that is proportional to the volume of the zone is injected. The injections are made while walking around in the zone in order to distribute the tracer gas evenly. In order to avoid unequal tracer gas concentrations between the zones due to decay during injection, the injections shall be performed as quickly as possible.

After injection in all zones, the air is mixed within and between the zones as described above to secure a homogeneous tracer gas distribution. Immediately after mixing, all internal doors are set to their desired positions and the first sample is taken, using a 50 ml plastic syringe, at a representative location or while walking around between zones. Six subsequent samples are thereafter taken in each zone of interest, with equal time intervals using clean and labelled 50 ml syringes, which are capped after filling. The preferred sampling interval is determined so that the samplings are distributed evenly within a time period, which is equal to the anticipated mean age of air, which in the present case is 2 h.

The capped syringes are delivered to a laboratory, which can perform GC/ECD analysis of the SF_6 concentration in the samples.

D.2.4.2 Simulated data

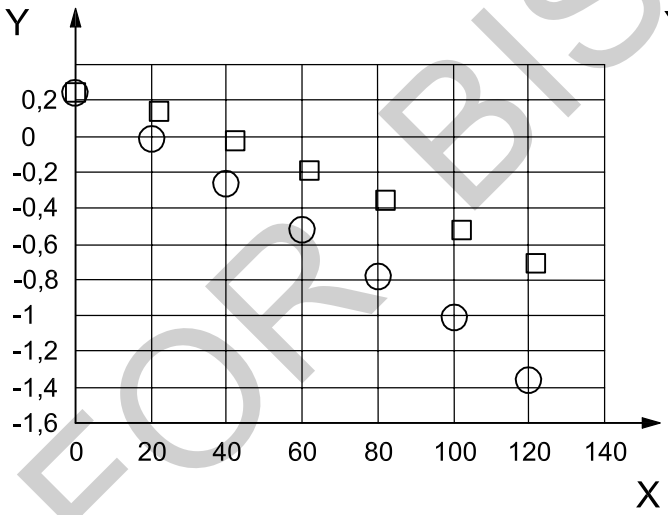
The result in this simulated experiment is shown in Table D.2 together with area calculations as in the example of automatic sampling. The result is plotted in Figures D.3 and D.4.

Table D.2 — Analysed concentration of tracer gas in manually taken air samples

Bedroom						Kitchen					
Time min	φ $cm^3 \cdot m^{-3}$	$\ln(\varphi)$ $cm^3 \cdot m^{-3}$	A_{trap} $cm^3 \cdot m^{-3}$ min	A_{exp} $cm^3 \cdot m^{-3}$ min	$A_{trap} - A_{exp}$ $cm^3 \cdot m^{-3}$ min	Time min	φ $cm^3 \cdot m^{-3}$	$\ln(\varphi)$ $cm^3 \cdot m^{-3}$	A_{trap} $cm^3 \cdot m^{-3}$ min	A_{exp} $cm^3 \cdot m^{-3}$ min	$A_{trap} - A_{exp}$ $cm^3 \cdot m^{-3}$ min
0	1,27	0,24				0	(1,27)[a]	(0,24)			
20	0,98	–0,02	22,6	22,4	0,6 %	22	1,15	0,14	26,6	26,6	0,1 %
40	0,77	–0,26	17,5	17,4	0,5 %	42	0,97	–0,03	21,2	21,1	0,2 %
60	0,59	–0,52	13,6	13,5	0,6 %	62	0,83	–0,19	18,0	18,0	0,2 %
80	0,46	–0,78	10,5	10,5	0,5 %	82	0,70	–0,35	15,3	15,3	0,2 %
100	0,36	–1,01	8,2	8,2	0,5 %	102	0,59	–0,52	13,0	12,9	0,2 %
120	0,25	–1,37	6,2	6,1	1,0 %	122	0,49	–0,71	10,9	10,8	0,3 %

NOTE A_{trap} is the interval area calculated using linear interpolation; A_{exp} is the interval area calculated using exponential interpolation.

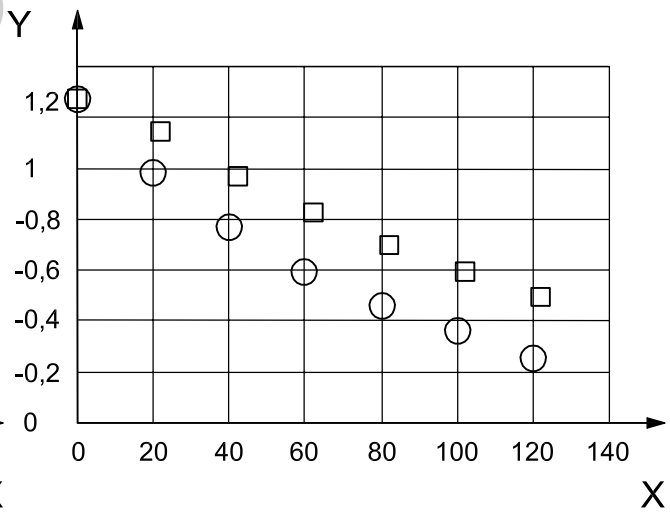
[a] The parentheses indicate the assumed initial concentration (that should be the same in all rooms).



Key

X time, in minutes
Y $\ln(\varphi)$, in $cm^3 \cdot m^{-3}$
O bedroom
□ kitchen

Figure D.3 — Logarithmic plot during decay



Key

X time, in minutes
Y φ, in $cm^3 \cdot m^{-3}$
O bedroom
□ kitchen

Figure D.4 — Linear plot during decay

D.2.4.3 Calculation of local mean ages of air

From an inspection of the logarithmic plot (Figure D.3), it is decided to use the samples taken between 40 min and 120 min as the range of exponential decay for the kitchen. For the bedroom, the decay is assumed to be exponential from the beginning.

The calculation is performed similarly to the one in the preceding example with automatic sampling.

a) The plot of the natural logarithm (ln) of tracer gas concentration as a function of time is shown in Figure D.3.

b) The beginning of the linear part in the logarithmic plot is identified by inspection to be 60 min for the kitchen. For the bedroom, the curve is linear from the beginning. The end of the linear region is chosen to 120 min.

c) With the help of a spreadsheet programme, the least squares trend-line for the kitchen is calculated as $\ln(\varphi) = -0{,}0087\ t + 0{,}35$ (using data between 62 min and 122 min) which yields $\lambda = 0{,}008\ 7\ \text{min}^{-1}$ or $0{,}52\ \text{h}^{-1}$. For the bedroom, the whole interval between 0 min and 120 min can be used, which yields the correlation equation $\ln(\varphi) = -0{,}013\ 1\ t + 0{,}25$. The λ-parameter for the bedroom is thus $0{,}013\ \text{min}^{-1}$ or $0{,}79\ \text{h}^{-1}$.

d) Since the decay in the bedroom is exponential from the beginning of the measurement, there is no need for a numerical integration. The local mean age of air is directly obtained from the inverted value of λ, i.e. the $\bar{\tau} = 1/\lambda = 1/0{,}79 = 1{,}27$ h. In the kitchen, a numerical integration from $t = 0$ min to $t = 102$ min (arbitrarily chosen within the linear part of the decay) yields $A_{(0\text{-}102)} = 26{,}6 + 21{,}2 + 18{,}0 + 15{,}3 + 13{,}0 = 94{,}1\ \text{cm}^3 \cdot \text{m}^{-3} \cdot \text{min}$

e) As the last contribution to the area, the extrapolated area from $t = 102$ to $t = \infty$ is computed.

$$A_{\text{rest}} = \frac{\varphi_{\text{e}}}{\lambda} = \frac{0{,}58}{0{,}008\ 7} = 67{,}2\ \text{cm}^3 \cdot \text{m}^{-3} \cdot \text{min} \qquad \text{(D.9)}$$

where $\varphi_{\text{e}} = \text{e}^{\ln\varphi(t_{\text{e}})}$ and $\ln\varphi(t_{\text{e}})$ are obtained by inserting $t = 102$ min in the correlation equation [see step c)].

The total integrated area $A_{\text{tot}} = A_{(0\text{-}102)} + A_{\text{rest}} = 161{,}3\ \text{cm}^3 \cdot \text{m}^{-3} \cdot \text{min}$

f) The local mean age of air in the kitchen is calculated from the total integrated area divided by the initial concentration [Equation (1)].

$$\bar{\tau} = \frac{A_{\text{tot}}}{\varphi_{t=t0}} = \frac{161{,}3}{1{,}27} = 127\ \text{min} = 2{,}12\ \text{h} \qquad \text{(D.10)}$$

D.2.4.4 Evaluation of uncertainty in the given example

The estimate of uncertainties is calculated similarly to the case of automatic sampling.

$$s_{A_{\text{num}}} = \Delta t(n-1)/\sqrt{n}\, s_{\text{meas}} \qquad \text{(D.11)}$$

yields

$$s_{A\text{num}} = 20 \times 5 \frac{0{,}02}{\sqrt{6}} = 0{,}82\ \text{cm}^3 \cdot \text{m}^{-3} \cdot \text{min}$$

where it is assumed that the absolute uncertainty of concentration determination is $0{,}02\ \text{cm}^3/\text{m}^3$ and the six first samples are used for the numerical integration.

$$s_{\text{rest}} = A_{\text{rest}} \sqrt{s_{\lambda}^2 + s_{\ln\varphi,t_e}^2} \tag{D.12}$$

yields

$$s_{\text{rest}} = 67{,}2 \times \sqrt{0{,}028^2 + 0{,}012^2} = 67{,}2 \times 0{,}030 = 2{,}03\ \text{cm}^3 \cdot \text{m}^{-3} \cdot \text{min}$$

where the relative uncertainty of the slope s_{λ} and the relative uncertainty of the expectation value of concentration at $t = 102$ min are calculated using conventional least squares technique.

The relative uncertainty of the area under the curve is computed as

$$s_{\text{area}} = \frac{\sqrt{s_{A\text{num}}^2 + s_{A\text{rest}}^2}}{A_{\text{num}} + A_{\text{rest}}} = \frac{\sqrt{0{,}82^2 + 2{,}03^2}}{161{,}3} = 1{,}4\ \% \tag{D.13}$$

s_{φ_0} shall be estimated using an informed guess based on recorded data. In the present case, it can be estimated using the uncertainty of the least squares equation for the bedroom, where the decay seems to be purely exponential from the outset. Using conventional least squares calculation of the uncertainty of the intercept at $t = 0$ yields $s_{\varphi_0} = 2{,}2$ %.

Adding together the contribution of uncertainties [Equation (D.1)], the following is obtained

$$s_{\tau} = \sqrt{0{,}014^2 + 0{,}022^2} = 2{,}6\ \%$$

D.3 Homogeneous emission method

D.3.1 Tracer gas injection

The purpose of tracer gas injection in the homogeneous emission technique is to establish constant and equal injection rates per volume unit in all parts of the ventilated system. The tracer gas injection can either be active or passive.

D.3.2 Tracer gas sampling

The sampling can either be passive (diffusive) or active. The passive sampling yields an average value of the local mean ages of air during an extended time, while active sampling yields instantaneous values. Active sampling can be automatic, yielding information on ventilation conditions as a function of time, or manual, yielding information on selected instants.

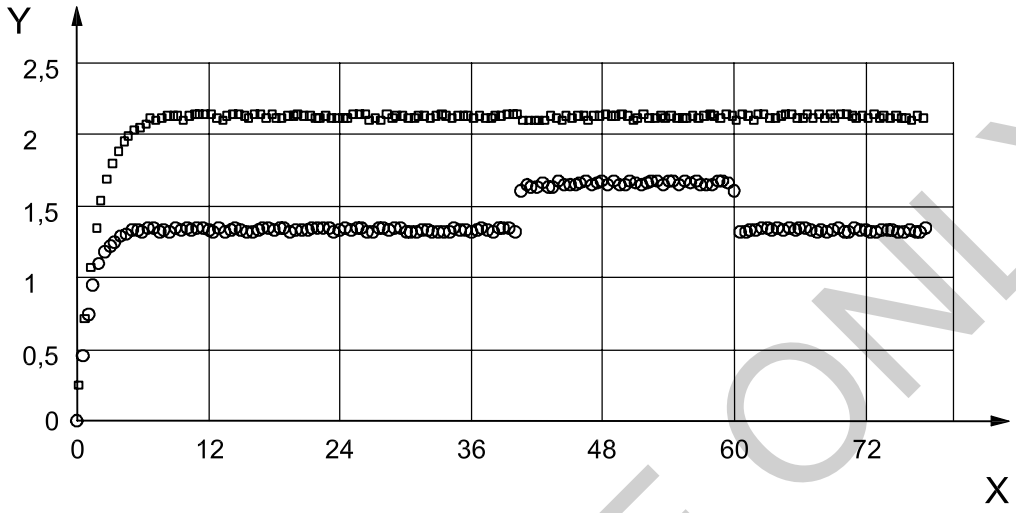
D.3.3 Example of homogeneous emission using active injection and active sampling

D.3.3.1 Simulated experiment

In this example, tracer gas SF_6 is injected into the three zones of the dwelling using a commercially available doser. This equipment can be programmed to inject the tracer gas at up to six different ports. Programming the fraction of time that the different ports are open regulates the amount injected. The tracer gas is mixed with air before dispensing to the different ports in order to avoid excessive concentration and density. Polyethylene tubes (4 mm inner diameters) are used to distribute the tracer gas to the three different zones. The tracer gas/air mixture is released behind a low-capacity fan in each room, in order to improve the tracer gas distribution in the rooms. Other equipment for controlled release and distribution of tracer gas can also be used, but in all cases, the release rate shall be carefully calibrated to match the zone volumes.

Sampling is performed during 80 h at 15 min intervals in the bedroom and in the kitchen. Analysis is performed with multi-gas monitor, which uses infrared absorption with a photoacoustic detector to analyse the tracer gas concentration.

Tracer gas SF_6 is injected at a rate of 1 $cm^3 \cdot m^{-3} \cdot h^{-1}$. Altogether, 122,4 ml per hour is distributed in the dwelling. In order to illustrate the effect of changing the air distribution pattern, the door between the bedroom and the living room is simulated to be open from 40 h to 60 h after beginning the injection. The simulated result is shown in the diagram in Figure D.5.



Key

X hours from the start of injection

Y tracer gas SF_6, $cm^3 \cdot m^{-3}$

O bedroom

□ kitchen

Figure D.5 — Result of tracer gas concentration measurement using homogeneous emission technique with active injection and sampling — From 40 h to 60 h, the door to the bedroom is open (simulated data)

D.3.3.2 Calculation of local mean ages of air

The local mean age of air is computed from the quotient of the steady state concentration and the tracer gas emission rate per volume unit.

$$\bar{\tau} = \frac{\varphi}{(q_V / V)} \qquad \text{(D.14)}$$

After 10 h of injection, a steady state is approached. Table D.3 below shows the result of the average value of the concentration measurements and the averages of the calculated local mean ages during different periods.

Table D.3 — Average steady state concentrations during decay — From 40 min to 60 min, the bedroom door is open

	Bedroom		Kitchen	
		$\bar{\tau}$		$\bar{\tau}$
	cm^3/m^3	h	cm^3/m^3	h
10 h to 40 h	1,33 ± 0,01	1,33	2,13 ± 0,01	2,13
40 h to 60 h	1,65 ± 0,15	1,65	2,12 ± 0,01	2,12
60 h to 80 h	1,34 ± 0,01	1,34	2,12 ± 0,01	2,12

D.3.3.3 Estimates of uncertainty:

The relative uncertainty of the local mean ages of air using the homogeneous emission technique is determined from the standard deviation of the contributing factors:

$$s_{\tau}^2 = s_{\text{meas}}^2 + s_{\text{distr}}^2 \tag{D.15}$$

The relative standard deviation of the measured concentration is made up of the uncertainty of the analysis instrument, which depends on the calibration of the instrument, its drift and instability. It is assumed here that the instrument is calibrated against a standard SF_6/air mixture which is known within limits $\pm s_{\text{cal}}$ and that the instrument yields a standard deviation around the mean of s_{anal}. The total concentration measurement variance is therefore

$$s_{\text{meas}}^2 = s_{\text{cal}}^2 + s_{\text{anal}}^2 \tag{D.16}$$

It is assumed that any deviation between the nominal concentration of the calibration standard and the mean of measured values on this standard (systematic error), is accounted for using a correction constant.

The uncertainty in the homogeneous emission rate depends on how well the emission rates into the different zones can be measured and kept constant. The relative uncertainty in the regulation of the injection rate should be known from calibration and is designated s_{inject}.

There is a further factor in the homogeneous emission rate that shall be accounted for when computing the uncertainty. This error is due to any known inability to achieve a homogeneous distribution. This uncertainty is different in different zones and should be calculated the following way:

Set (q_V/V) as the average injection rate of tracer per volume in the ventilated system and ($q_V{}^p / V^p$) as the injection rate in a specific zone p divided by the volume of this zone.

$$s_{\text{inhom}} = \frac{\left| q_V / V - q_V{}^p / V^p \right|}{q_V / V + q_V{}^p / V^p} \tag{D.17}$$

The total variance is therefore computed by

$$s_{\tau}{}^2 = s_{\text{cal}}^2 + s_{\text{anal}}^2 + s_{\text{inject}}^2 + s_{\text{inhom}}^2 \tag{D.18}$$

There is an additional uncertainty in the measurement due to incomplete mixing of tracer gas within the zone. This uncertainty in determining the zone average of the local mean age can only be evaluated by measuring at different positions within a zone.

Variations due to changes in the ventilation rate and air distribution with time can be evaluated by analysing the time variations of the concentration measurement. It should be noted that such variation can be much larger than the method uncertainty calculated by the technique mentioned above.

D.3.3.4 Evaluation of uncertainty in the given example

$$s_{\tau} = \sqrt{s_{\text{meas}}^2 + s_{\text{inject}}^2 + s_{\text{inhom}}^2} \tag{D.19}$$

The uncertainty in analysis s_{meas} can be estimated from the standard deviation of the sampling and analysis system as determined from repeated analysis of a calibration gas with similar concentration. Such standard deviation is typically $s_{\text{meas}} = 3$ %.

The relative uncertainty in the regulation of the injection rate s_{inject} should be known from calibration. A typical value is $s_{\text{inject}} = 3$ %.

s_{inhom} is the uncertainty due to any known inability to achieve a homogeneous distribution of tracer gas. The reason for such inhomogenity of tracer gas distribution may be that the regulation equipment does not allow the user to make an exact match to a desired injection rate. The matching between desired and regulated injection rate may be different in different zones (refer to D.3.3.2 estimates of uncertainty above for calculating s_{inhom} in different zones).

If s_{inhom} is neglected in the given example, the relative uncertainty in measurement of the local mean age of air using the homogeneous emission technique with active injection and sampling, applying Equation (D.19), is

$$s_\tau = \sqrt{0{,}03^2 + 0{,}03^2} = 4{,}2\ \%$$

It should be noted that the estimate of uncertainty only refers to a single measurement. If the uncertainty of an average of several measurements is to be estimated, the standard deviation of the mean should be determined using conventional techniques. Observe that random errors in single measurements tend to cancel each other when computing an average. However, uncertainties due to systematic errors remain. Therefore, it is advisable to estimate the uncertainty of an average value from Equation (D.20).

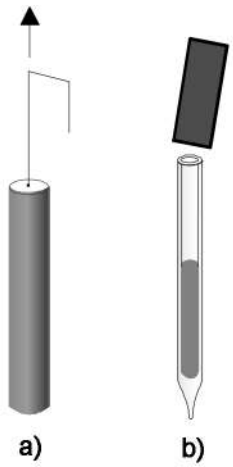
$$s_{average} = \sqrt{\frac{s_{series}^2}{n-1} + s_{cal}^2 + s_{distr}^2} \qquad \text{(D.20)}$$

where s_{series} is the relative standard deviation in the time series with the n measurements on which the average is computed.

D.3.4 Example of homogeneous emission using passive injection and passive sampling

D.3.4.1 General

The homogeneous emission technique with passive injection and passive sampling is usually used in order to determine the time average of the local mean ages of air during an extended time period. In this example, passive tracer gas sources of the adjustable capillary type and passive diffusive sampler tubes with activated carbon sorbent are used (see Figure D.6).



Key

a capillary tracer gas source, with emission adjustment device

b passive sampler with charcoal sorbent

Adjustment of the emission rate from a capillary source can be provided by a metal wire extending to different depths into the capillary tube.

Figure D.6 — Example of source and sampler capsules

In the literature, several types of passive sources and samplers have been described. Some of these are commercially available from companies that also perform tracer gas analysis. The emission rate of passive sources shall be carefully calibrated before use. They exhibit a strong temperature dependency and this shall be accurately known. The diffusive sampling rate of the passive samplers shall also be carefully measured before use. Commercially available sources and samplers have undergone careful calibration and testing.

D.3.4.2 Planning of test

It is decided that the local mean ages of air shall be determined in a one-family house as averages during one week. A sketch of the house is prepared and the room volumes calculated (Figure D.7). The house also has a cellar. The total volume of the living space is 248 m^3 and the volume of the cellar connected via the staircase 140 m^3. On the ground floor, 33 m^3 is identified as small enclosed spaces with only exhaust air or without supply air (bathroom, laundry and wardrobes). These small spaces need not be equipped with tracer gas sources.

Information on the calculated room volumes is sent to a company, which delivers twelve adjusted and labelled tracer gas sources, eight of which are to be distributed on the ground floor and four in the cellar.

D.3.4.3 Performance of test

The twelve labelled tracer gas sources and the five passive tracer gas samplers are distributed on the walls of the rooms according to the instruction from the delivering company. After positioning the sources, the passive samplers are distributed and de-capped (kitchen, hall, children's bedroom, office and cellar). Sources, samplers and temperature loggers are positioned at such a height that they are out of reach of small children. The occupants are informed about the purpose of the measurement and instructed not to remove the equipment. A protocol and a return box is left, so that the occupants can stop the measurement themselves after a week by capping the samplers and send them together with the temperature loggers by mail to the laboratory for analysis. The sources are sent in a separate package the next day in order to avoid contamination.

D.3.4.4 Results

Table D.4 below shows the zone volumes, the emission rates, the amount of tracer gas in the samplers and the calculated local mean ages of air in the different rooms. The total exposure time T is 164 h. The (equivalent) air sampling rate of the passive samplers κ is 16 ml/h.

Table D.4 — Analysed tracer gas amount, emission rates and computed mean ages of air in rooms using a passive tracer gas technique

Room	Volume V m^3	Emission rate q_m µg/h	Tracer amount M ng	Mean age of air $\bar{\tau}$ h
Living room	68	35		
Kitchen	31	16	3,6	2,7
Hall	38	19	3,7	2,8
Play room	24	12		
Children's bedroom	24	12	4,5	3,4
Parents' bedroom	41	21		
Office	22	11	3,4	2,5
Cellar	140	70	1,9	1,4

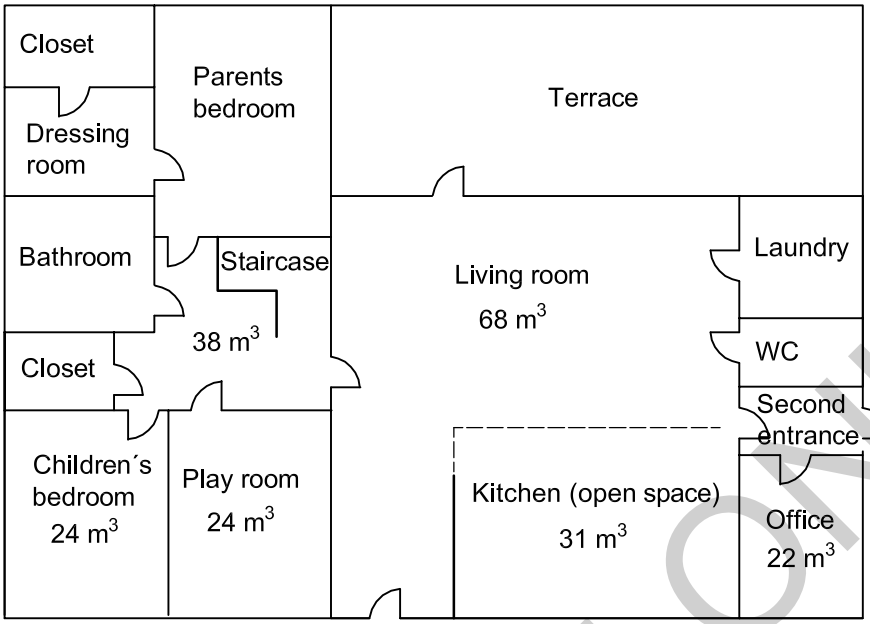


Figure D.7 — Plan sketch for use in the calculation of tracer gas distribution and for use as a complement to the protocol to indicate the positions of sources and samplers

The average tracer gas concentration ρ_a at a sampler position is evaluated from the analysed tracer gas amount M.

$$M = \kappa \cdot T \cdot \rho_a \tag{D.21}$$

The local mean age of air $\bar{\tau}$ is calculated from

$$\bar{\tau} = \frac{\rho_a}{q_m / V} \tag{D.22}$$

where q_m / V is the average emission rate per volume unit (in for example, $\mu g \cdot h^{-1} \cdot m^{-3}$).

D.3.4.5 Estimates of uncertainty of local mean ages of air

The estimate of the total inaccuracy s of a determined local mean age of air is calculated as follows:

$$s = \sqrt{s_{\text{source}}^2 + s_{\text{sampl}}^2 + s_{\text{meas}}^2 + s_{\text{inhom}}^2} \tag{D.23}$$

where

s_{source} is the uncertainty of the overall emission rate. It is composed of the uncertainty of the total emission rate in the ventilated system which should be computed from the relative standard deviation of individual sources (as determined by calibration) divided by the square root of the number of sources in the system + uncertainty due to inadequate temperature compensation;

s_{sampl} is the relative uncertainty of sampling. It should be estimated as the relative standard deviation of sampling rate as determined by calibration + uncertainty due to non-representative sampling because of insufficient mixing in the zone;

s_{meas} is the relative uncertainty due to analysis (reproducibility + drift + uncertainty of calibration). (max. 0,08);

s_{inhom} is the relative uncertainty due to any deviation from the homogeneous tracer gas emission rate occur in individual zones. The error due to such deviations is dependent on the actual coupling (in the airflow sense) between the particular zone and the rest of the ventilated system. Since the magnitude of this coupling is usually unknown the estimate of the local mean age of air will be associated with an uncertainty (refer to the example in D.3.3.3 for how to calculate s_{inhom}).

D.3.4.6 Evaluation of uncertainty in the given example

With twelve sources, each with a relative uncertainty of emission rate of 5 % and with relative uncertainty of 3 % due to uncertain temperature compensation, the uncertainty of sources becomes

$$s_{source} = \sqrt{0{,}05^2/12 + 0{,}03^2} \quad \text{(D.24)}$$

The uncertainty of sampling can be calculated from

$$s_{sampl} = \sqrt{0{,}05^2 + s_{mix}^2/(n-1)} \quad \text{(D.25)}$$

where the uncertainty in the calibration of the sampling rate is assumed to be 5 %.

s_{mix}^2 denotes the mixed variance due to variation of individual sampling tubes and non-representative sampling in the zone, which should be determined from the relative standard deviation of n samplers in the zone. If only one sampler is used (for example in a small zone), $s_{mix}^2/(n-1)$ should be replaced by $0{,}05^2$ for a normally mixed zone.

s_{meas} = 0,03 (3 %) is a typical value for the relative uncertainty of tracer gas analysis using liquid extraction and GC/ECD analysis. However, the relative uncertainty grows rapidly as the tracer gas amount decreases.

If a deviation from homogeneous distribution of emission rates is neglected, a typical total uncertainty of local mean age estimation amounts to 11 % in this example.

$$s = \sqrt{s_{source}^2 + s_{sampl}^2 + s_{meas}^2 + s_{inhom}^2} = \sqrt{(0{,}05^2/12 + 0{,}03^2) + (0{,}05^2 + 0{,}05^2) + 0{,}08^2 + 0} = 0{,}11$$

A typical total uncertainty of local mean age estimation amounts to 11 % in this example.

It should be noted that the estimate of uncertainty only refers to the average of the local mean ages of air during the measurement period. Any variations due to changes in the ventilation rate and air distribution with time are not included. This can only be evaluated by analysing the time variations of the concentration.

Annex E
(informative)

Air quality relevance of local mean age of air and expression of results

E.1 Air quality relevance of the local mean age of air

E.1.1 Mean age of air and air quality

The "local mean age of air" indicates the length of time the air surrounding a particular point in space has spent on average within the ventilated system. The longer the air has spent indoors, the greater the likelihood that the air has accumulated contaminants from indoor sources. The local mean age of air could be therefore an air quality indicator. The air surrounding the point may however have spent different times in different zones of the ventilated system.

The pattern of distribution of mean ages of air in a building describes how the ventilation air is distributed within the building. The local mean age of air is closely connected to the time it takes to renew the air at the particular location.

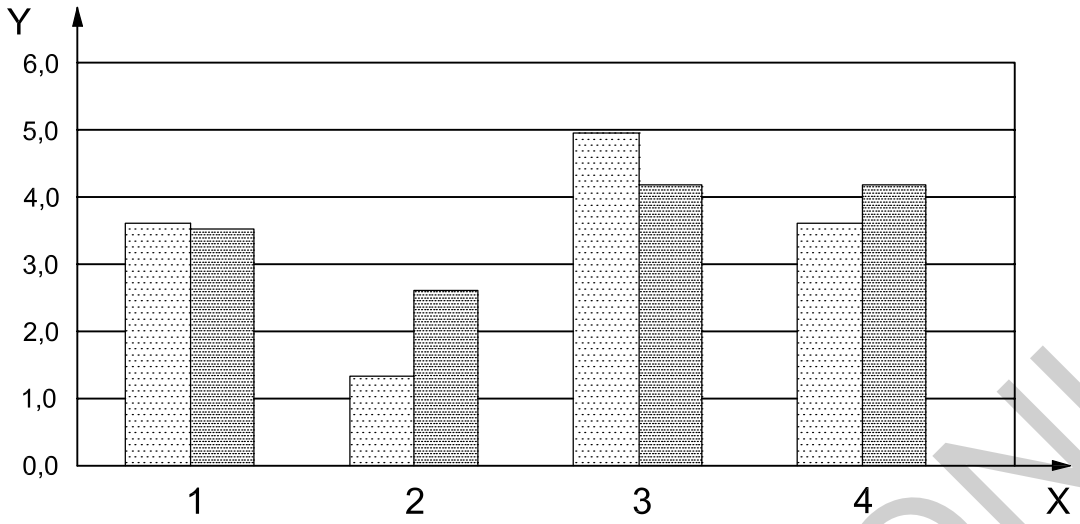
E.1.2 Example: Estimation of contaminant emission rates

An approximate value of the overall emission rate of a contaminant C per cubic metre of space $\left\langle {q_w}^{\mathrm{C}} / V \right\rangle$, whose concentration is measured simultaneously with the mean age of air, can be obtained using the following procedure.

First, calculate the average concentration $\left\langle \rho^{\mathrm{C}} \right\rangle$ of the contaminant C in the ventilated system by computing the volume-weighted concentrations. Then, divide this by the average mean age of air in the system $\langle \bar{\tau} \rangle$, which is computed from the volume-weighted local mean ages of air.

$$\left\langle {q_w}^{\mathrm{C}} / V \right\rangle \approx \frac{\left\langle \rho^{\mathrm{C}} \right\rangle}{\langle \bar{\tau} \rangle} \qquad \text{(E.1)}$$

It is not possible to say how this contaminant emission rate is distributed between the zones, without having additional information on the airflow patterns within the system. It is however possible to compare the distribution of expected concentration with the actual concentration distribution. The expected zone concentrations with a homogenous distribution of contaminant emission rates can be estimated by multiplying the computed $\left\langle {q_w}^{\mathrm{C}} / V \right\rangle$ value by the local mean ages of air in the different zones.



Key

X room

Y concentration ρ^C, mg· m^{-3}

measured concentration

expected concentration

1 living room

2 bedroom

3 kitchen

4 bathroom

Figure E.1 — A comparison between measured contaminant concentration and the calculated expected concentration assuming a homogeneous emission yields information on the distribution of contaminant sources

Rooms that show higher concentration than expected have a higher emission rate per cubic metre (m^3) than calculated $\left\langle q_w{}^C / V \right\rangle$, while rooms with lower values have a smaller emission rate per cubic metre (m^3) than calculated.

E.2 Expression of results

The local mean ages of air in the different zones are the primary results of the measurements according to this part of ISO 16000. However, there are a number of secondary or deduced quantities of the ventilation condition in a building that also might be recorded as test results:

a) the room-specific ventilation flow rate (h^{-1});

b) the average mean age of air (h);

c) the nominal time constant (h);

d) the air exchange efficiency;

e) the local air exchange indices;

f) the specific ventilation flow rate (ACH) (h^{-1});

g) the total ventilation flow rate ($m^3 \cdot h^{-1}$).

Under special circumstances, these parameters can be calculated from the known volumes and local mean ages of air in the different zones, into which the ventilated system is divided.

The definitions and calculation of those additional quantities are given below.

The room-specific ventilation flow rate (h^{-1}) is the inverse of the local mean age of air in a zone. This quantity has formerly often been referred to as "local air change rate" (local ACH). The advantage of this parameter lies in its close resemblance to the well-known specific ventilation flow rate (ACH), which is defined only for the ventilated system as a whole.

The average mean age of air in the ventilated system indicates how old, on average, the air is in the ventilated system. It is calculated from the volume-weighted average of local mean ages of air in the different zones.

$$<\tau> = \Sigma(V_i \tau_i)/\Sigma V_i$$

where

V_i is the zone volume;

τ_i is the local mean age of air.

In this calculation, only those zones are included for which the local mean age has been determined (i.e. those zones equipped with both tracer gas sources and samplers).

The air exchange time is defined as twice the average mean age of air in the ventilated system.

The nominal time constant is defined from the total volume of the ventilated system divided by the total ventilation flow rate. It is also equal to the mean age of air leaving the system. It should if possible be computed from the extract-flow-weighted average mean ages of air measured by samplers located close to identified air extract points. If the extract flows are not known, a simple arithmetic mean of measured mean ages of air at the extract points should be taken. If air extract points are not identifiable the average mean age of the system may be taken as an approximation of the nominal time constant. However, when one of these approximate methods is used, an uncertainty value should be given which is equal to the standard deviation of the individual mean ages from the average.

The air exchange efficiency is defined as the ratio of the nominal time constant to the air exchange time in the system. This parameter describes how well the ventilation air is utilized compared with the ventilation with an ideal "piston flow" through the ventilated system, with the same ventilation flow rate. For a fully mixed system, the air exchange efficiency is 50 %.

The air exchange index is the ratio of the nominal time constant to the local mean age of air. This index describes how well a local space is ventilated compared with the ventilation in a fully mixed system with the same total ventilation flow rate.

The specific ventilation flow rate is defined as the total flow rate of outside air entering into a ventilated system, divided by the volume of the ventilated system. This quantity is equivalent to the formerly used quantity "air change rate" (ACH). The specific ventilation flow rate is not locally defined for a zone (also see: "room-specific flow rate"). It should be calculated from the reciprocal value of the nominal time constant.

The total ventilation flow rate is computed from the ratio of the total volume of the ventilated system to the determined nominal time constant. The total volume shall include all spaces of the ventilated system and not only the volume of the investigated zones.

E.3 Note on measurement and interpretation of "purging flow rate"

E.3.1 Definition

The "purging flow rate" U is a ventilation concept which indicates how effective the ventilation is in removing locally emitted contaminants from a zone. It is defined from the following equation:

$$\rho^{C} = \frac{{q_w}^{C}}{U} \tag{E.2}$$

where

ρ^{C} is the steady state concentration in the zone;

${q_w}^{C}$ is the emission rate of the contaminant within that zone.

Note that this equation only holds if the same contaminant is not emitted anywhere else in the ventilated system.

If the same contaminant is also emitted in other zones j of the ventilated system, the following equation should be used for the steady state concentration of the contaminant in zone i:

$$\rho_i^{C} = \frac{\left({q_w}^{C}\right)_i + \sum_{j \neq i} P_{ij} \left({q_w}^{C}\right)_j}{U_i} \tag{E.3}$$

where

P_{ij} is the transfer probability of contaminants emitted with emission rates $\left({q_w}^{C}\right)_j$ in other zones j into zone i.

The purging flow rate in a zone can easily be measured using a tracer gas with a known constant emission rate in a zone (and no other zone) and measuring the steady state concentration within that zone. When using the homogeneous emission technique for measuring the local mean ages of air, the purging flow rate in a zone can be determined simultaneously by using a tracer gas of a different type in that zone.

E.3.2 Interpretation of the purging flow rate

The purging flow rate U can be interpreted as the flow rate of outside air to the ventilated system, which is available in a specific zone to dilute contaminants. The maximum value of U is the total ventilation flow rate to the system, and occurs for example when there is good mixing between zones.

According to multi-zone theory, the purging flow rate can be interpreted as composed of ventilation flow rates q_i directly from outside into the different zones:

$$U_i = q_i + \sum_{j \neq i} P_{ij} q_j \tag{E.4}$$

where

P_{ij} is the transfer probability of air from zone j into zone i;

q_i is the flow rate of outside air directly to zone i.

Bibliography

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

[2] ISO 16017-1, *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 1: Pumped sampling*

[3] ISO 16017-2, *Indoor, ambient and workplace air — Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography — Part 2: Diffusive sampling*

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Indoor air —

Part 10:
Determination of the emission of volatile organic compounds from building products and furnishing — Emission test cell method

Air intérieur —

Partie 10: Dosage de l'émission de composés organiques volatils de produits de construction et d'objets d'équipement — Méthode de la cellule d'essai d'émission

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16000-10 was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 264, *Air quality*, in collaboration with Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 6, *Indoor air*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

ISO 16000 consists of the following parts, under the general title *Indoor air*:

— *Part 1: General aspects of sampling strategy*

— *Part 2: Sampling strategy for formaldehyde*

— *Part 3: Determination of formaldehyde and other carbonyl compounds — Active sampling method*

— *Part 4: Determination of formaldehyde — Diffusive sampling method*

— *Part 5: Measurement strategy for volatile organic compounds (VOCs)*

— *Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS/FID*

— *Part 7: Sampling strategy for determination of airborne asbestos fibre concentrations*

— *Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions*

— *Part 9: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test chamber method*

— *Part 10: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test cell method*

— *Part 11: Determination of the emission of volatile organic compounds from building products and furnishing — Sampling, storage of samples and preparation of test specimens*

The following parts are under preparation:

— *Part 12: Sampling strategy for polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzo-furans (PCDFs) and polychlorinated biphenyls (PCBs)*

— *Part 13: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls and polychlorinated dibenzo-p-dioxins/dibenzofurans — Collection on sorbent-backed filters with high-resolution gas chromatographic/mass spectrometric analysis*

— *Part 14: Sampling strategy for nitrogen dioxide (NO_2)*

— *Part 15: Measurement of nitrogen dioxide (NO_2)*

— *Part 16: Detection and enumeration of moulds — Sampling of moulds by filtration*

— *Part 17: Detection and enumeration of moulds — Culture-based method*

This corrected version of ISO 16000-10:2006 incorporates the following corrections:

— in Clause 2, on page 1, 2006 has been added after ISO 16000-11;

— in 3.11, on page 2, Note 1 has been revised to align it with the corrected version of ISO 16000-9:2006;

— in Clause 10, on page 7, ISO 16000-11:2005 has been replaced by ISO 16000-11:2006.

Introduction

The determination of volatile organic compounds (VOCs) emitted from building products using emission test cells in conjunction with the standardised sampling, storage of samples and preparation of test specimens has objectives such as:

— to provide manufacturers, builders, and end users with emission data useful for the evaluation of the impact of building products on the indoor air quality;

— to promote the development of improved products;

— on-site investigation of building product surfaces.

The method can in principle be used for most building products used indoors.

Indoor air —

Part 10: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test cell method

1 Scope

This part of ISO 16000 specifies a general laboratory test method for determination of the area specific emission rate of volatile organic compounds (VOCs) from newly produced building products or furnishing under defined climate conditions. The method can in principle also be applied to aged products. The emission data obtained can be used to calculate concentrations in a model room.

According to the definition of an emission test cell, it is also possible to perform non-destructive emission measurements on building products on-site in buildings. However, the procedure for such measurements is not described in this part of ISO 16000.

Sampling, transport and storage of materials to be tested, and preparation of test specimens are described in ISO 16000-11. Air sampling and analytical methods for the determination of VOCs are described in ISO 16000-6 and ISO 16017-1[20].

An example of an emission test cell is described in Annex C of this part of ISO 16000.

For the determination of formaldehyde emissions from wood-based panels, refer to EN 717-1:2004 [21] and ISO 12460-1 [1]. However, this part of ISO 16000 is also applicable to wood-based panels and other building products in order to determine the emission rate of formaldehyde. The measurement procedure for formaldehyde is described in ISO 16000-3 [2].

2 Normative references

The following referenced documents are indispensable for the application 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 554:1976, *Standard atmospheres for conditioning and/or testing — Specifications*

ISO 16000-11:2006, *Indoor air — Part 11: Determination of the emission of volatile organic compounds from building products and furnishing — Sampling, storage of samples and preparation of test specimens*

3 Terms and definitions

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

3.1
air change rate
ratio of the volume of clean air brought into the emission test chamber per hour and the free emission test chamber volume measured in identical units

3.2
air flow rate
air volume entering into the emission test cell per time

3.3
air velocity
air speed over the surface of the test specimen

3.4
area specific air flow rate
ratio between the supply air flow rate and the area of the test specimen

3.5
building product
product produced for incorporation in a permanent manner in construction works

3.6
emission test cell
a small chamber for the determination of volatile organic compounds emitted from indoor materials/products that is placed on the surface of the test specimen and is designed so that the surface of the test specimen becomes a part of the emission cell

3.7
emission test cell concentration
concentration of a specific volatile organic compound, VOC_x, (or groups of volatile organic compounds) measured in the emission test cell outlet

3.8
product loading factor
ratio of exposed surface area of the test specimen and the free emission test cell volume

3.9
recovery
measured mass of a target volatile organic compound in the air leaving the emission test cell during a given time period divided by the mass of target volatile organic compound added to the emission test cell in the same time period, expressed in percent

NOTE The recovery provides information about the performance of the entire method.

3.10
sample
part or piece of a building product that is representative of the production

3.11
specific emission rate
q_m
product specific rate describing the mass of a volatile organic compound emitted from a product per time at a given time from the start of the test

NOTE 1 Area specific emission rate, q_A, is used in this part of ISO 16000. Several other specific emission rates can be defined according to different requirements, e.g. length specific emission rate, q_l, volume specific emission rate, q_V, and unit specific emission rate, q_u

NOTE 2 The term “area specific emission rate” is sometimes used in parallel with the term “emission factor”.

3.12
target volatile organic compound
product specific volatile organic compound

3.13
test specimen
part of the sample specially prepared for emission testing in an emission test cell in order to simulate the emission behaviour of the material or product that is tested

3.14
total volatile organic compounds
TVOC
sum of the concentrations of identified and unidentified volatile organic compounds eluting between and including *n*-hexane and *n*-hexadecane

NOTE 1 For quantification of the identified compounds, their individual responses are used. The areas of the unidentified peaks are converted on molecular mass basis to concentrations using the toluene response factor [3].

NOTE 2 Due to practical reasons to taken into account for emission test chambers, this definition differs slightly from that in ISO 16000-6:2004. In ISO 16000-6, TVOC are related to the sampling medium Tenax TA®1) on which the TVOC are adsorbed.

3.15
volatile organic compound
VOC
organic compound that is emitted from the test specimen and all those detected in the test cell outlet air

NOTE 1 Due to practical reasons to be taken into account for emission test chambers, this definition differs from that in ISO 16000-6:2004. In ISO 16000-6, the definition is based on the boiling point range (50 °C to 100 °C) to (240 °C to 260 °C).

NOTE 2 The emission test method described in this part of ISO 16000 is optimum for the range of compounds specified by the definition of total volatile organic compounds (TVOC).

4 Symbols and abbreviated terms

The symbols and abbreviated terms used in this part of ISO 16000 are given below.

Symbol	Name	Unit
ρ_x	mass concentration of a VOC_x in the emission test cell	micrograms per cubic metre
L	product loading factor	square metres per cubic metre
n	air change rate	changes per hour
q	area specific air flow rate ($= n/L$)	cubic metres per square metre and hour
q_A	area specific emission rate	micrograms per square metre and hour
q_l	length specific emission rate	micrograms per metre and hour
q_m	mass specific emission rate	micrograms per gram and hour
q_V	volume specific emission rate	micrograms per cubic metre and hour
q_u	unit specific emission rate	micrograms per unit and hour
t	time after start of the test	hours or days

1) Tenax TA® is the trade name of a product manufactured by Supelco, Inc. This information is given for the convenience of users of this part of ISO 16000 and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

5 Principle

The principle of the test is to determine the area specific emission rates of VOCs emitted from the surface of a product test specimen. The test is performed in an emission test cell at constant temperature, relative air humidity, and area specific air flow rate. Measurements of the VOC concentration in the air at the outlet are representative of the air in the emission test cell.

Area specific emission rates at a given time, t, are calculated from the emission test cell air concentrations and the area specific air flow rate, q (see Clause 13).

With knowledge of the concentration in the air, the air flow through the emission test cell, and the surface area of the test specimen, the area specific emission rates of VOCs from the product under test can be determined.

6 Emission test cell system

6.1 General

An emission test cell system designed and operated to determine area specific emission rates of VOCs from building products shall contain the following: emission test cell, clean air generation and humidification system, monitoring and control systems, to ensure that the test is carried out according to specified conditions [4], [5], [6], [7].

For solid products with smooth surface, the emission test cell is placed directly against the surface of the product test specimen. To secure air tightness, other products shall be placed in specially constructed test specimen holders.

General specifications and requirements that apply to all types of emission test cells in this part of ISO 16000 are given in 6.2 to 6.6 below.

Quality assurance / quality control activities shall be carried out as in Annex A.

6.2 Emission test cell materials

The emission test cell and the parts of the sampling system coming in contact with the emitted VOCs (all tubings and couplings) are normally made of surface treated (polished) stainless steel or glass. However, in all cases the requirements in 6.3 and 6.5 shall be fulfilled.

The sealing material that links together the emission test cell and the test specimen shall be low emitting and low adsorbing and shall not contribute to the emission test cell background concentration.

6.3 Air supply

The emission test cell shall be supplied with pure and humidified air and have a device for controlling the air flow rate with an accuracy of $\pm$ 5 %.

6.4 Air tightness

The emission test cell shall be airtight in order to avoid uncontrolled air exchange with external air.

The emission test cell shall be operated slightly above atmospheric pressure to avoid any influence from the laboratory atmosphere.

The emission test cell is considered sufficiently tight if the inlet and outlet air flows differ by less than 5 %.

Products with a large air permeability or irregular surface may cause leakage. According to the demand for air tightness given above they shall therefore be placed in airtight test specimen holders.

6.5 Air sampling devices

The exhaust air (at the emission test cell outlet) shall be used for sampling. Sampling of the outlet air (e.g. with a sampling pump) is achieved by connecting adsorbent tubes to the outlet couplings.

The sum of sampling air flows shall be smaller than 90 % of the inlet air flow to the emission test cell.

A multiport sampling manifold can provide the flexibility for duplicate air sampling. The sampling manifold shall enter directly to the outlet air stream If a duct shall be used, it shall be as short as possible and maintained at the same temperature as the emission test cell.

NOTE The exhaust from the emission test cell should be ducted into a fume hood, ensuring that any chemicals emitted from the test material are isolated from the laboratory environment.

6.6 Recovery and sink effects

The recovery of a target VOC can be determined using a VOC source of known specific emission rate in the emission test cell. The concentrations generated shall be of similar magnitude as those expected during the emission tests of building products.

Recovery tests shall be performed in the test cell on an inert surface (glass or stainless steel), using toluene and *n*-dodecane. Test cell air concentrations shall be determined at 24 h after start of the test. The mean recovery shall be greater than 80 % for toluene and *n*-dodecane. The results of this recovery test shall be reported in the test report as concentration expected versus concentration measured.

NOTE 1 Low recovery of hygroscopic VOCs may occur in humidified air.

NOTE 2 Sink effects, leaks or poor calibration can cause difficulties to meet the minimum requirements. Sink and adsorption characteristics are very much dependent on the type of compound emitted. Additional recovery tests using target VOCs with different molecular weight and polarity can be used to increase understanding of these effects.

7 Apparatus

The equipment necessary for carrying out an emission test are listed below.

7.1 Clean air supply, e.g. pressurised purified air or synthetic air in gas cylinders.

7.2 Emission test cell system.

7.3 Humidification system.

7.4 Air humidity and temperature monitoring systems.

7.5 Air flow meters.

7.6 Facilities for recovery testing.

7.7 Either cleaning agent for the emission test cell, or oven for heating and cleaning the emission test cell.

8 Test conditions

8.1 Temperature and relative air humidity

Products for use in Europe shall be tested at temperature and relative air humidity 23 °C, 50 % RH during the emission test (ISO 554). The tolerances are ± 2 °C and ± 5 % RH.

For products with applications under other climatic conditions alternative temperature and air humidity conditions may be used, preferably as specified in ISO 554.

8.2 Supply air quality and background concentration

Supply air shall not contain any VOCs at levels greater than the emission test cell background requirements.

Background concentrations shall be low enough not to interfere with the emission determinations beyond quality assurance limits.

The TVOC background concentration shall be lower than 20 µg/m^3. The background concentration of any single target VOC shall be lower than 2 µg/m^3.

The water used for humidification shall not contain interfering VOCs.

8.3 Air velocity

The calculated or measured air velocity over the surface of the test specimen shall be in the range of 0,003 m/s to 0,3 m/s.

NOTE The air velocity can be important for evaporative controlled emissions, e.g. from liquid products. This depends on the substrate.

EXAMPLE Examples of air velocities are given in Annex C.

8.4 Area specific air flow rate and air change rate

The emission test cell concentration depends on the area specific air flow rate that is selected as a parameter in designing the test conditions.

EXAMPLE Examples of area specific air flow rates are given in Annex B of this part of ISO 16000.

9 Verification of the test conditions

9.1 General

All control measures shall be traceable to a certified standard according to the quality assurance and quality control schemes (Annex A of this part of ISO 16000).

9.2 Temperature and relative air humidity control systems

Control of temperature can be made by placing the emission test cell within a location controlled to the required temperature.

Control of relative air humidity and temperature can be made by various systems with e.g. built-in humidity control of the supply air.

Temperature and relative air humidity shall be measured independently of the systems for controlling the temperature and relative air humidity.

9.3 Test conditions in the emission test cell

Temperature, relative air humidity, and air flow rate shall be measured with instruments meeting the following accuracy:

— temperature ± 1,0 °C;

— relative air humidity ± 3 % RH;

— air flow rate ± 3 %.

The relative air humidity shall be measured at the air outlet. The temperature sensors shall be placed either in the emission test cell or in the air outlet.

9.4 Air velocity and air flow rate in the emission test cell

The air flow rate shall be checked and readjusted prior to air sampling using a calibrated gas flow meter. The air flow rates shall not vary by more than ± 5 % of the set value. The air velocity in the emission test cell shall be constant.

NOTE If the test is carried out with a gas volume meter / flow meter that is not permanently installed, be aware that the back pressure introduced by the meter can lower the flow rate through the emission test cell.

9.5 Emission test cell air tightness

The emission test cell air tightness shall be checked at the beginning of an emission test, by comparison of air flow rates at the inlet and the outlet ports, see 6.4.

10 Test specimens

Studies of the emission of VOCs from building products in emission test cells require proper handling of the product prior to testing.

Follow the procedures for test specimen preparation as specified in Annex A (for solid products) and in Annex B (for liquid products) of ISO 16000-11:2006.

11 Emission test cell preparation

The emission test cell shall be cleaned in accordance with either 11.1 or 11.2.

11.1 Cleaning by using a detergent

The emission test cell is cleaned by washing the inner surface with a diluted alkaline detergent, followed by two separate rinsings with freshly distilled water. Then wash the inner surface with non-denatured ethanol or other appropriate solvent.

11.2 Cleaning by thermal desorption

The emission test cell can also be cleaned by heating in a vacuum oven at elevated temperature (70 °C to 100 °C) over night.

12 Test method

12.1 Background concentrations

Place the emission test cell on a clean and planar surface (e.g. glass or stainless steel). An air sample of the emission test cell background is taken before the start of a new emission test to quantify any background contribution of volatile organic compounds from the empty emission test cell.

Background concentrations shall meet the requirements in 8.2.

12.2 Test specimen location in the emission test cell

The positioning of the emission test cell shall ensure that the direction of the air flow is evenly distributed over the emitting surface of the test specimen.

12.3 Time for measurements of emission test cell air concentration

The concentration measurements shall be carried out at predefined sampling times. Depending on the objective of the test, it can be appropriate to sample the air at additional times. Air sampling duration for concentration measurements depends on the analytical methods to be used and they shall be documented.

Duplicate air samples shall be taken at (72 ± 2) h and (28 ± 2) days after the start of the test.

After termination of the emission test, the emission test cell shall be cleaned according to Clause 11.

Emission test duration is determined by the purpose of the test. For long-term testing, the test specimen shall be stored under controlled conditions as prescribed in 8.1, if it is removed from the emission test cell. During this storage, the aging process of the test specimen shall be similar to that occurring in the test cell. Any contamination by other stored test specimens has to be avoided. The test specimen shall then be re-introduced into the test cell at least 24 h prior to air sampling. Each removal of the test specimen has to be documented in the test protocol.

NOTE 1 If decay studies are required, air samples can be taken after 1, 3, 7, 14, 28 and 56 days, or longer, after the start of the test.

Background concentrations of VOCs should be sufficiently controlled in order to avoid contamination of test specimens.

NOTE 2 To minimize contamination of test specimens between testing times, well ventilated shelves or storage cabinets can be used.

13 Calculation of area specific emission rates and expression of results

At a given test condition, ρ_x depends on the area specific emission rate of the test specimen and the air flow rate through the emission test cell. For individual VOCs, the compounds found both in the material and in the background shall be subtracted compound by compound. For TVOC, the measured background shall be subtracted. The relation between ρ_x, the area specific emission rate (q_A) and the area specific air flow rate (q) of the emission test cell can be expressed as:

$$\rho_x = q_A \cdot (L/n) = q_A/q \quad (1)$$

Equation (1) shows that the area specific air flow rate, q, equals the n/L ratio. For a given product tested under given emission test cell conditions, the concentration of VOC_x depends on the area specific air flow rate.

The measured concentration, ρ_x, of a VOC in the outlet air from the emission test cell shall be converted to an area specific emission rate, q_A. ρ_x is the mean concentration of a VOC_x calculated from a duplicate air samples as described in 12.3.

$$q_A = \rho_x \cdot q \quad \text{at time } t \tag{2}$$

The result shall be related to the time of the emission measurement after placing the test specimen in the emission test cell and may be reported quantitatively as the area specific emission rate, of individual VOCs and/or TVOC according to the objective of the test.

The sum of emitted compounds, TVOC, should be regarded only as a factor specific to the product studied and only to be used for comparison of products with similar target VOC profiles.

NOTE For certain purposes, area specific emission rates can be calculated from time concentration profiles, or by means of various mathematical models, e.g. first-order decay from concentration time data. This and other models are referred to in References [8] and [9].

14 Performance characteristics

Performance characteristics of this test method when used in conjunction with ISO 16000-6, are discussed in ISO 16000-6 and ISO 16017-1.

15 Test report

The test report shall include the following information:

a) test laboratory:

   1) name and address of the laboratory;

   2) name of the responsible person;

   3) description of the equipment and methods used (test cell, clean air system, environmental control, sample collection, analytical instrumentation, standard generation and calibration);

b) sample description:

   1) type of product (and brand name if appropriate);

   2) sample selection process (e.g. random);

   3) product history (date of production, date of arrival to the test laboratory);

c) test specimen preparation:

   1) date and time of unpacking and test specimens preparation (hour, day, month and year);

   2) method of preparation, including thickness and substrate, including for liquid products the substrate, the amount per unit area, and/or the thickness;

d) experimental conditions and procedures:

   1) test cell conditions (temperature, relative air humidity, air change rate, air velocity);

   2) test specimen area and loading ratio;

   3) sampling of emitted compounds (adsorbent used, volume sampled, sampling duration and times after introduction into the cell);

e) data analysis:

describe the method used to derive specific emission rates from measured cell concentrations (specify mathematical models or equations used);

f) results:

specific emission rates shall be reported for each test specimen, for individual VOCs and/or TVOC, at the times of air sampling;

g) quality assurance / quality control:

1) background test cell concentrations of target compounds;

2) recovery data of toluene and *n*-dodecane (to evaluate sinks);

3) results of duplicate sampling/analysis;

4) quality of the environmental variables (temperature, relative air humidity, air change rate, air velocity).

Annex A
(normative)

System for quality assurance/quality control

A.1 General

Emission cell testing of organic emissions from indoor materials/products shall be conducted within the framework of a Quality Assurance Project Plan (QAPP). The QAPP shall contain a project description, data quality objectives/acceptance criteria, QA/QC approaches/activities, and QA/QC audits.

A.2 Project description

A brief description shall include what materials are to be tested; how the testing is to be conducted; and who is responsible for various project activities. The project experimental design shall contain the necessary information for this portion of the QAPP.

A.3 Data quality objectives/Acceptance criteria

This section of the QAPP defines the precision, accuracy, and completeness desired for each parameter being measured.

A.4 QA/QC Approaches/Activities [10]

The types of QA/QC activities that can be specified in the QAPP include establishment of a system of records/notebooks to ensure proper operation of equipment and recording of data, such as:

a) sample log to record receipt, storage, and disposition of materials;

b) GC standards preparation log to document preparation of all organic compound substances;

c) permeation tube log to record weight loss data for all permeation tubes;

d) calibration logs to contain environmental systems calibration data;

e) instrument maintenance logs to document maintenance and repairs of all equipment;

f) materials testing logs in which to record all pertinent information for each test, including sample details, sample ID number, and GC run ID number;

g) sorbent cartridge cleanup/desorption log detailing thermal cleanup and QC validation of sorbent cartridges;

h) separate electronic log to document location and content of electronically stored data;

i) manuals governing operation or all equipment used by the project.

QC activities are carried out by project staff in a routine, consistent manner to provide necessary feedback in operation of all measurement systems. Such activities can include:

— routine maintenance and calibration of systems;

— daily recording of GC calibration accuracy and precision (i.e. control charting);

— timely monitoring of percent recovery of the internal standard that was added to all samples;

— collection and analysis of duplicate samples;

— QC checking of organic collection sorbent tubes;

— periodic analysis of audit gases supplied by an independent source.

A.5 QA/QC Audits

Finally, the QA/QC program shall include periodic audits by QA personnel to evaluate compliance with QAPP protocols.

Annex B
(informative)

Examples of area specific air flow rates in a model room

Table B.1 — Examples of area specific air flow rates in a model room

Model room [a]	Area specific air flow rate $m^3/(m^2 \cdot h)$ or n/L
17,4 m^3, $n = 0,5\ h^{-1}$:	
Floor area = 7 m^2	1,2
Wall area = 24 m^2	0,4
Sealant area = 0,2 m^2	44
[a] See Reference [5].	

NOTE A calculated concentration may differ from reality. Also one should remember that the figure of emission rate is a mean for one hour, but one day later the emission may have changed many times.

Annex C
(informative)

Example of an emission test cell

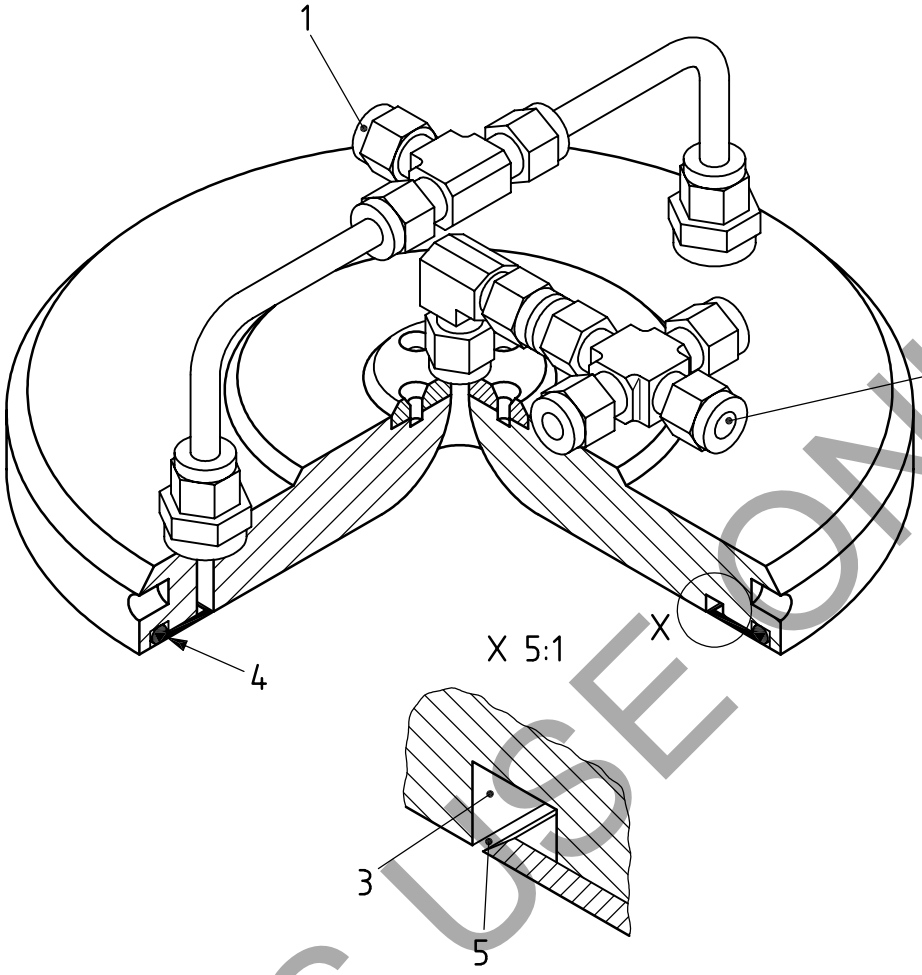
Volume (m^3)	$3,5 \times 10^{-5}$	—	—	—
Maximum exposed test surface area (m^2)	0,017 7	—	—	—
Inlet air slit (mm)	1,0	—	—	—
Diameter (mm)	150	—	—	—
Height at centre (mm)	18	—	—	—
Maximum material loading (m^2/m^3)	507	—	—	—
Airflow rate (l/min)	0,100	0,300	1,400	2,800
Air change rate, n (h^{-1})	171	514	2 400	4 800
Air velocity [a] at slit (m/s)	0,003 5	0,01	~ 0,05	~ 0,1
Area specific airflow rate [b] [$m^3/(h \cdot m^2)$]	0,34	1	5	9
Reynolds number (20°C), Re				10
Wall surface micro structure [c] R_a (µm)	< 0,1			
Wall sink		Time to reach cell equilibrium for polar VOCs < 2 h at an air supply of 400 ml/min (air velocity ≈ 0,014 m/s)		
Recovery percentage of VOC (%) [d]				
Dodecane	106 ± 2			
2-Ethylhexanol	99 ± 2			

[a] Calculated according to the geometry and airflow.

[b] Total exposed area of the test specimen.

[c] Inner surface is hand polished → uniform surface microstructure, R_a = Roughness value (see ISO 1302-02 [19]).

[d] The air supply was 100 ml/min at 50% relative air humidity, but for 2-ethylhexanol, 0% relative air humidity was used instead.



Key

1 air inlet
2 air outlet
3 channel
4 sealing material
5 slit

NOTE For further information, see References [11] to [19].

Figure C.1 — Description of an example of an emission test cell — General description in three dimensions of the field and laboratory emission cell

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3) FLEC® is the trade name of a product manufactured by CHEMATEC. This information is given for the convenience of users of this part of ISO 16000 and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

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