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Indoor air —

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

Air intérieur —

*Partie 12: Stratégie d'échantillonnage des polychlorobiphényles (PCB), des polychlorodibenzo-*p*-dioxines (PCDD), des polychlorodibenzofuranes (PCDF) et des hydrocarbures aromatiques polycycliques (HAP)*

Reference number
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Contents

Page

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 16000-12 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 by impaction*
- *Part 19: Sampling strategy for moulds*
- *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 for building products — Micro-chamber method*
- *Part 27: Standard method for the quantitative analysis of asbestos fibres in settled dust*
- *Part 28: Sensory evaluation of emissions from building materials and products*

The following parts are planned:

- *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*

Furthermore, VOC measurements by pumped and diffusive sampling are specified in:

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*

Introduction

ISO 16000 (all parts) specifies general requirements relating to the measurement of indoor air pollutants and the necessary conditions to be observed before or during the sampling of individual pollutants or groups of pollutants as well as the measurement procedures themselves (see Foreword).

Sampling of polychlorinated biphenyls (PCBs), polychlorinated dibenzo-*p*-dioxins (PCDDs) also known as polychlorinated oxanthrenes, and polychlorinated dibenzofurans (PCDFs) in indoor air is described in ISO 16000-13 whereas the corresponding extraction, clean-up and analysis by high-resolution gas chromatography/mass spectrometry is specified in ISO 16000-14. For sampling and analysis of PAHs, ISO 12884 may be employed.

Several PCBs, PCDDs/PCDFs, and PAHs are considered to be potential human carcinogens. There are 209 individual PCBs (congeners), 75 PCDDs and 135 PCDFs. The most toxic PCBs are those that are coplanar and structurally similar to PCDDs. The most toxic PCDD is 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). The toxicity of PCBs and PCDDs/PCDFs are calculated according to an internationally accepted system (see Annex A and Reference [1]). In 1997 (updated in 2005), a group of experts of the World Health Organization (WHO) fixed toxic equivalent factors (TEFs) for PCDDs/PCDFs and 12 PCBs, known as dioxin-like PCBs (Reference [1]) (see Annex A). These 12 dioxin-like PCBs consist of four non-ortho PCBs and eight mono-ortho PCBs (no or only one chlorine atom in 2-, 2'-, 6- and 6'-position), having a planar or mostly planar structure, see Table A.2.

The principal sources of PCDDs/PCDFs in indoor air are impurities in wood preservatives containing pentachlorophenol (PCP) and emissions from fires involving chlorinated products. PCBs are emitted into the indoor air primarily from concrete sealers, certain paints, or electrical capacitors; their use for these applications has been banned in many countries in recent years. Emissions from nearby landfills and abandoned industrial sites may also contribute PCBs and PCDDs/PCDFs to the indoor environment. The major origin of PAHs indoors is from combustion processes (mostly tobacco smoke and smoke from open fires).

Except for the case where there are direct indoor sources, PCBs and PCDDs/PCDFs enter indoor air from ambient air by ventilation. However, in ambient air these compounds are usually found at extremely low concentrations; e.g. several femtograms per cubic meter for PCDDs/PCDFs and about 10 pg/m^3 to several hundred picograms per cubic meter for total PCBs. The compounds addressed in this part of ISO 16000 are usually distributed between the gas and particle phases in ambient or indoor air, depending on the temperature, humidity, degree of chlorination, their concentration and capacity to associate with suspended particulate matter. Separate analyses of the filter and vapour trap will not reflect the original atmospheric phase distributions at normal ambient temperatures because of volatilization of compounds from the filter and should not be attempted.

Shipping of PCDD/PCDF standard reference materials shall comply with national legal regulations. They shall be transported in special containers that are commercially available. Handling should only be done by trained operators.

The sampling strategy specified in this part of ISO 16000 presupposes familiarity with ISO 16000-1.

This part of ISO 16000 uses the definition of indoor environments given by the Expert Council on Environmental Matters (see ISO 16000-1 and Reference [2]): dwellings — having living rooms, bedrooms, DIY (do-it-yourself) rooms, sports rooms and cellars, kitchens and bathrooms; workrooms or work places — in buildings that are not subject to health and safety inspections in regard to air pollutants (e.g. offices, sales premises); public buildings — e.g. hospitals, schools, kindergartens, sport halls, libraries, restaurants and bars, theaters, cinemas or other function rooms); and the interiors of private and public transport vehicles.

This part of ISO 16000 is based on VDI 4300-2[3].

Indoor air —

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

1 Scope

This part of ISO 16000 specifies the planning of measurements for polychlorinated biphenyls (PCBs), polychlorinated dibenzo-*p*-dioxins (PCDDs) also known as polychlorinated oxanthrenes, polychlorinated dibenzofurans (PCDFs) and polycyclic aromatic hydrocarbons (PAHs) in indoor air. 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, e.g. with respect to the need for remedial action or the success of such an action.

An inappropriate measurement strategy may contribute more overall uncertainty to the measurement result than the measurement procedure itself.

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 12884, *Ambient air — Determination of total (gas- and particle-phase) polycyclic aromatic hydrocarbons — Collection on sorbent-backed filters with gas chromatographic/mass spectrometric analyses*

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

ISO 16000-13, *Indoor air — 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*

ISO 16362, *Ambient air — Determination of particle-phase polycyclic aromatic hydrocarbons by high performance liquid chromatography*

3 Sources and incidence of PCBs, PCDDs/PCDFs and PAHs

3.1 General

PCBs, PCDDs/PCDFs and PAHs get into indoor air from a variety of sources as explained in 3.2, 3.3, and 3.4. Owing to sorption effects, the compounds originating from primary sources can be sorbed by various surfaces that may then act as secondary sources.

Not all sources and processes that could result in elevated concentrations of these substances in indoor air are known as yet. Table 1 gives an overview of the highest yielding sources that can all be designated as primary. Depending on the strength and period of action of the individual primary sources, vaporization, diffusion, sorption or sedimentation processes lead to contamination of the surfaces in the room. Even after removal of the primary sources, these contaminated surfaces themselves can act as secondary sources.

Table 1 — Possible sources of PCBs, PCDDs/PCDFs and PAHs in indoor air

Class of substance	Sources
PCBs	PCB-containing jointing materials
	Defective capacitors, e.g. in lamps
	Defective transformers
	Paints and varnishes containing flame retardants
	Plasticizers used in plastics, e.g. in sealing material for expansion joints in prefabricated concrete construction
	Forming oil employed in concrete construction
	Soil tracked in from emissions and polluted sites
PCDDs/PCDFs	Pentachlorophenol-containing materials, e.g. wood preservative paints, leather
	Fires in the presence of halogenated materials
	Soil tracked in from emissions and polluted sites
PAHs	Tobacco smoke
	Smoke from open fires
	Dyes or products containing tar oil or pitch (e.g. as glue for parquet flooring)
	Soil tracked in from emissions and polluted sites
	Cooking

When there are no obligatory criteria of assessment for evaluating the indoor air, an initial evaluation of the results of the indoor air investigation can be carried out by comparison with the concentrations of the relevant substances in the ambient air. Table 2 shows some typical ambient air concentrations for benzo[*a*]pyrene (the guide component for PAHs), PCDDs/PCDFs [as toxic equivalents (TEQ) according to WHO, see Annex A.3] and PCBs [as the sum of the concentrations of six congeners; see footnote a) to Table 2].

Table 2 — Concentration ranges of PCBs, PCDDs/PCDFs and PAHs in the ambient air of urban areas

Class of substance	Ambient air, mean concentration range	
	urban level	high concentration site
PCBs [a]	5 ng/m^3 to 10 ng/m^3	—[b]
PCDDs/PCDFs [c]	0,05 pg/m^3 to 0,15 pg/m^3	0,15 pg/m^3 to 0,5 pg/m^3
PAHs (only benzo[*a*]pyrene)	0,5 ng/m^3 to 1 ng/m^3	1 ng/m^3 to 21 ng/m^3(Reference [7])

[a] Sum of the six PCB congeners (28, 52, 101, 138, 153, 180 according to the Ballschmiter System), multiplied by 5 to calculate the total PCB content.

[b] PCBs are ubiquitous, increased concentrations are encountered only in the immediate vicinity of contaminated buildings.

[c] Toxic equivalents, see Annex A.

3.2 PCBs

In the past, PCBs have been deliberately and openly employed indoors in a number of materials so as to achieve certain material properties. Thus, polymer-based sealing materials containing PCBs as plasticizers have been employed especially in buildings using the open concrete slab method of construction. In addition, lightweight boards treated with PCB-containing emulsion paints have been used for suspended ceilings, and wooden surfaces painted with PCB-containing flame retardants have also been found.

Closed systems are, for example, small PCB-containing capacitors which have found widespread use, among other things, in lamps. Due to government mandates and voluntary restrictions applied by manufacturers, PCBs are no longer used in capacitors, either in lamps or elsewhere.

If there are important sources of emission in the vicinity of the building being examined, the ambient air shall also be considered as a source.

3.3 PCDDs/PCDFs

PCDDs/PCDFs are present as impurities in pentachlorophenol (PCP). They can get into the indoor environment from pentachlorophenol-containing materials used up to the end of the 1970s and to a small extent up to the middle of the 1980s (Reference [4]). PCB-containing jointing compounds can also contain PCDDs/PCDFs and release them into room air.

In the case of fire, chlorine-containing organic materials, e.g. electric cable sheathing, floor coverings, and PVC door and window frames give rise to PCDDs/PCDFs bound to soot and other particles, which deposit on surfaces and, if not cleaned off, are a continual source of pollution in the indoor air. Recommendations for the renovation, evaluation, disposal, and procedures in the case of rooms contaminated in this way have been prepared by the German Federal Health Office (References [5] and [6]).

3.4 PAHs

PAHs are formed in all incomplete-combustion processes. The best known example is cigarette smoking. However, chimneys that do not draw properly or candles burning with a sooty flame can give rise to measurable amounts of PAHs. They can also be released by pitch-containing materials used in interior construction work.

4 Measurement procedure

4.1 General

Most PCBs, PCDDs/PCDFs and PAHs belong to the semi-volatile group of organic compounds. In indoor air, they are encountered both bound to particles (suspended and settled dust) and in the gas phase.

Sampling and analytical procedures for pollution measurement are subject to standardization (see Table 3).

Table 3 — Sampling and analytical procedures

Class of substance	Procedure	Brief description
PCBs	ISO 16000-13	Sampling using either a low volume sampler or a high volume sampler with a polyurethane foam or other suitable adsorbent material preceded by a particle filter.
PCDDs/PCDFs	ISO 16000-13	Sampling using either a low volume sampler or a high volume sampler with a polyurethane foam or other suitable adsorbent material preceded by a particle filter.
PAHs	ISO 12884, ISO 16362, national standards	ISO 12884 and ISO 16362 apply to ambient air and indoor air measurements. In the latter case, the user shall take into consideration that, due to noise, only a low volume sampler should be used (see ISO 16000-13). In this case, some adaptation is necessary.

4.2 PCBs

Sampling should be conducted with a quiet, low-volume sampler (flow rate between 1,2 m^3/h and 2,8 m^3/h), if possible. If required to detect lower concentration levels, a high-volume sampler (flow rate between 6 m^3/h and 16 m^3/h) may be employed with certain limitations. In either case, no more than 10 % of the room air volume shall be sampled per hour. High-volume samplers are typically very noisy and cannot be used in occupied areas. Appropriate samplers and analytical procedures are described in ISO 16000-13.

The PCBs are extracted from the filter and the solid sorbent, and subjected to multistage chromatography to remove the impurities and analysed by gas chromatography/mass spectrometry (GC/MS).

4.3 PCDDs/PCDFs

Sampling should be conducted with a quiet, low-volume sampler (flow rate between 1,2 m^3/h and 2,8 m^3/h) if possible. If required to detect lower concentration levels, a high-volume sampler (flow rate between 6 m^3/h and 16 m^3/h) may be employed with certain limitations. In either case, no more than 10 % of the room air volume shall be sampled per hour. High-volume samplers are typically very noisy and cannot be used in occupied areas. Appropriate samplers and analytical procedures are described in ISO 16000-13.

The PCDDs/PCDFs are extracted from the filter and the solid sorbent, and subjected to multistage chromatography to remove the impurities and analysed by GC/MS.

4.4 PAHs

For total PAH measurements, the same sampling protocol described in 4.1 and 4.2 shall be employed (see ISO 16000-13, ISO 12884 and ISO 16362 for appropriate samplers). A low volume sampler is the first choice. However, if only semi-volatile PAH (with 5 or more rings; vapour pressures less than 10^{-8} kPa or boiling points higher than 475 °C) are of interest, a sampler equipped with a particle filter only (not backed up by a vapour trap) may be employed (see ISO 16362).

For the analysis, the PAHs are extracted, the extracts filtered, and most of the solvent removed. In some cases, it may be necessary to separate off the polar nonaromatic components by means of column chromatography. The concentrates are separated by GC, high performance liquid chromatography or MS and the PAHs are determined using suitable detectors.

5 Measurement planning

5.1 General

Since PCBs, PCDDs/PCDFs and PAHs determinations require complicated and costly analyses, a measurement strategy shall be prepared for the representative determination of these substances. The purchaser and the laboratory shall agree on the sampling strategy which shall be based on this part of ISO 16000.

5.2 Status review before measurement

Before the indoor air measurements are started, carry out general studies relevant to the particular case. Investigate the background to any complaints and determine details of the nature of the building, room furnishings etc. (as specified in ISO 16000-1).

The preliminary work shall also include a status review of possible sources and processes of emission.

In many cases it is useful, by analysing samples of material to be considered as sources and in individual cases wipe samples, to obtain a rough guide as to the extent to which the substances in question actually play a role in the indoor environment being examined. A procedure based on the particular case or on the type of source, as presented briefly in the following examples, has proven appropriate.

The settled house dust and tracked-in soil may be analysed to obtain an indication of the potential exposures of room occupants to PCBs, PCDDs/PCDFs and PAHs. Sampling and boundary conditions to be taken into account for this method are described in Reference [8].

5.2.1 PCBs

As mentioned in Clause 4, PCBs in interior spaces may be attributed to various sources. To obtain a rough estimate of possible PCB pollution in buildings with non-uniform levels of contamination, it is useful to conduct a status review of possible sources.

The procedure for investigating possible PCB pollution in interior rooms is given in Annex B.

5.2.2 PCDDs/PCDFs

PCDD/PCDF measurements are generally not necessary in a room containing wood treated with preservatives containing pentachlorophenol (PCP). If information about PCDD/PCDF concentrations is desired, measurements should only be carried out if the quotient, Q, in reciprocal metres, according to Equation (1) (Reference [9]):

$$Q = \frac{A}{V} \qquad (1)$$

where

A is the treated wood area, in metres squared;

V is the room volume, in metres cubed

is $\geqslant 0{,}2$ m^{-1} and the PCP mass fraction is more than 50 mg per kilogram of wood.

In the case of fires, PCDD/PCDF measurements are not generally required (Reference [6]). The occurrence of PCDDs/PCDFs in the case of fire and the procedure to be observed are discussed in detail in Annex C.

5.2.3 PAHs

If a composition containing tar oil (e.g. as wood preservative) has been employed in the past, it can be assumed on the basis of the product-specific composition that a potential source of PAHs is present. Valuable indications of possible indoor air pollution by PAHs can be obtained by analysing the benzo[*a*]pyrene content (guide component) of the sample of the suspected source material.

5.3 Measurement objective (and indoor climatic conditions)

Before indoor air measurements are carried out, the measurement objective shall be clearly defined. Conceivable objectives are:

a) information about the average concentration under usual conditions;

b) information about the peak concentration (special conditions);

c) checking compliance to a guide value;

d) information about the ratio of indoor and ambient air concentrations.

5.3.1 Information about the average concentration under usual conditions

Sampling shall be performed taking into consideration the users' behaviour (habits and activities) during normal use of the room or at least under conditions that correspond to those of normal use of the room. This means that, *inter alia*, temperature and ventilation conditions in the room during the measurement are within the usual range for the room.

In order to rule out influences of discontinuous emissions (open flames, open chimney, smoking), the initial conditions shall be defined as far as possible beforehand. To achieve this, ventilate the room well, then keep the doors and windows closed for about 8 h (preferably overnight). Start the measurement after such conditioning of the room.

When examining rooms ventilated with a heating, ventilation and air conditioning (HVAC) system, allow the system to operate under usual conditions for at least 3 h before sampling.

Similarly, in the case of rooms for which there are ventilation instructions (e.g. schools, kindergartens) a complete use cycle (time between two ventilations) should be allowed to elapse before the measurement.

For the measurement to be reliable, the room examined shall be utilized as usual. This is due to the fact that many of the targeted compounds are associated with particulate matter that can be resuspended by the activities of room occupants, thereby influencing indoor air concentrations.

However, for various reasons, e.g. because of the noise produced by the sampling apparatus or a ban on use imposed by the authorities, it may not be possible to carry out the sampling in the presence of the users of the room. The suspended particulate matter concentrations can then be lower than when the room is used as usual. This can lead to underestimation of the PCB, PCDD/PCDF and PAH concentrations in the indoor air.

5.3.2 Information about the peak concentration (special conditions)

Peak concentrations can contribute to a better estimate of the overall situation and can be obtained by carrying out measurements under low air replacement and high room temperature conditions.

However, unrealistically extreme situations should be avoided for such monitoring. Only in exceptional cases should peak pollution levels be measured at room temperatures above 26 °C (see Reference [10]). Air replacement should be restricted to infiltration (closed windows and doors for naturally ventilated rooms and the HVAC system switched off for artificially conditioned rooms). Particular care shall be taken to meet the air volume and sampling time requirements specified in Table 4. The conditions shall be established by means of a sufficiently long preliminary running time (at least 8 h, preferably overnight).

Table 4 — Sample volumes and duration of sampling for measurement of indoor air

Class of substance	**Sample volume** m^3	**Measurement time for low volume sampler** h	**Measurement time for high volume (16 m^3/h) sampler** h
PCBs	5 to 10[a]	2 to 4	—[c]
PCDDs/PCDFs	400	150	25
	60[b]	22	4
PAHs	5 to 10	2 to 4	—[c]

[a] If coplanar PCBs are to be determined the same sampling volumes as for PCDDs/PCDFs may be required.

[b] Analysis by means of a gas chromatograph coupled with a high resolution mass spectrometer.

[c] Not recommended.

5.3.3 Checking compliance with a guide value

If there are guide values for individual substances, the objective of measurement is frequently to check adherence to such values. Here, the conditions set down in the definition of the value shall be observed when carrying out the measurement. If appropriate specifications have not been defined, the usual concentration should be measured as in 5.3.1 under the usual use conditions.

In measurements of PCBs, it has been found that concentrations have a significant temperature dependence. Owing to higher temperatures in summer, values measured in winter under otherwise comparable conditions are as a rule significantly below indoor air concentration in summer (Reference [11]).

It is not possible to extrapolate the values measured in winter to the conditions prevailing in summer, since the dependence of the indoor air concentration on the wall temperature and the ventilation rate is not sufficiently well known at present and depends on the circumstances of the individual case.

If it is not possible to wait for summer measurement, a rough guide can be obtained by carrying out a measurement in winter at an increased room temperature. This circumstance shall be recorded in the measurement report.

5.3.4 Information about the ratio of indoor and ambient air concentrations

In some cases, especially when no guide values or information about the concentrations or sources usually present in rooms are available, the measurement objective can be to obtain information about the ratio of indoor and ambient air concentrations (see 5.6). The indoor and ambient air are then measured simultaneously.

The ambient air samples should be taken in the vicinity of the building, ensuring that the sampling point is sufficiently far from the building (from about >10 m to 100 m).

In the case of HVAC systems, the ambient air has to be measured in the vicinity of the air intake. When comparing the values obtained for ambient and indoor air, it may be necessary to remember that, depending on the time of year, there can be a considerable temperature difference between the two sampling points.

5.4 Sampling time and measurement frequency

The measurements shall be carried out when the desired conditions (ventilation, room usage) have been established (see 5.2).

The conditions prevailing during sampling shall be recorded as specified in ISO 16000-1, Annex D, Clauses A to G.

The sampling time is determined both by the measurement objective (see 5.3) and by the detection limit of the measurement method employed. The latter determines the minimum air volume to be sampled for the individual groups of substances (see Table 4).

It is also to be noted that the sample air volume drawn in per hour shall not exceed 5 % to 10 % of the room volume. This restriction is intended to keep changes in the room atmosphere caused by sampling to a minimum. If this restriction is not observed, false measurement results have to be expected, e.g. because of an air-purifying action resulting from sampling and displaced equilibria between materials and the air of the room. A high volume sampler with a flow rate of >16 m^3/h can only be used in sufficiently large rooms.

Since many of indoor rooms studied have a room volume <140 m^3, an apparatus having a flow rate of less than 10 m^3/h shall be used to keep the requirement specified in the preceding paragraph. This condition is met by a low volume sampler which has an air throughput of <3 m^3/h.

In view of the often high renovation costs, it is in any case necessary to verify an indoor air analysis by means of a repeat measurement. It is possible to depart from this principle only if the analytical costs and the effort required are in a severe disproportion to the possible renovation costs.

5.5 Sampling location

The choice of the sampling location is largely determined by the considerations in 5.2. However, further general aspects require consideration in the selection of the sampling location; these are specified in ISO 16000-1.

The sampling location within the room to be examined tends to be of subordinate importance for the substances under consideration here. The intake point should be between 1 m and 1,5 m above the floor and be at least 1 m from the wall.

In the case of PCB pollution caused by jointing material, whether the same technical PCB mixture has been incorporated at all places in a building shall be ascertained, wherever possible; if the PCB content of the jointing materials is the same, it is possible that different PCB concentrations in the indoor air can occur depending on which product has been used.

5.6 Comparative measurements

In many cases, assessment of measurement results obtained in indoor air investigations present difficulties because of the lack of evaluation criteria.

Here, a comparison by means of parallel measurements either with the situation in another room of the same building that can be regarded as unpolluted or with the ambient air concentration can be helpful. The figures in Table 2 can serve as initial information about possible ambient air concentrations.

The general local pollution or the concentration caused by a source in the vicinity of the building is determined by a measurement made at about 10 m to about 100 m from the building.

If it is possible that the indoor pollution originates from the building proper and is transported from the building exterior to the interior by diffusion of air (an example is the emission of PCBs from sealing material that has been employed on the external wall), the ambient air measurement should be carried out in the immediate vicinity of the building (about 1 m) to clarify the pollution path.

If appropriate, comparative samples, which can later be analysed only if necessary, should be taken as a precaution.

5.7 Quality assurance

The measurement plan shall specify the 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.

Important criteria to be taken into account and those for selection of a contractor or laboratory to perform the measurements should address the following questions.

- Does the measuring laboratory have a documented quality assurance system (e.g. according to ISO/IEC 17025[16])?
- Which calibration procedures are used, how often and how extensively?
- Which methods will be used to identify the PCBs, PCDDs/PCDFs, and PAHs?
- Are collocated measurements necessary?
- How are the uncertainties defined (e.g. according to ISO Guide 98:1995[17])?
- Does the laboratory participate in interlaboratory tests?

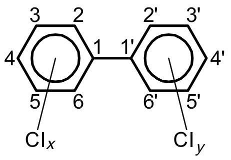
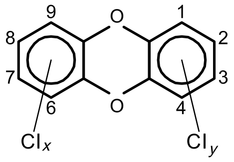
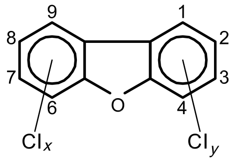
Annex A
(informative)

Structures, toxicity and calculation of toxic equivalents

A.1 Structures of PCBs, PCDDs and PCDFs

The PCDDs and PCDFs are described in more detail in ISO 16000-13.

Table A.1 — Structures of PCBs, PCDDs and PCDFs and number of possible isomers

			
	PCBs Polychlorinated biphenyls	**PCDDs** Polychlorinated dibenzo-*p*-dioxins	**PCDFs** Polychlorinated dibenzofurans
No. chlorine atoms	**No. PCB isomers**	**No. PCDD isomers**	**No. PCDF isomers**
1	3	2	4
2	12	10	16
3	24	14	28
4	42	22	38
5	46	14	28
6	42	10	16
7	24	2	4
8	12	1	1
9	3	—	—
10	1	—	—
Total	**209**	**75**	**135**

A.2 Structures of coplanar PCBs

Table A.2 — Structures of 12 selected coplanar polychlorinated biphenyls

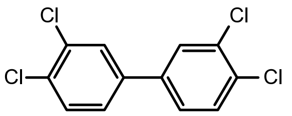
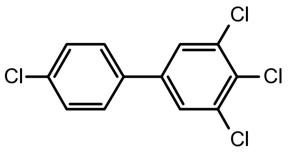
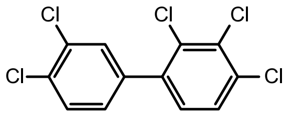
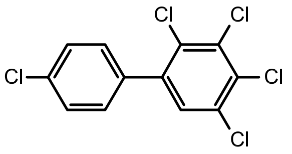
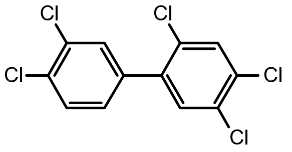
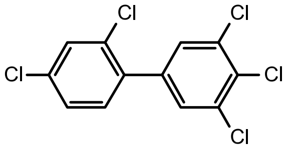
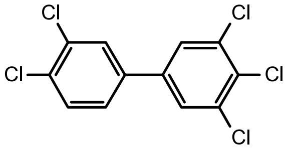
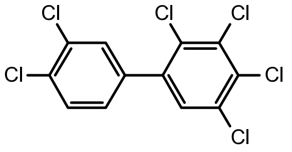
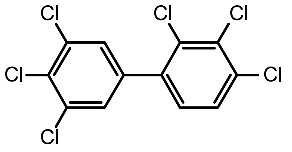
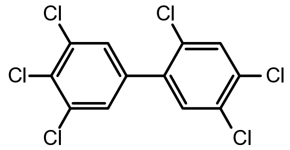
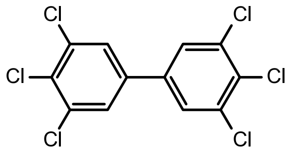
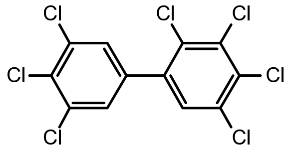
IUPAC name and synonyms	Empirical formula	Molar mass g/mol	Structural formula
3,3',4,4'-tetrachlorobiphenyl 3,3',4,4'-TeCB PCB-77	$C_{12}H_6Cl_4$	291,9	
3,4,4',5-tetrachlorobiphenyl 3,4,4',5-TeCB PCB-81	$C_{12}H_6Cl_4$	291,9	
2,3,3',4,4'-pentachlorobiphenyl 2,3,3',4,4'-PeCB PCB-105	$C_{12}H_5Cl_5$	326,4	
2,3,4,4',5-pentachlorobiphenyl 2,3,4,4',5-PeCB PCB-114	$C_{12}H_5Cl_5$	326,4	
2,3',4,4',5-pentachlorobiphenyl 2,3',4,4',5-PeCB PCB-118	$C_{12}H_5Cl_5$	326,4	
2',3,4,4',5-pentachlorobiphenyl 2',3,4,4',5-PeCB PCB-123	$C_{12}H_5Cl_5$	326,4	
3,3',4,4',5-pentachlorobiphenyl 3,3',4,4',5-PeCB PCB-126	$C_{12}H_5Cl_5$	326,4	
2,3,3',4,4',5-hexachlorobiphenyl 2,3,3',4,4',5-HxCB PCB-156	$C_{12}H_4Cl_6$	360,9	
2,3,3',4,4',5'-hexachlorobiphenyl 2,3,3',4,4',5'-HxCB PCB-157	$C_{12}H_4Cl_6$	360,9	

Table A.2 (*continued*)

IUPAC name and synonyms	Empirical formula	Molar mass g/mol	Structural formula
2,3',4,4',5,5'-hexachlorobiphenyl 2,3',4,4',5,5'-HxCB PCB-167	$C_{12}H_4Cl_6$	360,9	
3,3',4,4',5,5'-hexachlorobiphenyl 3,3',4,4',5,5'-HxCB PCB-169	$C_{12}H_4Cl_6$	360,9	
2,3,3',4,4',5,5'-heptachlorobiphenyl 2,3,3',4,4',5,5'-HpCB PCB-189	$C_{12}H_3Cl_7$	396,3	

A.3 Toxicity and calculation of the toxic equivalents for PCBs and PCDDs/PCDFs

In the environment, PCDDs/PCDFs never appear as single compounds but always as a complex mixture associated with other structurally related ("dioxin-like") compounds such as PCBs.

The toxic equivalent (TEQ) system uses 2,3,7,8-TCDD as the standard to which the toxicities of the other compounds are related. This relation is based on the assumption that PCDDs/PCDFs and dioxin-like compounds act through the same mechanism. The toxic effects are assessed through subchronic toxicity studies and from certain biochemical properties such as the aryl hydrocarbon receptor binding capacity.

The toxic potential of a single congener is indicated through its toxic equivalence factor (TEF) describing the individual toxicity relative to the toxic effect of 2,3,7,8-TCDD. For the TEQ calculation, the amount or concentration of each relevant congener is multiplied by the corresponding TEF. When all congeners are given as "equivalents of 2,3,7,8-TCDD" they can simply be added up and the resulting TEQ represents the total toxicity of the mixture (see Table A.3).

Even if there still remain uncertainties concerning the toxicity of PCDDs/PCDFs, international toxic equivalency factors (I-TEF) have been established by NATO/CCMS (see Reference [12] and Table A.3). Recently WHO (see Reference [1]) has standardized the toxicity of 2,3,7,8-chloro-substituted dioxins and furans and certain dioxin-like PCBs. For all other congeners which may be present in a sample, a TEQ value of zero is assigned.

The NATO/CCMS scheme has been adopted internationally as a basis for the TEQ determination. During recent years, the toxicity of PCDDs/PCDFs has been reported mainly in I-TEQ.

The most recent TEQ scheme, developed by the World Health Organization (WHO) and the International Programme on Chemical Safety (IPCS) standardizes the toxicity of 17 dioxin and furan congeners and includes for the first time 12 dioxin-like PCBs (see Reference [1]). It reflects current knowledge about toxic effects of PCDDs/PCDFs and dioxin-like PCBs (see Table A.3).

The WHO-TEQ approach is linked to a WHO recommendation concerning a tolerable daily intake (TDI) for humans of 1 pg to 4 pg WHO-TEQ per kilogram body weight (including PCBs) that should not be exceeded. The TDI was recommended on the basis of critical effects (including developmental, reproductive, hormonal, immune system and neurobehavioural effects), dose-response relationships and quantitative risk extrapolation.

In the sense of an international harmonized risk assessment, which should be based on the most current knowledge, it appears to be reasonable to accept the WHO-TEQ system and to discuss the WHO-TDI as an assessment scale for future risk assessment at the international level.

The calculation of the PCDD/PCDF TEQ results is normally performed by using the international toxic equivalency factors (I-TEF) of NATO/CCMS (see above). The calculation of the PCDDs/PCDFs and dioxin-like PCBs (coplanar and non-ortho PCBs) TEQ is only possible using the toxic equivalency factors of WHO (WHO-TEQ$_{PCB}$). The calculation schemes are not mutually compatible (see Table A.3). The calculation is mandated according to NATO/CCMS (I-TEQ) by some countries and WHO (WHO-TEQ$_{PCB}$) by others; consequently, the results and the calculation scheme shall be reported.

Table A.3 — WHO toxic equivalency factors (WHO-TEFs) (see Reference [1]) and international toxic equivalency factors (I-TEFs) (see Reference [12])

Congener	WHO-TEF	I-TEF
2,3,7,8-TCDD	1	1
1,2,3,7,8-PeCDD	1	0,5
1,2,3,4,7,8-HxCDD	0,1	0,1
1,2,3,6,7,8-HxCDD	0,1	0,1
1,2,3,7,8,9-HxCDD	0,1	0,1
1,2,3,4,6,7,8-HpCDD	0,01	0,01
OCDD	0,000 3	0,001
2,3,7,8-TCDF	0,1	0,1
1,2,3,7,8-PeCDF	0,03	0,05
2,3,4,7,8-PeCDF	0,3	0,5
1,2,3,4,7,8-HxCDF	0,1	0,1
1,2,3,6,7,8-HxCDF	0,1	0,1
1,2,3,7,8,9-HxCDF	0,1	0,1
2,3,4,6,7,8-HxCDF	0,1	0,1
1,2,3,4,6,7,8-HpCDF	0,01	0,01
1,2,3,4,7,8,9-HpCDF	0,01	0,01
OCDF	0,000 3	0,001
Non-ortho PCB		
3,4,4',5-TeCB (81)	0,000 1	—
3,3',4,4'-TeCB(77)	0,000 3	—
3,3',4,4',5-PeCB (126)	0,1	—
3,3',4,4',5,5'-HxCB (169)	0,03	—
Mono-ortho PCB		
2,3,3',4,4'-PeCB (105)	0,000 03	—
2,3,4,4',5-PeCB (114)	0,000 03	—
2,3',4,4',5-PeCB (118)	0,000 03	—
2',3,4,4',5-PeCB (123)	0,000 03	—
2,3,3',4,4',5-HxCB (156)	0,000 03	—
2,3,3',4,4',5'-HxCB (157)	0,000 03	—
2,3',4,4',5,5'-HxCB (167)	0,000 03	—
2,3,3',4,4',5,5'-HpCB (189)	0,000 03	—

Annex B
(informative)

Procedure for investigating possible sources of indoor PCB pollution with a view to possible renovation

Currently known PCB sources are listed in Table 1. In practice, the following sources are of particular importance:

a) PCBs as plasticizers in sealing materials;

b) PCBs as flame retardants in emulsion paints for suspended ceilings;

c) PCBs as flame retardants for wood surfaces; and

d) PCB-containing capacitors in lamps.

The year in which the building or the parts of the building were constructed as well as the year in which interior fittings were installed give a first indication of the presence of many PCBs. For the first three cases, which are examples of so-called “open” use of PCBs, the latest time for use in buildings may be regarded as about 1980. The largest number of examples was found in buildings constructed in the mid-1970s. The use of PCB-containing capacitors was widely discontinued in the mid-1980s.

These primary sources have generally resulted in contamination of the entire room. All surfaces can act as low-intensity secondary sources.

In the case of primary open sources, a PCB content of 1 g/kg and more is usually found. For secondary sources, significantly lower PCB mass fractions have been observed (e.g. <1 g/kg). Targeted removal of the primary sources and cleaning or removal of the secondary sources have to go hand in hand during renovation.

If it is suspected that PCB-containing sealing materials had been used in a building, it has proven useful to take samples of material from various places in the building and to analyse them for their PCB content. Care needs to be taken in such a case that all types of joints such as building expansion joints and seals around windows, floors and doors as well as joints in bathrooms and staircases are considered as PCB sources. PCBs are present only in permanently elastic seals based on polysulfide and not in aged seals that appear brittle (e.g. those based on polyacrylate). As an alternative in case of a suspected PCB pollution, it has been proven to inspect the building, to take representative air samples with regard to PCBs and to take, in parallel, material samples from different locations and to analyse them regarding PCBs.

A further PCB source with partly considerable PCB contents may be roughcasts (see Reference [13]).

PCBs were also used in paints, mostly until the end of the 1970s, to a small extent also until the middle of the 1980s. PCBs served both to increase the elasticity of the paints and as flame retardants. As a result, PCBs in wall paints can be found in emergency escape routes of public buildings and also in areas where oil paints, flow-on paints and the like were used. A Beilstein test carried out on the spot can give an indication of high chlorine contents. In this test, a sample of paint is brought into close contact with a copper mesh or a copper sheet. On heating, e.g. with a soldering torch, the flame takes on a green colour in the presence of chlorine-containing compounds. A positive result should be confirmed by subsequent analysis of the material.

It has to be taken into account that larger buildings were frequently constructed in several stages at intervals in time and individual parts of building may even have been constructed by different companies. In such cases, samples may have to be taken in the different storeys of the building. Only after such screening analyses can representative and therefore meaningful indoor air measurements be planned and carried out for a building.

Apart from sealing materials, particleboard pre-painted with a PCB-containing paint during manufacturing and intended for use with suspended ceilings, may also be a source of PCBs. Particular attention therefore has to be paid to the presence of such boards when examining the building.

In some countries, e.g. Germany, wood fiber ceiling boards may be another important source of PCBs in indoor air. According to manufacturer information, these boards were painted with a highly chlorinated PCB-containing flame retardant paint up to and including 1972. The PCB mass fraction of the paint on the board side facing the room is about 15 %; the resulting PCB content of the board as a whole is about 1 %.

Since PCBs have been used to a relatively large extent by the paints industry, PCBs may also be present in older paints. Thus, wooden ceiling panels also need to be examined for the presence of flame retardant paints. Such paints can be seen as a clearly visible, non-uniformly distributed whitish coating. If such surfaces are present, samples should be taken of the board down to a maximum depth of 1 mm to 2 mm using a suitable tool, and checked for PCBs.

Capacitors generally have a lifetime of more than 10 years, so that some of them may still currently contain PCBs. Information as to whether a capacitor contains PCBs is given by the type designation marked on the device. Corresponding lists have been published in some countries (see Reference [14]). However, it should be noted that there is no uniform, compulsory labelling. It thus will not be possible to successfully classify the capacitor type in every case. In the case of leaking or burst capacitors, a PCB analysis of the insulating liquid released or else a wipe sample will indicate whether PCBs could have entered the room air.

In Reference [9], the following recommendations are considered appropriate.

- Indoor air concentrations below 300 ng of PCBs per metre cubed may be regarded as tolerable in the long term (precautionary value).
- In the case of indoor air concentrations between 300 ng and 3 000 ng of PCBs per metre cubed, it is recommended that the source of air contamination be traced. Sources should be eliminated or at least their emissions should be minimized taking into account the aspect of adequateness (e.g. by ventilating at regular intervals and thorough cleaning and removal of dust from the rooms). The target value is less than 300 ng of PCBs per metre cubed.
- Indoor air concentrations above 3 000 ng of PCBs per metre cubed should be avoided with regard to other possible uncontrollable exposure to PCB. If such elevated concentrations are found, the PCB determination should be repeated immediately. If the value is confirmed, prompt measures are to be taken, depending on the level of pollution, to reduce the indoor air PCB concentration in order to avoid health risks posed by staying in these rooms. The remediation measures have to be appropriate to effectively reduce the intake of PCBs. Here too, the target value is less than 300 ng of PCBs per metre cubed (guide value for remediation).

Annex C
(informative)

Indoor investigations for PCDDs/PCDFs after fires

C.1 General

It is known that fires involving halogen-containing substances can give rise to PCDDs/PCDFs. To simplify the procedure for examination or sampling in the case of indoor investigations, surface samples are generally employed for making the assessment.

Information about the toxic equivalents determined in past cases of fire may be found in Reference [15].

A cleaning recommendation for indoor areas affected by fire was issued in 1990 in Germany according to which PCDD/PCDF examinations should only be carried out in a few cases (see Reference [5]). According to this recommendation, sampling should be carried out only in the case of large fires in which relatively large amounts of PVC, cables, capacitors, transformers, sealing materials and plastics are burnt. This applies particularly when it may be assumed that polychlorinated biphenyls, polychlorinated benzenes or polychlorinated phenols have been involved in the fire.

The procedure described (Clause C.2) is restricted to the rooms or buildings adjoining the site of the fire that are affected by the deposition of soot from the fire and does not relate to the seat of the fire itself. It is intended to contribute to an assessment of the extent of hazards in indoor rooms around the seat of the fire. Pollution from primary sources is to be expected if the concentrations found are from one to several micrograms per kilogram in material samples or per square meter in surface samples. Lower values are as a rule the result of secondary pollution via the air.

C.2 Procedure

Wipe samples should be taken in areas having a higher level of soot pollution. Subsequent analysis should at first be restricted to the samples (rooms) that are presumed to be the most polluted. The necessity of further investigations can be derived from the first results.

Sampling is preferably carried out on horizontal, smooth surfaces at various places in the room by brushing the soot from a defined area in order to be able to determine the PCDD/PCDF concentration on both an area and mass basis. The total area sampled is chosen according to the detection limit of the analytical method employed subsequently. Thus, when using a low-resolution GC/MS apparatus, a total area of at least 1 m^2 is required, while 100 cm^2 are sufficient for high-resolution instruments.

In the case of greasy soot deposits, representative samples cannot be obtained by brushing off the surfaces. In such a case, sampling is carried out by wiping the appropriate areas with an adsorbent material that has been moistened with a wetting solvent (e.g. toluene). The material itself shall not influence the analysis and may therefore have to be cleaned beforehand. If the surfaces are all rough (e.g. masonry, wallpaper, textiles), the outer layer of the material has to be taken off mechanically. The analytical result can only be reported on an area basis in such cases.

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